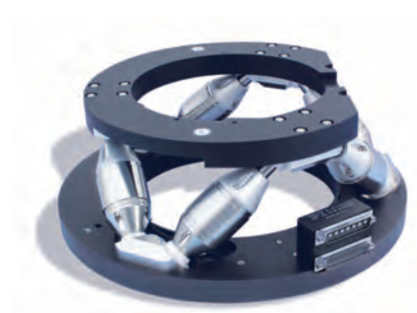
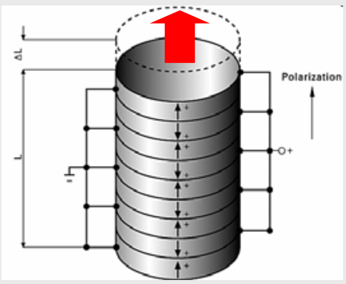
Piezo Mechanisms

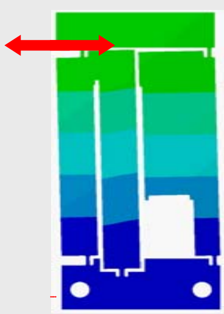


Not all Piezo Mechanisms are Created Equal

Direct Actuators: Piezo Z-Stacks, Shear (X, XY)

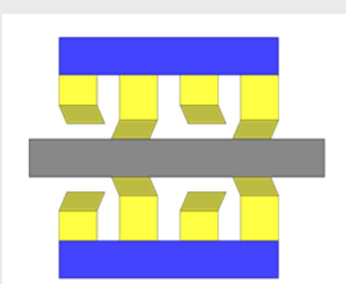


- Direct Motion = High Force & Very Fast Response (to Microseconds)
- Travel Range typically 10µm to 300µm
- Z, X, XYZ Motion
- No Wear & Tear



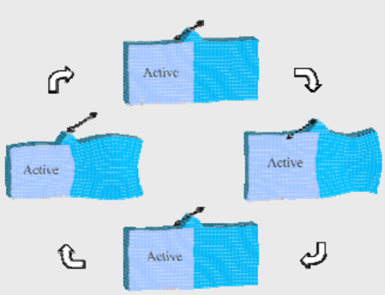
Piezo Flexure Lever Actuators

- Flexure Guiding System
- Response <1 msec
- Travel to 2 mm, Compact



PiezoWalk® Linear Motors

- Travel to 20 mm (basically unlimited)
- Sub-Nanometer Resolution
- High Force, to 800 N



Ultrasonic Piezo Linear Motors

- Long Travel
- Fast: 350 mm/sec
- Low Profile, Self Locking

All: Sterile, Low Power, No Lubricants, Non- Magnetic, Vacuum Compatible; High Resolution: Sub-Nanometer to Sub-Micron

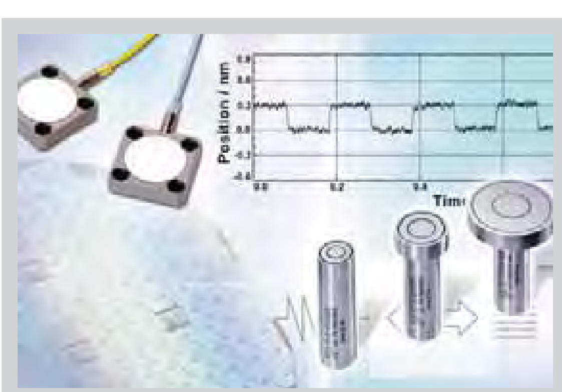
More Info: Click Images

Products

Piezo Linear Actuators & Motors

Piezo Nanopositioning Systems & Stages

Piezo Micropositioning Systems



Nanometrology

Moving the Nanoworld

NanoAutomation®: Precision Positioning for Science and Industry

PI headquarters in Karlsruhe

Future Technology Solutions

Today PI delivers micro- and nanopositioning solutions for all important high-tech markets:

- Semiconductor Technology
- Optical Metrology, Microscopy
- Biotechnology and Medical Devices
- Precision Automation and Handling
- Precision Machining
- Data Storage
- Photonics, Fiber Optics, Telecom
- Nano Technology
- Microsystems Technology
- Aerospace Engineering
- Astronomy

PI reception desk: Our employees look forward to your visit

PI is market and technological leader for precision positioning systems with accuracies well under one nanometer. Nanometer-range motion control is the key to worlds where millions of transistors fit on one square millimeter, where molecules are manipulated, where thousands of "virtual slices" are made in the observation of living cells, or where optical fiber bundles no larger than a human hair are aligned in six degrees of freedom.

Worlds We Call NanoWorlds

Continuous innovation and reinvestment of profits over the decades has allowed PI to attain its present market status. This status is also based on long-term customer relationships and on the freedom to transform ideas into reality.

Over 30 Years Experience

When PI introduced piezoelectric nanopositioning technology more than 30 years ago, typical customers were research labs and universities working on laser cavity tuning, Fabry-Perot interferometers and filters. Few foresaw that whole industrial sectors like semiconductor manufacturing or biotechnology would become dependent on progress in nanopositioning. Today, not even the precision machining industry can do without nanometer-level positioning systems.

Key Technologies In-House

PI follows a vertical integration strategy designed to develop and maintain all key technologies in-house. We supervise each and every step from design to delivery in the following areas: software, precision mechanics, digital and analog control electronics, sub-nanometer capacitive position sensors, piezo ceramics and piezo actuators. This assures the highest quality and reduces cost.

The PI Group

High Quality and Strong Brands on a Global Scale

PI-USA headquarters in Massachusetts

PI—World Market Player

As a privately run company with a healthy growth rate, over 500 employees and a flexible, vertically integrated organization, PI can meet the most diverse requirements in the area of innovative precision positioning and supply customers anywhere in the world with outstanding products.

International Service and Sales Network

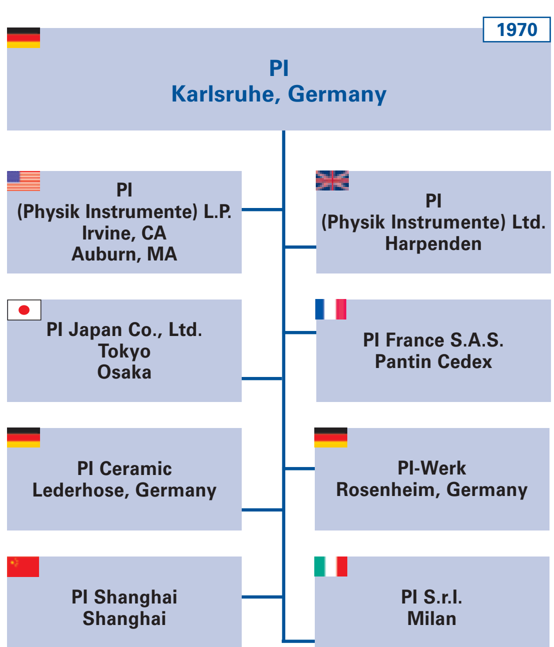
PI has established subsidiaries for sales and service in the most important local markets all over the world and maintains nanometrology test labs on three continents. In addition to PI’s main R&D and manufacturing centers in Europe, PI Shanghai and PI USA provide development and manufacturing capabilities to meet the specific demands of local markets faster. In addition to the branch offices, PI has distributors in many other industrial countries. A network of highly qualified personnel around the world assures successful, long-term relationships with customers.

Quality and Brand Policy

We measure the quality and reliability of our products against the strictest of standards. ISO 9001 certification, which also emphasizes points like customer expectations and satisfaction, has been accorded in 1994, making PI the first manufacturer of nanopositioning technology following this standard. PI's Integrated Management System (IMS) includes also Environmental Protection and Job Safety (according to ISO 14001:2004 and OHSAS 18001:1999). This system assures legal conformity of all procedures as well as continuous optimization of the processes at all PI locations.

PI brands and colors are well known throughout the high-tech world. PIFOC® is almost used as a synonym for objective positioners in general and PICMA® stands for the highest reliability in piezo actuator products.

PI stands for quality and precision – worldwide.



PI Ceramic

Leading in Piezo Technology

PI Ceramic—a PI Subsidiary—is a world-class supplier of high-performance piezoelectric actuator and transducer components and subassemblies.

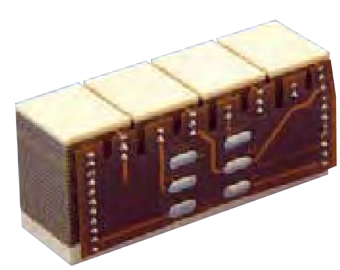
High-Tech manufacturing: Vacuum coating (sputtering) of piezo ceramics

PI Ceramic also develops and produces all piezo ceramic drive systems employed in PI's precision positioning systems. This makes PI the only supplier of nanopositioning equipment in the world to manufacture its own piezo ceramic drives. This capability allows the flexibility to provide custom engineered piezo ceramic components. It also allows PI to offer the most reliable piezo stages in the world, based upon the award-winning PICMA® actuator technology and to develop innovative drive solutions such as PILine® ultrasonic ceramic motors and NEXLINE® high-force ceramic motors.

In the tradition of the former Keramische Werke Hermsdorf (KWH, until 1990), the PI Ceramic staff embodies knowledge and expertise in the field of piezo and ceramic technology. Since 1992, PI Ceramic has been developing and producing piezo ceramics, worldwide known as PIC: PI piezo Ceramics.

PI Ceramic Strengths

- State-of-the-Art Piezo Assemblies, Transducers and Subsystems
- Design & Manufacture of Key Components for Capital Equipment & Research
- Custom and Standard Solutions
- Short Delivery Through Highly Flexible Processing
- All Key Technologies and Equipment In-House
- ISO 9001-2000, ISO 14001 and OHSAS 18001 Certified



Ceramic high-force piezo motor module

Experience and Innovation

Product Development for Faster Time-To-Market

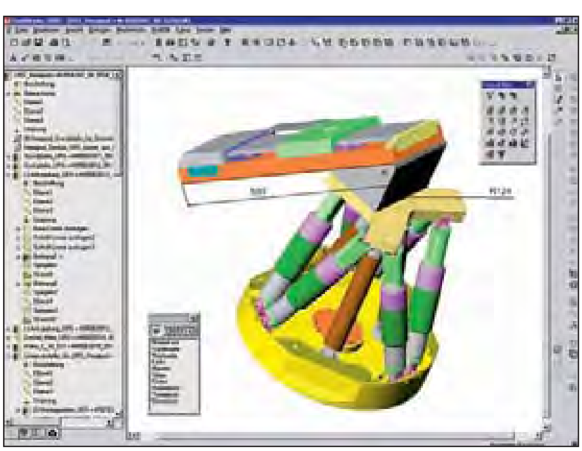
Wall of Fame: More than 100 patented and patent pending technologies related to nanopositioning, motion control and piezoelectric drive systems.

The heart of PI is the R&D department, where physicists and engineers work on technologies which will fulfill tomorrow's stringent requirements for our customers.

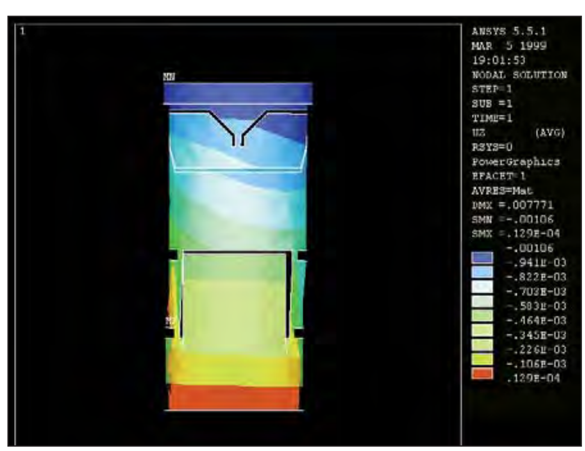
With a large percentage of PI's OEM business based on custom-designed products, the wide ranging know-how, long experience and initiative of the developers is crucial to success. Another important factor is time-to-market, the fast availability of prototypes for evaluation, which are close to the serial product.

PI R&D engineers employ state-of-the-art FEA (finite element analysis) simulation tools and CAD software to develop new electronics and mechanics systems. This assures functionality, precision and performance before the first prototype is ever built.

Photonics Circle of Excellence Award—one of a number of international distinctions received by PI for product innovation



CAD Software (custom 6-DOF Hexapod shown on screen)



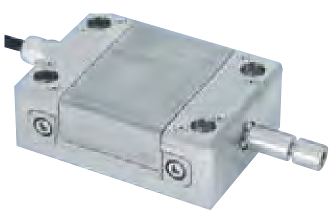
FEA stress simulation showing wire-EDM-cut flexure joint of a tip/tilt mirror system for astronomical telescopes

PiezoWalk® Linear Motors / Actuators

PiezoWalk® Precision Drives

Millimeter Travel, Nanometer Resolution, High Forces

PiezoWalk® drives break away from the limitations of conventional Nanopositioning actuators. They offer a basically unlimited travel range and still provide the characteristic features of a piezoelectric actuator: an open-loop resolution down to 30 picometers and a very high stiffness for dynamic operation and force generation. PI offers two product lines based on different versions of the PiezoWalk® principle: NEXLINE® and NEXACT®. Both provide specific advantages depending on the application.

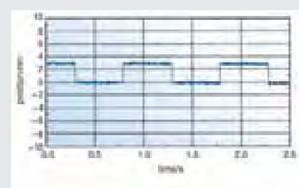


Custom PiezoWalk® linear actuator

PiezoWalk® piezo stepping drives usually consist of several individual piezo actuators and generate motion through succession of coordinated clamp / unclamp and shear-motion cycles (steps). Each cycle provides only a few microns of motion, but running at hundreds of hertz, the drive achieves continuous motion in the mm/second range.

The PiezoWalk® working principle provides high force capabilities, resolution and repeatability. These properties are typically better for piezo stepping actuators compared to inertia drives or ultrasonic motors.

The operation is possible in two different modes: a high-resolution, high dynamics analog mode within a single step, and a step mode with virtually unlimited travel range.



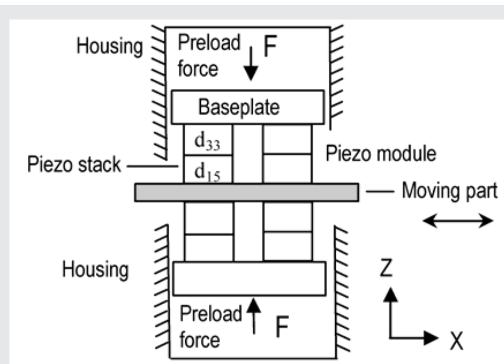
50 picometer steps with a NEXLINE® drive, measured with external ultra-high-resolution capacitive sensor. This performance provides a big safety margin for next generation nanotechnology applications

Index

Features and Advantages of PiezoWalk® Drives

- Very high resolution, limited typically only by the sensor. In fine-adjustment, analog mode, resolution of 30 picometers has been demonstrated.
- High force generation and stiffness. NEXLINE® drives can hold and generate forces to 600 N, NEXACT® to 15 N.
- PiezoWalk® drives hold a stable position to nanometer level in power-off mode. Due to the actuator design, the maximum clamping force is applied at rest.
- Because a position can be held with zero operating voltage, leakage currents cannot affect the integrity of the piezo drive.
- PiezoWalk® drives are available for non-magnetic applications such as super-conductivity experiments. They do not create magnetic fields nor are they influenced by them.
- The active parts in PiezoWalk® drives are made of vacuum-compatible ceramics. The drives also work in UV-light environments.
- NEXLINE® drives can survive shock loads of several g during transportation.
- PiezoWalk® drives are available in three levels of integration to provide flexibility for OEMs: OEM drives, packaged actuators and integrated into complex positioning systems such as multi-axis translation stages or 6-DOF Hexapods.

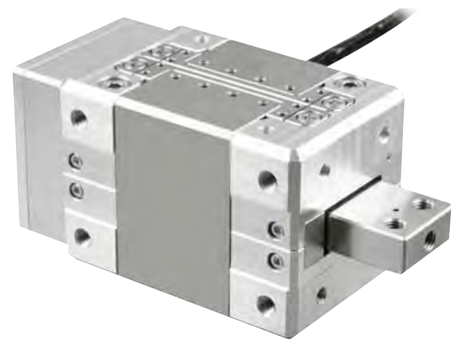
6-axis parallel-kinematic nanopositioning system (Hexapod) with N-215 based NEXLINE® high-load actuators for use in strong magnetic fields



NEXLINE® linear actuator principle

NEXLINE® High-Force Drives for Nanopositioning

NEXLINE® systems are based on very rugged, high-efficiency shear and clamping actuators and incorporate a preloading mechanism to provide pushing and holding forces up to 600 N with high lifetime. The rigid design with resonant frequencies of hundreds of hertz allows the construction of very stiff structures and helps to suppress vibration. The analog operating mode can be used for dithering and active vibration cancellation.



N-215 high-load NEXLINE® linear drive provides holding forces to 600 N and 20 mm travel

Compact NEXACT® Drives for Moderate Forces

NEXACT® drives use bending actuators which combine the feed forward and the clamping cycles. They provide push/pull forces to 15 N with maximum velocities of more than 10 mm/s at low operating voltages of 40 V. The compact and cost-effective NEXACT® drives are available with various drive electronics, ranging from cost-effective OEM drives for open-loop operation in stepping mode to the sophisticated E-861 servo-controller for high-resolution, closed-loop linear translation stages.

N-310 actuartor with E-861 servo-controller (integrated drive electronics)

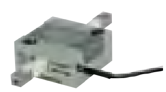
Typical Applications for PiezoWalk® Motors / Actuators

Semiconductor Technology

Nanoalignment Systems with Long Travel Ranges
Nanoimprint
CD Testing
Mask and Wafer Alignment
Objective Precision Positioning
Lithography
Optics Testing

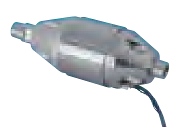
Biotechnology, Life Science, Medical Design, Medical Technology

Flow Cytometry
Cell Sorting
Electrophysiology, Patch Clamp
Intra-Cell Metrology
Cell Penetration
Microdosing
Handling
OCT, WLI
Diagnostics
Dermatology
Ophthalmology



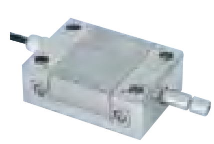
Nanotechnology, Nanofabrication, NanoAutomation®

Nanoimprint
Nanoassembly
Nanofabrication
Nanojoining
Nanomechanics
Nanomaterials Testing
Microgrippers, Manipulators



Aeronautics, Image Processing, Cryogenic & Vacuum Environments

Microwave Antenna Precision Alignment
Precision Linear Actuators
Beamline Experiments
Angular Alignment
Sample Positioning



N-111 NEXLINE® Piezo Mechanical Linear Actuator

Nanopositioning Over Long Travel, PiezoWalk® Principle

N-111 compact OEM nanopositioning actuator. In principle the movement by piezo steps allows an infinite travel range

- **Travel Range 10 mm**
- **Resolutionto 0.025 nm Open-Loop, 5 nm Closed-Loop**
- **Up To 50 N Force Generation and 70 N Holding Force**
- **Self Locking at Rest, No Heat Generation**
- **Non-Magnetic and Vacuum-Compatible Working Principle**
- **Cleanroom Compatible**

The innovative N-111 NEXLINE® OEM linear actuators are compact actuators for nanopositioning with travel ranges to 10 mm, high resolution, and generated forces to 50 N. The operating principle is based on coordinated motion of a number of highly preloaded linear and shear piezo elements acting on a runner. NEXLINE® drives thus combine long travel ranges with piezo-class precision. For closed-loop operation without an additional position sensor the N-111.2A is equipped with a linear encoder that provides 5 nm resolution over the full travel range. In open-loop operation position resolution down to 25 picometers can be achieved by use of a high-dynamics analog mode.

Application Examples

- Semiconductor technology
- Semiconductor testing
- Wafer inspection
- Nano lithography
- Nano-imprinting
- Nanometrology
- Active vibration damping
- Motion in strong magnetic fields

NEXLINE® Working Principle for Application Flexibility

NEXLINE® PiezoWalk® drives can be used wherever high loads must be positioned very precisely over long distances and then perhaps subjected to small-amplitude dynamic adjustment, as for active vibration control. By varying the combination of longitudinal and shear piezo elements, the step size, dynamic operating range (analog travel), clamping force, speed and stiffness can all be optimized for a particular application.

One Working Principle – Different Operating Modes

NEXLINE® PiezoWalk® drives overcome the limitations of conventional nanopositioning systems in their combination of long travel ranges and high resolution and stiffness. The piezoceramic clamping and shear elements act directly on a moving runner that is coupled to the moved object. While in full step mode the runner can be moved over larger distances with maximum velocity, nanostepping mode allows uniform motion with highly constant speed. In open-loop operation any position resolution may be achieved which only depends on the stability of the control signal. Analog operation over a distance of less than one step enables high-dynamics positioning with resolutions far below one nanometer.

Choice of Controllers for Optimization

NEXLINE®operation is supported by two motion controller models providing different features. The E-755 controller offers full functionality for nanometer precise positioning. The E-712 supplies more sophisticated linearization algorithms resulting in very smooth motion with highly constant velocity. It can also provide higher speed with maximum force.

Patented Technology

The products described in this document are in part protected by the following patents:
German Patent No. 10148267
US Patent No. 6,800,984

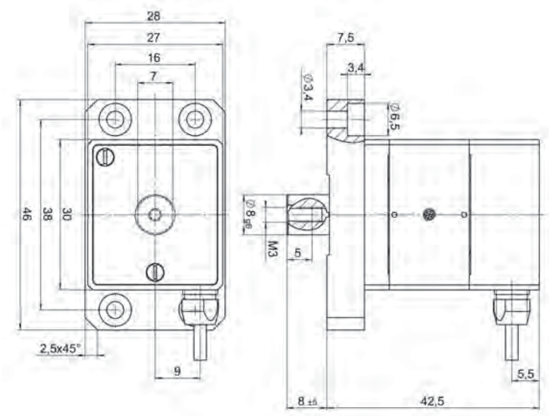
Ordering Information

N-111.20
NEXLINE® OEM Piezo Stepping Actuator, 10 mm, 50 N

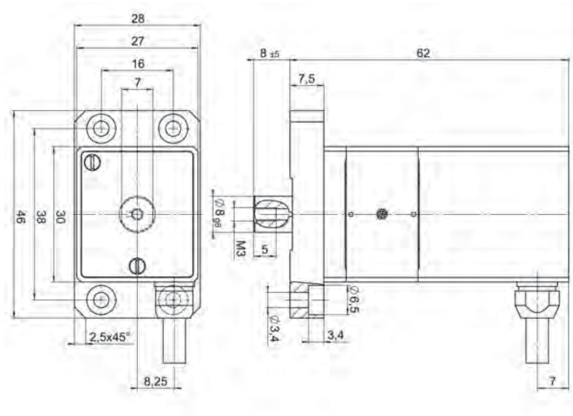
N-111.2A
NEXLINE® OEM Piezo Stepping Actuator, 10 mm, 50 N, Linear Encoder, 5 nm Resolution

Ask about custom designs!

Z / tip / tilt platform with NEXLINE® drives and position sensors; 300 mm (12'') diameter, 200 N load capacity, 1.3 mm travel range, 10 mrad tilt range



N-111.20 dimensions in mm



N-111.2A dimensions in mm

Technical Data

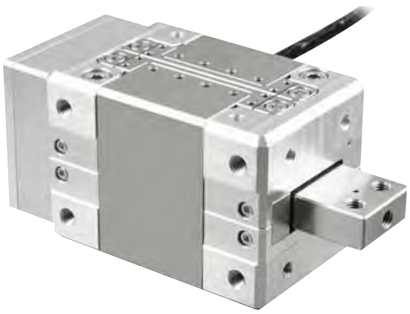
Model	N-111.20	N-111.2A	Tolerance
Active axes	X	X	
Motion and positioning			
Travel range	10 mm	10 mm	
Step size (in step mode)	10 nm to 7 µm	10 nm to 7 µm	
Travel range in analog mode	±2 µm	±2 µm	
Integrated sensor	–	Linear encoder	
Open-loop resolution	0.025 nm	0.025 nm	typ.
Closed-loop resolution	–	5 nm	
Max. velocity (10 % duty cycle, full step mode)*	1.0 mm/s	1.0 mm/s	
Max. velocity (100 % duty cycle, full step mode)*	0.6 mm/s	0.6 mm/s	
Max. velocity (100 % duty cycle, nanostepping mode)**	0.4 mm/s	0.4 mm/s	
Mechanical properties			
Stiffness in motion direction	16 N/µm	16 N/µm	±20%
Drive force (active)***	50 N	50 N	max.
Holding force (passive)	70 N	70 N	min.
Drive properties			
Motor type	NEXLINE®	NEXLINE®	
Operating voltage	±250 V	±250 V	
Miscellaneous			
Operating temperature range	-40 to 80 °C	-40 to 80 °C	
Material	Aluminium stainless steel, titanium	Aluminium stainless steel, titanium	
Mass	245 g	325 g	
Cable length	1.5 m	1.5 m	±10 mm
Connector	Sub-D connector NEXLINE® single-channel	Sub-D connector NEXLINE® single-channel plus sensor connector	
Recommended controller	E-755,101, E-712	E-755.1A1, E-712	

* Depending on drive electronics. Data refer to operation together with E-712 controller.
** Depending on drive electronics. Data refer to operation together with E-712 controller. Together with the E-755 controller a velocity of up to 0.1 mm/s (closed-loop) and 0.2 mm/s (open-loop) can be achieved. The maximum speed in nanostepping mode is set so as to ensure the highest possible velocity constancy, with no speed fluctuations while steps are being performed.
*** Data refer to full step mode operation.

PI

N-216 NEXLINE® Linear Actuator

High-Force PiezoWalk® Drive for Long-Range Nanopositioning



N-216 NEXLINE® High-Load Actuator. Feed motion is realized by piezo stepping motion which allows basically unlimited travel ranges with nanometer accuracy

- **Travel Range 20 mm**
- **Resolutionto 0.03 nm Open-Loop, 5 nm Closed-Loop**
- **Up to 800 N Holding Force**
- **Self Locking at Rest**
- **Non-Magnetic and Vacuum-Compatible Working Principle**
- **Cleanroom Compatible**

N-216 NEXLINE® high-load linear actuators are ultra-precision nanopositioning actuators with travel ranges to 20 mm and push / pull forces to 600 N. The operating principle is based on coordinated motion of a number of highly preloaded linear and shear piezo elements acting on a runner. NEXLINE® drives combine long travel ranges with piezo-class precision.

N-216 comes in two versions for open- or closed-loop operation, as well as in two different load configurations. Closed-loop versions are equipped with a linear encoder for direct position measurement of the moving runner. The encoder features 5 nm resolution over the full travel range. In open-loop operation a positioning resolution to 30 picometers can be realized by use of the high-dynamics analog operation mode.

Application Example

- Semiconductor technology
- Semiconductor testing
- Wafer inspection
- Nano lithography
- Nano-imprinting
- Nanometrology
- Active vibration damping
- Motion in strong magnetic fields

Unlimited Lifetime

The application area of NEXLINE® drives often lies in the difficult-to-access internals of machines, where nanometer-realm adjustment and vibration cancellation are required. Long lifetime is therefore a basic requirement for NEXLINE® actuators. To promote long lifetime, the controller can reduce the operating voltage on all the piezo elements to zero at any position and still maintain the full holding force.

One Working Principle – Different Operating Modes

NEXLINE® PiezoWalk® drives overcome the limitations of conventional nanopositioning systems in their combination of long travel ranges and high resolution and stiffness. The piezoceramic clamping and shear elements act directly on a moving runner that is coupled to the moved object. While in full step mode the runner can be moved over larger distances with maximum velocity, nanostepping mode allows uniform motion with highly constant speed. In open-loop operation any position resolution may be achieved which only depends on the stability of the control signal. Analog operation over a distance of less than one step enables high-dynamics positioning with resolutions far below one nanometer.

Choice of Controllers for Optimization

NEXLINE®operation is supported by two motion controller models providing different features. The E-755 controller offers full functionality for nanometer precise positioning. The E-712 supplies more sophisticated linearization algorithms resulting in very smooth motion with highly constant velocity. It can also provide higher speed with maximum force.

Ordering Information

N-216.10
NEXLINE® Piezo Stepping High-Load Actuator, 20 mm, 300 N, Open-Loop

N-216.1A
NEXLINE® Piezo Stepping High-Load Actuator, 20 mm, 300 N, Linear Encoder, 5 nm Resolution

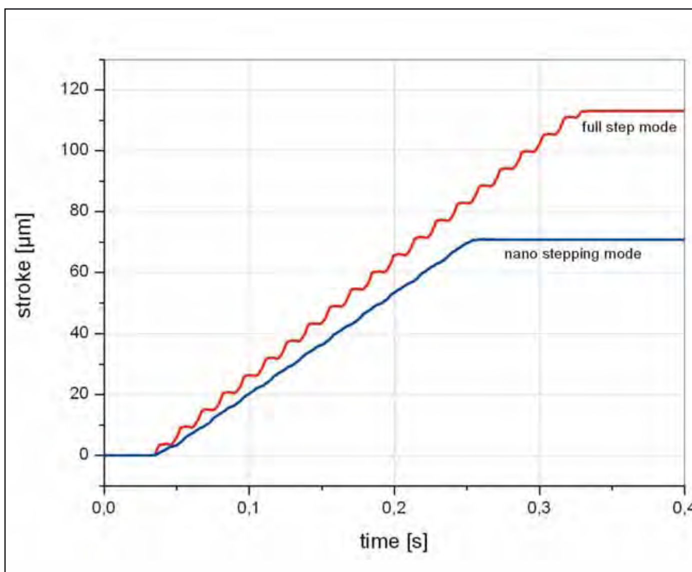
N-216.20
NEXLINE® Piezo Stepping High-Load Actuator, 20 mm, 600 N, Open-Loop

N-216.2A
NEXLINE® Piezo Stepping High-Load Actuator, 20 mm, 600 N, Linear Encoder, 5 nm Resolution

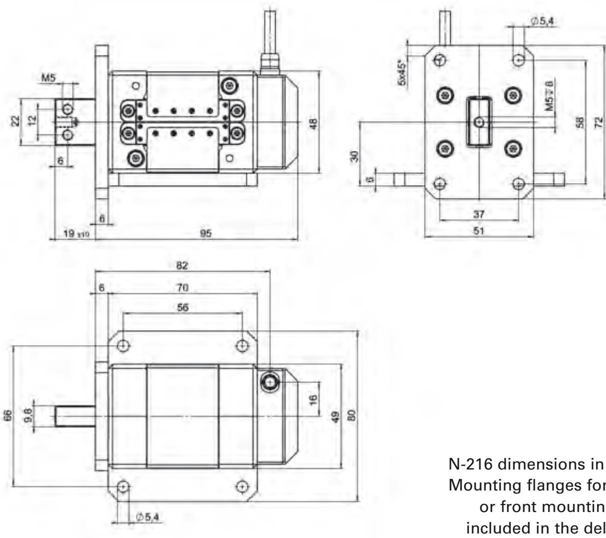
Ask about custom designs!

Patented Technology

The products described in this document are in part protected by the following patents:
German Patent No. 10148267
US Patent No. 6,800,984



Motion mode comparison of a NEXLINE® actuator: The nanostepping mode provides a very smooth motion. Full step mode allows higher speed



N-216 dimensions in mm. Mounting flanges for side or front mounting are included in the delivery

6-axis parallel kinematics (Hexapod) with integrated NEXLINE® high-load actuators, suitable for applications in strong magnetic fields

Technical Data

Model	N-216.10 / N-216.1A	N-216.20 / N-216.2A	Tolerance
Active axes	X	X	
Motion and positioning			
Displacement	20 mm	20 mm	
Step size (in step mode)	10 nm to 10 µm	10 nm to 10 µm	
Travel range in analog mode	±3 µm	±3 µm	
Integrated sensor	N-216.10: none N-216.1A: linear encoder	N-216.20: none N-216.2A: linear encoder	
Open-loop resolution	0.03 nm	0.03 nm	typ.
Closed-loop resolution	– / 5 nm (N-216.1A)	– / 5 nm (N-216.2A)	
Max. velocity (10 % duty cycle, full step mode)*	1.0 mm/s	1.0 mm/s	
Max. velocity (100 % duty cycle, full step mode)*	0.6 mm/s	0.6 mm/s	
Max. velocity (100 % duty cycle, nanostepping mode)**	0.4 mm/s	0.4 mm/s	
Mechanical properties			
Drive force (active)***	300 N	600 N	max.
Holding force (passive)	400 N	800 N	min.
Drive properties			
Motor type	NEXLINE®	NEXLINE®	
Operating voltage	±250 V	±250 V	
Miscellaneous			
Operating temperature range	-40 to 80 °C	-40 to 80 °C	
Material	Aluminum, stainless steel	Aluminum, stainless steel	
Mass	1150 g	1250 g	
Cable length	2.0 m	2.0 m	
Connector	Sub-D connector NEXLINE® single-channel N-216.1A: plus sensor connector	Sub-D connector NEXLINE® single-channel N-216.2A: plus sensor connector	
Recommended controller	E-755, E-712	E-755, E-712	

* Depending on drive electronics. Data refer to operation together with E-712 controller.

** Depending on drive electronics. Data refer to operation together with E-712 controller. Together with the E-755 controller a velocity of up to 0.1 mm/s (closed-loop) and 0.2 mm/s (open-loop) can be achieved. The maximum speed in nanostepping mode is set so as to ensure the highest possible velocity constancy, with no speed fluctuations while steps are being performed.

*** Data refer to full step mode operation.

N-310 NEXACT® OEM Miniature Linear Motor/Actuator

Compact, High-Speed PiezoWalk® Drive

N-310 Actuator with E-861 Servo-Controller (integrated drive electronics)

- **20 mm Standard Travel Range, Flexible Choice of the Runner Length**
- **Compact and Cost-Effective Design**
- **0.03 nm Resolution****
- **To 10 N Push/Pull Force**
- **Low Operating Voltage**
- **Self Locking at Rest, No Head Dissipation, Nanometer Stability**
- **Non-Magnetic and Vacuum-Compatible Working Principle**

N-310 NEXACT® PiezoWalk® linear drives feature travel ranges of 20 mm and push/pull force capacities to 10 N in a compact package of only 25 x 25 x 12 mm. With their high resolution, NEXACT® drives, are ideal for high-precision positioning over long travel ranges.

Application Examples

- Semiconductor technology
- Wafer inspection
- Nano lithography
- Surface Measurement Technique
- Profilometry
- Microscopy
- Motion in strong magnetic fields

The N-310 can be operated in open-loop and closed-loop mode (with the addition of an external position sensor). A variety of NEXACT® controllers facilitates the integration into micro- or nanopositioning applications.

Advantages of PiezoWalk® Piezo Stepping Drives

NEXLINE® and NEXACT® drives offer several advantages over traditional drive technologies:

- Resolution in the picometer range
- Compact dimensions
- High drive forces from ten newtons (NEXACT®) up to several hundred newtons (NEXLINE®)
- High-dynamics performance with sub-microsecond response
- Self-locking when powered down; no holding current
- Zero backlash, no wear or maintenance, no mechanical components like gears or leadscrews.
- Non-Magnetic and Vacuum Compatible Operating Principle

Working Principle for Application Flexibility

NEXACT® PiezoWalk® technology overcomes the limitations of conventional nanopositioning drives and combines virtually unlimited travel ranges with high stiffness in a very small package. Furthermore, NEXACT® actuators provide piezo-class resolution (far below one nanometer) and millisecond responsiveness. The special drive design reduces the operating voltage to 45 V and below.

In operation, piezoceramic bending elements act on the runner, which is connected to the moving part of the application. The length of the runner determines the travel range. Force capacity, resolution and velocity are determined by the piezo geometry and drive electronics and are scalable. To move the runner over longer distances the stepping mode is used, whereas for distances smaller than one step, the linear (analog) mode enables high-dynamics positioning with resolutions far below one nanometer.

Wear- and Maintenance-Free

In contrast to ordinary DC or stepper motor drives, the PiezoWalk® drives effect linear motion directly, without the need to transform rotation with mechanical elements such as gears, leadscrews and nuts. Therefore, mechanical limitations such as backlash and wear are eliminated and the drive is maintenance-free.

Ordering Information

N-310.01
NEXACT® OEM linear drive, 20 mm, 10 N

Ask about custom designs

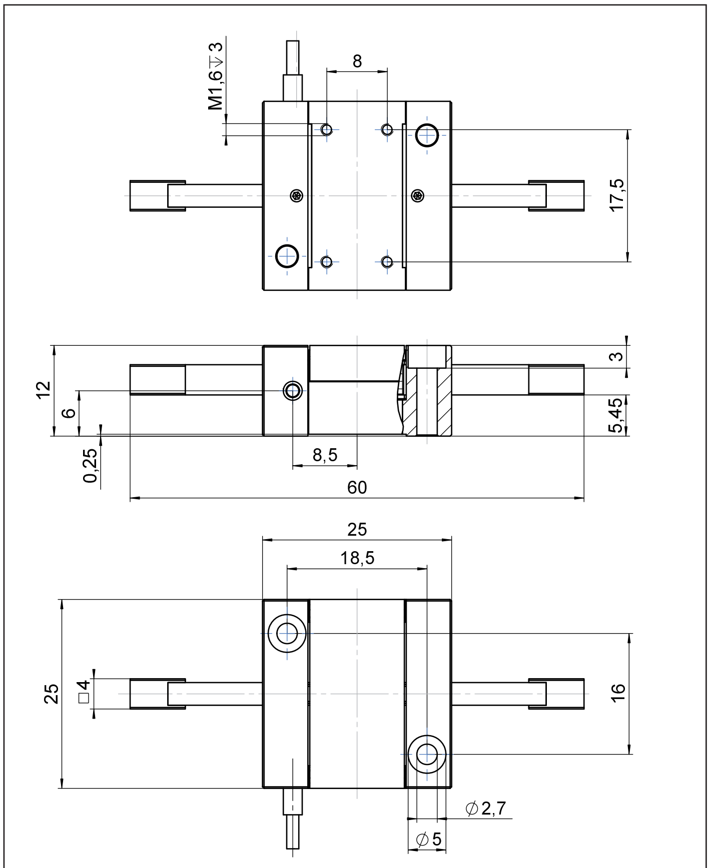
Self-Locking PiezoWalk® Piezo Stepping Drive

NEXLINE® and NEXACT® exhibit high stiffness and are self-locking even when powered down due to the clamping action of the piezo actuators in the mechanics. This entails nanometer position stability at rest, with no heat dissipation or servo-dither.

Controller and Drive Electronics Optimized for the Application

NEXACT® actuators require special drive electronics to control the complex stepping sequences. The E-860 series NEXACT® controllers are available in different open-and closed-loop versions. For example, the E-861 includes a complete NEXACT® servo-controller with low-noise, 24-bit drivers and a powerful DSP. It also comes with ample software for easy integration and highly effective computer control. For applications which do not require the highest resolution lower-priced drive electronics, ranging all the way to OEM boards, can be ordered.

The products described in this document are in part protected by the following patents: German Patent No. P4408618.0



N-310.01 Actuator, dimensions in mm


Translation stage with N-310 NEXACT® drive. The positioner offers 20 mm travel range with an encoder resolution of 25 nm

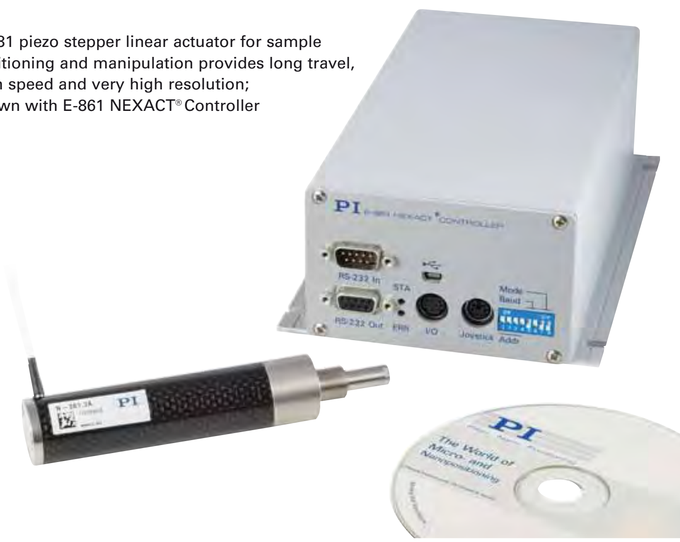
Model	N-310.01	Tolerance
Active axes	X	
Motion and positioning		
Travel range	20 mm	
Step size (in step mode)	5 nm to 5 µm	
Travel range in analog operation	7 µm	max.
Open-loop resolution	0.03 nm**	typ.
Step frequency	1.5 kHz*	max.
Max. speed	10 mm/s*	max.
Mechanical properties		
Push/Pull force (active)	10 N	max.
Drive properties		
Drive type	NEXACT® linear drive	
Operating voltage	-10 V to +45 V	
Miscellaneous		
Operating temperature range	0 to 50 °C	
Body material	Stainless steel, non-magnetic	
Mass	50 g	±5 %
Cable length	1.5 m	±10 mm
Connector	HD Sub-D connector 15 pin, single channel	
Recommended controller/driver	E-860-series (see p. 1-20)	

*Depending on the control electronics.
**Depending on the drive electronics. 5 nm with E-861.

N-381 NEXACT® Linear Actuator, Manipulator, Piezo Stepper

High-Resolution PiezoWalk® Linear Actuator with Optional Position Sensor

N-381 piezo stepper linear actuator for sample positioning and manipulation provides long travel, high speed and very high resolution; shown with E-861 NEXACT® Controller



- **Travel Range 30 mm**
- **Zero-Wear Piezo Stepping Drive, Ideal for Micro- and Nano-Manipulation**
- **Integrated Linear Encoder Option for Highest Accuracy with 20 nm Resolution**
- **Very High Acceleration, e.g. for Cell Penetration**
- **Two Operating Modes: Continuous Stepping Mode and Continuously Variable, High-Dynamics Analog Mode for 30 pm Resolution****
- **Up to 10 N Force Generation**
- **Self Locking at Rest, no Heat Generation**
- **Smooth Motion, no Closed-Loop Jitter**
- **Vacuum-Compatible and Non-Magnetic Versions**

The compact N-381 linear actuators are ideal drives and micro manipulators e.g. for biotechnology and nanotechnology applications. Rapid accelerations, velocities of 10 mm/s and forces up to 10 N enable high-dynamics and throughput for automation tasks. The PiezoWalk® drive principle allows long travel ranges and fast oscillations of 7 µm amplitude with frequencies up to several 100 Hz. This “analog mode” can be used to provide rapid acceleration, e.g. in cell penetration applications, or smooth motion for dynamic laser tuning or even for active damping of oscillations. Two models are available: The N-381.3A model is equipped with a high-resolution position sensor, allowing sub-micrometer repeatability in closed-loop operation. The N-381.30 open-loop version is intended for high precision applications where the absolute position is not important or is controlled by an external loop (video, laser, quadcell, etc.).

Application Examples

- Drive unit for scanning stage
- Cell manipulation, biohandling
- Micromanipulation
- Life science
- Photonics
- Laser tuning
- Motion in strong magnetic fields

Piezo Stepping Drive—the Multi-Functional Piezo Linear Motor

A great advantage characteristic of the NEXACT® piezo stepping drive is its dual-mode operating principle combining the best features of other piezo motor designs, such as high resolution, high force and high speed into one compact unit. At the target position the drive requires no current and generates no heat while providing long-term, nanometer stability. This autolocking feature also completely eliminates servo-jitter as it occurs with other closed-loop motors. Since motion is not based on dynamic friction as with piezo inertial drives (stick-slip-motors) but solely caused by the nanometer precise motion of clamped piezo actuators, there is no wear to limit the lifetime. When operated in closed-loop, excellent velocity control is achieved.

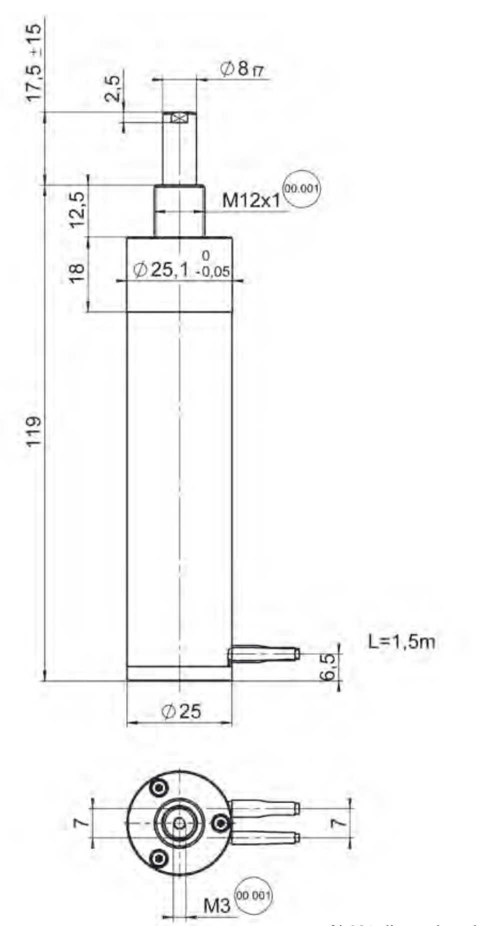
Ordering Information

N-381.3A
NEXACTUATOR® Linear Actuator, 30 mm, 20nm Encoder Resolution

N-381.00
NEXACTUATOR® Linear Actuator, 30 mm, Open-Loop

Available on request

Ask about custom designs!



N-381 dimensions in mm

Working Principle for Application Flexibility

NEXACT® PiezoWalk® technology overcomes the limitations of conventional nanopositioning drives and combines virtually unlimited travel ranges with high stiffness in a very small package. Furthermore, NEXACT® actuators provide piezo-class resolution (far below one nanometer) and millisecond responsiveness. The special drive design reduces the operating voltage to 45 V and below.

In operation, piezoceramic bending elements act on the runner, which is connected to the moving part of the application. The length of the runner determines the travel range and can be chosen as required. To move the runner over longer distances the stepping mode is used, whereas for distances smaller than one step, the analog mode enables high-dynamics positioning with resolutions far below one nanometer.

Controllers and Drivers Optimized for the Application

NEXACT® actuators require special drive electronics to control the complex stepping sequences. The E-861 (see p.1-20) includes a complete NEXACT® servo-controller with low-noise drivers and a powerful DSP. It also comes with ample software for easy integration and highly effective computer control. For applications which do not require the highest resolution, the E-862 (see p. 3-10) lower-priced drive electronics, can be ordered.

The products described in this document are in part protected by the following patents:

German Patent No. P4408618.0

Model	N-380 Open-Loop	N-381 Closed-Loop
Active axes	X	X
Motion and positioning		
Travel range	30 mm	30 mm
Step size (in step mode)	0.1 to 15 µm	–
Integrated sensor	–	Incremental linear encoder
Sensor resolution	–	20 nm*
Travel range in analog mode	7 µm	7 µm
Open-loop resolution	0.03 nm**	0.03 nm**
Closed-loop resolution	–	20 nm*
Step frequency	0 to 800 Hz	–
Max. velocity	10 mm/s*	10 mm/s*
Mechanical properties		
Stiffness in motion direction	2.4 N/µm	2.4 N/µm
Max. push / pull force (active)	10 N	10 N
Max. holding force (passive)	15 N	15 N
Lateral force	10 N	10 N
Drive properties		
Drive type	NEXACT® linear drive	NEXACT® linear drive
Operating voltage	-10 V to +45 V	-10 V to +45 V
Miscellaneous		
Operating temperature range	0 to 50 °C	0 to 50 °C
Material	Stainless steel / CFRP	Stainless steel / CFRP
Mass	250 g	255 g
Cable length	1.5 m	1.5 m
Connector	15-pin HD-Sub-D connector, one channel	15-pin HD-Sub-D connector, one channel
Recommended controller/driver	E-860 series (see p. 1-20)	E-861.1A1 (see p. 1-20)

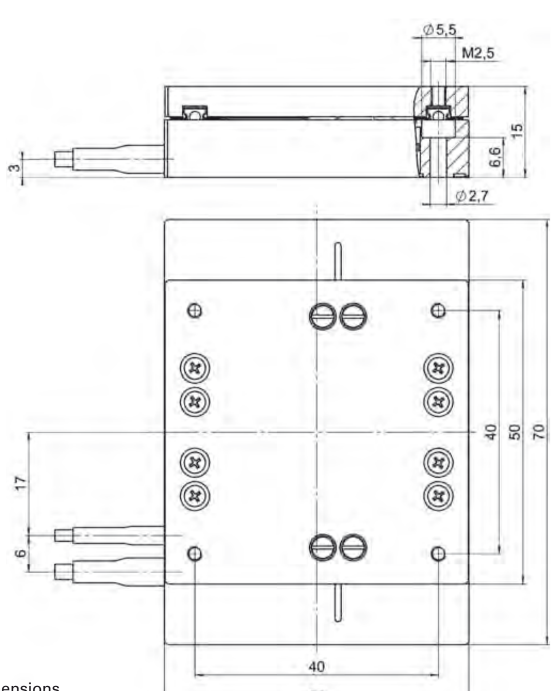
*With E-861. Depending on drive electronics.
**Depending on the drive electronics. 1 nm with E-861.

N-661 Miniature Linear Slide with NEXACT® Drive

PiezoWalk® Drive Provides Nanometer Precision, Smooth Motion and Rapid Response

The N-661 miniature linear stage integrates a PiezoWalk® NEXACT® linear motor combined with a high-resolution linear encoder. It provides 20 mm travel and resolution down to the nanometer range.

- **Travel Range 20 mm**
- **Self Locking at Rest, no Heat Generation, no Servo Dither**
- **Compact Design: 70 x 50 x 20 mm**
- **Zero-Wear Piezo Stepping Drive, Ideal for Micro- and Nano-Manipulation**
- **Integrated Linear Encoder Option for Highest Accuracy with 20 nm Resolution**
- **Two Operating Modes: Continuous Stepping Mode and Continuously Variable, High-Dynamics Analog Mode for 30 pm Resolution**
- **Up to 10 N Force Generation**



Dimensions of N-661.21A

The compact N-661 nanopositioning stage is based on the NEXACT® PiezoWalk® drive. This dual-mode, high-performance piezo stepping linear motor can provide sub-nanometer resolution and high force, along with very rapid response. When run in its analog mode, fast oscillations with amplitudes up to 7 microns and resolutions down to 30 pm can be achieved. This mode is of great value in high-throughput applications as well as in dynamic laser tun-ing, cell penetration applications, or even for active vibration damping. The stage is equipped with a precision guiding system and an optical linear encoder to enable highly repeatable positioning.

Ordering Information

N-661.21A
Miniature NEXACT® Translation Stage, 20 mm, Linear Encoder, 20 nm Resolution

Ask about custom designs

Application Examples

- Life science
- Photonics
- Laser tuning
- Motion in strong magnetic fields

The products described in this document are in part protected by the following patents: German Patent No. P4408618.0

Technical Data

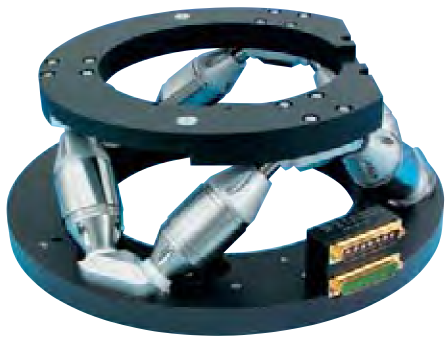
Model	N-661.21A
Active axes	X
Motion and positioning	
Travel range	20 mm
Step size in stepping mode (open-loop)	To 5 µm
Integrated sensor	Linear encoder
Sensor resolution	20 nm *
Travel range in analog mode	7 µm
Open-loop resolution	0.03 nm
Closed-loop resolution	20 nm*
Bidirectional repeatability	200 nm
Pitch	500 µrad
Yaw	150 µrad
Max. Step frequency (open-loop)	0.8 kHz
Max. velocity	10 mm/s*
Mechanical properties	
Stiffness in motion direction	2.4 N/µm
Max. load capacity	20 N
Max. push / pull force (active)	10 N
Max. holding force (passive)	15 N
Lateral Force	20 N
Drive properties	
Drive type	NEXACT® linear drive
Operating Voltage	-10 V to +45 V
Miscellaneous	
Operating temperature range	0 to 50 °C
Material	Aluminum
Mass	150 g
Cable length	1.5 m
Connector	15-pin sub-HDD connector, one channel
Recommended controller/driver	E-861.1A1 Controller for NEXACT® (see p. 1-20)

*With E-861. Depending on drive electronics.

PI

N-515K Non-Magnetic Piezo Hexapod

6-Axis Precision Positioning System with NEXLINE® Linear Drives



6-axis parallel kinematics (Hexapod) with integrated N-215 NEXLINE® high-load actuators, suitable for applications in strong magnetic fields

- **Travel Ranges 10 mm Linear, 6° Rotation**
- **Large Clear Aperture Ø 202 mm**
- **Non-Magnetic**
- **Nanometer Resolution**
- **Low-Profile: 140 mm Height Only**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**
- **Up to 500 N Force Generation**
- **Self Locking at Rest, No Heat Generation**

Model	Travel Range	Load capacity	Dimensions
N-515KNPH NEXLINE® Piezo Hexapod	X, Y, Z: 10 mm θ_X, θ_Y, θ_Z: 6°	50 kg	Outer Ø baseplate, 380 mm Ø moved platform (top) 300 mm 140 mm height

N-510 High-Force NEXLINE® Z/Tip/Tilt Platform

Nanometer Precision for Semiconductor Industry, Wafer Alignment

Z, tip, tilt nanopositioning platform with 3 integrated drives (tripod design)

- **Self Locking at Rest, No Heat Generation**
- **Vacuum Compatible and Non-Magnetic Designs Feasible**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**
- **NEXLINE® Piezo Walking Drive Free from Wear and Tear**
- **Load Capacity 200 N**
- **High Precision with Integrated 5 nm Incremental Sensors + Picometer Resolution Dithering Mode**

Model	Travel	Load capacity	Linear velocity	Dimensions
N-510 NEXLINE® Z, tip, tilt platform	1,3 mm vertical range 10 mrad tilt angle	200 N	0.2 mm/s	Ø 300 mm (12´´) clear aperture Ø 250 mm

N-510K High-Stiffness NEXLINE® Z Stage

High-Precision Positioning, with Capacitive Sensors

The N-510KHFS hybrid-drive nanopositioner offers maximum accuracy for semiconductor inspection applications

- **Self Locking at Rest, No Heat Generation**
- **Hybrid Drive: PiezoWalk® plus PICMA®**
- **Travel Range: 400 µm Coarse + 40 µm Fine**
- **2 nm Closed-Loop Resolution**
- **Direct Metrology: One Single Control Loop with Capacitive Sensors**
- **High Push and Holding Force to 25 N**
- **Piezo Walking Drive w/o Wear and Tear & Outstanding Lifetime due to PICMA® Piezo Actuators**

Model	Vertical V travel	elocity	Bidirectional repeatability	Load capacity	Dimensions
N-510KHFS Hybrid-Focus System	400 µm coarse 40 µm fine	1 mm/sec	50 nm (full travel)	25 N	Ø 300 mm 68.5 mm height

Notes on Specifications for PiezoWalk® Drives

Motion and Positioning

Travel Range

The maximum allowed travel is limited by the length of the output shaft in a PiezoWalk® drive. If present, the distance between two limit switches defines the travel range.

Step size (in step mode)

In step mode, the step size can be defined within the given range. Bigger steps allow higher velocity while smaller steps are for fine adjustment tasks.

Analog mode travel range

The analog mode travel range describes approximately half of the maximum stepsize. The analog travel mode allows for sub-nanometer motion resolution.

Open-loop resolution

Resolution of PiezoWalk® drives is basically infinitesimal because it is not limited by stiction and friction. Instead of resolution, the noise equivalent motion in analog mode is specified. Values are typical results (RMS, 1 sigma).

Closed-loop resolution

Requires position feedback. Resolution of PiezoWalk® drives is basically infinitesimal because it is not limited by stiction and friction. Instead of resolution, the noise equivalent motion in closed-loop analog mode is specified. Values are typical results (RMS, 1 sigma). For linear encoders, the closed-loop resolution describes the resolution of the of the position feedback sensor system.

Step frequency

Maximum operating frequency of the drive in step mode. The step frequency depends on the controller. It is recommended to operate PiezoWalk® drives with PI controllers only.

Max. velocity

The maximum velocity depends on the used controller. The main parameters which influence the velocity are the step frequency and the step size.

Mechanical properties

Stiffness in motion direction

The stiffness in motion direction has a typical tolerance of ±20 %

Push/pull force (active)

Active force limit in operating direction. The maximum force depends on the velocity.

Holding force (passive)

A main feature of piezomotor linear drives is the self-locking capability at rest without current consumption and heat generation.

Drive properties

Operating voltage

Max. voltage range for the analog mode travel range. The voltage is supplied by the PI drive electronics.

Miscellaneous

Operating temperature range

Safe operation, no damage to the drive. All technical data specified in the data sheet refer to room temperature (22 °C ±3 °C)

Mass

Typical tolerance: ±5 %

Cable length

Typical tolerance: ±10 mm

Recommended controller / driver

To reach the specifications and to avoid damage, it is strongly recommended to use PI drive and control electronics only. The drive electronics supplies the operating voltage and supports the motion modes of a PiezoWalk® drive.

PILine® Ultrasonic Piezo Linear Motors

High-Speed Precision Actuators

PILine® Ultrasonic Piezomotors – Working Principle

PILine® linear piezomotors are based on a novel, patented ultrasonic drive developed by PI. Ultrasonic oscillations of a piezoceramic actuator are transferred to linear motion along a friction bar, which is attached to the moving part of a mechanical setup.

At the heart of the system is a monolithic piezoceramic plate, segmented by two electrodes. Depending on the desired direction of motion, the left or right electrode of the piezoceramic plate is excited to produce high-frequency eigenmode oscillations at tens to hundreds of kilohertz. An alumina friction tip (pusher) attached to the plate moves along an inclined linear path at the eigenmode frequency.

The pusher is preloaded against the friction bar which is attached to the slider, turntable, etc. Through its oscillations, it provides micro-impulses that drive the moving part forward or backwards.

With each oscillatory cycle, the mechanics executes a step of a few nanometers; the macroscopic result is smooth motion with a virtually unlimited travel range. State-of-the-art ultrasonic motors can produce accelerations to 5 g and velocities to 500 mm/s.

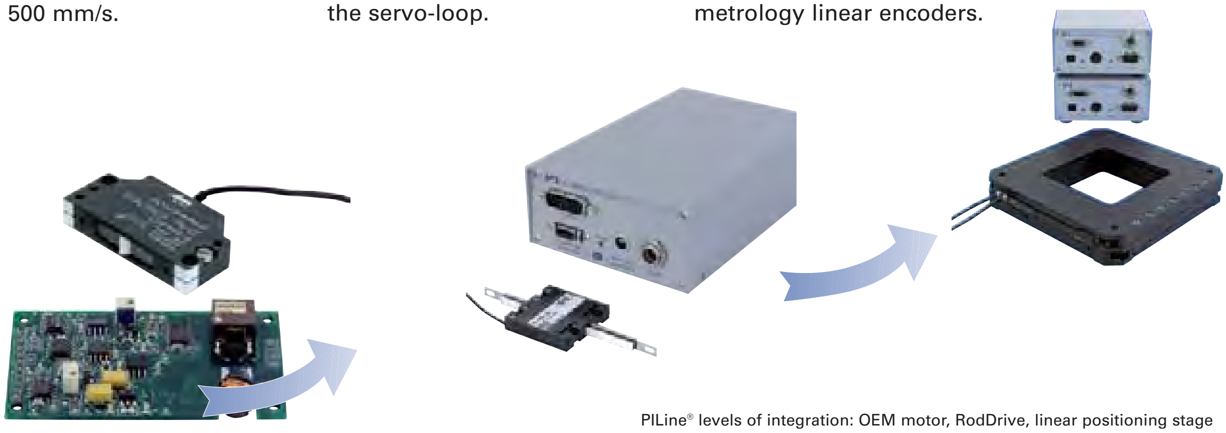
Ultrasonic motors cannot provide the unlimited resolution of linear piezo actuators and flexure-guided piezo positioning stages. These motors transfer motion through friction, which is why their repeatability is limited to about 50 nm. Much higher resolution and holding forces can be achieved with PiezoWalk® piezomotors / drives (see p. 1-3 *ff*).

PILine® Levels of Integration

PILine® ultrasonic drive products are offered in three different levels of integration. The drive electronics and controller can be chosen accordingly.

- P-661 and P-664 OEM motors require the greatest amount of care at the customer's site. Motor and friction bar – the length depends on the desired travel range – have to be integrated into a mechanical setup. Operation requires preload of the motor against the friction bar, guiding and, if necessary, the servo-loop.
- M-674 RodDrives can replace classical drive elements like rotary motor / leadscrew assemblies, or magnetic linear drives integrated into a micropositioner or handling device. Integration requires guiding and – if necessary – the servo-loop.
- Linear positioning stages represent the highest level of manufacturer integration. The piezomotor is integrated completely in a high-quality mechanical setup including the servo-loop with direct-metrology linear encoders.

State-of-the-art PILine® ultrasonic motors are based on a simple construction allowing for the design of low-cost drive units and extremely compact, high-speed micro-positioning stages smaller than a matchbox



PILine® levels of integration: OEM motor, RodDrive, linear positioning stage

Features and Advantages of PILine® Ultrasonic Piezomotors

■ Compact Size: the direct-drive principle allows the design of ultra-compact translation stages. The M-662, for example, provides 20 mm travel in a 28 x 28 x 8 mm package.

■ Low Inertia, High Acceleration, Speed and Resolution: PILine® drives achieve velocities to 500 mm/s and accelerations to 5 g. They are also very stiff, a prerequisite for their fast step-and-settle times – on the order of a few milliseconds – and provide resolution to 10 nm. The lack of a leadscrew means no lubricant flow or material relaxation to cause submicron creep. There is also no rotational inertia to limit acceleration and deceleration.

■ Excellent Power-to-Weight Ratio: PILine® drives are optimized for high performance in a minimum package. No comparable drive can offer the same combination of acceleration, speed and precision.

■ Safe: The minimum inertia of the moving platform together with the "slip clutch" effect of the drive provide better protection of precision fixtures / devices than leadscrew-driven stages. Despite the high speeds and accelerations, there is a much lower risk of pinching fingers or other injuries than with conventional drives. This means users may not need interlocks, light curtains or other measures to keep them safe.

■ Self-Locking Feature: PILine® drives create a braking force when not energized without the position shift common with conventional mechanical brakes. Other benefits of the self-locking are the elimination of servo dither and steady-state heat dissipation.

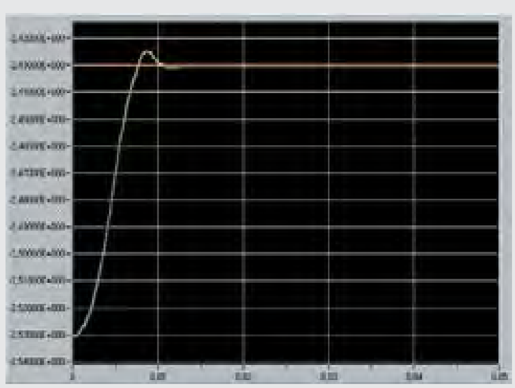
■ Vacuum Compatibility: Vacuum compatible versions of PILine® drives are available.

■ Negligible EMI: PILine® drives do not create magnetic fields nor are they influenced by them, a decisive advantage in many applications.

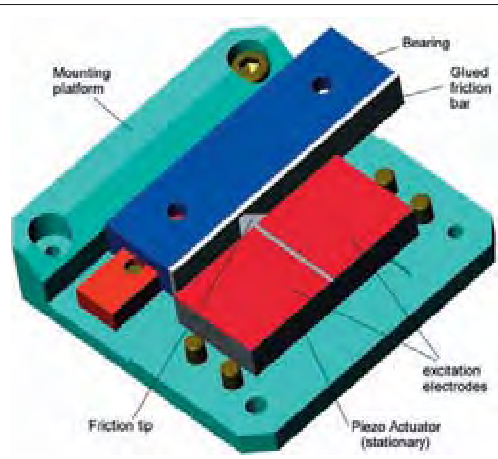
■ Custom Solutions / Flexibility for OEMs: PILine® drives are available in open-loop and closed-loop translation stages and as OEM components. PI develops and manufactures all piezo ceramic components in-house. This gives us the flexibility to provide custom motors (size, force, environmental conditions) for OEM and research applications.

■ Quality, Lifetime, Experience: Based on PI's 4 decades of experience with piezo nanopositioning technology, PILine® drives offer exceptional precision and reliability with an MTBF of >20,000 hours. Rotating components such as gears, shafts and moving cables that are prone to failure in conventional motion systems, are not part of the PILine® design.

Custom high-force ultrasonic piezo motors can provide forces to 50 N



Settling behavior of a PILine® M-663 linear stage, 100 µm step. A stable position to within 0.1 µm can be reached in only 10 ms



Principle design of a PILine® ultrasonic piezomotor-driven translation stage

Typical Applications for PILine® Ultrasonic Motors

Microscopy/Imaging

Fast sample positioning
XY-stages
Long range scanning

Biotechnology, Life Science

Microdosing
Dispensing
Nano/microliter pumps
Fast positioning
Bio-handling

Medical Design, Medical Technology

Screening
Fast positioning
Cell penetration, microdosing
Handling
Non-magnetic actuators

Nanotechnology, Nanofabrication, NanoAutomation®

Precision positioning of components (linear and rotation)
Precision actuation
Microgrippers
Manipulators

Semiconductor Technology

Long-range placement and positioning

Variety of PILine® ultrasonic piezomotors, translation stages and motion controllers

P-661 PILine® Piezo Linear Drive

Fast, Compact OEM Ultrasonic Linear Motor

PILine® P-661 OEM piezo linear motor

- **Patented Principle Features with High Forces in Small Space**
- **Max. Velocity 500 mm/s**
- **Acceleration to 5 g**
- **Min. Incremental Motion to 0.05 µm**
- **Self-Locking to 1.5 N**
- **No Electro-Magnetic Fields**
- **MTBF 20,000 h**
- **Integrated Actuators & Positioning Systems Also Available**

PILine® Linear Motors – Small, Fast, Highly Effective

Despite their small size, PILine® linear motors generate high driving and holding forces.

Application Examples

- Biotechnology
- R&D
- Semiconductor testing
- Mass storage device testing
- Metrology
- Micromanipulation
- Microscopy
- Photonics packaging
- Quality assurance testing

PILine® motors have a new, patented, ultrasonic drive developed by PI. The core piece of the system is a piezoceramic plate, which is excited to produce high-frequency eigenmode oscillations. A friction tip attached to the plate moves along an inclined linear path at the eigenmode frequency. Through its contact with the friction bar, the moving part of the mechanics drives forward or backwards. With each oscillatory cycle, the mechanics executes a step of a few nanometers; the macroscopic result is smooth motion with a virtually unlimited travel range.

High Speed and Acceleration

PILine® piezomotor drives can provide accelerations of up to 5 g and speeds of up to 500 mm/s, together with high resolution and high holding force. Because the ceramic stator is pressed against the slider, holding forces are generated when the motor ist powered down. The result is very high position stability without the heat dissipation common in conventional linear motors.

Accessories for Easy Integration

PILine® piezomotors require a special drive electronics to generate the ultrasonic oscillations for the piezoceramic element. The drive electronics is available as OEM board, stand-alone device or integrated controller and therefore not inclued in the delivery. PI offers friction bars with different lengths.

Long Lifetime

PI has over 30 years experience with piezo technology and nanopositioning. PILine® drives offer high precision and reliability, with over 20,000 hours MTBF. This is because PILine® piezo linear motor drives have no mechanical components such as shafts and gears which can cause failures in conventional motors.

Ordering Information

P-661.P01
PILine® Miniature Linear Piezomotor, 2 N

Accessories:

P-661.B01
Friction Bar for P-661 PILine® Miniature Linear Piezomotor, 15 mm

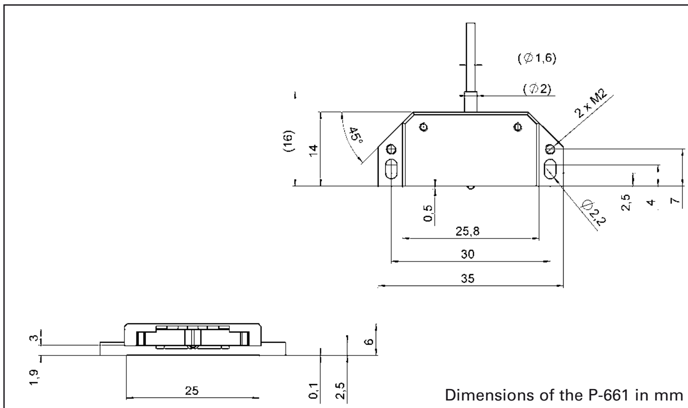
P-661.B02
Friction Bar for P-661 PILine® Miniature Linear Piezomotor, 25 mm

P-661.B05
Friction Bar for P-661 PILine® Miniature Linear Piezomotor, 55 mm

C-184.161
Analog OEM Driver Board for PILine® P-661 Motors

C-185.161
Analog Stand-Alone Drive Electronics with Power Supply for PILine® P-661 Motors

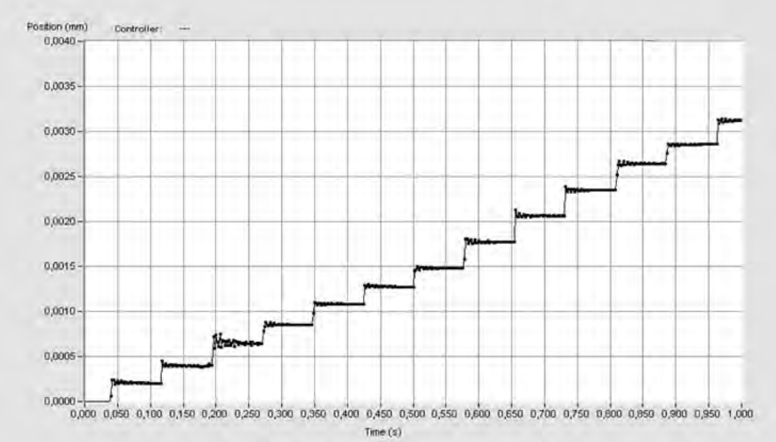
Controller for closed-loop operation are available as C-867 s. p. 4-116.



Dimensions of the P-661 in mm

Note

The products described in this document are in part protected by the following patents:
US Pat. No. 6,765,335
German Patent No. 10154526



0.3 µm steps performed by P-661 piezomotor integrated in an M-662 translation stage

Technical Data

Model	P-661.P01	Units	Tolerance
Motion and positioning			
Travel range	No limit*	mm	
Minimum incremental motion, open-loop	0.05**	µm	typ.
Max. velocity	500	mm/s²	
Mechanical properties			
Stiffness when powered down	0.7	N/µm	±10 %
Holding force when powered down	1.5	N	max.
Push / pull force	2	N	max.
Preload on friction bar	9	N	±10 %
Drive properties			
Resonant frequency	210	kHz	typ.
Motor voltage range	120 (peak-peak) 42 (RMS)	V	
Operating voltage drive electronics	12	V	
Electrical power drive electronics	5	W	
Miscellaneous			
Operating temperature range	-20 to +50	°C	
Body material	Al (black anodized)		
Mass	0.01	kg	±5 %
Cable length	1.6	m	±10 mm
Connector	Open leads		
Recommended controller/driver	C-184.161 OEM board C-185.161 in box		
Dimensions	14 x 35 x 6	mm	
MTBF	>20,000	h	

* The travel range of piezo linear motors is virtually unlimited and depends on the length of the friction bar, which is available separately.
** The minimum incremental motion is a typical value that can be achieved in the open-loop mode of a piezomotor stage. To reach the specs it is important to follow the mounting guidelines of the OEM-motors.

U-164 PILine® Piezo Linear Drive

Fast, Compact OEM Ultrasonic Linear Motor

OEM ultrasonic piezo linear motor U-164.01

- **Patented Principle Features with High Forces in Small Space**
- **Easy Mounting**
- **Max. Velocity 500 mm/s**
- **Acceleration up to 5 g**
- **Min. Incremental Motion to 0,05 µm**
- **Self Locking, Push-/Pull Forces to 4 N**
- **No Electro-Magnetic Fields**
- **Integrated Actuators & Positioning Systems Also Available**

PILine® Linear Motors—Small, Fast, Highly Effective

Despite their small size, PILine® linear motors generate high driving and holding forces. PILine® piezo motors have a new, patented, ultrasonic drive developed by PI. The core piece of the system is a piezoceramic plate, which is excited with high-frequency eigenmode oscillations. A friction tip attached to the plate moves along an inclined linear path at the eigenmode frequency. Through its contact with the friction bar, the moving part of the mechanics drives forward or backwards. With each oscillatory cycle, the mechanics executes a step of a few nanometers; the macroscopic result is smooth motion with a virtually unlimited travel range.

Application Examples

- Biotechnology
- R&D
- Semiconductor testing
- Mass storage device testing
- Metrology
- Micromanipulation
- Microscopy
- Photonics packaging
- Quality assurance testing

High Speed and Acceleration

PILine® piezomotor drives can provide accelerations of up to 5 g and speeds of up to 500 mm/s, together with high resolution and high holding force. Because the ceramic stator is pressed against the slider, holding forces are generated when the motor ist powered down. The result is very high position stability without the heat dissipation common in conventional linear motors.

Accessories for Easy Integration

The PILine® motors require a special drive electronics to generate the ultrasonic oscillations for the piezoceramic element. The drive electronics is available as OEM board, standalone device or integrated inside a controller and therefore not included in the delivery. PI offers friction bars with different lengths.

Long Lifetime

PI has over 30 years experience with piezo technology and nanopositioning. PILine® drives offer high precision and reliability. This is because PILine® piezo linear motor drives have no mechanical components such as shafts and gears which can cause failures in conventional motors.

Ordering Information

U-164.01
PILine® Piezo Linear Motor, 4 N

Accessories:

P-664.B01
Friction Bar for PILine® Miniature Linear Piezomotor, 15 mm

P-664.B02
Friction Bar for PILine® Miniature Linear Piezomotor, 25 mm

P-664.B05
Friction Bar for PILine® Miniature Linear Piezomotor, 55 mm

C-184.164
Analog OEM Driver Board for PILine® Motors

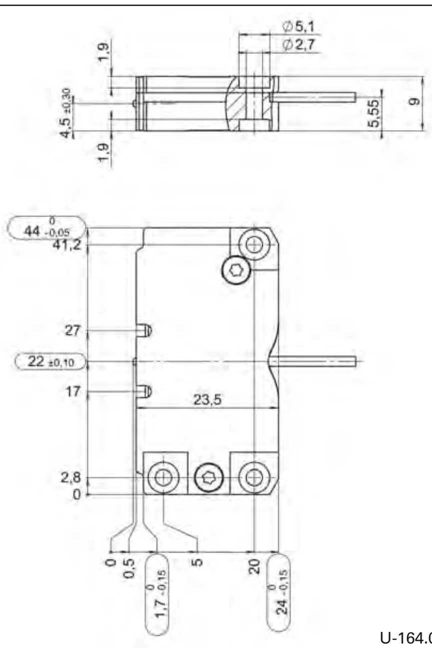
C-185.164
Analog Stand-Alone Drive Electronics with Power Supply for PILine® Motors

Controllers for closed-loop operation are available as C-867 (see p. 4-116).

Ask about custom designs!

Patent Information

The products described in this document are in part protected by the following patents:
US Pat. No. 6,765,335
German Patent No. 10154526



U-164.01, dimensions in mm

PI

Technical Data (preliminary)

Model	U-164.01	Unit	Tolerance
Motion and positioning			
Displacement	unlimited*	mm	
Minimum incremental motion, open-loop	0.05**	µm	typ.
Max. velocity	500	mm/s	
Mechanical properties			
Stiffness when powered down	3	N/µm	±10 %
Holding force when powered down	3	N	Max.
Push / pull force	4	N	Max.
Preload on friction bar	18	N	±10 %
Drive properties			
Resonant frequency	155	kHz	typ.
Motor voltage	60 (RMS)	V	
Operating voltage driver electronics	12	V	
Max. el. power consumption driver	10	W	
Miscellaneous			
Operating temperature range	-20 to +50	°C	
Body material	Al (black anodized)		
Mass	0.02	kg	±5 %
Cable length	1.0	m	±10 mm
Connector	Open leads		
Recommended controller/driver	C-184.164 OEM board C-185.164 in box		

*The travel range of piezo linear motors is virtually unlimited and depends on the length of the friction bar, which is available separately.
**The minimum incremental motion is a typical value that can be achieved in the open-loop mode of a piezomotor stage. To reach the specifications it is important to follow the mounting guidelines of the OEM-motors.

M-674K High-Precision Z Actuator for Bio-Automation

Ceramic PILine® Motor and Linear Encoder for High Speed & Precision

Equipped with two ultrasonic piezo-motors, the slim M-674KCPP offers up to 7 N push and pull force. The 9 mm width is matched to standard multiwell plate sizes, ideally suited to automation tasks in biotechnology

- **High Speed to 100 mm/sec**
- **High Push/Pull Force to 7 N**
- **Extremely Slim Design, Matched with Standard Multiwell Plates**
- **Stackable**
- **Integrated Linear Encoder for Highest Accuracy**
- **Self Locking at Rest**
- **Non-Magnetic and Vacuum-Compatible Working Principle**

Model	Travel	Push/pull force	Velocity	Resolution	Dimensions
M-674KCPP Compact PILine® Positioner	50 mm	7 N	100 mm/s	0.1 µm	120 x 40 x 9 mm

M-664K Vertical Drive for Bio-Automation

High-Speed, Compact, Cost-Effective, Stackable PILine® Actuator

Stack of 8 M-664KCEP linear actuators, shown with well plate. The integrated ceramic piezomotor provides high speeds to 100 mm/sec. The low-profile design with only 9 mm width allows stacking for multi-channel dispensing in bio-automation tasks

- **High Speed to 100 mm/sec**
- **Slim Design, Matched with Standard Multiwell Plates**
- **Travel range 50 mm**
- **Cost-Effective Design**
- **Stackable**
- **Non-Magnetic and Vacuum-Compatible Working Principle**
- **Self Locking at Rest**

Model	Travel	Push/pull force	Max. closed-loop velocity	Resolution	Dimensions
M-664KCEP Compact PILine® Positioner	50 mm	5 N	100 mm/s	0.5 µm	120 x 40 x 9 mm

M-682K Non-Magnetic Translation Stage

Low-Profile, High-Speed with Piezo Ceramic Motor

Custom non-magnetic M-682KNMS linear stage with integrated RodDrive linear motor

- **Integrated Non-Magnetic PILine® RodDrive**
- **Travel Range 50 mm**
- **Integrated Linear Encoders with 0.1 µm Resolution**
- **Up to 6 N Force Generation**
- **Closed-Loop Velocity up to 100 mm/s**
- **Low Profile, Small Footprint**

Model	Travel	Load capacity	Max. push/pull force	Dimensions
M-682KNMS PILine® Positioner	50 mm	50 N	6 N	110 x 110 x 20 mm

Details on Specifications for PILine® Drives

Motion and positioning

Travel range

The maximum allowed travel is limited by the length of the friction bar in a PILine® drive. The distance between the two limit switches gives the travel range.

Minimum incremental motion

The typical minimum motion that can be executed for a given input in open-loop operation, which is sometimes referred to as practical or operational resolution. The data table states typical measured values. For repeatable minimum incremental motion, a position feedback sensor and servo loop is required.

For repeatable nanometer or subnanometer resolution see the Piezo Flexure Stages / High-Speed scanning Systems (p. 2-3 *ff*), PiezoWalk® Motors / Actuators (p. 1-3 *ff*) and Piezo Actuators & Components (p. 1-61 *ff*) Sections.

Max. velocity

This is the short-term peak value for horizontal mounting, with no load, and not intended for continuous operation. The average velocity and continuous velocity are lower than the peak value and depend on the load conditions and other environmental parameters.

Mechanical properties

Stiffness when powered down

Stiffness in motion direction. Typical tolerance: ±10%

Push / pull force

Active force limit in operating direction. The maximum force depends on the velocity.

Holding force when powered down

A main feature of piezomotor linear drives is the self-locking capability at rest, without current consumption and heat generation. Piezomotor characteristics cause a decline of the holding-force in long-term off-time. The data refer to the long-term minimum holding force.

Drive properties

Resonant frequency

Ultrasonic excitation frequency of the piezo ceramic actuator

Motor voltage range

Required excitation voltage range.

Operating voltage drive electronics

Supply voltage for the drive electronics. It is recommended to operate PILine® drives with suitable PI drive electronics only, referred to in the individual data table.

Miscellaneous

Operating temperature range

Safe operation, no damage to the drive. All technical data specified in the data sheet refer to room temperature (22 °C ±3 °C).

Mass

Typical tolerance: ±5%

Cable length

Typical tolerance: ±10 mm

Recommended controller/driver

To reach the specifications and to avid damage to the drive, it is strongly recommended to use PI driver and control electronics only. Compatible controllers already include the ultrasonic drive electronics

PI

Drive properties

Drive type / Operating voltage
ActiveDrive™: The operating voltage (usually 24 VDC) for the ActiveDrive™ motors is provided by an external power supply (included in the delivery).
DC motors: DC servo motors require a supply voltage of up to 12 VDC. The operating voltage is usually given as differential value where the magnitude determines the velocity, and the sign determines the motion direction.
Stepper motors: PI stepper motors are usually driven in chopper mode.

Electrical power

Motor manufacturer's information.

Torque

Motor manufacturer's information.

Miscellaneous

Operating temperature range

Safe operation, no damage to the mechanics. All technical data specified in the data sheet refer to room temperature (22 °C ±3 °C).

Material

Micropositioning stages are typically made of anodized aluminum or stainless steel. Small amounts of other materials may be used (for bearings, preload, coupling, mounting, etc.).
For special applications other materials are possible like Invar.
Al: Aluminum
N-S: Nonmagnetic stainless steel
St: Steel
I: Invar

Mass

Typical tolerance: ±5 %

Cable length

Typical tolerance: ±10 mm

Recommended motor controller

Compatible motor controllers are described in the "Servo & Stepper Motor Controllers" (see p. 4-109 *ff*) Section.

For further information read "Micropositioning Fundamentals" Section (see p. 4-127 *ff*).

Piezo Motor Controllers

E-861 PiezoWalk® NEXACT® Controller/Driver

Networkable Controller for NEXACT® Linear Drives and Positioners

PiezoWalk® System: E-861.1A1 NEXACT® Controller with open-loop N-310.01 NEXACT® linear drive; suitable for installation in stage with linear encoder

- **For NEXACT® Drives and Positioning Systems**
- **Complete System with Controller, Integrated Power Amplifiers and Software**
- **Open-Loop Operation, or Closed-Loop with Linear Encoder**
- **High Performance at Low Cost**
- **Daisy-Chain Networking for Multi-Axis Operation**
- **Non-Volatile Macro Storage for Stand-Alone Functionality with Autostart Macro**
- **I/O for Automation, Joystick for Manual Operation**
- **Parameter Changes On-the-Fly**

The new, compact E-861 controller is designed to operate NEXACT® linear drives and closed-loop positioning systems using them, simply and precisely. In perfect harmony with the mechanics, the E-861 supports both motion modes of the PiezoWalk® stepping drive: for longer moves, the stepping mode, and for moves shorter than typically 7 µm, the analog mode, which provides high-dynamics positioning with resolutions of less than 1 nm. The NEXACT® drive design minimizes piezo operating voltages to 45 V and below.

Flexible Automation

E-861 controllers offer a number of features to support automation and handling. For example, macros can be stored in non-volatile memory.

A programmable autostart macro allows stand-alone operation without external communication. Upon power-up, the macro with its internal command sequence is executed automatically.

For easy synchronization of motion with internal or external trigger signals, four input and four output lines are provided.

Multi-Axis Operation

Up to 16 E-861 controllers can be networked and controlled over a single PC interface.

Such daisy chain networks are flexible, can be extended at any time and are compatible with other PI controllers (e.g. DC servo-motor and stepper motor controllers).

Ordering Information

E-861.1A1
NEXACT® Controller, 1 Channel, Linear Encoder

Easy System Setup, Comprehensive Software

All parameters can be set and checked by software. System setup and configuration is done with the included PIMikroMove user-interface software. Interfacing to custom software is facilitated with included LabView drivers and DLLs. With the PI General Command Set (GCS), system programming is the same with all PI controllers, so controlling a system with a variety of different controllers is possible without difficulty.

Technical Data

Model	E-861.1A1
Function	Controller for NEXACT® drives / systems
Drive type	NEXACT® linear drive
Channels	1
Motion and control	
Servo characteristics	P-I-D servo control, parameter change on-the-fly
Trajectory profile modes	Trapezoidal
Encoder input	Analog encoder input sine-cosine, interpolation circuit preset for differential transmission, 1 V_{pp} amplitude and 2.5 V offset of the encoder signal
Stall detection	Servo off, triggered by programmable position error
Input limit switch	2 x TTL (pull-up/pull-down, programmable)
Input reference switch	1 x TTL
Electrical properties	
Output power	max. 40 W
Output voltage	-10 to +45 V
Current consumption	max. 2 A
Interfaces and operation	
Communication interfaces	USB 1.0, RS-232 (9-pin (m) Sub-D)
Motor connector	Sub-D 15-pin (f) High Density
Sensor connector	Sub-D 15-pin (m) High Density
Controller network	Up to 16 units on single interface
I/O ports	4 analog/digital in, 4 digital out (TTL)
Command set	PI General Command Set (GCS)
User software	PIMikroMove, PI Terminal
Software drivers	GCS-DLL, LabVIEW drivers
Supported functionality	Start-up macro; data recorder for categories like current position or velocity; internal safety circuitry: watchdog timer
Manual control (optional)	Joystick, Y-cable for 2D motion, pushbutton box
Miscellaneous	
Operating voltage	24 V included: external power supply, 24 V, 2.0 A
Operating temperature range	0 to +50 °C
Mass	1.1 kg
Dimensions	206 x 130 x 66 mm (with mounting rails)

E-862 NEXACT® Drive Electronics

Low-Cost Drive Electronics for NEXACT® Piezo Stepping Drives

Cost-effective E-862 OEM drive electronics

Ordering Information

E-862.100
NEXACT® Driver, 1 Channel, OEM Board, DSP based

Accessories:

C-819.20
Analog Joystick for 2 Axes

C-819.20Y
Y-Cable for Connecting 2 Controllers to C-819.20

For closed-loop systems the E-861.1A1 controller (s. p. 1-20) is available:

E-861.1A1
NEXACT® Controller, 1 Channel, Linear Encoder

Ask about custom designs!

- **For NEXACT® PiezoWalk® Drives & Stages**
- **Combined Step Generator and Power Amplifier**
- **Cost-Effective Design**
- **Interface for Automation, Joystick for Manual Operation**

The E-862 drive electronics is designed to put open-loop NEXACT® linear drives and stages into operation. E-862 supports the nanostepping mode of NEXACT® piezo stepping drives, which is ideal to cover a certain distance in the fastest possible way. The final position is stable without further current consumption.

Simple Control – High Resolution

The driver uses a ±10 V signal that controls the velocity of the NEXACT® drive. The motion is resolved down to nanometers, depending on the drive and its mechanical integration.

Joystick Operation and Interface for Automation

Stand-alone operation is possible by connecting a joystick. As an alternative, the required ±10 V signals can be sent over an analog interface.

PiezoWalk® Working Principle for Application Flexibility

NEXACT® piezo stepping drives combine high forces and a basically unlimited travel range in a compact package. In operation, piezoceramic bending elements act on the runner, which is connected to the moving part of the application. The length of the runner can be chosen freely and determines the stroke. Force capacity, resolution and velocity are determined by the piezo geometry and drive electronics. The drive design allows lower operating voltages of maximum 45 V. Furthermore, NEXACT® actuators have the high stiffness and resolution characteristic of piezo actuators of far below one nanometer.

Advantages of PiezoWalk® Piezo Stepping Drives

NEXLINE® and NEXACT® drives offer several advantages over drives with with traditional technologies:

- Resolution in the picometer range
- Compact dimensions
- High drive forces to 10 N (NEXACT®) and up to several 100 N (NEXLINE®)
- High dynamic performance with sub-millisecond response
- Self-locking when powered down; no holding current
- Zero backlash, no wear or maintenance, no mechanical components like gears or leadscrews.
- Non-magnetic and vacuum compatible operating principle

Closed-Loop Systems for Repeatable Positioning

The step size of piezo stepping drives depends on the applied load and a direct conversion of step count to travel is not possible. Therefore, for positioning tasks a closed-loop system is recommended.

Technical Data

Model	E-862.100
Function	Drive electronics for NEXACT® drives / stages
Drive type	NEXACT® drive
Channels	1
Motion resolution	12 bit
Input limit switch	2 x TTL (active high, to be activated)
Electrical properties	
Output power	max. 40 W
Output voltage range	0 to +45 V
Current	max. 1.6 A
Interfaces and operation	
Control	±10 V analog velocity control (Mini-DIN, 9-pin)
Motor connector	HD Sub-D 15-pin. (f)
Manual control (optional)	Joystick, Y-cable for control of 2 axes with joystick
Miscellaneous	
Operating voltage	24 V External power supply (24 V, 2 A), not included
Operating temperature range	0 to +50 °C
Mass	0.64 kg
Dimensions	166 x 100 x 46 mm

Note: All specifications for NEXACT® drives refer to use with E-861 controller. Compared to that, the E-862 drive electronics provides only a unipolar output voltage. Therefore, push force and velocity achievable with E-862 are derated by 20 %.

E-755 Digital NEXLINE® Controller

Controller for Picometer-Precision PiezoWalk® Linear Actuators / Positioners

E-755 digital NEXLINE® controller with N-214 nanopositioner, 20 mm travel range.

- **Special Control Algorithms for NEXLINE® Nanopositioning Linear-Motor Actuators**
- **32-Bit Digital Filters**
- **24-Bit DAC Resolution**
- **Fully Programmable Low-Pass and Notch Filters**
- **Non-Volatile User Settings and Last-Position Data**
- **Daisy-Chain Networking for up to 16 Axes**
- **PI GCS (General Command Set) Compatible**

E-755 digital single-axis nano-positioning controllers are designed to drive the patented NEXLINE® nanopositioning linear drives. Combining advanced control technology and sensor signal processing with special drive algorithms, the E-755 can provide precision motion control over hundreds of millimeters with picometer-range resolution. Coordinated action of shearing and clamping piezo elements is what allows NEXLINE® to break through the barriers of conventional nanopositioning actuators.

The E-755 offers two different control modes for the NEXLINE® walking drives: a high-resolution, high dynamics direct piezo mode, with basically unlimited resolution (analog mode), and a long-range stepping mode with theoretically unlimited travel range.

Application Examples

- Semiconductor technology
- Quality assurance testing in semiconductor industry
- Astronomical telescopes
- Truss structures
- Active vibration control
- Alignment in high magnetic fields, as in particle physics, atomic fusion and superconductivity research

High-Resolution Servo-Control

E-755 controllers are based on powerful 32-bit DSPs and come in open- and closed-loop versions. Both versions feature four high-resolution (24-bit) linear amplifiers with the output range of ±250 V required to control a single-axis NEXLINE® drive. For the closed-loop models, high-resolution incremental position sensors are supported by special excitation and read-out electronics.

The sensors supported may provide better than nanometer resolution. A power-down routine in the E-755 firmware saves the current position, allowing a closed-loop system to be ready for operation without referencing next time it is powered up.

NEXLINE® Working Principle for Application Flexibility

NEXLINE® PiezoWalk® drives are ideal wherever high loads must be positioned very precisely over long distances and then perhaps subjected to small-amplitude dynamic adjustment, as for active vibration control. By varying the characteristics of the longitudinal and shear piezo elements, the step size, dynamic operating range (analog travel), clamping force, speed and stiffness can all be optimized for a particular application.

NEXLINE® PiezoWalk® piezoceramic clamping and shearing elements act directly on a moving runner that is coupled to the moved part in the application. While the runner can bemoved large distances in step mode, high-dynamics positioning over distances of less than one step is possible with resolutions far below one nanometer in analog mode. The patented PiezoWalk® thus overcomes the limitations of conventional nanopositioning actuators and combines long travel ranges with high resolution and stiffness.

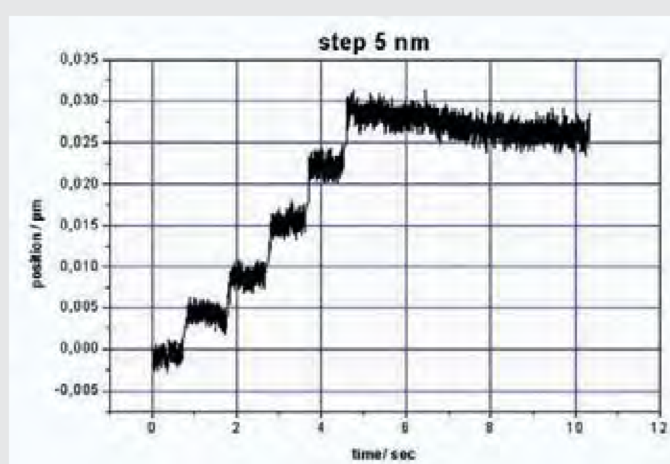
Extreme Actuator Lifetime

To eliminate long-term offset voltages, which limit the lifetime of conventional piezo drives, the E-755 controller uses a special procedure to bring the actuator to a full-holding-force, zero-voltage condition, no matter where it may be along its travel range. Due to the resulting long lifetime, NEXLINE® nanoposition-

Ordering Information

E-755.1A1
Digital Controller for NEXLINE® Nanopositioning Linear Drives, Incremental Sensors

E-755.101
Digital Controller for NEXLINE® Nanopositioning Linear Drives



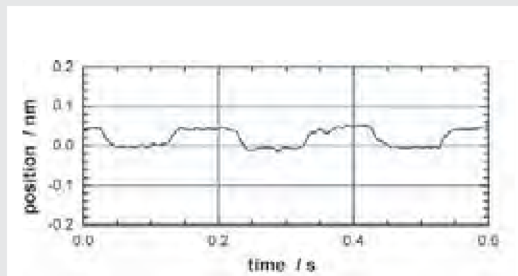
Steps of 5 nm performed by a system consisting of an N-214 NEXLINE® nanopositioner and an E-755.1A1 controller, measured by a high-resolution interferometer. Note the excellent system response to consecutive 5 nm step commands. In this case the closed-loop resolution is limited by the linear encoder in the N-214 (5 nm / increment); the E-755 can work with linear encoders with sub-nanometer resolution ing actuators are ideal for installation in inaccessible locations deep inside complex equipment, where nanometer -precise alignment and vibration cancellation are required.

Linearization

E-755-controlled nanopositioning systems provide outstanding linearity, achieved by digital polynomial linearization. The linearization can improve linearity to 0.001 % over the full travel range.

The products described in this datasheet are in part protected by the following patents:
German Patent No. 10148267
US Patent No. 6,800,984

Six-axis nonmagnetic Hexapod with N-215-based NEXLINE® high-load actuators for use in high magnetic fields. The system is driven by six E-755 controllers and additional hardware/firmware to automatically perform the necessary parallel-kinematics coordinate transformation



Steps of 50 picometers with a NEXLINE® drive in open-loop mode measured with external, ultra-high-resolution, capacitive sensor

Model	E-755.1A1	E-755.101
Funktion	Digital controller for NEXLINE® nanopositioning linear drives with incremental encoder	Digital controller for NEXLINE® nanopositioning linear drives
Axes	1	1
Processor	DSP 32-bit floating point, 50 MHz	DSP 32-bit floating point, 50 MHz
Sensor		
Sensor channels	1	–
Servo update time	0.2 ms	–
Sensor sampling time	0.1 ms	–
Dynamic cycle time	0.2 ms	0.1 ms
Servo characteristics	P-I, notch filter	–
Sensor type	Incremental sensor	–
Amplifier		
Amplifier channels	4	4
Output voltage	-250 to +250 V	-250 to +250 V
Peak output power per channel	5.5 W	5.5 W
Average output power per channel	3 W, limited by temperature sensor	3 W, limited by temperature sensor
Peak current	44 mA	44 mA
Average current per channel	25 mA, limited by temperature sensor	25 mA, limited by temperature sensor
Current limitation	Short-circuit-proof	Short-circuit-proof
Resolution DAC	24 bit	24 bit
Interfaces and operation		
Communication interfaces	RS-232	RS-232
Piezo connector	Sub-D Special	Sub-D Special
Sensor connector	15-pin sub-D connector	–
Controller network	Daisy-chain, up to 16 units	Daisy-chain, up to 16 units
Command set	GCS	GCS
User software	PIMikroMove™, NanoCapture™ , PITerminal	PIMikroMove™, NanoCapture™ , PITerminal
Software drivers	LabVIEW drivers, DLLs	LabVIEW drivers, DLLs
Supported functionality	NEXLINE® Control algorithms (closed-loop), data recorder, position storage	NEXLINE® Control algorithms (open-loop), data recorder
Display	Status LEDs	Status LEDs
Linearization	4th order polynomial	4th order polynomial
Miscellaneous		
Operating temperature range	5 to 50 °C	5 to 50 °C
Overtemp protection	Deactivation at 70 °C	Deactivation at 70 °C
Dimensions	264 x 260 x 47 mm	264 x 260 x 47 mm
Mass	2.3 kg	2.3 kg
Operating voltage	24 V (power supply included)	24 V (power supply included)
Power consumption	48 W, 2 A max.	48 W, 2 A max.

PI

C-867 Controller for PILine® Piezo Linear Drives

Servo-Controller with Integrated Driver for High-Speed Ultrasonic Piezo Motors

C-867 piezomotor controller together with an extremely low-profile M-692 positioner with integrated piezoceramic PILine® linear drive

- **Optimized for PILine® Ultrasonic Piezo Linear Motors**
- **High-Bandwidth Encoder Inputs Allow High Speed and Resolution**
- **PID Servo-Control with Dynamic Parameter Switching**
- **Integrated Piezo Motor Power Driver**
- **USB, RS-232 and Analog Interfaces (e. g. for Joystick)**
- **4 + 4 Programmable TTL-I/Os for Flexible Automation**
- **Data Recorder**
- **Daisy-Chain Networking for up to 16 Axes**
- **Powerful Macro Programming Language, e. g. for Stand-Alone Operation**
- **Extensive Software Support, LabVIEW, DLL ...**

The C-867 controller is especially designed for closed-loop positioning systems equipped with PILine® piezo linear motor drives. A compact case contains both drive electronics for the piezo ceramic motors and components for controlling and communication.

Application Examples

- Biotechnology
- Microscopy
- Fiber positioning
- Automation
- Photonics / integrated optics
- Quality assurance testing
- Testing equipment

The controller can be operated from a host PC either via a USB port or an RS-232 interface. Alternatively, a stand-alone operation is possible. Here, stored macro commands can be executed, or manual control by joystick or pushbutton box is possible.

Two models are available: C-867.160 is used to operate single-axis positioning systems, the two-channel C-867.260 is used with XY scanning stages.

Highly Specialized PID Servo-Controller

The C-867 is based on a highly specialized DSP (Digital Signal Processor) that handles the PID servo-control algorithm as well as other system functions. Because of the motion properties typical for ultrasonic piezomotors, the controller has a number of advanced features, including dynamic control parameter adaption. By automatically switching between gainsets for dynamic and static operation an optimized settling behavior within a couple of 10 milliseconds is achieved. The broadband encoder input (50 MHz) allows high resolution encoders to be used with the outstandingly high accelerations and velocities that PILine® drives deliver.

Highest Stability by Frequency Control

The integrated piezomotor drive electronics support all PILine® ultrasonic piezomotors used for the M-66x to M-69x positioning stage series.

Drift in the mechanical frequency of the motor caused by temperature or load changes is automatically compensated by a frequency-control loop which adjusts the operating frequency of the driving voltage. This leads to the highest stability in pushing force, velocity and closed-loop control.

Software / Programming

In addition to the user software for setup, system optimization and operation, comprehensive LabVIEW and DLL libraries are provided.

The PIMikroMove™ user software provides the PITuningTool for optimizing system performance. Graphic displays show the system's behaviour and facilitate parameter setting.

Advantages of PILine® Micropositioning Systems

Positioning systems equipped with ceramic ultrasonic drives of the PILine® series provide several advantages over positioners that apply classic drive technology:

- Smaller dimensions
- Higher holding force when powered down; no holding current
- Increased acceleration of up to 5 g
- Increased velocity of up to 500 mm/s or 720°/s
- No leadscrews, gears or other mechanical components, no wear or maintenance
- No lubricants
- Non-magnetic and vacuum-compatible operating principle

Ordering Information

C-867.160
Piezomotor Controller with Drive Electronics, Networkable, for PILine® Systems

C-867.260
Piezomotor Controller with Drive Electronics, 2 Channels, for PILine® Systems

Accessories:

C-819.20
Analog Joystick for 2 axes

C-819.20Y
Y-Cable for Connecting 2 Controllers to C-819.20

C-170.PB
Pushbutton Box, 4 Buttons and 4 LEDs

Ask about custom designs!

The two-channel C-867.260 controller operates XY scanning stages, here:
a customized M-686 stage for microscopy

Technical Data

Model	C-867.160	C-867.260
Function	Controller and drive electronics for PILine® piezomotors / systems	
Drive type	PILine® motors, single and dual drives with P-661, P-664, U-161 or U-164	
Channels	1	2
Motion and control		
Servo characteristics	Programmable PID V-ff filter, parameter changes on the fly	
Trajectory profile modes	Trapezoidal	
Encoder input	A/B differential signals, 50 x 10^6 impulses/s	
Stall detection	Servo off, triggered by programmable position error	
Limit switch	2 x TTL per channel (programmable)	
Reference switch	1 x TTL per channel (active high / low, programmable)	
Electrical properties		
Max. output power / channel	15 W	
Max. output voltage / channel	200 V_{pp}	
Interfaces and operation		
Communication interfaces	USB, RS-232	
Motor connector	MDR14	2 x MDR14
Controller network	Up to 16 units on single interface	
I/O ports	4 analog/digital in, 4 digital out (Mini-DIN, 9-pin) digital: TTL analog: 0 to 5 V	
Command set	PI General Command Set (GCS)	
User software	PIMikroMove	
Software drivers	GCS-DLL, LabVIEW drivers	
Supported functionality	Start-up macro; macro; data recorder for recording parameters as motor input voltage, velocity, position or position error	
Manual control	Pushbutton box, joystick, Y-cable for control of 2 axes with joystick	Pushbutton box, joystick
Miscellaneous		
Operating voltage	24 VDC from external power supply (included)	
Current consumption	300 mA + motor current (2 A max.)	600 mA + motor current (4 A max.)
Operating temperature range	+5 °C to +40 °C	
Mass	1.0 kg	2.4 kg
Dimensions	206 x 130 x 66 mm (including mounting rails)	320 x 150 x 80.5 mm (including mounting rails)

C-184 · C-185 PILine® Drive Electronics

OEM Boards and Stand-Alone Units fot Ultrasonic Piezomotors

C-185.D64 single-channel bench-top driver electronics with PILine® M-674 RodDrive featuring travel ranges up to 150 mm and 7 N drive force at 450 mm/s

- **For PILine® Ultrasonic OEM Motors and Positioners**
- **Accepts Analog Drive Signal from Standard Controller**
- **Available as Cost-Effective OEM board and Plug-and-Play Desktop Unit**

The C-184 OEM-board and the C-185 stand-alone unit are single-channel drive electronics for PILine® ultrasonic piezomotors and PILine® stages. Piezomotor drive electronics convert analog input signals into the high-frequency drive signals necessary to excite the required oscillations in the piezomotor stator which cause the motion. Both the C-184 and C-185 are available in three versions, for use with different motors and translation stages.

OEM and Integrated Electronics

The philosophy behind the design of PILine® ultrasonic drives dictates that they be easily adaptable to customer requirements. This includes making the drive electronics both independent of control signal type and available either as an OEM board or as a stand-alone unit in its own case. While the OEM boards are the most economic solution for large quantities, the stand-alone units make it possible to plug a system with PILine® stages together and put it into operation quickly and easily, for example for system evaluation purposes.

Analog Control

Both drivers control the motor speed based on an analog signal from 0 to 10 V. With an external position sensor and a servo controller, it is possible to set up a very fast, closed-loop system.

For optimum closed-loop system performance, the C-867 (see p. 4-116) piezo servo-controller is recommended.

Advantages of PILine® Micropositioning Systems

The ultrasonic piezoceramic drives used in PILine® micropositioners have a number of advantages over classical drives:

- Higher Accelerations, up to 5 g
- Speeds up to 500 mm/s
- Small Form Factor
- Self-Locking When Powered Down
- No Shafts, Gears or Other Rotating Parts
- Non-Magnetic and Vacuum-Compatible Drive Principle

Note

The products described in this document are in part protected by the following patents:
US Pat. No. 6,765,335
German Patent No. 10154526

Ordering Information

C-184.161
Analog OEM Driver Board for PILine® P-661 Motors

C-185.161
Analog Stand-Alone Drive Electronics with Power Supply for PILine® P-661 Motors

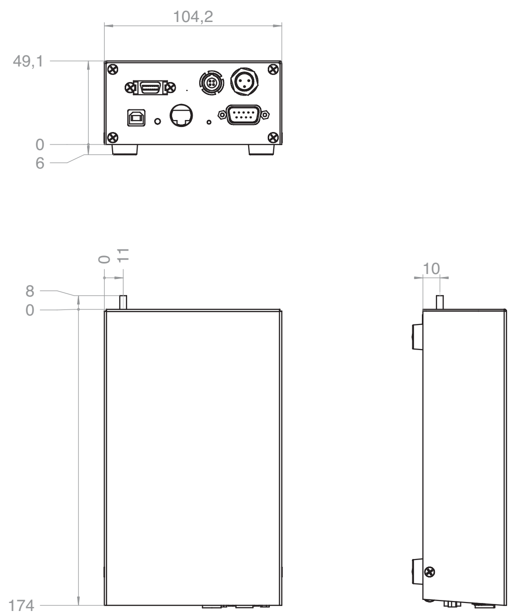
C-184.164
Analog OEM Driver Board for PILine® P-664 Motors

C-185.164
Analog Stand-Alone Drive Electronics with Power Supply for PILine® P-664 Motors

C-184.D64
Analog OEM Driver Board for PILine® RodDrive M-674

C-185.D64
Analog Stand-Alone Drive Electronics with Power Supply for PILine® RodDrive M-674

C-184.164 OEM driver board with PILine® P-664 OEM motor



Dimensions of single-channel bench-top C-185 in mm

Technical Data

Model	C-184	C-185
Function	Analog drive electronics (OEM board) for PILine® C-184.161: P-661 Motors & Positioners C-184.164: P-664 Motors & Positioners C-184.D64: M-674 RodDrive	Analog single-channel driver box for PILine® C-185.161: P-661 Motors & Positioners C-185.164: P-664 Motors & Positioners C-185.D64: M-674 RodDrive
Channels	1	1
Electrical properties		
Control in	Differential, -10 V up to +10 V, polarity controls direction	Differential, -10 V up to +10 V, polarity controls direction
Operating voltage	12 V, ±10 %	12 VDC external power supply (included)
Output power / channel	Model dependent: C-184.161: 5 W C-184.164: 10 W C-184.D64: 15 W	Model dependent: C-185.161: 5 W C-185.164: 10 W C-185.D64: 15 W
Output voltage / channel	Model dependent: C-184.161: 120 V_{PP} / 42 V_{RMS}, 210 kHz C-184.164: 168 V_{PP} / 60 V_{RMS}, 155 kHz C-184.D64: 190 V_{PP} / 67 V_{RMS}, 155 kHz	Model dependent: C-185.161: 120 V_{PP} / 42 V_{RMS}, 210 kHz C-185.164: 168 V_{PP} / 60 V_{RMS}, 155 kHz C-185.D64: 190 V_{PP} / 67 V_{RMS}, 155 kHz
Interfaces and operation		
Motor connector	Solder pads	LEMO connector or MDR connector, 14-pin
I/O ports	Solder pads	Sub-D connector, 15-pin
Miscellaneous		
Operating temperature range	+5 to +40 °C	+5 to +40 °C
Mass	C-184.161, C-184.164: 15 g C-184.D64: 24 g	690 g
Dimensions	65 x 38 mm	174 x 104 x 49 mm (without ground connection, pads and fitting panel) 182 x 104 x 49 mm (with ground connection)

Piezo Technology Made Affordable

PiezoMove OEM Flexure Actuators: Speed, Precision & Long Travel Ranges

PiezoMove: Moving, Positioning, Scanning

Microfluidics, Biotechnology, Medical Engineering, Adaptronics

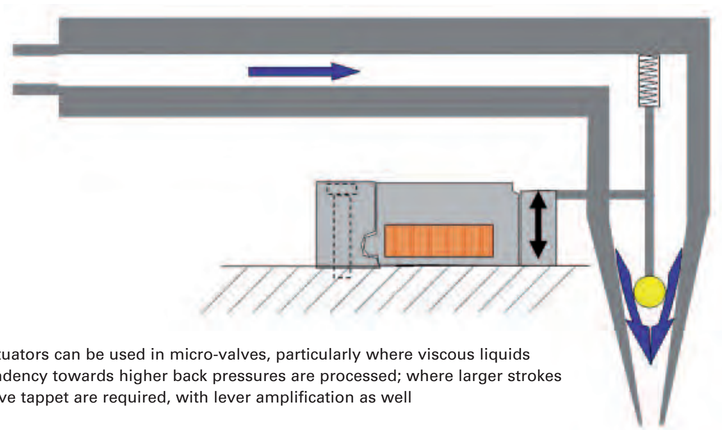
Piezo = nano = expensive?

Piezo actuators can do a lot more than "just" precision. Their excellent dynamics and high force play a crucial role in many areas, while the (nanometer) precision is of lesser importance: e.g. for fast switching, vibration cancellation, or to adjust tools in machines.

In these applications the piezo actuator is one – if not the only – solution and in the case of the new PiezoMove OEM actuators, at a very attractive price.

PiezoMove OEM actuators: Apply motion, how and where it is required

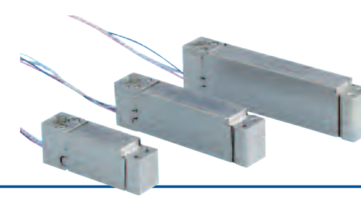
PiezoMove actuators combine guided motion and long travel ranges up to 1 mm and provide precision in the 10 nm range if ordered with the position sensor option. They are very compact, easy to integrate, require no maintenance and provide service life of Billions (10^9) of cyles.



Linear actuators can be used in micro-valves, particularly where viscous liquids with a tendency towards higher back pressures are processed; where larger strokes of the valve tappet are required, with lever amplification as well

PI supplies a variety of standard integration levels and also customized versions: From simple piezo stack components and preloaded linear actuators through to 6-axis positioning systems with sub-nanometer precision.

3 Actuator Families



P-601: Travel ranges to 400 µm, slight tilt

P-602: Travel ranges to 1000 µm, slight tip and tilt, high stiffness

P-603: Travel ranges to 500 µm, slight tilt, cost-optimized for high quantities

Application fields

Microfluidics:

Valves, pumps, microliter and nanoliter dosing

Biotechnology:

Cell manipulation, patch-clamp, microarrays, nanoliter dosing, dispensers, microstructuring with imprint processes

Medical engineering:

Diaphragm pumps, valves, dosing, injection, sample handling

Mechatronics, adaptronics:

Active structures, vibration isolation, active tools, structure deformation

Laser technology, metrology:

Cavity tuning, adjustment of optics or slit widths, sample positioning, beam control

PiezoMove: Travel Ranges to 1 mm

Easy Integration and Adaptation

Systems Thinking

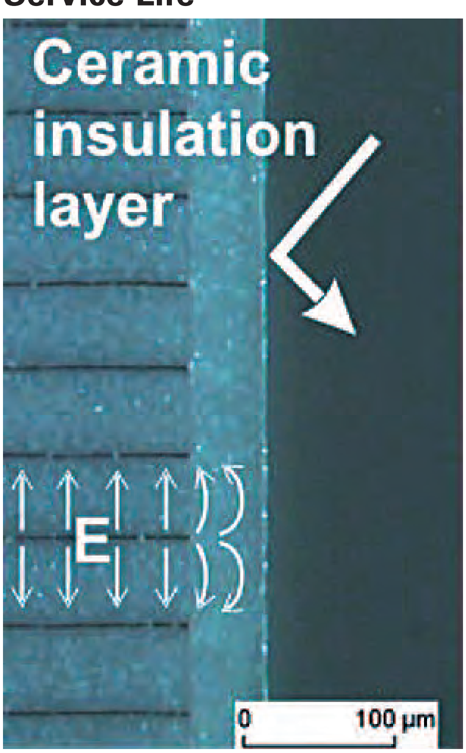
PI provides a range of different control electronics for PiezoMove actuators.
These range from solderable OEM piezo driver modules to advanced digital motion controllers.
PI's wide range of actuators and control electronics allows for an optimum match of performance and cost for any application.
In addition to standard products, modified or completely custom engineered solutions are available at competitive prices. The following parameters can be modified to suit an application:

- Travel range
- Dynamics
- Force
- Precision

Levels of Integration: From Stack Actuator to 6-Axis Stage

	Stack actuators	Lever-amplified actuators	Positioning systems
Travel ranges	up to approx. 150 µm	up to 1 mm	up to 2 mm
Axes moved	one	one	up to three linear axes and three tip/ tilt axes
Sensors	SGS optional	SGS optional	SGS or direct measuring capacitive sensors
Linearity	up to 99.8 %	up to 99.8 %	over 99.9 %
Guidance	none	flexures for rotations <10"	flexures for rotations <2"
Space required	low	low	depends on features
Price	low	low	depends on features
Integration effort	high	low	low

PI Actuators Offer Longer Service Life



The ceramic insulating layer prevents the penetration of water molecules and reliably protects the sensitive internal electrodes from mechanical damage and dirt

Different Piezo Solutions: Simple Piezo Components to Complex (Nano) Positioning Systems

Actuator: Piezo ceramic stack actuators are the driving force in many of PI's motion systems. Piezo actuators can move very rapidly due to their high stiffness; response times are as short as microseconds and scan frequencies up to several tens of kilohertz are feasible. The resolution is virtually unlimited, depending only on the electrical noise of the driver, making piezo actuators predestined for precision motion applications. The displacement of basic actuators is limited to a few tens of micrometers, however, and they need to be handled with care.

Preloading and Decoupling Against Lateral Forces: Encased piezo stacks can handle higher forces. The housing can decouple the piezo ceramics from lateral forces. Integrated mechanical preloading allows dynamic operation with higher loads.

Guiding System: Piezo ceramic stacks do not move in perfectly straight lines. For precise linear motion, a guiding system is required. Flexures guarantee the best performance because they provide frictionless, backlash-free motion and unlimited lifetime. If designed well, preloading and decoupling of unwanted forces can also be integrated without negative effects on the system stiffness.

Lever Amplification for Longer Travel Ranges: The guiding system can be designed in such a way that it acts like a mechanical lever and increases the displacement of the piezo ceramic stack. Lever amplifiers reduce the system stiffness and this is where experience pays off. PI uses CAD modeling, FEA analysis and laser vibrometry for design optimization and testing. Based on 3 decades of experience with piezo flexure design PI actuators provide the best combination of lifetime, stiffness, precision and size.

Sensor: Position feedback sensors are available when absolute position information is required. Strain gauge sensors (lower cost, accuracy to 0.5%) and capacitive sensors (higher precision to 0.01 %) are available.

Controller: The higher the demands placed on the system precision, the larger the role played by the motion controller. Open-loop actuators can be controlled directly via a voltage amplifier. To achieve maximum positional accuracy and scanning linearity, however, closed-loop control and digital control algorithms are indispensable.

Multi-Axis Positioners are constructed as parallel-kinematic systems for the highest possible precision, and controlled by advanced digital nanopositioning controllers.

P-603 PiezoMove Linear Actuator

Low-cost and with Large Travel Ranges

P-603 linear actuators with 500 and 100 µm travel range (from left to right). CD for size comparison

- **Frictionless, High-Precision Flexure Guiding System**
- **Travel Ranges to 500 µm**
- **Cost-Effective Design**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Available with Integrated Position Sensor**
- **Ideal OEM Actuators for Precision Motion Control in Optics, Medical, Biotech and Microfluidics Applications**
- **Custom Designs with Larger Travel or Faster Response and Non-Magnetic Versions Feasible**

P-603 PiezoMove flexure-guided piezo actuators integrate a frictionless high-efficiency motion amplifier to combine large travel ranges up to 500 µm with high stiffness and very fast response. The flexure guides reduce tip at the drive head to a minimum saving the cost for additional guiding systems when integrating these actuators in micro-dispensing devices, pumps or servo valves. The overall precision of 10s of nanometers also makes these devices ideal for nanomanipulation applications.

Application Example

- Nanopositioning
- CCD / CMOS camera technology / Micro scanning
- Cell manipulation, biohandling
- Medical technology
- Micropumps
- Micro-dispensing
- Slit width adjustment
- Cavity Tuning
- Beam stabilization
- Photonics / integrated optics
- Switches

Options and Custom Versions

For OEM applications, PiezoMove actuators can be modified in various ways to suit the customer's requirements. The stiffness and force generation can be influenced via the lever design and the dimensions of the piezo ceramics used in the actuator. If only a small force and low guiding accuracy are required, large strokes of several 100 µm and high frequencies can be achieved with small actuators, e.g. for micropump drives. For high-accuracy applications, an integrated position feedback sensor is available. The actuators were designed to allow for considerable cost savings in large production runs.

OEM Control Electronics

PI also supplies a variety of controllers to match the actuators. These range from simple amplifier modules (see p. 2-164) and analog closed-loop OEM controllers (see p. 2-110) to high-performance digital controllers (see p. 2-100*ff*). The great choice of actuators and controllers allows customers to select the optimum combination of performance and cost for their application.

Increased Lifetime Through Humidity Resistance

The monolithic ceramic-encapsulated design provides better humidity protection than polymer-film insulation. Diffusion of water molecules into the insulation layer is greatly reduced by the use of cofired, outer ceramic encapsulation. Due to their high resonant frequency the actuators are suitable for highly dynamic applications with small loads; depending on the load an external preload for dynamic applications is recommended. The high Curie temperature of 320° gives PICMA® actuators a usable temperature range extending up to 150 °C, far beyond 80°C as is common for conventional multilayer actuators. With conventional multilayer actuators, heat generation – which is proportional to operating frequency – either limits the operating frequency or duty cycle in dynamic operation, or makes ungainly cooling provisions necessary. At the low end, operation down to a few Kelvin is possible (with reduced travel range).

Ordering Information

PiezoMove® OEM Linear Actuator with High Stiffness

P-603.[ ][ ][ ]

- **1** Travel Range 100 µm
- **3** Travel Range 300 µm
- **5** Travel Range 500 µm

- **00** Open loop
- **S0** SGS Sensor
- **SL** SGS Sensor, LEMO Connector

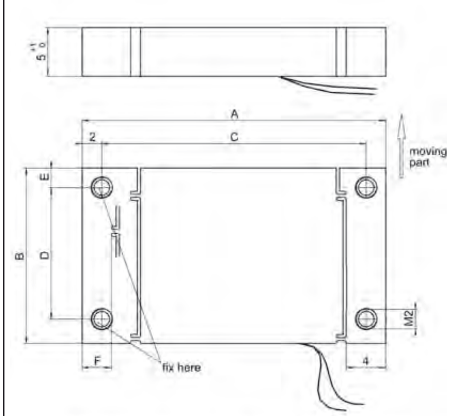
Ask about custom designs!

The flexure guiding system prevents tip and tilt at the drive head!

Levels of Integration: From Stack Actuator to 6-Axis Stage

	Stack actuators	Lever-amplified actuators	Positioning systems
Travel ranges	up to approx. 150 µm	up to 1 mm	up to 2 mm
Axes moved	one	one	up to three linear axes and three tip/ tilt axes
Sensors	SGS optional	SGS optional	SGS or direct measuring capacitive sensors
Linearity	up to 99.8 %	up to 99.8 %	over 99.9 %
Guidance	none	flexures for rotations <10"	flexures for rotations <2"
Space required	low	low	depends on features
Price	low	low	depends on features
Integration effort	high	low	low

Flexure guided, lever-amplified actuators form a reasonably priced and easily integrated class of products between conventional piezo stack actuators and the complex piezo nanopositioning systems



	A	B	C	D	E	F
P-603.1xx	31	18	27	13,5	2	3
P-603.3xx	51	20	47	13,5	3,25	3,5
P-603.5xx	60	20	56	16	2	3

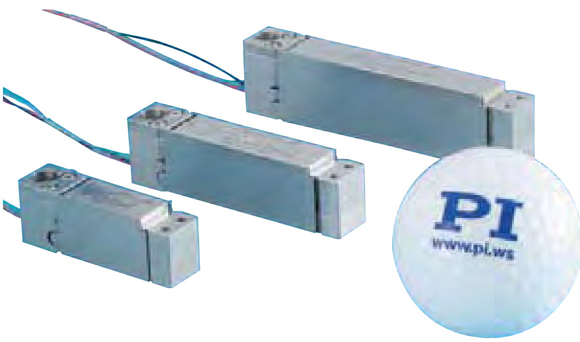
P-603 dimensions in mm

Model	P-603.1S0 P-603.1SL	P-603.3S0 P-603.3SL	P-603.5S0 P-603.5SL	P-603.x00 open-loop versions	Units	Tolerance
Active axes	X	X	X	X		
Motion and positioning						
Integrated sensor	SGS	SGS	SGS	–		
Open-loop travel, -20 to +120 V	100	300	550	as P-603.xS0	µm	min. (+20%/-0)
Closed-loop travel	100	300	500	–	µm	calibrated
Open-loop resolution	0.2	0.3	0.4	as P-603.xS0	nm	typ.
Closed-loop resolution	2	4	7.5	–	nm	typ.
Linearity, closed-loop	0.3	0.3	0.3	–	%	typ.
Repeatability	8	10	30	–	nm	typ.
Mechanical properties						
Stiffness in motion direction	0.25	0.14	0.06	as P-603.xS0	N/µm	±20%
Unloaded resonant frequency	900	450	300	as P-603.xS0	Hz	±20%
Blocking force	20	35	25	as P-603.xS0	N	max.
Drive properties						
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical Capacitance	1.5	3.1	3.7	as P-603.xS0	µF	±20%
Dynamic operating current coefficient	1.9	1.3	1.6	as P-603.xS0	µA/(Hz•µm)	±20%
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Stainless steel	Stainless steel	Stainless steel	Stainless steel		
Dimensions	31x18x5	50x20x5	51x20x5	as P-603.xS0	mm	
Mass	0.02 / 0.031	0.032 / 0.043	0.038 / 0.049	as P-603.xS0	kg	±5%
Cable length	0.5	0.5	0.5	0.5	m	±10 mm
Sensor / voltage connection	S-version: open leads SL-version: LEMO connector (SGS Sensor)	S-version: open leads SL-version: LEMO connector (SGS Sensor)	S-version: open leads SL-version: LEMO connector (SGS Sensor)	Open leads		

Recommended controller / amplifier
E-610 controller / amplifier see p. 2-110, E-625 bench-top controller see p. 2-114

P-601 PiezoMove™ Z-Actuator

Flexure-Guided OEM Piezo Actuator with Long Stroke to 400 µm



PiezoMove™ Lever-amplified piezo actuators of the P-601 series

- **Flexure Guidance for Frictionless, Ultra-Straight Motion**
- **Travel Ranges to 400 µm**
- **Resolution to 0.2 nm**
- **High Dynamics and Stiffness**
- **Custom Designs with Longer Travel or Faster Response and Non-Magnetic Versions Feasible**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Choice of Closed-Loop and Open-Loop Models**
- **Ideal OEM Actuator for Precision Motion Control in Optics, Medical, Biotech and Microfluidics Applications**

The flexure-guided, lever-amplified PiezoMove™ P-601 actuators provide large vertical travel ranges up to 400 µm, fast response and high positioning accuracy in a very small package. With settling times of only a few milliseconds and a resolution in the sub-nanometer range they are well suited for both static and dynamic applications.

P-601 PiezoMove™ lever-amplified actuators cover the range between direct-driven preloaded piezo translators, such as the P-840 series (see p. 1-74) and single-axis nanopositioning stages, like the P-611 series (see p. 2-20). Compared to direct-driven piezo translators, lever-amplified actuators offer larger travel ranges and much higher lateral stiffness and guiding precision. Compared to single-axis nanopositioning stages, they offer significantly smaller sizes. PiezoMove™ lever-amplified actuators feature a resolution to 0.2 nm and a repeatability to 8 nm.

Application Example

- Nanopositioning
- Imaging
- High-speed switching
- Patch clamp
- Micro-dispensing
- Semiconductor testing
- Adaptronics / Automation
- Photonics / integrated optics
- Biotechnology

OEM Actuator with Integrated Guidance

With their highly precise, frictionless flexure guidance, a very high stiffness and excellent straightness of motion are achieved. Together with their small dimensions and the cost-effective design, the P-601 lever amplified actuators are especially suited for OEM applications. Versions with strain-gauge sensors (SGS) are equipped with a full bridge circuit that is insensitive to thermal drift. Versions without sensors are also available for open-loop applications such as in high-speed switches and pumps. In addition to the standard steel models, special invar and non-magnetic versions are available on request.

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Ordering Information

P-601.1S
PiezoMove™ OEM Flexure-Guided, Lever-Amplified Actuator, 100 µm, SGS-Sensor

P-601.3S
PiezoMove™ OEM Flexure-Guided, Lever-Amplified Actuator, 250 µm, SGS-Sensor

P-601.4S
PiezoMove™ OEM Flexure-Guided, Lever-Amplified Actuator, 400 µm, SGS-Sensor

P-601.1SL
PiezoMove™ OEM Flexure-Guided, Lever-Amplified Actuator, 100 µm, SGS-Sensor, LEMO Connector

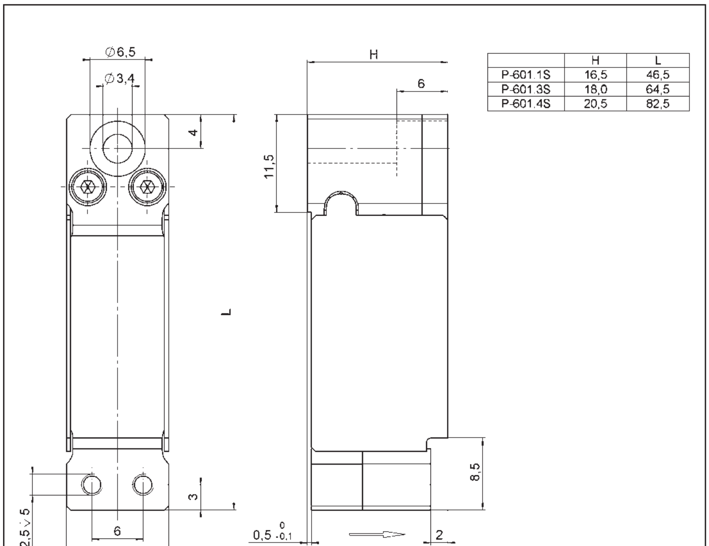
P-601.3SL
PiezoMove™ OEM Flexure-Guided, Lever-Amplified Actuator, 250 µm, SGS-Sensor, LEMO Connector

P-601.4SL
PiezoMove™ OEM Flexure-Guided, Lever-Amplified Actuator, 400 µm, SGS-Sensor, LEMO Connector

P-601.10
PiezoMove™ OEM Flexure-Guided, Lever-Amplified Actuator, 100 µm, Open-Loop

P-601.30
PiezoMove™ OEM Flexure-Guided, Lever-Amplified Actuator, 250 µm, Open-Loop

P-601.40
PiezoMove™ OEM Flexure-Guided, Lever-Amplified Actuator, 400 µm, Open-Loop



P-601 dimensions in mm

Technical Data

Model	P-601.1S P-601.1SL	P-601.3S P-601.3SL	P-601.4S P-601.4SL	P-601.x0 Open-loop versions	Units	Tolerance
Active axes	Z	Z	Z	Z		
Motion and positioning						
Integrated sensor	SGS	SGS	SGS	–		
Open-loop travel, -20 to +120 V	100	250	400	as P-601.xS	µm	min. (+20 %/-0 %)
Closed-loop travel	100	250	400	–	µm	calibrated
Open-loop resolution	0.2	0.3	0.4	as P-601.xS	nm	typ.
Closed-loop resolution	2	6	12	–	nm	typ.
Linearity, closed-loop	0.1	0.3	0.3	–	%	typ.
Repeatability	8	10	30	–	nm	typ.
Runout θ_X, θ_Y	20 / 10	20 / 10	20 / 10	as P-601.xS	µrad	typ.
Mechanical properties						
Stiffness in motion direction	0.8	0.38	0.28	as P-601.xS	N/µm	±20 %
Unloaded resonant frequency	750	440	350	as P-601.xS	Hz	±20 %
Resonant frequency @ 30 g	620	350	290	as P-601.xS	Hz	±20 %
Push/pull force capacity in motion direction	30/10	20/10	15/10	as P-601.xS	N	Max.
Lateral force	30	30	30	as P-601.xS	N	Max.
Drive properties						
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	as P-601.xS		
Electrical capacitance	1.5	3.1	4.6	as P-601.xS	µF	±20 %
Dynamic operating current coefficient	1.9	1.6	1.4	as P-601.xS	µA/(Hz•µm)	±20 %
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Stainless steel	Stainless steel	Stainless steel	Stainless steel		
Mass without cables	0.05	0.08	0.11	as P-601.xS	kg	±5 %
Cable length	S-version: 0.3 SL-version: 1.5	S-version: 0.3 SL-version: 1.5	S-version: 0.3 SL-version: 1.5	0.3	m	±10 mm
Sensor / voltage connection	S-version: open leads SL-version: LEMO	S-version: open leads SL-version: LEMO	S-version: open leads SL-version: LEMO	Open leads (no sensor)		

Recommended controller / amplifier
E-610 controller / amplifier (p. 2-110), E-625 bench-top controller (p. 2-114)

P-602 PiezoMove Flexure Actuator with High Stiffness

Integrated Guiding System, High Force and Large Travel Ranges

P-602 linear actuator family featuring travel ranges of 100, 500, and 1000 µm (from left to right)

Ordering Information

PiezoMove® OEM Linear Actuator with High Stiffness

P-602. ☐ ☐☐

- **1** Travel Range 100 µm
- **3** Travel Range 300 µm
- **5** Travel Range 500 µm
- **8** Travel Range 1000 µm

- **00** Open-loop
- **S0** SGS Sensor
- **SL** SGS Sensor, LEMO Connector

PiezoMove® OEM Linear Actuators with High Force

P-602. ☐ ☐☐

- **1** Travel Range 100 µm
- **3** Travel Range 300 µm
- **5** Travel Range 500 µm

- **08** Open-loop
- **S8** SGS Sensor
- **L8** SGS Sensor, LEMO Connector

Ask about custom designs!

- **Frictionless Flexure Guiding System for Straight Motion**
- **Integrated Motion Amplifier for Travel Ranges to 1 mm**
- **High Dynamics and Stiffness, Forces to 400 N, Backlash-Free Construction**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Available with Integrated Position Sensor**
- **Custom Designs with Larger Travel or Faster Response and Non-Magnetic Versions Feasible**
- **Ideal for OEM-Applications in Adaptronics, Biotechnology or Microfluidics**

P-602 PiezoMove flexure-guided piezo actuators integrate a frictionless high-efficiency motion amplifier to combine large travel ranges up to 1 millimeter with high stiffness and very fast response. They do not contain any components that require maintenance or are subject to wear or tear. The flexure guides eliminate tip motion permitting only for a very slight tilt at the drive head. This design feature saves the cost for additional guiding systems when integrating these actuators in applications for the active control of tools, vibrations or deformations for accuracies down to a few 10s of nanometers.

Application Examples

- Nanopositioning
- Adaptronics
- Active vibration control
- Nano-imprinting
- Active Tool control
- Laser technology
- Semiconductor technology
- Active and adaptive optics

Options and Custom Versions

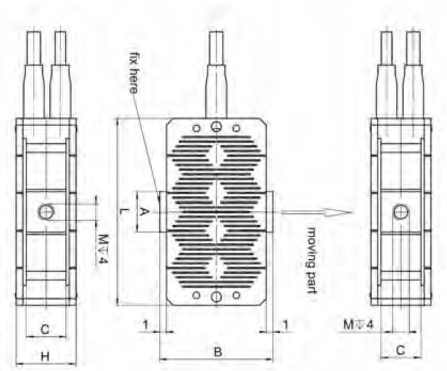
For OEM applications, PiezoMove actuators can be modified in various ways to suit the customer's requirements. The stiffness and force generation can be influenced via the lever design and the dimensions of the piezo ceramics used in the actuator. If only a small force and low guiding accuracy are required, large strokes of several 100 µm and high frequencies can be achieved with small actuators, e.g. for micropump drives. For high-accuracy applications, an integrated position feedback sensor is available. The actuators were designed to allow for considerable cost savings in large production runs.

OEM Control Electronics

PI also supplies a variety of controllers to match the actuators. These range from simple amplifier modules (see p. 2-164) and analog closed-loop OEM controllers (see p. 2-110) to high-performance digital controllers (see p. 2-100*ff*). The great choice of actuators and controllers allows customers to select the optimum combination of performance and cost for their application.

Ceramic-Insulated Piezo Actuators Provide Superior Lifetime

The highest possible reliability is assured by employing the award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with a ceramic-only insulation which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

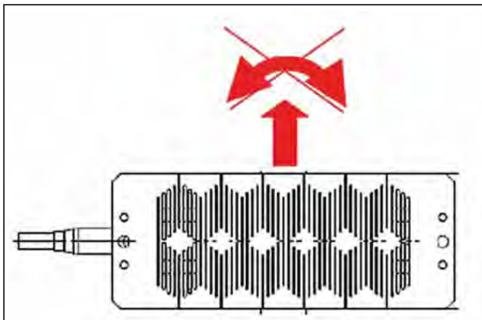


	L	B	H
P-602.1xx	28	17	9
P-602.3xx	46	19	9
P-602.5xx	85	26	9
P-602.8xx	126	34	14
P-602.1x8	28	22	14
P-602.3x8	46	24	14
P-602.5x8	85	31	14

	M	A	C
P-602.1xx	M2,5	6	6
P-602.3xx	M2,5	6	6
P-602.5xx	M2,5	6	6
P-602.8xx	M4	10	11
P-602.1x8	M2,5	6	11
P-602.3x8	M2,5	6	11
P-602.5x8	M2,5	6	11

P-602 dimensions in mm

PI offers a large variety of standard and custom lever-amplified piezo actuators for almost any application



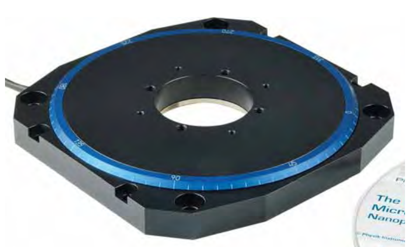
P-602: Flexure guides provide straight motion with no tip and minimum tilt

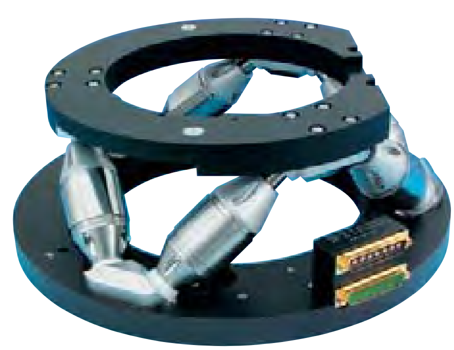
Technical Data (preliminary)

Model	P-602.100 P-602.1S0 P-602.1SL	P-602.300 P-602.3S0 P-602.3SL	P-602.500 P-602.5S0 P-602.5SL	P-602.108 P-602.1S8 P-602.1L8	P-602.308 P-602.3S8 P-602.3L8	P-602.508 P-602.5S8 P-602.5L8	P-602.800 P-602.8S0 P-602.8SL	Units	Tolerance
Active axes	X	X	X	X	X	X	X		
Motion and positioning									
Integrated sensor	- / SGS / SGS	- / SGS / SGS	- / SGS / SGS	- / SGS / SGS	- / SGS / SGS	- / SGS / SGS	- / SGS / SGS		
Open-loop travel, -20 to +120 V	120	300	600	100	300	500	1000	µm	min. (+20%/-0)
Closed-loop travel	- / 100 / 100	- / 300 / 300	- / 500 / 500	- / 100 / 100	- / 300 / 300	- / 500 / 500	- / 1000 / 1000	µm	
Open-loop resolution	0.2	0.3	0.4	0.2	0.3	0.4	0.5	nm	typ.
Closed-loop resolution	- / 2 / 2	- / 3 / 3	- / 3 / 3	- / 2 / 2	- / 3 / 3	- / 3 / 3	- / 7 / 7	nm	typ.
Linearity, closed-loop	- / 0.5 / 0.5	- / 0.5 / 0.5	- / 0.5 / 0.5	- / 0.5 / 0.5	- / 0.5 / 0.5	- / 0.5 / 0.5	- / 1.5 / 1.5	%	typ.
Repeatability	- / 10 / 10	- / 20 / 20	- / 35 / 35	- / 10 / 10	- / 20 / 20	- / 35 / 35	- / 60 / 60	nm	typ.
Mechanical properties									
Stiffness in motion direction	0.8	0.35	0.3	2.3	0.75	0.65	0.4	N/µm	± 20%
Unloaded resonant frequency	1000	450	230	1000	450	230	150	Hz	± 20%
Blocking force	80	105	150	230	225	325	400	N	max.
Drive properties									
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-888	PICMA® P-888	PICMA® P-888	PICMA® P-888		
Electrical Capacitance	1.5	3.1	6.2	6	13	26	39	µF	± 20%
Dynamic operating current coefficient	1.9	1.3	1.6	7.5	5	6	4	µA/(Hz•µm)	± 20%
Miscellaneous									
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel		
kg	28 x 17 x 9	46 x 19 x 9	85 x 26 x 9	28 x 22 x 14	46 x 24 x 14	85 x 31 x 14	126 x 34 x 14	mm	
Mass	0.022	0.04	0.105	0.05	0.088	0.215	0.355	kg	± 5%
Cable length	0.5 / 0.5 / 2	0.5 / 0.5 / 2	0.5 / 0.5 / 2	0.5 / 0.5 / 2	0.5 / 0.5 / 2	0.5 / 0.5 / 2	0.5 / 0.5 / 2	m	± 10 mm
Sensor / voltage connection	0- and S-version: open leads SL-version: LEMO connector	0- and S-version: open leads SL-version: LEMO connector	0- and S-version: open leads SL-version: LEMO connector	0- and S-version: open leads L-version: LEMO connector	0- and S-version: open leads L-version: LEMO connector	0- and S-version: open leads L-version: LEMO connector	0- and S-version: open leads SL-version: LEMO connector		

Recommended controller / amplifier
E-610 controller / amplifier see p. 2-110, E-625 bench-top controller see p. 2-114

Piezo Micropositioning Stages

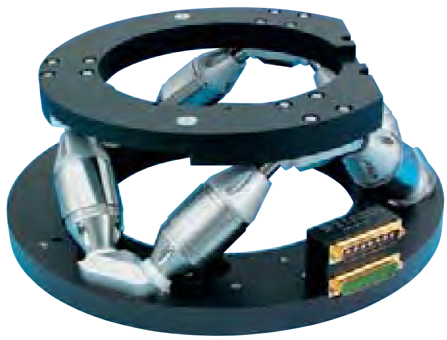




PI

N-515K Non-Magnetic Piezo Hexapod

6-Axis Precision Positioning System with NEXLINE® Linear Drives



6-axis parallel kinematics (Hexapod) with integrated N-215 NEXLINE® high-load actuators, suitable for applications in strong magnetic fields

- **Travel Ranges 10 mm Linear, 6° Rotation**
- **Large Clear Aperture Ø 202 mm**
- **Non-Magnetic**
- **Nanometer Resolution**
- **Low-Profile: 140 mm Height Only**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**
- **Up to 500 N Force Generation**
- **Self Locking at Rest, No Heat Generation**

Model	Travel Range	Load capacity	Dimensions
N-515KNPH NEXLINE® Piezo Hexapod	X, Y, Z: 10 mm θ_X, θ_Y, θ_Z: 6°	50 kg	Outer Ø baseplate, 380 mm Ø moved platform (top) 300 mm 140 mm height

N-510 High-Force NEXLINE® Z/Tip/Tilt Platform

Nanometer Precision for Semiconductor Industry, Wafer Alignment

Z, tip, tilt nanopositioning platform with 3 integrated drives (tripod design)

- **Self Locking at Rest, No Heat Generation**
- **Vacuum Compatible and Non-Magnetic Designs Feasible**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**
- **NEXLINE® Piezo Walking Drive Free from Wear and Tear**
- **Load Capacity 200 N**
- **High Precision with Integrated 5 nm Incremental Sensors + Picometer Resolution Dithering Mode**

Model	Travel	Load capacity	Linear velocity	Dimensions
N-510 NEXLINE® Z, tip, tilt platform	1,3 mm vertical range 10 mrad tilt angle	200 N	0.2 mm/s	Ø 300 mm (12´´) clear aperture Ø 250 mm

N-510K High-Stiffness NEXLINE® Z Stage

High-Precision Positioning, with Capacitive Sensors

The N-510KHFS hybrid-drive nanopositioner offers maximum accuracy for semiconductor inspection applications

- **Self Locking at Rest, No Heat Generation**
- **Hybrid Drive: PiezoWalk® plus PICMA®**
- **Travel Range: 400 µm Coarse + 40 µm Fine**
- **2 nm Closed-Loop Resolution**
- **Direct Metrology: One Single Control Loop with Capacitive Sensors**
- **High Push and Holding Force to 25 N**
- **Piezo Walking Drive w/o Wear and Tear & Outstanding Lifetime due to PICMA® Piezo Actuators**

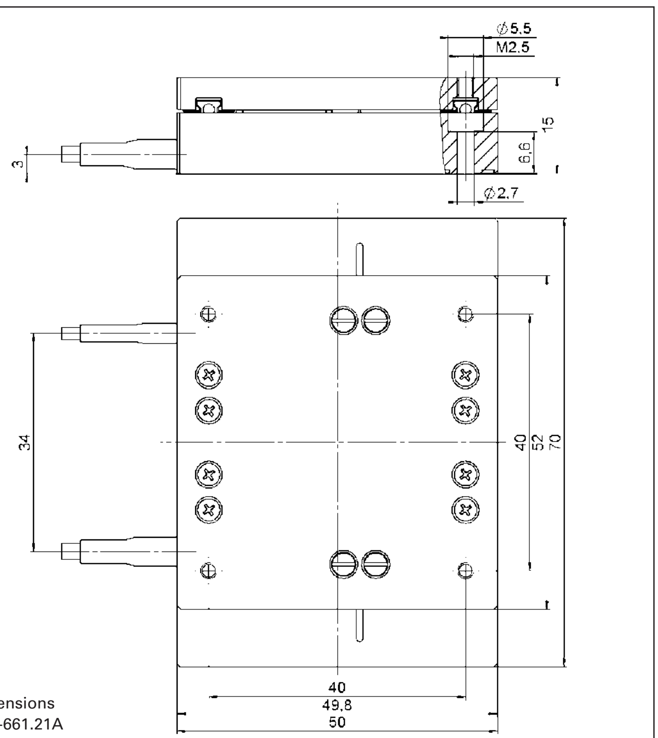
Model	Vertical travel	Velocity	Bidirectional repeatability	Load capacity	Dimensions
N-510KHFS Hybrid-Focus System	400 µm coarse 40 µm fine	1 mm/sec	50 nm (full travel)	25 N	Ø 300 mm 68.5 mm height

N-661 Miniature Linear Slide with NEXACT® Drive

PiezoWalk® Drive Provides Nanometer Precision, Smooth Motion and Rapid Response

The N-661 miniature linear stage integrates a PiezoWalk® NEXACT® linear motor combined with a high-resolution linear encoder. It provides 20 mm travel and resolution down to the nanometer range.

- **Travel Range 20 mm**
- **Self Locking at Rest, no Heat Generation, no Servo Dither**
- **Compact Design: 70 x 50 x 20 mm**
- **Zero-Wear Piezo Stepping Drive, Ideal for Micro- and Nano-Manipulation**
- **Integrated Linear Encoder Option for Highest Accuracy with 20 nm Resolution**
- **Two Operating Modes: Continuous Stepping Mode and Continuously Variable, High-Dynamics Analog Mode for 30 pm Resolution**
- **Up to 10 N Force Generation**



Dimensions of N-661.21A

The compact N-661 nanopositioning stage is based on the NEXACT® PiezoWalk® drive. This dual-mode, high-performance piezo stepping linear motor can provide sub-nanometer resolution and high force, along with very rapid response. When run in its analog mode, fast oscillations with amplitudes up to 7 microns and resolutions down to 30 pm can be achieved. This mode is of great value in high-throughput applications as well as in dynamic laser tuning, cell penetration applications, or even for active vibration damping. The stage is equipped with a precision guiding system and an optical linear encoder to enable highly repeatable positioning.

Ordering Information

N-661.21A
Miniature NEXACT® Translation Stage, 20 mm, Linear Encoder, 20 nm Resolution

Ask about custom designs

Application Examples

- Life science
- Photonics
- Laser tuning
- Motion in strong magnetic fields

The products described in this document are in part protected by the following patents: German Patent No. P4408618.0

Technical Data

Model	N-661.21A
Active axes	X
Motion and positioning	
Travel range	20 mm
Step size in stepping mode (open-loop)	To 5 µm
Integrated sensor	Linear encoder
Sensor resolution	20 nm *
Travel range in analog mode	7 µm
Open-loop resolution	0.03 nm
Closed-loop resolution	20 nm*
Bidirectional repeatability	40 nm
Pitch	50 µrad
Yaw	50 µrad
Step frequency	1.5 kHz
Max. velocity	10 mm/s*
Mechanical properties	
Stiffness in motion direction	2.4 N/µm
Max. push / pull force (active)	10 N
Max. holding force (passive)	15 N
Lateral Force	50 N
Drive properties	
Drive type	NEXACT® linear drive
Operating Voltage	-10 V to +45 V
Miscellaneous	
Operating temperature range	0 to 50 °C
Material	Aluminum
Mass	150 g
Cable length	1.5 m
Connector	15-pin sub-HDD connector, one channel
Recommended controller/driver	E-861.1A1 Controller for NEXACT® (see p. 1-20)

*With E-861. Depending on drive electronics.

M-661 · M-662 PILine® Miniature Linear Motor Stage

With Ultrasonic Piezo Linear Drives

PILine® M-662 (left side) and M-661 stages are the smallest piezo-motor-driven translation stages available on the market that achieve speeds of up to 500 mm/s

- **Smallest Translation Stages with Linear Motor Drive**
- **Travel Ranges to 20 mm**
- **Max. Velocity 500 mm/s**
- **Acceleration to 5 g**
- **Incremental Motion to 50 nm**
- **Self Locking at Rest**
- **XY-Combination Possible**
- **MTBF 20.000 h**
- **Vacuum Versions to 10^{-7} hPa**

M-661 and M-662 PILine® translation stages offer accelerations to 5 g with millisecond response and velocities to 500 mm/sec in an extremely compact package. Providing travel ranges to 20 mm, they are among the smallest motorized translation stages currently on the market. Both models are designed for open-loop operation (a similar closed-loop stage with linear encoder is available as model M-663. The M-662, with its square footprint, is also suitable for use in XY configurations. For applications where the smallest dimensions are essential, the P-652 micro stage is offered.

Application Examples

- Biotechnology
- Micromanipulation
- Microscopy
- Quality assurance testing
- Semiconductor testing
- Metrology
- Mass storage device testing
- R&D
- Photonics packaging

Working Principle

PILine® piezo motors use a new, patented, ultrasonic drive developed by PI. A the heart of the system is a piezo ceramic plate, which is excited with high-frequency eigenmode oscillations. A friction tip attached to the plate moves along an inclined linear path at the eigenmode frequency. Through its contact with the friction bar, the moving part of the mechanics drives forward or backwards. With each oscillatory cycle, the mechanics execute a step of a few nanometers; the macroscopic result is smooth motion with a virtually unlimited travel range.

Advantages of PILine® Micropositioning Systems

The ultrasonic piezoceramic drives used in PILine® micropositioners have a number of advantages over classical drives:

- Higher Accelerations, up to 5 g
- Speeds up to 500 mm/s
- Small Form Factor
- Self-Locking When Powered Down
- No Shafts, Gears or Other Rotating Parts
- Non-Magnetic and Vacuum-Compatible Drive Principle

Choice of Drive Electronics

Special driver electronics are required to create the ultrasonic oscillations for PILine® piezo-motors. The driver controls the motor speed as a function of an analog ±10 V signal. The driver is not included, as it is available in different versions, from the low-priced C-184.161 OEM-board to the C-185.161 bench-top unit. The stage and the driver electronics, however, must be ordered together, so that they can be tuned to one-another for optimum performance.

Ordering Information

M-661.370
PILine® Translation Stage, 18 mm, Open-Loop

M-662.470
PILine® Translation Stage, 20 mm, Open-Loop, XY Mountable

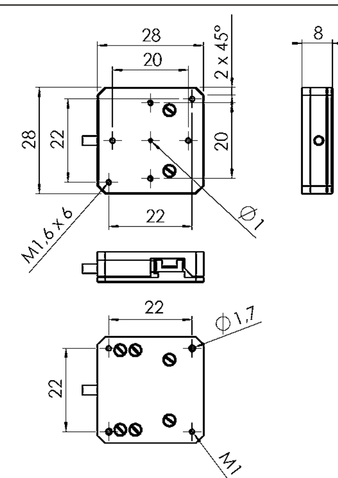
Accessories:

C-184.161
Analog OEM Driver Board for PILine® P-661 Motors

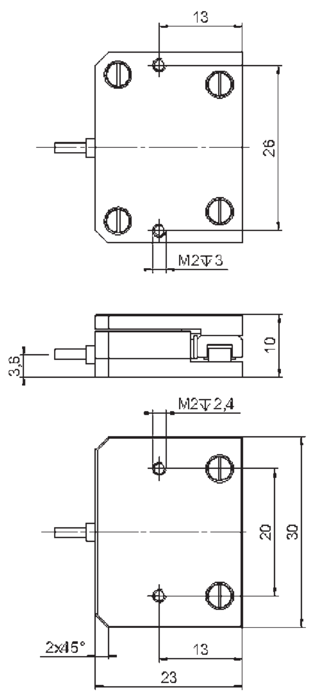
C-185.161
Analog Stand-Alone Drive Electronics with Power Supply for PILine® P-661 Motors

Notes

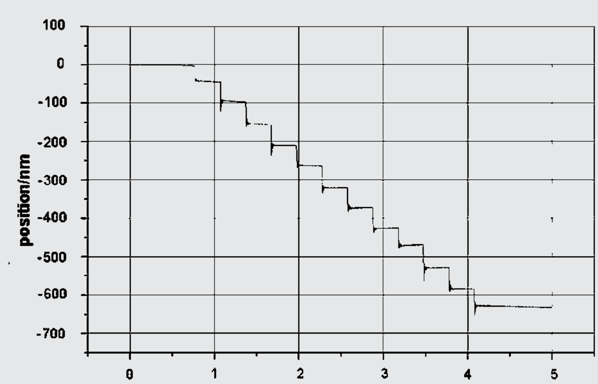
The products described in this document are in part protected by the following patents:
US Pat. No. 6,765,335
German Patent No. 10154526



M-662 dimensions in mm



M-661 dimensions in mm



50 nm steps created with a system incorporating an M-662.470 open-loop piezo linear motor stage

Technical Data

Model	M-661.370	M-662.470	Units	Tolerance
Motion and positioning				
Travel range	18	20	mm	
Min. incremental motion	0.05*	0.05*	µm	typ.
Max. velocity	500	500	mm/s	
Mechanical properties				
Max. load	5	5	N	
Max. push/pull force	1	1	N	
Max. holding force	2	2	N	
Drive properties				
Motor type	P-661 PILine® ultrasonic piezomotor drive	P-661 PILine® ultrasonic piezomotor drive		
Operating voltage	120 (Peak-Peak)** 42 (RMS)**	120 (Peak-Peak)** 42 (RMS)**	V	
Electrical power	5***	5***	W	nominal
Current	400***	400***	mA	
Miscellaneous				
Operating temperature range	-20 to +50	-20 to +50	°C	
Material	Al (black anodized)	Al (black anodized)		
Dimensions	30 x 23 x 10	28 x 28 x 8		
Mass	0.03	0.03	kg	±5 %
Cable length	1.5	1.5	m	±10 mm
Connector	LEMO connector	LEMO connector		
Recommended controller/driver	C-184.161 OEM board C-185.161 Bench-top	C-184.161 OEM board C-185.161 Bench-top (p. 1-36)		

*The minimum incremental motion is a typical value that can be achieved in the open-loop mode of a piezomotor stage. To obtain it, it is important to follow the mounting guidelines in the motor documentation.
**The stage supply power is drawn from the drive electronics, which runs on 12 VDC.
***For drive electronics.

M-663 PILine® Linear Motor Stage

Compact, Fast, with Ultrasonic Piezo Linear Drives, Direct Position Measurement

PILine® M-663 micropositioning stages with integrated linear encoder and C-867 controller/driver in the background

- **Smallest Translation Stage with Closed-Loop Linear Motor and Encoder**
- **Travel Range 19 mm**
- **Max. Velocity 400 mm/s**
- **Acceleration up to 10 g**
- **Direct Metrology Linear Encoder**
- **0.1 µm Resolution**
- **XY Combination Possible**
- **Vacuum-Compatible Versions Available**

PILine® M-663 micropositioning systems offer high velocities of up to 400 mm/s and travel ranges of 19 mm in a compact package. The M-663 is the smallest closed-loop translation stage with piezomotor drives currently on the market. Its square footprint makes it suitable for use in compact XY configurations.

Application Examples

- Biotechnology
- Micromanipulation
- Microscopy
- Quality assurance testing
- Metrology
- Mass storage device testing
- R&D
- Photonics packaging

Working Principle

PILine® motors have a new, patented, ultrasonic drive developed by PI. The core piece of the system is a piezoceramic plate, which is excited to produce high-frequency eigenmode oscillations. A friction tip attached to the plate moves along an inclined linear path at the eigenmode frequency. Through its contact with the friction bar, the moving part of the mechanics drives forward or backwards. With each oscillatory cycle, the mechanics executes a step of a few nanometers; the macroscopic result is smooth motion with a virtually unlimited travel range.

Advantages of PILine® Micropositioning Systems

The ultrasonic piezoceramic drives used in PILine® micropositioners have a number of advantages over classical drives:

- Higher Accelerations, up to 5 g
- Speeds up to 500 mm/s
- Small Form Factor
- Self-Locking When Powered Down
- No Shafts, Gears or Other Rotating Parts
- Non-Magnetic and Vacuum-Compatible Drive Principle

Optimized Controller and Drive Electronics

PILine® motors require a special drive electronics to generate the ultrasonic oscillations for piezoceramic element. For optimum performance the highly specialized C-867 (see p. 4-116) motion controller is recommended. This sophisticated controller also inte-grates the drive electronics. Furthermore, the controller has a number of special features, including dynamic parameter switching for an optimized high-speed motion and settling behavior to take into account the motion characteristics typical of piezomotors. The broad-band encoder input (50 MHz) supports the outstanding high accelerations and velocities of PILine® drives at high resolutions.

Optionally, for use with third party servo controllers, the C-185 analog drive electronics (stand-alone unit) is available. It controls the motor speed by an analog ±10 V signal. For optimum performance the driver must be tuned together with the mechanics and should be ordered at the same time as the motor/stage.

Ordering Information

M-663.465
PILine® Translation Stage, 19 mm, Linear Encoder, 0.1 µm Resolution

M-663.Y65
PILine® Translation Stage, 19 mm, Linear Encoder, 0.1 µm Resolution, turned cable outlet, XY mountable

M-663.46V
PILine® Translation Stage, 19 mm, Linear Encoder, 0.1 µm Resolution, Vacuum Compatible to 10^{-6} hPa

Accessories:

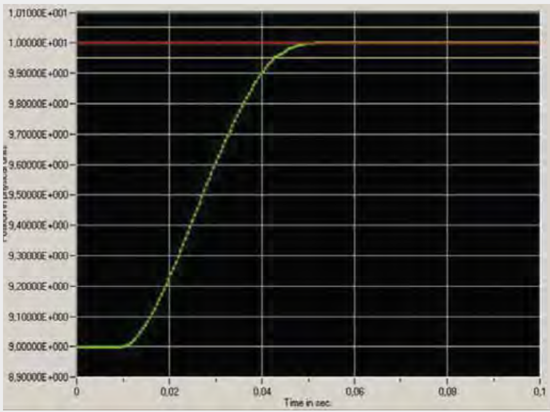
C-867.161
Piezomotor Controller with Drive Electronics, 1 Channel, for PILine® Systems with P-661 Motors

Driver for use with separate controller:

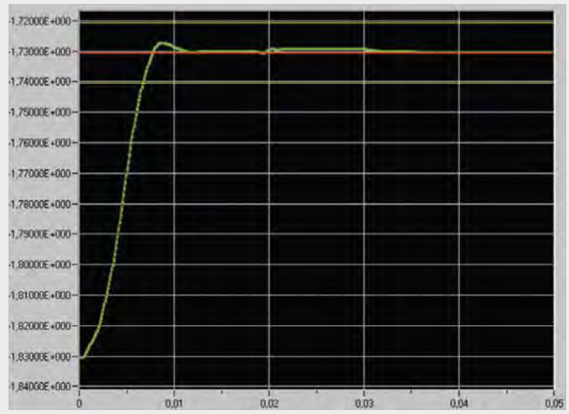
C-185.161
Analog Stand-Alone Drive Electronics with Power Supply for PILine® P-661 Motors

Note

The products described in this document are in part protected by the following patents:
US Pat. No. 6,765,335
German Patent No. 10154526



A 1 mm step performed by an M-663 stage with 300 g load controlled by a C-867 controller/driver reaches the end position in less than 40 ms

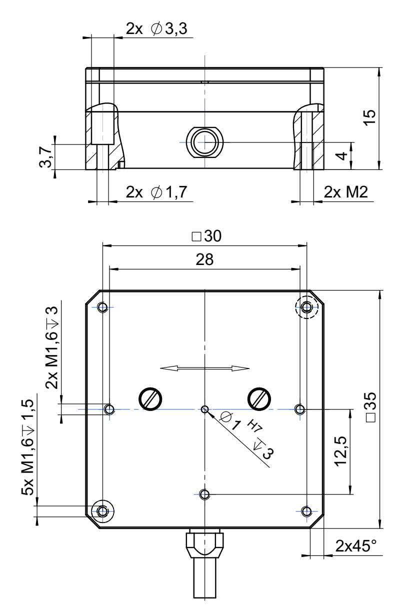


An M-663 with 100 g load settles to 0.1 µm accuracy in 10 ms after a 100 µm step, measured with C-867 controller/driver

Technical Data

Model	M-663.465	Units	Tolerance
Active axes	X		
Motion and positioning			
Travel range	19	mm	
Integrated sensor	Linear encoder		
Sensor resolution	0.1	µm	
Min. incremental motion	0.3	µm	typ.
Bidirectional repatability	±0.3	µm	typ.
Unidirectional repeatability	0.2	µm	typ.
Pitch	300	µrad	typ.
Yaw	300	µrad	typ.
Max. velocity	400	mm/s	
Reference switch repeatability	1	µm	typ.
Mechanical properties			
Max. load	5	N	
Max. push/pull force	2	N	
Max. holding force	2	N	
Drive properties			
Motor type	P-661 PILine® ultrasonic piezomotor		
Motor voltage range	120 (peak-peak)* 42 (RMS)*	V	
Electrical power	5**	W	nominal
Current	400**	mA	
Reference switch	Hall-effect		
Miscellaneous			
Operating temperature range	-20 to +50	°C	
Material	Al (black anodized)		
Dimensions	35 x 35 x 15	mm	
Mass	40	g	±5 %
Cable length	1.5	m	±10 mm
Connector	MDR, 14-pin		
Recommended controller/driver	C-867.161 Single-axis controller/driver (p. 4-116) C-185.161 Drive electronics (p. 1-36)		

*Power is supplied by the drive electronics which runs on 12 V DC
**For drive electronics

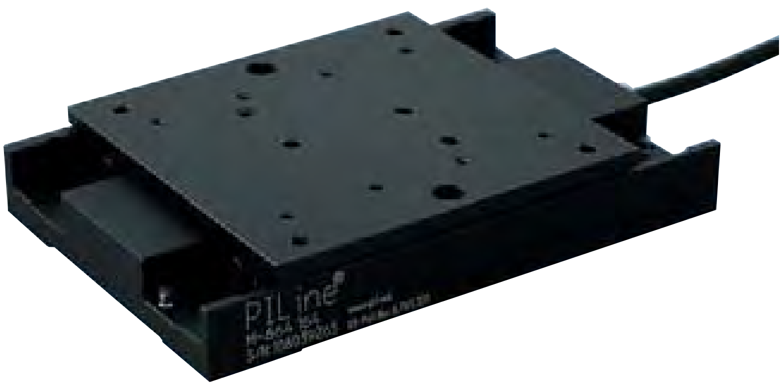


M-663
dimensions in mm

XY combination of two M-663s; CD for size comparison

M-664 PILine® Linear Motor Stage

Low-Profile High-Speed with Ultrasonic Piezo Linear Drives & Direct Position Measurement



Fast and compact M-664 piezo translation stage with linear encoder

- **Travel Range 25 mm**
- **Max. Velocity 400 mm/s**
- **Ultra-Low Profile, 15 mm**
- **Direct Metrology Linear Encoder with 0.1 µm Resolution**
- **High Guiding Accuracy with Crossed Roller Bearings**
- **Compact XY Combinations**
- **Piezo Linear Motor with 4 N Drive Force**
- **Self Locking at Rest**

M-664 micropositioning systems are low-profile, high-accuracy translation stages with linear encoders. The M-664 stage is next-larger in the series of piezomotor-driven stages of which the M-663 (see p. 4-28) is the smallest. For improved guiding accuracy, the M-664 uses two crossed roller bearings mounted on ground aluminum profiles. The integrated P-664 PILine® linear motor can generate forces up to 4 N and maximum closed-loop velocities to 400 mm/s over a 25 mm travel range.

Application Examples

- Biotechnology
- Micromanipulation
- Microscopy
- Quality assurance testing
- Metrology
- Mass storage device testing
- R&D
- Photonics packaging

Advantages of PILine® Micropositioning Systems

The ultrasonic piezoceramic drives used in PILine® micropositioners have a number of advantages over classical drives:

- Higher Accelerations, up to 5 g
- Speeds up to 500 mm/s
- Small Form Factor
- Self-Locking When Powered Down
- No Shafts, Gears or Other Rotating Parts
- Non-Magnetic and Vacuum-Compatible Drive Principle

Optimized Controller and Drive Electronics

PILine® motors require a special drive electronics to generate the ultrasonic oscillations for the piezoceramic element. For optimum performance the highly specialized C-867 motion controller (see p. 4-116) is recommended. This sophisticated controller also integrates the drive electronics. Furthermore, the controller has a number of special features, including dynamic parameter switching for an optimized high-speed motion and settling behavior to take into account the motion characteristics typical of piezomotors. The broadband encoder input (50 MHz) supports the outstanding high accelerations and velocities of PILine® drives at high resolutions.

Ordering Information

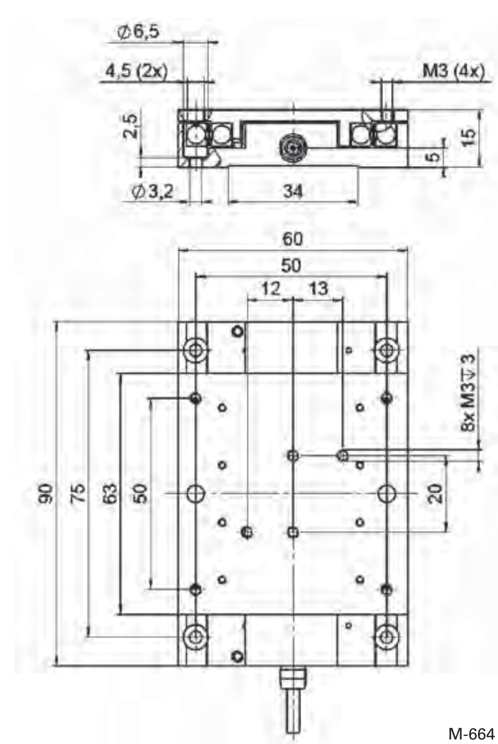
M-664.164
PILine® Micro Positioning Stage with P-664 Piezo Linear Motor, 25 mm, 4 N

Ask about custom designs!

Optionally, for use with third party servo controllers, the C-185 analog drive electronics (stand-alone unit, see p. 1-36) is available. It controls the motor speed by an analog ±10 V signal. For optimum performance this driver must be tuned together with the stage and should be ordered at the same time as the motor/stage.

Notes

The products described in this document are in part protected by the following patents:
US Pat. No. 6,765,335
German Patent No. 10154526



M-664 dimensions in mm

PI

PILine® Micropositioning stages: M-682, M-664 and M-663 (from left)

Technical Data

Model	M-664.164	Tolerance
Active axes	X	
Motion and positioning		
Travel range	25 mm	
Integrated sensor	Linear encoder	
Sensor resolution	0.1 µm	
Min. incremental motion	0.3 µm	typ.
Bidirectional repeatability	0.2 µm	typ.
Unidirectional repeatability	0.2 µm	typ.
Pitch	±50 µrad	typ.
Yaw	±50 µrad	typ.
Max. velocity	400 mm/s	
Reference switch repeatability	1 µm	typ.
Mechanical properties		
Max. load	25 N	
Max. push/pull force	4 N	
Max. holding force	3 N	
Drive properties		
Motor type	P-664 PILine® ultrasonic piezo drive	
Operating voltage	168 V (peak-to-peak) * 60 V (RMS) *	
Electrical power	10 W **	nominal
Current	800 mA **	
Limit and reference switches	Hall-effect	
Miscellaneous		
Operating temperature range	-20 to +50 °C	
Material	Al (black anodized)	
Dimensions	90 x 60 x 15 mm	
Mass	0.190 kg	±5 %
Cable length	1.5 m	±10 mm
Connector	MDR, 14-pin	
Recommended controller/driver	C-867.164 single-axis controller/driver C-185.164 drive electronics	

*The stage supply power is drawn from the drive electronics, which runs on 12 V.
**For drive electronics

M-683 PILine® Precision Micro Translation Stage

Low-Profile & High-Speed with Ultrasonic Piezomotors, Direct Position Metrology

M-683.2U4 (50 mm) low-profile translation stage with integrated high-speed ceramic linear motors

- **Max. Velocity 350 mm/s**
- **Low Profile: Only 21 mm Height**
- **Compact XY Combination Possible**
- **Up to 6 N Force Generation**
- **Direct Metrology Linear Encoder, 0.1 µm Resolution**
- **Travel Range 50 mm**
- **Excellent Guiding Accuracy Through Crossed Roller Bearings**
- **PILine®: Non-Magnetic and Vacuum-Compatible Working Principle**
- **Self Locking at Rest**

M-683 precision micropositioning stages make use of PILine® ultrasonic piezo linear motors enabling a compact design and low profile. An integrated linear encoder enables closed-loop control with 0.1 µm resolution. The M-683 translation stages use paired crossed-roller bearings mounted on ground-aluminum profiles for better guiding accuracy. Integrated U-164 PILine® linear motors provide push forces to 6 N and a maximum velocity of up to 350 mm/s. The stages can be arranged to form compact XY systems. If an additional Z-axis is required, the M-110 microstage series (see page 4-22) is recommended due to its higher holding force. The M-683 design is scalable and can be extended to provide longer travel ranges to 300 mm. Vacuum-compatible versions are also available on request.

Application Examples

- Biotechnology
- Micromanipulation
- Microscopy
- Quality assurance testing
- Metrology
- Semiconductor testing
- Mass storage device testing
- R&D
- Photonics packaging

Limit and Reference Switches

For the protection of your equipment, non-contact limit and reference switches are installed. The reference switch supports advanced automation applications with high precision.

Advantages of PILine® Micro Positioning Systems

PILine® ultrasonic ceramic drives provide several advantages over classical motors and drivers:

- Higher Acclerations, up to 5 g
- Speeds up to 500 mm/s
- Small Form Factor
- Self-Locking when Powered Down
- No Shafts, Gears or Other Rotating Parts
- No Lubricants
- Non-Magnetic and Vacuum Compatible Operating Principle

Optimized Controller and Drive Electronics

For optimum performance the highly specialized C-867 motion controller (see page 4-116) is recommended. This dedicated piezo motor controller also integrates the drive electronics which PILine® motors require to generate the ultrasonic oscillations for the piezoceramic element.

Furthermore, the controller has a number of special characteristics, including continuous automatic drive frequency adjustment, dynamic parameter switching for optimized high-speed motion and settling behavior and some other features to address the requirements of ultrasonic motors. The broad-band encoder input (50 MHz) supports the outstanding high accelerations and velocities of PILine® drives at high resolutions.

Optionally, for use with third party servo controllers, the C-185 analog drive electronics (stand-alone unit) (see page 1-36) is available. It accepts an analog ±10 V signal to control the motor velocity. For optimum performance the driver must be tuned together with the mechanics and should be ordered at the same time as the motor/stage.

Ordering Information

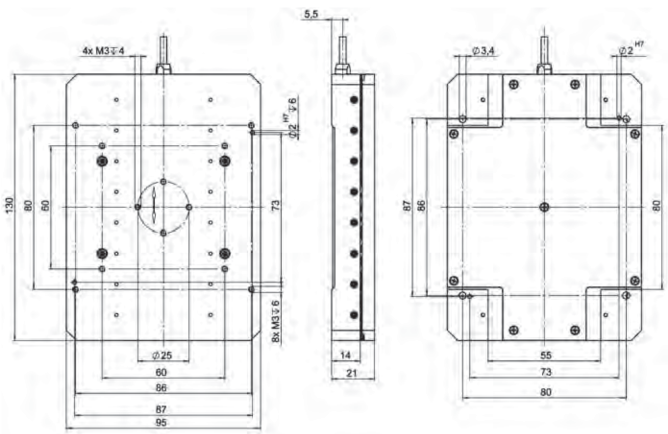
M-683.2U4
PILine® High-Speed Linear Stage, 50 mm, 6 N

Accessories:

M-110.05
Adapter bracket for vertical mount of M-110 stages on M-683 stages

Patent Protection

The products described in this document are in part protected by the following patents:
US Pat. No. 6,765,335
German Patent No. 10154526



M-683.2U4 dimensions in mm

Technical Data

Model	M-683.2U4	Tolerance
Active axes	X	
Motion and positioning		
Travel range	50 mm	
Integrated sensor	Linear encoder	
Sensor resolution	0.1 µm	
Min. incremental motion	0.3 µm	typ.
Bidirectional repeatability	±1 µm	typ.
Unidirectional repeatability	0.2 µm	typ.
Pitch	±150 µrad	typ.
Yaw	±50 µrad	typ.
Max. velocity	350 mm/s	
Reference switch repeatability	1 µm	typ.
Mechanical properties		
Max. load capacity	50 N	
Max. push / pull force	6 N	
Max. holding force	6 N	
Drive properties		
Motor type	2 x U-164 PILine® ultrasonic piezo drive	
Operating Voltage	60 V_{rms}*	
Electrical power	15 W**	nominal
Power consumption	1.5 A**	
Reference Switch	optical	
Limit Switches	Hall-effect	
Miscellaneous		
Operating temperature range	0 to +50 °C	
Material	Al (black anodized)	
Dimensions	130 x 95 x 21 mm	
Mass	0.65 kg	±5 %
Cable length	1.5 m	±10 mm
Connector	MDR, 14-pin	
Recommended controller / driver	C-867.160 single-axis controller / driver C-185.D64 drive electronics	

*Power to the motor is supplied by the drive electronics, which runs on 12 V DC, or by the controller (24 V).
**For drive electronics

M-511.HD Nano-Precision Heavy-Duty Stage

Hybrid DC/Piezo Precision Stage, High Speed, 2 nm Resolution

M-511.HD hybrid nanopostioner

- **Simultaneous Control of Piezo-Flexure Drives & DC-Servo/Ballscrew Drives**
- **100 mm Travel Range, 50 mm/sec Max. Velocity**
- **Reliable Execution of Nanometer Level Increments**
- **2 nm Linear Encoder Resolution**
- **Millisecond Settling Time to Nanometer Precision**
- **Frictionless Piezo Drive and Flexure-Decoupled Ballscrew**
- **Active Compensation of Backlash and Stick/Slip Effects**
- **Excellent Velocity Control**

The M-511.HD is an advancement on PI's proven M-5x1 precision micropositioning stage series. The new hybrid system overcomes the limitations of conventional precision positioning systems by combining the well-known advantages of piezo-flexure-drives (unlimited resolution and very rapid response) with the long travel ranges and high holding forces of a servo-motor/ballscrew arrangement. The M-511.HD allows velocities to 50 mm/s with an encoder resolution of 2 nm and load capacity of 50 kg for horizontal operation.

Application Examples

- Surface Inspection
- Microscopy
- Laser technology
- Interferometry
- Metrology

Long Travel Ranges with Nanometer Precision

The challenge of implementing hybrid technology is not only the positioning stage design, but also the use of high-resolution sensors over large travel ranges, the processing of the resulting high-frequency signals and the design of special control algorithms to take full advantage of the hybrid concept.

On the mechanical side, this is accomplished by decoupling the moving platform from the positioner's motor-ballscrew-drive by frictionless flexures and stiff, highly responsive piezo actuators. Due to its high stiffness and instantaneous, sub-millisecond range response, the integrated piezo flexure drive provides active stick/slip compensation during startup and settling and is the key to achieving consistent and repeatable nanometer level positioning increments. It also cancels out motion irregularities caused by the ball screw and significantly improves velocity control.

Servo-control of the system employs a single high-resolution position feedback sensor (direct metrology) which means that the inherent piezo precision is available over the entire travel range of 100 mm, and longer travel ranges are basically feasible. The resolution and the positioning accuracy mainly depend on the choice of the feedback sensor.

Hybrid Controller Technology is Key to Success

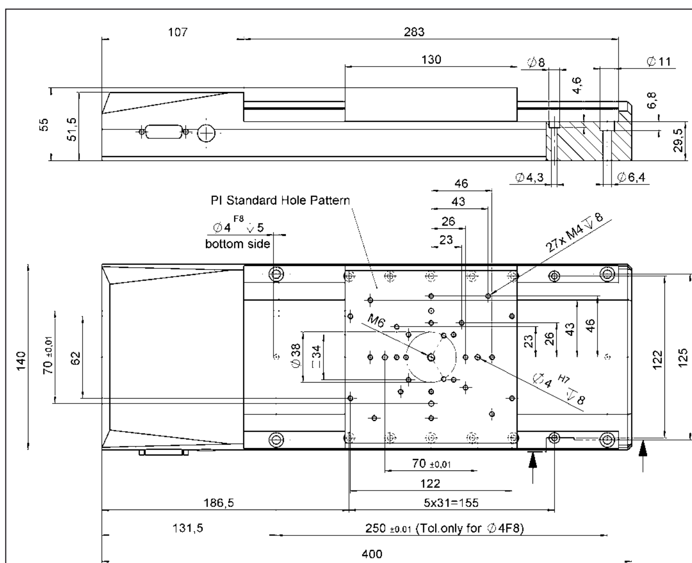
PI's highly specialized C-702 hybrid nanopositioning controller (see p. 4-118) compares the actual platform position (by reading the integrated linear encoder) with a calculated, smooth trajectory in real time. Its complex control algorithms continuously actuate both the piezoelectric and servo motor drives in a way to provide the best possible overall performance.

This makes hybrid systems ideal for applications where extremely smooth motion is required, where the position of an incident needs to be read and refound precisely, or where an externally specified target position needs to be hit within few a nanometers, such as in surface inspection or metrology.

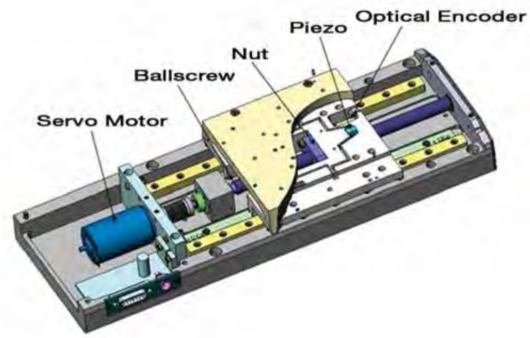
Ordering Information

M-511.HD
Ultra-High-Precision Hybrid Translation Stage, 100 mm Travel, 2 nm Linear Encoder Resolution

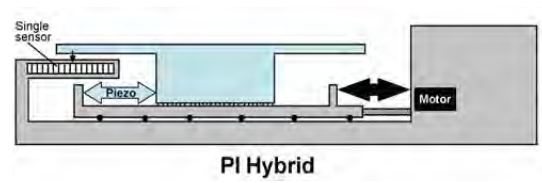
Ask about custom designs!



M-511.HD, dimensions in mm. Sub-D connector 26-pin, 3 m cable



Working principle of the M-511.HD. The platform is decoupled from the motor drive train by the piezo actuator and the flexure guides. This also reduces the inertia of the piezo-driven platform and allows for rapid response



PI Hybrid drive combines motorized and piezo positioning system with integrated, internal, high-resolution sensor in one control loop

Model	M-511.HD
Active axes	X
Motion and positioning	
Travel range	100 mm
Integrated sensor	Linear encoder
Sensor resolution	0.002 µm
Design resolution	0.002 µm
Min. incremental motion	0.004 µm
Hysteresis at the platform	0.01 µm
Unidirectional repeatability	0.01 µm
Accuracy	<0.05 µm
Pitch	±25 µrad
Yaw	±25 µrad
Straightness	1 µm
Flatness	1 µm
Max. velocity	50 mm/s
Origin repeatability	1 µm
Mechanical properties	
Drive screw	Recirculating ballscrews
Guiding	Precision linear guiding rails, recirculating ball bearings
Screw pitch	2 mm/rev.
Max. load	200 N
Max. push/pull force	80/80 N
Max. lateral force	200 N
Drive properties	
Drive type	Hybrid drive: DC motor with low-inertia, flexure-decoupled and piezo actuated stage platform
Motor type	DC motor
Operating voltage (motor)	24 V
Electrical power	30 W
Piezo drive type	PICMA® Multilayer piezo with flexure
Piezo voltage	±36 V
Limit and reference switches	Hall-effect
Miscellaneous	
Operating temperature range	-20 to +65 °C
Material	Al (black anodized)
Mass	5.1 kg
Recommended controller/driver	C-702 hybrid motor controller (p. 4-118)

PI

C-702 Hybrid System Controller

High Velocity-Constancy for Nanometer-Precision Hybrid DC/Piezo Nanopositioning Systems

C-702 Hybrid Controller

- Motion Controller & Driver for Simultaneous Operation of Closed-Loop DC Servo Motors and Piezo Actuators
- 2 Channels
- Sample Rate 10 kHz
- Piezo Resolution 24-bit
- Fast Serial Bus for Incremental High-Resolution Sensor
- Realtime Operating System
- Interfaces: TCP/IP Ethernet, RS-232, VGA, Keyboard

The C-702 digital hybrid motion controller has been designed for precision control of the M-511.HD (see p. 4-46) and M-714 (see p. 4-62) nanopositioning stages. Both are based upon the PI hybrid drive technology integrating piezoelectric and motorized drive components to form one motion and servo-control system. The result is a nanopositioning system for high loads that can follow a motion profile with nanometer position accuracy and high constancy of velocity over several millimeters of travel.

Application Examples

- Surface Inspection
- Microscopy
- Laser technology
- Interferometry
- Metrology

Highly Effective Servo-Control for a Complex Drive Technology

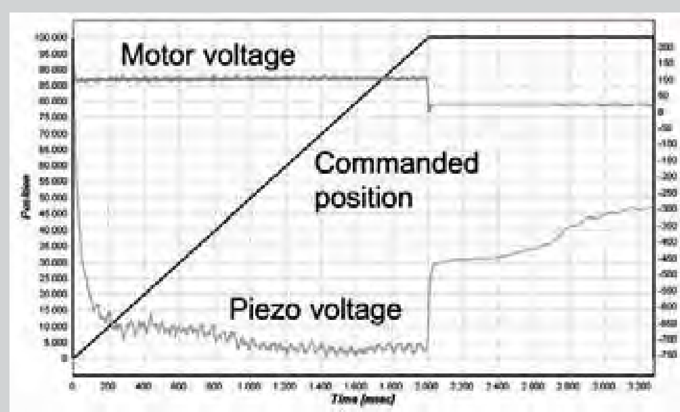
The optimized interaction between the piezoelectric and motorized drive components to make them a single motion unit requires a high-speed sensor as well as powerful control algorithms. The digital, 2-channel, C-702 controller, based on modern CPU technology with a real time operating system, has been designed for this task. It is able to read the position signals with virtually no delay and process the data immediately. The integrated piezo amplifiers use a high-resolution 24-bit DAC to fully support the high position resolution of the piezo actuators. The new ultra-fast broadband SSI interface for the optical linear encoder supports stage velocities of 300 mm/s at a resolution of 2 nm. With special cabling, external sensor signals, like those from an interferometer, can be used for servo-control via an SSI interface.

One Controller for One Motion System

In PI hybrid systems, the motor-leadscrew and piezo actuator are fully integrated to form one motion system. The motor and piezo act together at all times. The result is far more than a coarse-adjust/fine-adjust system: effects like startup stick/slip and backlash can be completely compensated and a motion profile with high constancy of velocity can be followed. Because of the high-piezo stiffness, setting to a few nanometers only takes a few milliseconds, significantly faster than with conventional, higher-inertia, linear-motor-driven stages. Furthermore minimal increments in the range of the sensor resolution can be reliably executed. To allow high velocities beyond 100 mm/sec and nanometer-range incremental resolution, position information must be transmitted and processed very rapidly and a complex control algorithm is required.

Ordering Information

C-702.00
Ultra-High-Precision
Hybrid Controller, 2 Channels

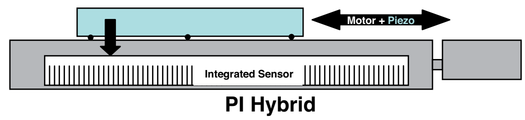


PI hybrid servo-controller output during a positioning command. The controller reads the system position off a high-resolution encoder and actuates both the motor and the piezoelectric actuator at the same time giving a system with the advantages of both drives

10 nm steps of an M-714 stage, as measured by an interferometer

PI

M-511.HD hybrid stage (left),
M-714.00 (right front) and the C-702 controller (rear)



6PI Hybrid drive combines DC motor and piezo actuator with integrated, internal, high-resolution sensor in one servo loop

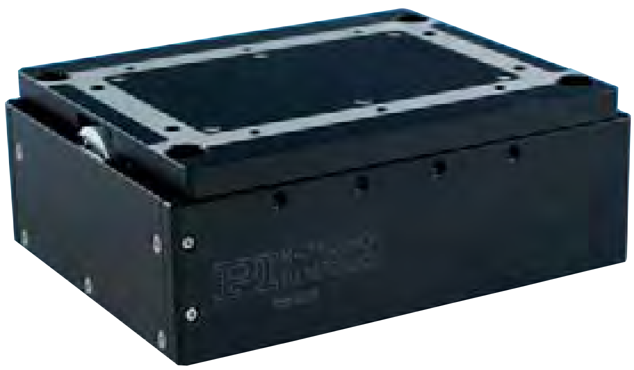
Technical Data

Model	**C-702.00**
Function	Motion Controller for Hybrid Nanopositioning Systems
Drive type	DC motor (PWM)/piezo
Channels	2
Motion and control	
Servo characteristics	PID V-ff filter, notch filter, hysteresis setting (motor); proportional-integral (P-I) algorithm with notch filter (piezo)
Sampling rate	10 kHz
Trajectory profile modes	Trapezoidal, S-curve
Processor	32-bit Intel Celeron
Position range	32 bit
Limit switches	2 lines per axis
Reference switch	1 line per axis
Motor brake	Software programmable
Electrical properties	
Operating voltage	24 VDC (via M-500.PS wide range power supply*)
Output power/channel	PWM: 19.5 kHz, 10-bit resolution
Piezo voltage	±36 V (24-bit resolution)
Power consumption	< 25 W
Interfaces and operation	
Communication interfaces	TCP/IP, RS-232, VGA, Keyboard
Motor connector	Sub-D connector, 26-pin**
Encoder input	Serial SSI interface for incremental encoder
Controller network	via TCP/IP
I/O ports	8 TTL inputs, 8 TTL outputs
Command set	ASCII, PI General Command Set (GCS)
User software	PIMikroMove®
Software drivers	GCS (PI General Command Set)-DLL, LabVIEW™ drivers
Supported functionality	Autostart macro, user-programmable macro
Miscellaneous	
Operating temperature range	+10 to +50 °C
Mass	1.35 kg
Dimensions	130 x 205 x 76 mm

*M-500.PS: wide range power supply, 100 to 250 VAC, 50 to 60 Hz
**Sub-D 26 contains connection for motor, piezo, reference and limit switches and sensor,
Internal heat sink with very silent fan

M-714 Nanometer-Precision Linear Stage

Heavy-Duty Precision Hybrid DC/Piezo Drive with High Guiding-Accuracy



Hybrid Z-positioner M-714.HD

- **Simultaneous Control of Piezo-Flexure Drives & DC-Servo/Ballscrew Drives**
- **7 mm Vertical Travel Range, 10 kg Load Capacity**
- **High Holding Forces with Minimum Power Consumption**
- **Integrated Precision Linear Encoder Provides 2 nm Resolution**
- **Active Backlash Compensation and Stick/Slip Compensation**
- **Frictionless Piezo Drive and Flexure-Decoupled Ballscrew**
- **Millisecond Settling Time to Nanometer Precision**

The M-714 was designed from the ground up to use the hybrid drive technology. The hybrid design overcomes the limitations of conventional precision positioning systems by combining the well-known advantages of piezo-flexure-drives (unlimited resolution and very rapid response) with the long travel ranges and high holding forces of a servo-motor/ballscrew arrangement. The M-714 can position loads up to 10 kg with nanometer precision over 7 mm in vertical or horizontal direction. Compared to high-resolution magnetic linear drives, the hybrid principle allows high holding forces with minimum power consumption, without counterbalancing the load. The angular deviation is less than ±10 µrad over the entire travel range of 7 mm.

Application Examples

- Surface Inspection
- Microscopy
- Laser technology
- Interferometry
- Metrology

Long Travel Ranges with Nanometer Precision

The challenge of implementing hybrid technology is not only the positioning stage design, but also the use of high-resolution sensors over large travel ranges, the processing of the resulting high-frequency signals and the design of special control algorithms to take full advantage of the hybrid concept.

On the mechanical side, this is accomplished by decoupling the moving platform from the positioner's motor-ballscrew-drive by frictionless flexures and stiff, highly responsive piezo actuators.

Due to its high stiffness and instantaneous, sub-millisecond range response, the integrated piezo flexure drive provides active stick/slip compensation during startup and settling and is the key to achieving consistent and repeatable nanometer level positioning increments. It also cancels out motion irregularities caused by the ball screw and significantly improves velocity control.

Servo-control of the system employs a single high-resolution position feedback sensor (direct metrology) which means that the inherent piezo precision is available over the entire travel range of 7 mm, and longer travel ranges are basically feasible. The resolution and the positioning accuracy mainly depend on the choice of the feedback sensor.

Hybrid Controller Technology is Key to Success

PI's highly specialized C-702 hybrid nanopositioning controller (see p. 4-118) compares the actual platform position (by reading the integrated linear encoder) with a calculated, smooth trajectory in real time. Its complex control algorithms continuously actuate both the piezoelectric and servo motor drives in a way to provide the best possible overall performance.

This makes hybrid systems ideal for applications where extremely smooth motion is required, where the position of an incident needs to be read and refound precisely, or where an externally specified target position needs to be hit within a few nanometers, such as in surface inspection or metrology.

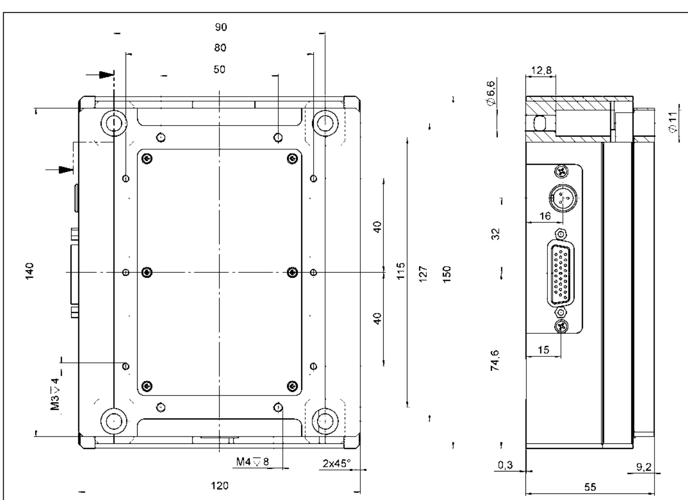
Ordering Information

M-714.2HD
Ultra-High Precision Hybrid Nanopositioning Stage, 7 mm Travel, 2 nm Linear Encoder Resolution

Ask about custom designs!

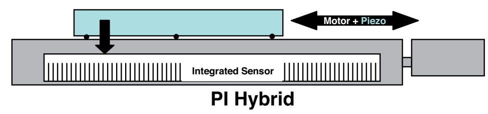
Notes

The M-714.2HD positioning system is optimized for vertical operation. If horizontal operation is intended, please note with your order.



M-714, dimensions in mm. Sub-D connector 26-pin, 3 m cable

10 nm steps of an M-714 stage, as commanded by a C-702 digital controller and measured by an interferometer



PI Hybrid drive combines motorized and piezo positioning system with integrated, internal, high-resolution sensor in one control loop

Technical Data

	M-714.2HD
Motion and positioning	
Travel range	7 mm
Integrated sensor	Linear encoder
Sensor resolution	0.002 µm
Design resolution	0.002 µm
Min. incremental motion	0.004 µm
Hysteresis at the platform	0.01 µm
Unidirectional repeatability	0.01 µm
Accuracy	<0.05 µm
Pitch	±10 µrad
Yaw	±10 µrad
Max. velocity	0.2 mm/s
Origin repeatability	1 µm
Mechanical properties	
Drive screw	Leadscrew
Guiding	Crossed-roller bearings
Screw pitch	1 mm/rev.
Gear ratio	80:1
Belt drive transmission ratio	3:1
Max. push/pull force	100/100 N
Self inhibition	100 N
Max. lateral force	200 N
Drive properties	
Drive type	Hybrid drive: DC-motor with low-inertia, flexure-decoupled and piezo actuated stage platform
Motor type	DC-motor, gearhead
Operating voltage (motor)	24 V
Electrical power	13 W
Piezo drive type	PICMA® Multilayer piezo with flexure
Piezo voltage	±36 V
Limit and reference switches	Hall-effect
Miscellaneous	
Operating temperature range	-20 °C to +65 °C
Material	Al (black anodized)
Mass	2.1 kg
Recommended controller/driver	C-702 hybrid motor controller (p. 4-118)

M-686 PILine® XY Piezo Linear-Motor Stage

Fast, Low Profile and Large Aperture with Direct Position Measurement

The M-686.D64 open-frame stage with closed-loop piezo motors provides 25 x 25 mm travel range

- **Integrated Closed-Loop Piezomotor Drives Provide High Speed to 100 mm/s**
- **Travel Ranges 25 x 25 mm**
- **Integrated Linear Encoders with 0.1 µm Resolution**
- **Compact Design: 32 mm Profile Height, 170 x 170 mm Footprint**
- **Clear Aperture 78 x 78 mm, 66 x 66 mm in Extreme Position**
- **Self-Locking at Rest**
- **Compatible with PI Piezo Nanopositioning / Scanning Stages**

M-686 open-frame piezomotor stages are mainly designed for automated positioning applications in microscopy. The optimized form factor with a low profile height of only 32 mm and the standardized mounting pattern allows the combination with many PI standard nanopositioning systems.

Application Examples

- Biotechnology
- Microscopy
- Scanning microscopy
- Confocal microscopy
- Semiconductor testing
- Handling

Space Saving Piezomotors

Compared to conventional motorized translation stages, the M-686 provides a lower profile and smaller footprint. The compact PILine® piezoelectric linear motors and high-resolution linear encoders make both, the lead screw duct and the flanged, bulky stepper motor employed in traditional stages obsolete. In addition, the piezomotors are self-locking at rest and hold the stage in a stable position without heating up.

Compatibility to PI Nanopositioning and Scanning Stages

A number of standard PI piezo flexure stages (150 x 150 mm footprint) can be mounted directly on the M-686 open-frame stage. Depending on the application, these highly specialized, ultra-precise nanopositioning systems are available as fast XY scanners (for fluorescence microscopy), as vertical Z positioners (3D imaging), or with up to 6 degrees of freedom.

Limit and Reference Switches

For the protection of your equipment, non-contact Hall-effect limit and reference switches are installed. The direction-sensing reference switch supports advanced automation applications with high precision.

Advantages of PILine® Micropositioning Systems

The ultrasonic piezoceramic drives used in PIline® micropositioners have a number of advantages over classical drives:

- Higher Accelerations, up to 5 g
- Speeds up to 500 mm/s
- Small Form Factor
- Self-Locking When Powered Down
- No Shafts, Gears or Other Rotating Parts
- Non-Magnetic and Vacuum-Compatible Drive Principle

Ordering Information

M-686.D64
XY Open-Frame Stage with Closed-Loop PILine® Piezomotor Drives, 25 x 25 mm, 7 N, 0.1 µm Linear Encoder

Ask about custom designs!

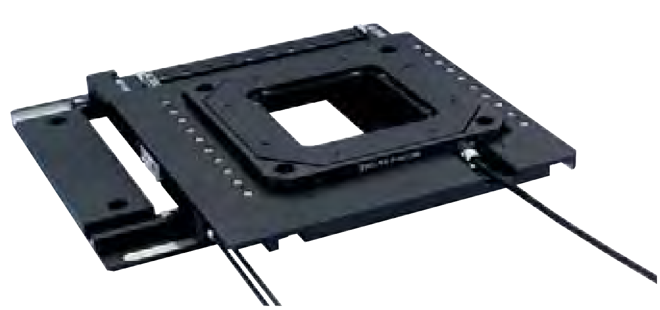
Notes

Nanopositioning stages that fit directly on the M-686:

P-561 to P-563
PIMars™ XYZ Nanopositioning systems with up to 300 µm travel

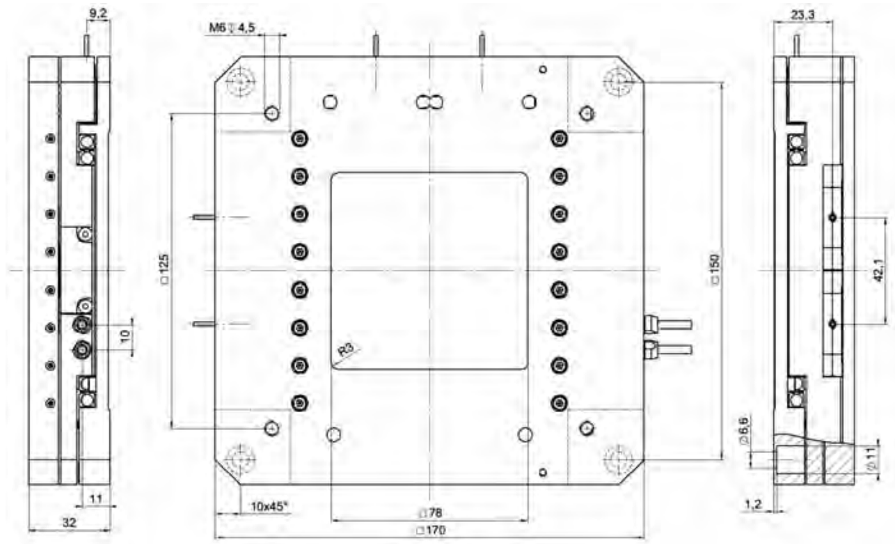
P-541.2 to P-542.2
Low-profile microscopy XY scanners

P-541.Z
Low-profile Z/tip/tilt piezo nanopositioning stages for microscopy



Customized M-686 stage with a bigger footprint, to sink the piezo Z scanner. The system height together with the P-541 piezo scanner is reduced to only 33 mm

PI



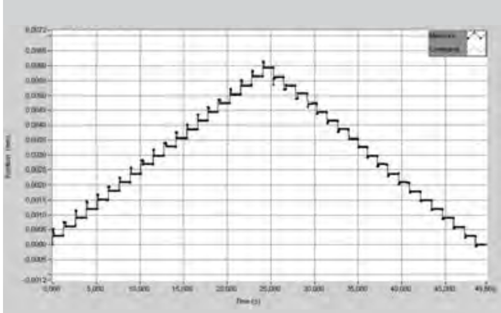
M-686.D64, dimensions in mm. The minimum aperture is 66 x 66 mm with both axes at the maximum position

Technical Data

Model	M-686.D64
Active axes	XY
Motion and positioning	
Travel range	25 x 25 mm
Integrated sensor	Linear encoder
Sensor resolution	0.1 µm
Design resolution	0.1 µm
Min. incremental motion	0.3 µm
Bidirectional repeatability	0.3 µm
Pitch / yaw	±50 µrad
Max. velocity	100 mm/s
Mechanical properties	
Load Capacity*	50 N
Max. push/pull force	7 N
Max. lateral force	4 N
Drive properties	
Motor type	2 x PILine® P-664 per axis
Operating voltage	190 V (Peak-Peak)** 67 V (RMS)**
Electrical power	10 W / axis***
Miscellaneous	
Operating temperature range	-20 to +50 °C
Material	Aluminium (black anodized)
Mass	1.2 kg
Cable length	1.5 m
Connector	2 x MDR connector, 14-pin
Recommended controller/driver	2 x C-867.D64 single-axis controller / driver 2 x C-185.D64 single-axis drive electronics for external servo-controllers (p. 4-116, p. 1-36)

*10 N for max. velocity
**The operating voltage or the piezomotor is supplied by the drive electronics which requires 12 VDC
***For drive electronics

M-686 open-frame stage with P-541.2DD piezo scanner on top, providing a resolution of 0.1 nm and a scanning range of 30 x 30 µm. The system height of the combination with the P-541 XY (or Z) piezo scanner is only 48 mm



0.3 µm steps performed by M-686

M-545 Open-Frame Microscope Stage

Long-Range Motion for Sample Positioning

M-545 manual XY microscopy stage with 25 x 25 mm travel shown with optional PInano™ piezo nanopositioner (200 µm motion in X, Y und Z) on top. The M-545 stage was designed to provide a stable basis for piezo stages, especially when the highest step-and-settle performance is required

- **Stable Platform for P-545 PInano™ Piezo Nanopositioning Systems**
- **Low Profile for Easy Integration: 30 mm**
- **25 mm x 25 mm Travel Range**
- **Micrometer Screws, Motor Upgrade Available**
- **For Nikon, Zeiss, Leica and Olympus Mikroscopes**

The M-545, 25 x 25 mm microscope stage, is designed to provide a stable platform for piezo scanning stages of the P-545 PInano™ series. These high-speed, high-resolution XY / XYZ piezo stages allow nanometer-precision adjustment of the specimen holder in up to three dimensions over 200 µm. The M-545 is also compatible with the following capacitive-feedback type piezo stages: P-733, P-5x7, P-5x8, P-54x and P-56x (s. p. 2-72).

The basic M-545 model is equipped with manual micrometers.

Motorizing for Automated Tasks

The M-545 XY-stage can be supplemented with motorized actuators M-229 (s. p. 1-44). The product number M-545.USC comprises the complete package of two stepper linear actuators with controller and joystick. M-545.USG includes two stepper linear actuators with mounting

Ordering Information

M-545.2MO
XY Microscope Stage, 25 x 25 mm, Micrometer Drive, High Stability, Compatible with PI Piezo Stages, for Olympus Microscopes

M-545.2MN
XY Microscope Stage, 25 x 25 mm, Micrometer Drive, High Stability, Compatible with PI Piezo Stages, for Nikon Microscopes

M-545.2ML
XY Microscope Stage, 25 x 25 mm, Micrometer Drive, High Stability, Compatible with PI Piezo Stages, for Leica Microscopes

M-545.2MZ
XY Microscope Stage, 25 x 25 mm, Micrometer Drive, High Stability, Compatible with PI Piezo Stages, for Zeiss Microscope

Versions for other microscopes on request.

Accessories

M-545.USC
Factory Installed Stepper-Mike Upgrade for M-545 XY Microscope Stages: Includes Stepper-Mikes, Joystick and Controller

M-545.USG
Factory Installed Stepper-Mike Upgrade for M-545 XY Microscope Stages: Includes Stepper-Mikes, Joystick

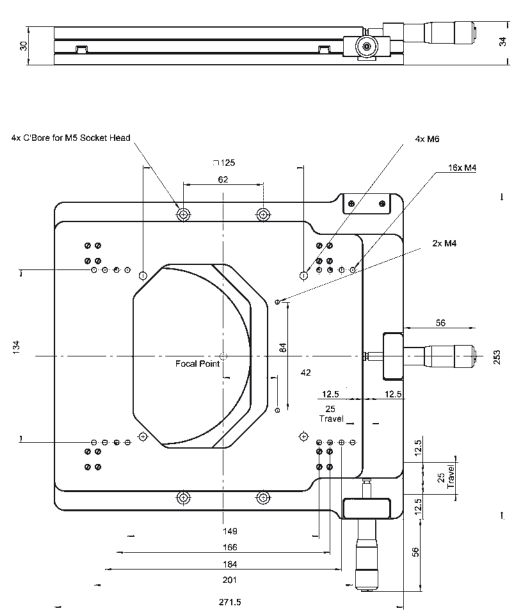
M-545.SHP
Adapter Plate for Sample Holders for M-545 XY Microscope Stages

Accommodates the following PI nanopositioning stage series:
P-517/518/527/528, P-541/542, P-560 PIMars and P-545 PInano™

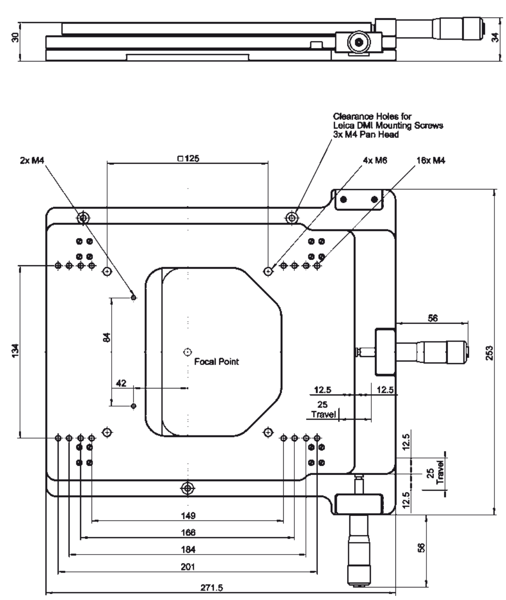
Adapter available for P-733 nanopositioners:

P-733.AP1
Adapter Plate for Mounting of P-733 Piezo Stages on M-545 XY Microscope Stage

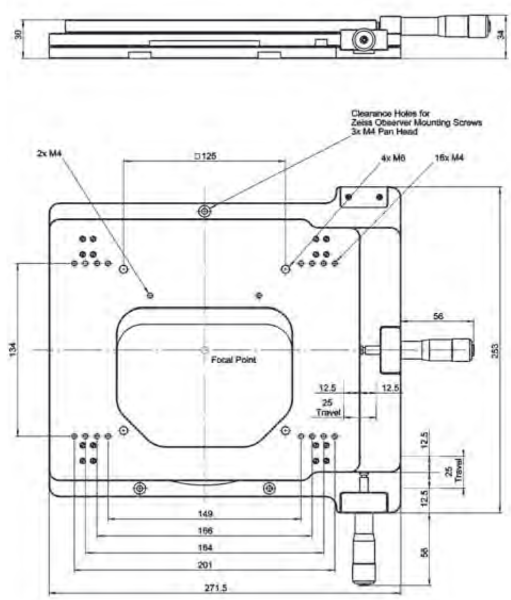
Additional accessories on request.



M-545.2MO, M-545.2MN dimensions in mm.
Mounting adapters for Olympus and Nikon microscopes respectively included in delivery



M-545.2ML dimensions in mm



M-545.2MZ dimensions in mm

Technical Data

Model	M-545.2M	Unit	Tolerance
Active axes	XY		
Motion and positioning			
Displacement	25 x 25	mm	
Min. incremental motion	1	µm	typ.
Min. incremental motion with M-229 stepper linear actuators	1	µm	typ.
Velocity with M-229 stepper linear actuators	1.5	mm/s	max.
Mechanical properties			
Max. load	50	N	
Preload	10	N	
Miscellaneous			
Material	Aluminum, stainless steel		
Mass	4	kg	±5%

Find further specifications on M-229 stepper linear actuators in the datasheet (s. p. 1-44)

F-130 · F-131 Compact XYZ Fiber Aligner

Nanometer Precision with Motor and Piezo Drive Combination

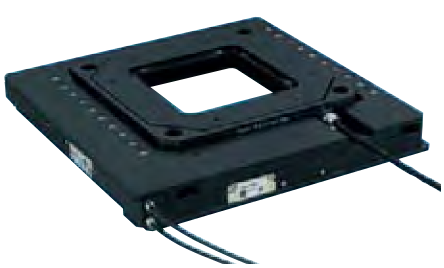
F-130.3SD XYZ Alignment System, 1 nm resolution, with optional F-603.22 ferrule holder

- Compact, Highly Responsive Coarse / Fine Positioning System, Ideal for Automated Photonics Alignment
- 5 or 15 mm Motorized Coarse Travel range, 50 nm Min. Incremental Motion
- Fast Piezo Drive with Resolution to 1 nm, 100 µm Fine Travel Range, Optional Position Feedback Sensors
- Choice of Motors: Stepper or Closed-Loop DC-Motor
- Recommended: C-880 Automation Controller
- Extensive Accessories, Software Support

Model	F-130.3SD & F-131.3SD	F-130.3SS & F-131.3SS	F-130.3OD & F-131-3OD	F-130.3OS & F-131.3OS
Drive	Closed-Loop DC motors, closed-loop PZT drives	Stepper motors, closed-loop PZT drives	Closed-Loop DC motors, open-loop PZT drives	Stepper motors, open-loop PZT drives
Motorized travel range (XYZ)	5 & 15 mm	5 & 15 mm	5 & 15 mm	5 & 15 mm
Closed-loop/open-loop resolution (PZT)	2/1	2/1	–/1	–/1

M-686K PILine® Microscopy Stage

Low Profile, Large Aperture, High Speed



- Integrated Closed-Loop Piezomotor Drives Provide High Speed to 100 mm/s
- Travel Ranges 25 x 25 mm
- Integrated Linear Encoders with 0.1 µm Resolution
- Low-Profile Combinations with PI Piezo Nanopositioning / Scanning Stages
- Clear Aperture 78 x 78 mm, 66 x 66 mm in Extreme Position
- Self-Locking at Rest

PI

Mechanical properties

Motor resolution

Resolution with micro-stepping specified for PI's stepper motor controllers.

Stiffness in motion direction

Typical tolerance: ±20 %

Max. normal load capacity

Centered, vertical load (horizontal installation).

Max. push / pull force

Active and passive force limit in operating direction, at center of stage. Some stages may be able to generate higher forces at the cost of reduced lifetime. Data for vacuum versions may differ.

Holding force when powered down

A main feature of piezomotor linear dirves is the self-locking capability at rest, without current consumption and heat generation. Piezomotor characteristics cause a decline of the holding-force in long-term off-time. The data refer to long-term minimum holding force.

Drive properties

Drive type / Operating voltage

ActiveDrive™: The operating voltage (usually 24 VDC) for the ActiveDrive™ motors is provided by an external power supply (included in the delivery).

DC motors: DC servo motors require a supply voltage of up to 12 VDC. The operating voltage is usually given as differential value where the magnitude determines the velocity, and the sign determines the motion direction.

Stepper motors: PI stepper motors are usually driven in chopper mode.

Electrical power

Motor manufacturer's information.

Torque

Motor manufacturer's information.

Miscellaneous

Operating temperature range

Safe operation, no damage to the mechanics. All technical data specified in the data sheet refer to room temperature (22 °C ±3 °C).

Material

Micropositioning stages are typically made of anodized aluminum or stainless steel. Small amounts of other materials may be used (for bearings, preload, coupling, mounting, etc.). For special applications other materials are possible like Invar.

Al: Aluminum
N-S: Nonmagnetic stainless steel
St: Steel
I: Invar

Mass

Typical tolerance: ±5 %

Cable length

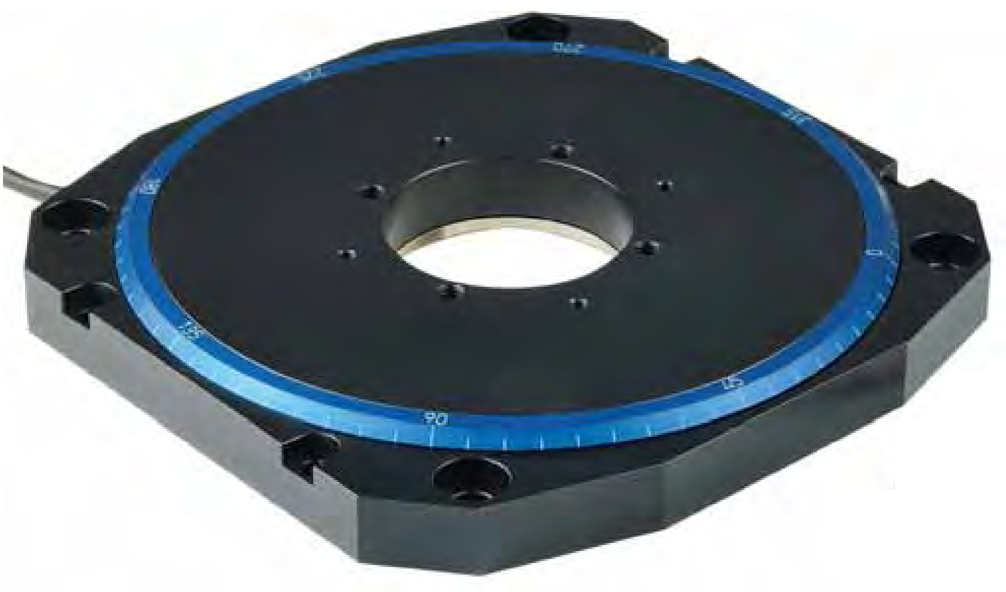
Typical tolerance: ±10 mm

Recommended motor controller

Compatible motor controllers are described in the "Servo & Stepper Motor Controllers" (see p. 4-109 *ff*) section

For further information read "Micropositioning Fundamentals" section (see p. 4-127 *ff*).

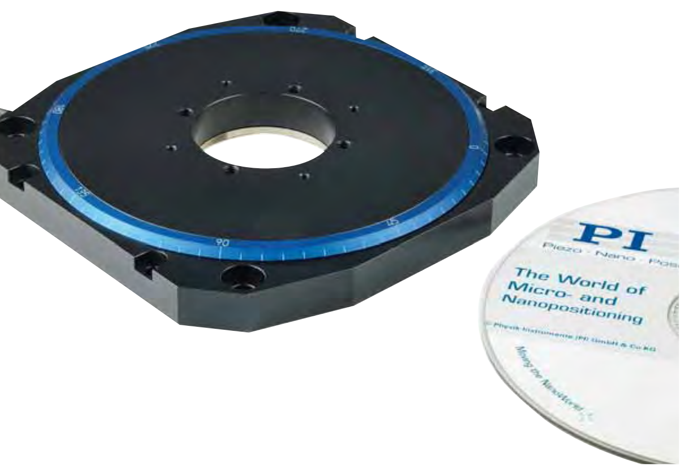
Piezo Rotary & Tilt Stages



PI

M-660 PILine® Rotation Stage

Fast Positioning, Ultra-Low Profile



The M-660 PILine® rotation stage allows high positioning speeds of up to 2 full turns/sec. The 36 mm Ø clear aperture offers flexible usage

- **Unlimited Travel Range**
- **Max. Velocity 720 °/s**
- **Low Profile: Only 14 mm in Height**
- **Self-Locking Ceramic Direct Drive: Energy Saving & High Position Stability**
- **Direct Metrology Linear Encoder, 34 µrad Resolution**
- **PILine® Direct Drive: Non-Magnetic and Vacuum-Compatible Working Principle**
- **Compact Combinations with Linear Stages**

M-660 precision rotation stages use PILine® ultrasonic piezo motors that act on a ceramic friction ring to drive the platform. This direct drive principle allows for the compact design and low profile of the stage. An integrated incremental encoder offers precision position control with up to 34 µrad resolution. The integrated U-164 PILine® linear motors provide a maximum torque of 0.3 Nm, independent from the direction of motion, and a maximum velocity of up to 720 °/sec. The maximum load is 2 kg.

Applicatotion Examples

- Biotechnology
- Micromanipulation
- Microscopy
- Quality assurance testing
- Metrology
- Mass storage device testing
- R&D
- Photonics packaging

M-660s can be built in different sizes or with other specifications, and they are available upon request as vacuum-compatible versions.

Advantages of PILine® Micropositioning Systems

Positioning systems equipped with ceramic ultrasonic drives of the PILine® series provide several advantages over positioners that apply classic drive technology:

- Smaller dimensions
- Higher holding force when powered down; no holding current
- Increased acceleration of up to 5 g
- Increased velocity of up to 500 mm/s or 720 °/s, resp.
- No leadscrews, gears or other mechanical components, no wear or maintenance
- No lubricants
- Non-magnetic and vacuum-compatible operating principle

Optimized Controller and Drive Electronics

For optimum performance, the highly specialized C-867 motion controller (s. p. 4-116) is recommended. This dedicated piezo motor controller also integrates the drive electronics which PILine® motors require to generate the ultrasonic oscillations on the piezoceramic element.

Furthermore, the controller has a number of special characteristics to address the requirements of ultrasonic motors, such as continuous automatic drive frequency adjustment, dynamic parameter switching for optimized high-speed motion and settling behavior. The broad-band encoder input (50 MHz) supports the outstanding high accelerations and velocities of PILine® drives at high resolutions.

Optionally, the C-185 analog drive electronics (stand-alone unit) (s. p. 1-36) is available for use with third party servo controllers. It accepts an analog ±10 V signal to control the motor velocity. For optimum performance, the driver must be tuned together with the mechanics and should be ordered at the same time as the motor / stage.

Ordering Information

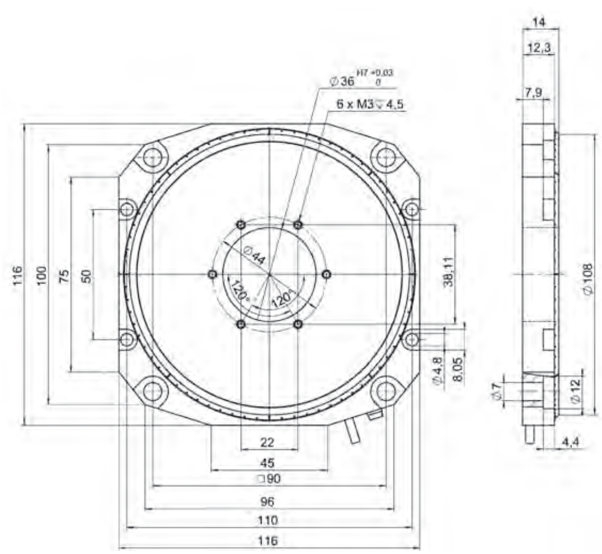
M-660.55
PILine® Rotation Stage, Ø 108 mm, 360°, 34 µrad Resolution

Ask about custom designs!

Patented Technology

The products described in this document are in part protected by the following patents:
US Pat. No. 6,765,335
German Patent No. 10154526

PI



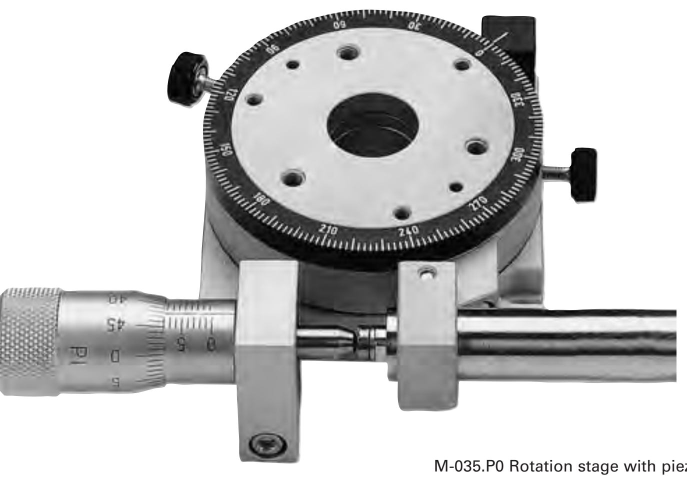
M-660.55, dimensions in mm

Model	M-660.55	Units	Tolerance
Active axes	Theta Z		
Motion and positioning			
Rotation range	No limit	°	
Integrated sensor	Incremental encoder		
Design resolution	34	µrad	typ.
Min. incremental motion	34	µrad	typ.
Bidirectional repeatability	34	µrad	
Max. velocity	720	°/s	
Mechanical properties			
Load capacity / axial force	20	N	max.
Holding force	0.3	Nm	max.
Max. torque cw/ccw (θ Z)	0.3	Nm	max.
Drive properties			
Motor type	2 x U-164 PILine® ultrasonic piezo drive		
Operating voltage	60 (RMS)*	V	
Electrical power	0.2	W	nominal
Current consumption**	0.3 (2 max.)	A	
Reference switch	optical		
Miscellaneous			
Operating temperature range	-20 to +50	°C	
Material	Al (black anodized)		
Mass	0.4	kg	±5%
Cable length	1.3	m	±10 mm
Connector	MDR, 14-pin		
Recommended controller / driver	C-867 single-axis controller / driver		

* The operating voltage is supplied by the drive electronics
** For drive electronics

M-035 Compact Precision Rotation Stage

Piezo Drive Option for Nanometer Precision



M-035.P0 Rotation stage with piezo drive

- **Sub-Microradian Resolution**
- **360° Coarse Range, up to 19° Fine Range with Resolution <1 µrad**
- **Precision Micrometer or DC Motor Drives**
- **Piezo Option for High-Resolution Scanning and Tracking**
- **Clear Aperture Ø 20 mm**

M-035 series precision rotation stages with tangent-arm drive feature high resolution, excellent repeatability and minimum wobble. The stages are equipped with double-row ball bearings for zero backlash and high load capacity. Both the rotation platform and the scale ring (graduated in 2-degree increments) can be independently coarse positioned over 360° degrees and then locked with screws.

Drive Options

A total of six different drive types are offered. They include various combinations of piezoelectric fine-positioner (closed-loop or open-loop), manual and motorized micrometer drives.

Manual Drive

The basic version, the M-035.50, is equipped with a micrometer drive and a zero-backlash magnetic coupling. The micrometer motion, when converted into rotation, provides a positioning range of 19° degrees. The resolution is approximately 23 µrad.

DC Motor Drive

The motorized version, the M-035.D01 features a high-resolution DC motor drive unit (M-227.10, see p. 1-42 *ff*) and has a range of about 12.6° with resolution of 2 µrad. A set of limit switches on the rotation stage protects against overtravel damage.

High-Resolution Piezo Option

For applications requiring extremely high angular resolution, models M-035.PS and M-035.P0 (with manual micrometer drive) and M-035.DS1 and M-035.DP1 (motorized) are available. They have an additional piezoelectric fine adjustment, which can also be used for dynamic operation. The piezo drive has a linear travel range of 45 µm with sub-nanometer-resolution, which converts to a rotation range of approx. 1 mrad and sub-µrad resolution.

The piezo drives in the M-035.PS and M-035.DS1 versions is also equipped with a position sensor, making closed-loop operation possible with higher stability, reproducibility and accuracy. For more details on the piezo drives, see the "Piezo Actuators" section.

Flexibility

M-035 stages without PZT or DC-motor drives can be upgraded at a later date.

Notes

For adapters, bracket, etc. see p. 4-90 *ff*

Ordering Information

M-035.50
Rotation Stage, Ø 60 mm, Micrometer Drive

M-035.P0
Rotation Stage, Ø 60 mm, Micrometer Drive + Piezo Drive

M-035.PS
Rotation Stage, Ø 60 mm, Micrometer Drive + Closed-Loop Piezo Drive

M-035.D01
Rotation Stage, Ø 60 mm, DC Motor Drive

M-035.DP1
Rotation Stage, Ø 60 mm, DC Motor + Piezo Drive

M-035.DS1
Rotation Stage, Ø 60 mm, DC Motor + Closed-Loop Piezo Drive

Upgrade Kits

M-035.U0
Upgrade Kits with Open-Loop Piezo Drive

M-035.US
Upgrade Kits with Closed-Loop Piezo Drive

M-035.UD
Upgrade Kits with DC Motor Drive (Factory installed)

Ask about custom designs!

Rotation Range Conversion

M-035 and M-036 rotation stages use a tangent-arm which extends beyond the platform. The angular equivalent of the linear actuator displacement can be calculated by the following equation:

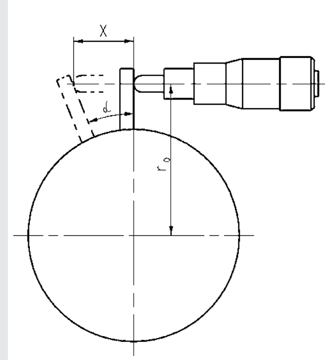
$\alpha \approx \arctan(x/r_0)$

where:
x = displacement of linear actuator [mm]
α = rotation angle [°]
r_o = distance of linear actuator contact point to center of rotation @ 0 degrees [mm]
r_o is 44 mm for the M-035 rotation stages and 66 mm for the M-036 rotation stages.

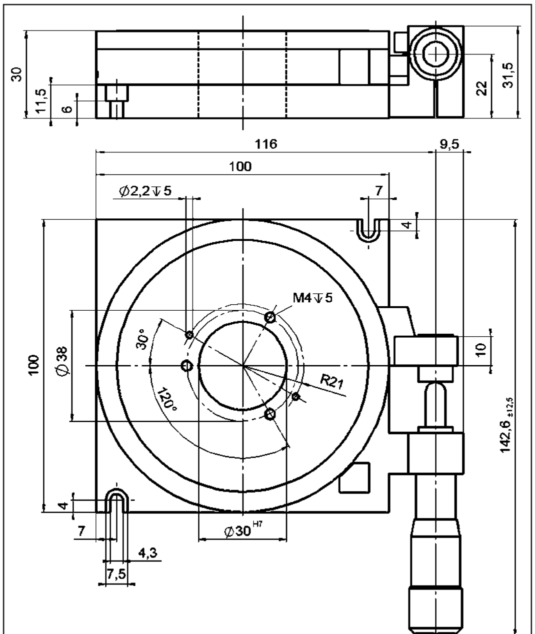
Example:

The rotation angle of an M-035 for a linear displacement x = 5 mm:

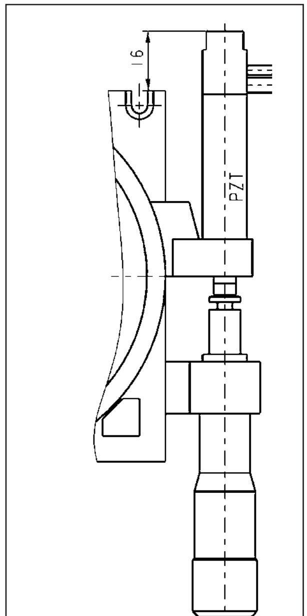
$\alpha \approx \arctan(5/44) \approx 6.48°$.



Relation between linear displacement and rotation



M-036.00 dimensions in mm



M-036.P0, M-036.PS dimensions in mm


M-036.DP1 rotation stage with DC-mike and piezo drive

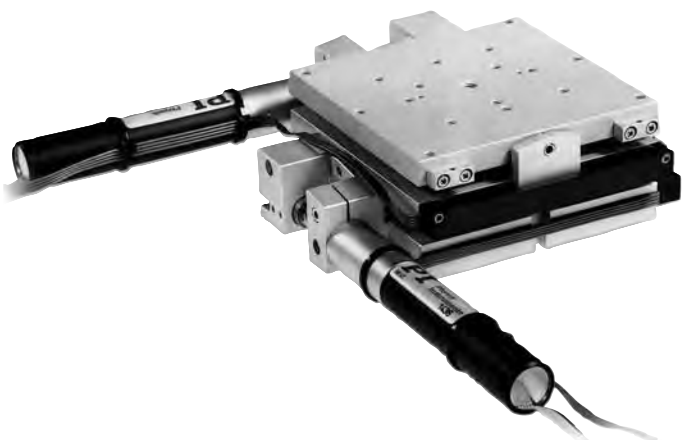
Technical Data

Model	M-036.00	M-036.P0	M-036.PS	M-036.D01	M-036.DP1	M-036.DS1	Units
Coarse rotation range	360	360	360	360	360	360	°
Rotation range (micrometer drive)	21	21	21	10 **	10 **	10 **	°
Rotation range (piezo drive)	–	700	700	–	700	700	µrad
Minimum incremental motion (piezo drive)	–	<1	<1	–	<1	<1	µrad
Repeatability (piezo drive)	–	–	2	–	–	2	µrad
Unidirectional repeatability (motor drive)	–	–	–	10	10	10	µrad
Backlash (motor drive)	–	–	–	40	40	40	µrad
Design resolution (motor drive)	–	–	–	0.08	0.08	0.08	µrad
Minimum incremental motion (motor drive)	–	–	–	2	2	2	µrad
Minimum incremental motion (micrometer drive)	23	23	23	–	–	–	µrad
Rotation / linear input	15	15	15	15	15	15	µrad/µm
Tangent-arm length	66	66	66	66	66	66	mm
Wobble	<75	<75	<75	<75	<75	<75	µrad
Max. velocity	–	–	–	0.8	0.8	0.8	°/s
Max. axial force	±400	±400	±400	±400	±400	±400	N
Max. torque (θ_x, θ_y)	±6	±6	±6	±6	±6	±6	Nm
Max. torque CW*	4.5	4.5	4.5	4.5	4.5	4.5	Nm
Max. torque CCW*	0.075	0.075	0.075	0.075	0.075	0.075	Nm
Drive (manual or motor)	M-624	M-624	M-624	M-227.25	M-227.25	M-227.25	
Piezo drive	-	P-840.30	P-841.30	-	P-840.30	P-841.30	
Mass	0.85	0.95	0.97	1.05	1.15	1.17	kg
Body material	Al, St	Al, St	Al, St	Al, St	Al, St	Al, St	
Recommended controllers	–	–	–	C-843, C-848, C-863	C-843, C-848, C-863	C-843, C-848, C-863 (p. 4-120, p. 4-122, p. 4-114)	
Recommended piezo controllers	–	E-660, E-610 E-500 System	E-610 E-500 System	–	E-660, E-610 E-500 System	E-610 (p. 2-110) E-500 System (p. 2-142)	

*CW: clockwise CCW: counter-clockwise
**Limited by limit switch position.

M-041 – M-044 Tip/Tilt Stage

Piezo Drive Option for Nanometer Precision



M-044.D01 tip/tilt stage

- One- & Two-Axis Tilt Stages
- Zero Backlash
- Sub-µrad Resolution
- Manual and DC-Motor Drives
- Compatible with Leading Industrial Motion Controllers
- Optional Piezo Drives for Tracking and Scanning

M-041 through M-044 are one- and two-axis (θ_X, θ_Y) tip/tilt stages for small loads. They are spring preloaded for elimination of backlash and feature resolution and repeatability superior to that of goniometric cradles. Versions with piezo translators allow ultra-high-resolution dynamic scanning and tracking. See the "Fast Steering Mirrors / Active Optics" section for fast, ultra-high-resolution, tip/tilt platforms (p. 2-79 *ff*).

The two basic versions (with part number extension .00) are equipped with manual micrometer drives providing 65 and 80 µrad minimum incremental motion, respectively. The versions with extension .D01 are equipped with closed-loop, DC-servo-motor drives (model M-227.10 (see p. 1-42) for further details and recommended motor controllers) providing 15 and 12 µrad minimum incremental motion, respectively. Sets of limit switches eliminate the possibility of overtravel.

High-Resolution Piezo Option

For sub-µrad resolution and dynamic tracking or scanning, optional open-loop/closed-loop piezo drive upgrade kits are available. See the P-840 and P-841 (see p. 1-74) in the "Piezo Actuators & Components" section for further details and recommended controllers. The piezo drives can also be ordered subsequently to upgrade manual or motorized systems.

Notes

See "Accessories", page 4-90 *ff.* for adapters, brackets, etc.

Ordering Information

M-041.00
Small Tilt Stage, Manual Micrometer Drive

M-041.D01
Small Tilt Stage, DC-Motor Drive

M-042.00
Small Tip/Tilt Stage, Manual Micrometer Drive

M-042.D01
Small Tip/Tilt Stage, DC-Motor Drive

M-043.00
Tilt Stage, Manual Micrometer Drive

M-043.D01
Tilt Stage, DC-Motor Drive

M-044.00
Tip/Tilt Stage, Manual Micrometer Drive

M-044.D01
Tip/Tilt Stage, DC-Motor Drive

Upgrades

M-041.U0
Open-Loop Piezo Drive Upgrade Kit for M-041 Tilt Stages

M-041.US
Closed-Loop Piezo Drive Upgrade Kit for M-041 Tilt Stages

M-042.U0
Open-Loop Piezo Drive Upgrade Kit for M-042 Tip/Tilt Stages

M-042.US
Closed-Loop Piezo Drive Upgrade Kit for M-042 Tip/Tilt Stages

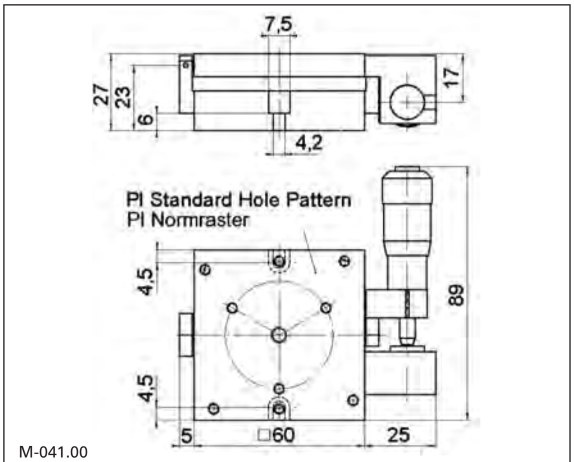
M-043.U0
Open-Loop Piezo Drive Upgrade Kit for M-043 Tilt Stages

M-043.US
Closed-Loop Piezo Drive Upgrade Kit for M-043 Tilt Stages

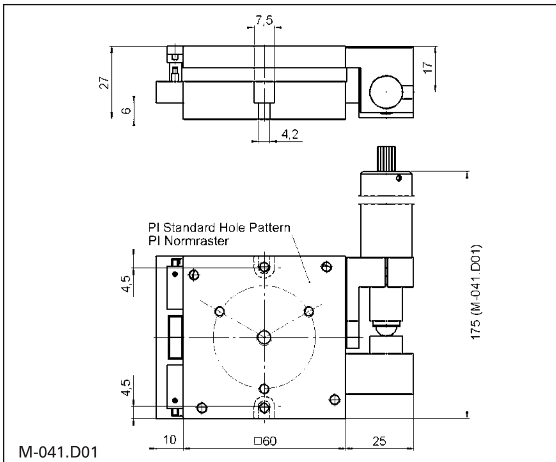
M-044.U0
Open-Loop Piezo Drive Upgrade Kit for M-044 Tip/Tilt Stages

M-044.US
Closed-Loop Piezo Drive Upgrade Kit for M-044 Tip/Tilt Stages

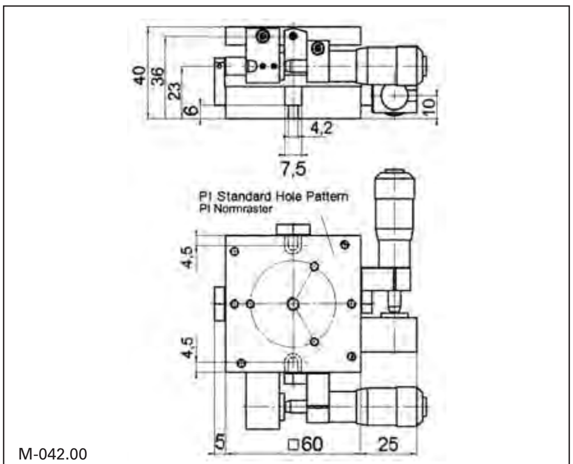
Ask about custom designs!



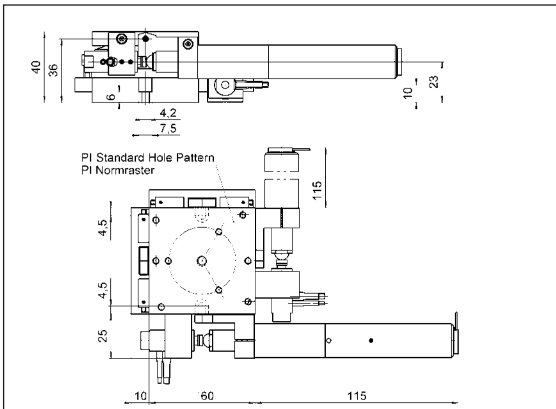
M-041.00
dimensions (in mm), see p. 4-91 for PI Standard Hole Pattern



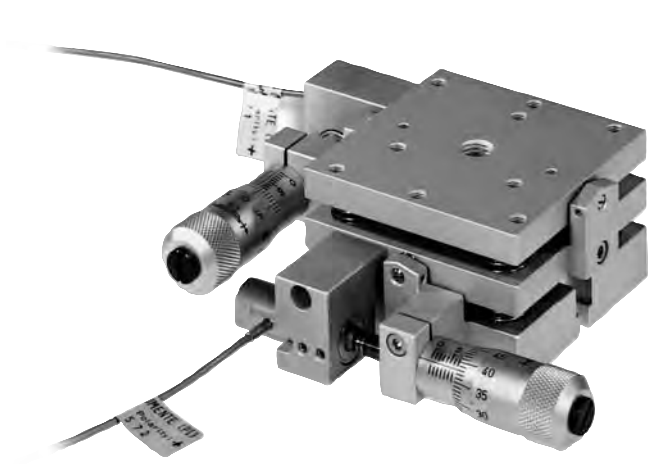
M-041.D01
dimensions (in mm), see p. 4-91 for PI Standard Hole Pattern

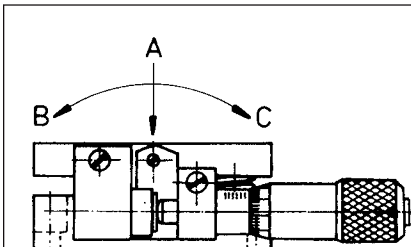


M-042.00
dimensions (in mm), see p. 4-91 for PI Standard Hole Pattern



M-042.D01 with optional PZT drives
(dimensions in mm), see p. 4-91 for PI Standard Hole Pattern


M-042.00 tip/tilt stage with optional PZT drives



Load and torque definition of M-041,
M-042, M-043 and M-044 tip/tilt stages

Piezo Stack Actuators & Components

Piezoelectric Actuators and Components

Advantages of PI Piezoelectric Actuators:

- Sub-Nanometer resolution
- Large force generation (up to 50,000 N and more)
- Microsecond-range response
- No backlash, stiction or friction
- Immune to magnetic fields
- Extremely low steady-state power consumption
- No wear and tear
- Vacuum and clean-room compatibility
- Operation at cryogenic temperatures possible

Piezoelectric translators are solid-state ceramic actuators which convert electrical energy directly into linear motion (mechanical energy) with virtually unlimited resolution.

Quality and Selection

PI offers a comprehensive assortment of high-resolution piezoelectric actuators and drives for industrial and scientific applications. In addition to the hundreds of models presented in this catalog, PI can also deliver custom designs. All manufacturing steps from the PZT powder to the finished product are controlled by PI. PI's proprietary PICMA® technology with ceramic encapsulation stands for high reliability and longer lifetime. Closed-loop piezo actuators and the corresponding control electronics are offered for higher linearity.

Applied directly to a substrate, or used as part of the structure itself, DuraAct™ patch tranducers can detect and produce vibrations or contour deformations at the source, inside the structure

Variety of piezoceramic stacks

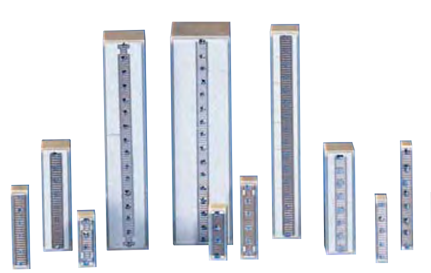
High-Force Piezo Systems

The long-established and successful high-force / high-voltage piezo system product line has been improved and completely reworked. All high-voltage piezo actuators now make exclusive use of the modern PICA™ Power piezo ceramics. For high dynamics applications, the integrated preload and low electric power requirements of the packaged PICA™ Power actuators is a special advantage.

Piezo-Electric All-Rounder— DuraAct™ Patch Tranducers

The laminated patch transducers are suitable both for actuator and sensor tasks in various fields such as adaptronics. Even in high-dynamics applications, the rugged design ensures reliability, high resistance to damage and a lifetime well over 10^9 cycles.

- High-dynamics actuators
- Adaptive systems
- Vibration and noise cancellation
- Deformation control and stabilization
- Structural health monitoring
- Energy harvesting

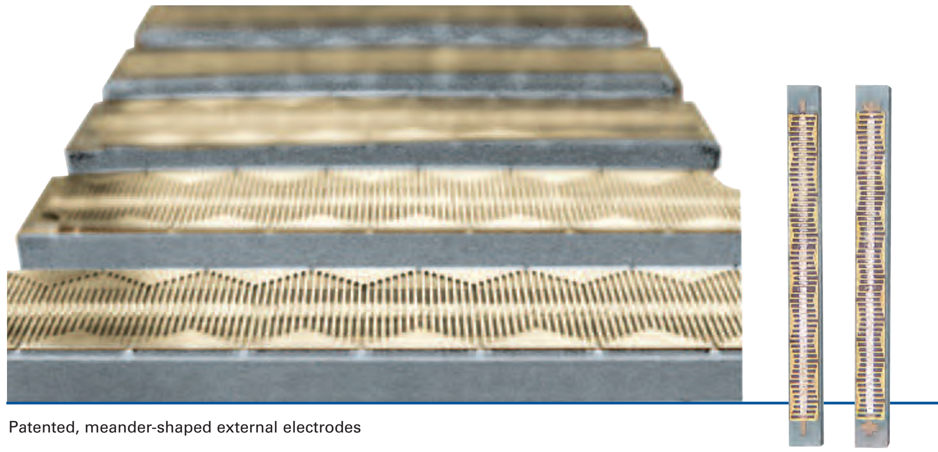


PICMA® piezoelectric actuators

PICMA®: Reliability and Continuous Further Development

Ceramic-Insulated, Piezoelectric Actuators Offer Superior Lifetime

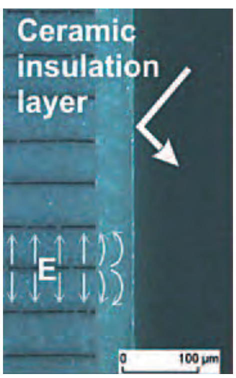
PICMA® multilayer piezo actuators are based on a special PZT (lead zirconate – lead titanate) ceramic, which ideally combines the desired characteristics of the components such as high stiffness, low electrical capacity, high specific displacement, low load and temperature dependence of the specifications and long lifetime.



Patented, meander-shaped external electrodes

Contacts for Large Electric Currents

Research on the termination electrodes led to a further improved design. The patented, meandering form of the external electrodes supplies the electric current evenly to the internal electrodes (Fig. 2). The contact here is chosen so that it remains electrically stable and mechanically flexible even at high currents up to 20 A and more, thus providing particularly dynamic control. This improves the lifetime of the actuator in applications with rapidly changing fields.



The ceramic insulating layer prevents the penetration of water molecules and reliably protects the sensitive internal electrodes from mechanical damage and dirt

Influences on the Lifetime of a Piezo-Ceramic Actuator

Three essential factors affect the lifetime of piezo ceramics in positioning applications: Humidity, operating voltage and temperature.

Penetrating moisture and the electric field applied can cause electrochemical transport processes in the component, which are accelerated by higher temperatures. The result is a short circuit between the electrodes, which can cause irreparable damage to the actuator.

The actual application determines the extent to which the individual factors have an impact.

The internal electrodes and the ceramic are jointly sintered (co-fired technology) to create a monolithic piezo-ceramic block (Fig. 1). This block is protected against humidity and damage from increased leak current by a ceramic insulation layer. Therefore, PICMA® actuators are far superior in terms of reliability and lifetime to conventional, polymer-coated, multilayer, piezoelectric actuators. The construction with the ceramic insulation layer results also in a high resonance frequency, making the actuators ideally suited for high-dynamics operation.

Large Temperature Range – Optimum UHV Compatibility – Minimal Outgassing – Neutral in Magnetic Fields

The particularly high Curie temperature of 320 °C allows for a usable tem-perature range of up to 150 °C, far beyond the 80 °C limit of conventional multilayer actuators. This and the exclusive use of inorganic materials provide the optimum conditions for use in ultra-high vacuums: No outgassing and high bake-out temperatures.

PICMA® piezoelectric actuators work at a reduced travel even in the cryogenic temperature range.
Thanks to their construction that is based solely on non-ferromagnetic materials, the actuators have an extremely low residual magnetism in the order of a few nanotesla.

Low Operating Voltage

In contrast to most commercially available multilayer piezo actuators, PICMA® actuators achieve their nominal displacement at operating voltages significantly below 150 V. This is achieved by using a particularly fine-grained ceramic material which allows a lower depth of the internal layers.
The products described in this document are at least partially protected by the following patents:
German patent no. 10021919
German patent no. 10234787
German patent no. 10348836
German patent no. 102005015405
German patent no. 102007011652
US patent no. 7,449,077

Safety with PICMA®

Long-Term Tests Prove the Superior Reliability

In positioning applications, the piezoelectric actuator is typically operated at constant voltage to maintain one position over an extended period of time. Here, the lifetime of piezoelectric actuators is affected especially by the voltage and the humidity.

Protective Ceramic Layer

The most important feature which protects PICMA® actuators against ingressing moisture is the monolithic construction with the ceramic insulation layer. The penetration of water molecules is effectively suppressed, which is impressively documented by measurements of the leak current (Fig. 3). Increased values are a sign of deteriorating insulation resistance and thus of a decrease in lifetime, as can be seen with polymer-coated actuators.

Realistic Study

Voltage	Failure Rate of PICMA® Actuators with Ceramic Insulation	Failure Rate of Conventional, Polymer-Coated Actuators
100 V DC	0 % (calculated MTTF: 1.3 · 10E6 h)	75 %
120 V DC	0 % (calculated MTTF: 178,000 h)	100 %
135 V DC	0 % (calculated MTTF: 49,000 h)	100 %
150 V DC	25 % (calculated MTTF: 15,500 h)	100 %

Tests under realistic conditions clearly confirm the high reliability of the ceramic-insulated PICMA® piezo actuators. Multilayer actuators were operated under conventional environmental conditions with different DC voltages. In this case, as well, PICMA® actuators with ceramic insulation convince by quite a margin: First failures occur only at 150 V, i.e. far above their specified nominal voltage, while after an 18-month test period only a small number of conventional polymer-insulated piezoelectric actuators are still functional. Test conditions: 22 °C, 55 % RH, testing period 18 months (13,400 h)

Tests Under Realistic and Extreme Conditions

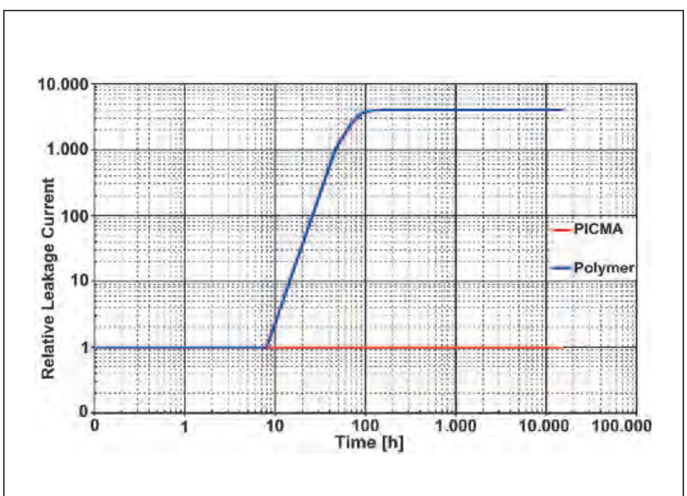
The high reliability makes it virtually impossible to experimentally measure the lifetime of PICMA® actuators under realistic operating conditions. To estimate the lifetime, tests under extreme conditions are used.

These tests are then confirmed in a long-term series of tests that are carried out under realistic conditions (see "Realistic study").

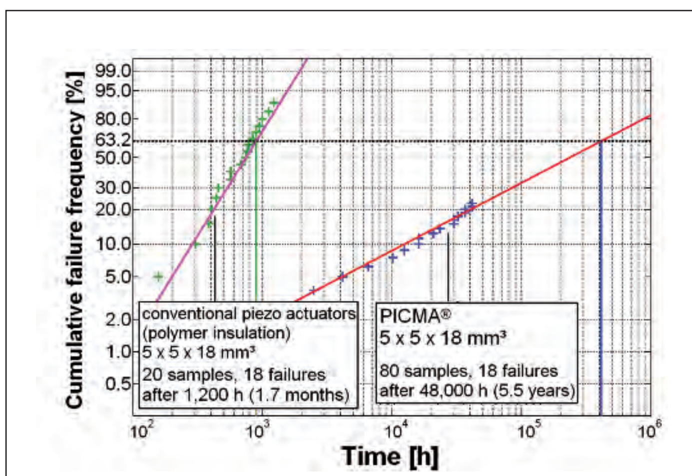
Accelerated Life Test

An increased relative humidity combined with high ambient temperatures and control voltages sometimes above the nominal voltage range leads here to an accelerated degradation of the piezo ceramics. The boundary conditions are subsequently corrected using a mathematical model and this results in a specification for the average lifetime (Mean Time To Failure, MTTF) in a realistic application. Conventional, polymer-coated piezoelectric actuators typically survive continuous use at increased humidity for about 30 days (Fig. 4), whereas PICMA® multilayer piezoelectric actuators are still working reliably after more than four years!

The results were obtained from a representative random sample of PICMA® 5 x 5 x 18 (P-885.50) and are typical for the complete PICMA® product range.



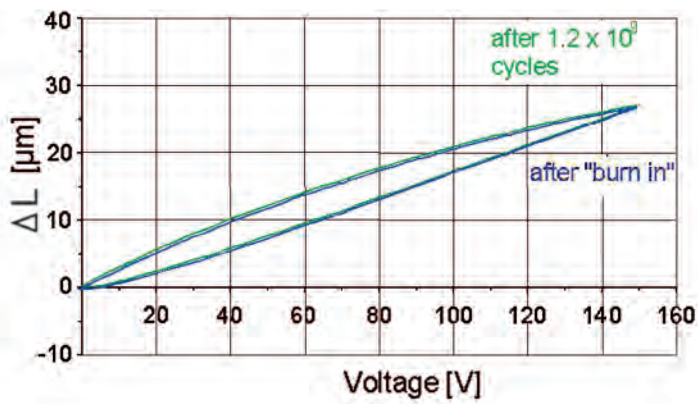
PICMA® piezoelectric actuators (bottom curve, red) compared to polymer-coated multilayer piezoelectric actuators. The high insulation resistance of the PICMA® actuators remains stable over several time decades, whereas conventional, polymer-coated actuators exhibit a significantly increased leak current after a few hours. (Test conditions: 100 V DC, 25 °C, 70 % relative humidity [RH])



Comparison of PICMA® and conventional piezo actuators insulated with a polymer coating. Results of an accelerated life test with increased humidity for accelerated aging (Test conditions: 100 V DC, 22 °C, 90 % RH). Statistical methods can be used to derive values under normal climatic operating conditions from this. The extrapolated average lifetime (MTTF) for PICMA® actuators is more than 400,000 h (approx. 45 years). All polymer-coated comparison samples fail, at the most, after only 1,600 hours (MTTF = 890 hours, about 1 month)

PICMA® Piezo Actuators under Permanent Cyclic Load

Dynamic Application: AC Voltage / AC Operation



Dynamic test series with eight PICMA® actuators 5 x 5 x 18 mm: Total number of cycles 4.0 x 10^9 cycles; 116 Hz sinusoidal control (1.0 x 10^7 cycles per day), 100 V unipolar operating voltage, 15 MPa preloading. Control measurements after each series of 10^9 cycles. Only insignificant decrease in the displacement.

Extraordinarily Robust: 10^{10} Working Cycles

Due to the stability of the material behavior and their mechanical construction, PICMA® actuators exhibit no signs of wear even after many billions of load cycles (Fig. 6).

The target of 10^{10} working cycles is especially important for industrial use. The proof for the reliability of the PICMA® technology is obtained by means of a test with particularly high control frequency.

Preloaded PICMA® actuators with dimensions of 5 x 5 x 36 mm were loaded at room temperature and average humidity with a sinusoidal signal of 120 V unipolar voltage at 1,157 Hz. This amounts to 10^8 cycles per day! Even at this high voltage and frequency there was not a single failure and the actuators showed no significant changes in displacement.

Dynamic Continuous Operation

Cyclic demands with a rapidly alternating electrical field and high control voltages (typically > 50 Hz; > 50 V) are common conditions for multilayer piezoelectric actuators, for example when used in valves, pumps or ultrasonic transducers.

The lifetime of the piezo element is in this case dominated by different factors to those affecting DC operation:

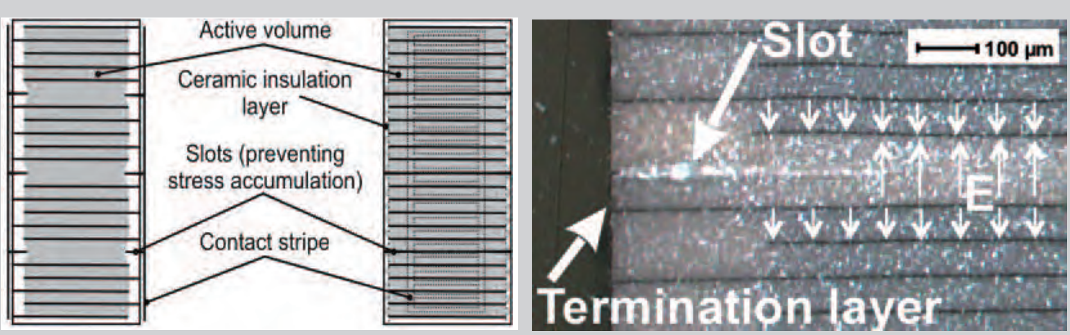
The impact of the dynamic forces and the changing state of the mechanical stress increases. Therefore, this can lead to the formation of cracks in the stack construction and hence to electrical discharges. The impact of the humidity, on the other hand, is negligible because it is reduced locally by the warming-up of the piezoceramic.

The most important factors affecting the lifetime are therefore the voltage and the type of the signal. In AC operation, the lifetime itself is not expressed as a time period but more sensibly as a number of cycles.

Longer Operating Periods and Higher Control Frequencies

The dynamic operation of PICMA® piezo elements benefits significantly from the large range of operating temperatures of up to 150 °C.

The intrinsic warming of the elements when dynamically controlled is proportional to the operating frequency. A higher operating temperature thus also allows higher control frequencies and longer periods of operation. Additionally, the displacement of the PICMA® piezoceramics exhibits only a low dependence on temperature.



Patented PICMA® design with lateral slots to avoid uncontrolled expansion cracks during dynamic control

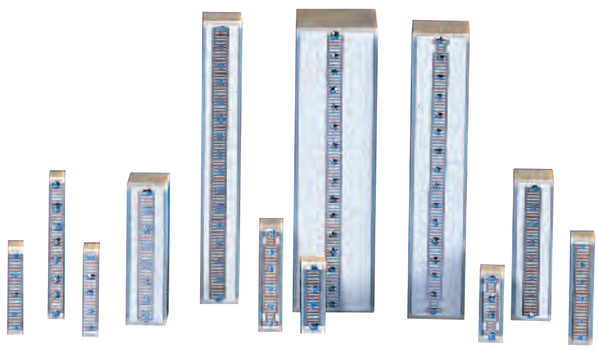
Also Stable in the AC Field

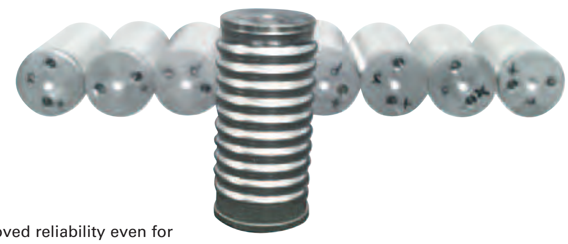
PI reduces the probability of crack formation by using a particular patented design with lateral slots. These reliably prevent the mechanical tensile stresses in the stack from becoming too high and the formation of uncontrolled additional cracks (Fig. 7). Furthermore, the patented meander-shaped construction of the termination electrodes (see Fig. 2) ensures all internal electrodes have a stable electrical contact even at extreme dynamic loads.

PI

P-882 · P-888 PICMA® Multilayer Piezo Stack Actuators

Ceramic-Insulated High-Power Actuators





Improved reliability even for permanently high humidity or splash water by hermetic encapsulation with inert gas filling. Available on request.

- **Superior Lifetime Even Under Extreme Conditions**
- **Very Large Operating Temperature Range**
- **High Humidity Resistance**
- **Excellent Temperature Stability**
- **High Stiffness**
- **Peak Current up to 20 A**
- **UHV Compatible to 10^{-9} hPa**
- **Sub-Millisecond Response / Sub-Nanometer Resolution**
- **Ideal for Dynamic Operation**

Ideal for Closed-Loop Operation

PICMA® actuators achieve positioning resolutions in the sub-nanometer range and response times in the microsecond range. The ceramic surface of the actuators is excellently suitable for mounting sensors, such as strain gauges. In contrast to polymer-coated actuators, the sensor can be applied directly to the ceramic of the PICMA® actuator, allowing for higher stability, linearity and measuring accuracy.

Technical Data / Product Order Numbers

Order numbers*	Dimensions A x B x L [mm]	Nominal displacement [µm] (0 – 100 V)	Max. displacement [µm] (0 – 120 V)	Blocking force [N] (0 – 120 V)	Stiffness [N/µm]	Electrical capacitance [µF] ±20 %	Resonant frequency [kHz] ±20 %
P-882.11	2 x 3 x 9	6.5 ±20 %	8 ±20 %	190	24	0.15	135
P-882.31	2 x 3 x 13.5	11 ±20 %	13 ±20 %	210	16	0.22	90
P-882.51	2 x 3 x 18	15 ±10 %	18 ±10 %	210	12	0.31	70
P-883.11	3 x 3 x 9	6.5 ±20 %	8 ±20 %	290	36	0.21	135
P-883.31	3 x 3 x 13.5	11 ±20 %	13 ±20 %	310	24	0.35	90
P-883.51	3 x 3 x 18	15 ±10 %	18 ±10 %	310	18	0.48	70
P-885.11	5 x 5 x 9	6.5 ±20 %	8 ±20 %	800	100	0.6	135
P-885.31	5 x 5 x 13.5	11 ±20 %	13 ±20 %	870	67	1.1	90
P-885.51	5 x 5 x 18	15 ±10 %	18 ±10 %	900	50	1.5	70
P-885.91	5 x 5 x 36	32 ±10 %	38 ±10 %	950	25	3.1	40
P-887.31	7 x 7 x 13.5	11 ±20 %	13 ±20 %	1700	130	2.2	90
P-887.51	7 x 7 x 18	15 ±10 %	18 ±10 %	1750	100	3.1	70
P-887.91	7 x 7 x 36	32 ±10 %	38 ±10 %	1850	50	6.4	40
P-888.31	10 x 10 x 13.5	11 ±20 %	13 ±20 %	3500	267	4.3	90
P-888.51	10 x 10 x 18	15 ±10 %	18 ±10 %	3600	200	6.0	70
P-888.91	10 x 10 x 36	32 ±10 %	38 ±10 %	3800	100	13.0	40

Standard piezo ceramic type: 252
Standard connection types: 100 mm pigtail
* For optional solderable contacts, change order number extension to .x0 (e.g. P-882.10)
Recommended preload for dynamic operation: 15 MPa
Maximum preload for constant force: 30 MPa
Resonant frequency at 1 V_{pp}, unloaded, free at both sides. The value is halved for unilateral clamping
Capacitance at 1 V_{pp}, 1 kHz
Operating voltage: -30 to +130 V; the lifetime depends on the voltage applied.
Operating temperature range: -40 to +150 °C
Standard mechanical interfaces: Ceramics
Available options: strain gauge sensors, special mechanical interfaces, etc.
Other specifications on request.

P-810 · P-830 Piezo Actuators

For Light and Medium Loads

P-810 & P- 830 piezo actuators

- **Outstanding Lifetime Due to PICMA® Piezo Ceramics**
- **Travel Range to 60 µm**
- **Pushing Forces to 1000 N**
- **Pulling Forces to 5 N**
- **Sub-Millisecond Response**
- **Sub-Nanometer Resolution**

The P-810 and P-830 series translators are high-resolution linear actuators for static and dynamic applications. They provide sub-millisecond response and sub-nanometer resolution.

Application Examples

- Static and dynamic precision positioning
- Fiber positioning
- Laser tuning
- Patch-Clamp
- Nanotechnology

Design

These actuators consist of a highly reliable monolithic multilayer piezoceramic stack protected by a stainless steel case. PI offers a variety of preloaded translators for applications involving higher tensile loads (see the "Selection Guide" on p. 1-62).

Ceramic Insulated Piezo Actuators Provide Long Lifetime

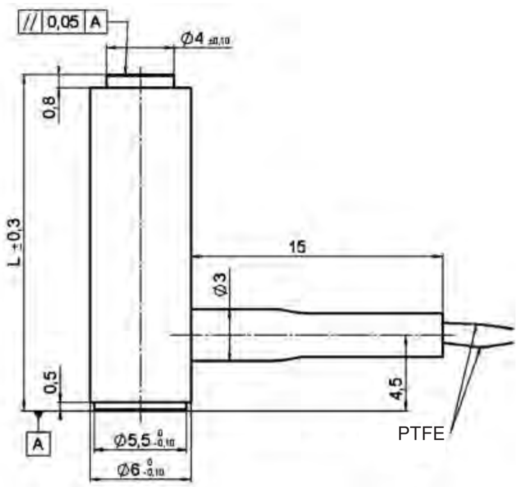
Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

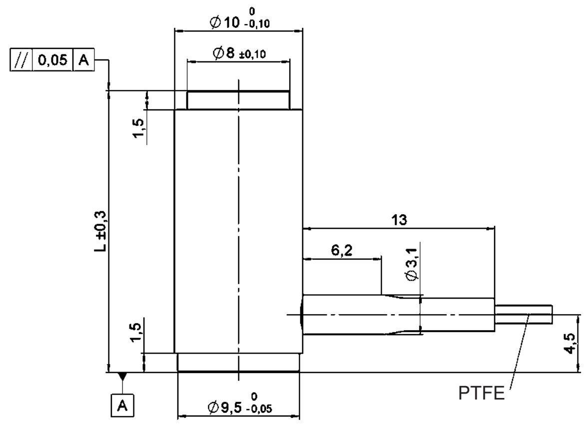
Mounting

Attachment is realized via the ferromagnetic end surfaces, with epoxy or magnets.
Read details in Mounting and Handling Guidelines (p. 1-67).
For extensions, adapter cables and connectors, see "Accessories" (p. 1-104 *ff*).

Piezo Drivers, Controllers & Amplifiers

High-resolution amplifiers and servo-control electronics, both digital and analog, are described in the "Piezo Drivers / Servo Controllers" section (see p. 2-99 *ff*).





P-810 dimensions in mm. Two 0.1 m long teflon insulated pigtails. Length L: see table. Max. torque at top piece: 0.08 Nm.

P-830 dimensions in mm. Two 0.1 m long teflon insulated pigtails. Length L: see table. Max. torque at top piece: 0.2 Nm.

Technical Data and Product Order Numbers

Order number	Travel range for 0 to 100 V [µm] ±20 %	*Resolution [nm]	**Static large-signal stiffness [N/µm] ±20 %	Push- / pull force capacity [N]	Electrical capacitance [µF] ±20 %	Dynamic operating current coefficient [µA / (Hz • µm)]	Resonant frequency (unloaded) [kHz] ±20 %	Mass [g] ±5 %	Length L [mm] ±0.3
P-810.10	15	0.15	14	50 / 1	0.3	3.0	22	4	20
P-810.20	30	0.3	7	50 / 1	0.7	3.0	15	6	38
P-810.30	45	0.45	4	50 / 1	1.0	3.0	12	8	56
P-830.10	15	0.15	57	1000 / 5	1.5	12.5	23	10	22
P-830.20	30	0.3	27	1000 / 5	3.0	12.5	14	16	40
P-830.30	45	0.45	19	1000 / 5	4.5	12.5	10	21	58
P-830.40	60	0.6	15	1000 / 5	6.0	12.5	8.5	27	76

*The resolution of piezo actuators is not limited by stiction or friction. Value given is noise equivalent motion with E-503 amplifier p. 2-144

**Dynamic small-signal stiffness is ~ 30 % higher. Operating temperature range: -20 to 120° C. Case: non-magnetic steel; end pieces: stainless steel. Recommended preload for dynamic operation: 10–20 MPa.

Recommended amplifiers / controllers

One channel: E-831 amplifier (p. 2-164), E-610 amplifier / controller (p. 2-110)

Multi-channel: E-663 amplifier (p. 2-136)

PI

P-820 Preloaded Piezo Actuators

For Light and Medium Loads

P-820.10 and P-820.30 piezo actuators

- **Outstanding Lifetime Due to PICMA® Piezo Ceramic Stacks**
- **Travel Range to 45 µm**
- **Pushing Forces to 50 N**
- **Pulling Forces to 10 N**
- **Sub-Millisecond Response, Sub-Nanometer Resolution**
- **Versions with Ball Tip**

The P-820 series piezo translators are high resolution linear actuators for static and dynamic applications. They provide sub-millisecond response and sub-nanometer resolution.

Design

These actuators consist of a friction-free, preloaded monolithic piezo ceramic stack integrated in a stainless steel housing.

Ceramic Insulated Piezo Actuators Provide Long Lifetime

The highest possible reliability is assured by employing the award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with a ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Mounting

Mounting is at the foot, with push/pull forces of less than 3 N, the actuator can be held by clamping the case. The versions with ball tip decouple torque and off-center forces from the piezo ceramic.
Read details in Mounting and Handling Guidelines (s. p. 1-67).

Accessories

To provide magnetic coupling, the P-176.30 magnetic adapter can be glued on (only for versions without ball tip).
P-176.30 Magnetic Adapter
For extensions, adapter cables and connectors, see "Accessories" in the piezo electronics chapter (s. p. 2-168 *ff*).

Piezo Drivers, Controllers & Amplifiers

High-resolution amplifiers and servo-control electronics, both digital and analog, are described in the "Piezo Drivers / Servo Controllers" (s. p. 2-99 *ff*) section.

Application Examples

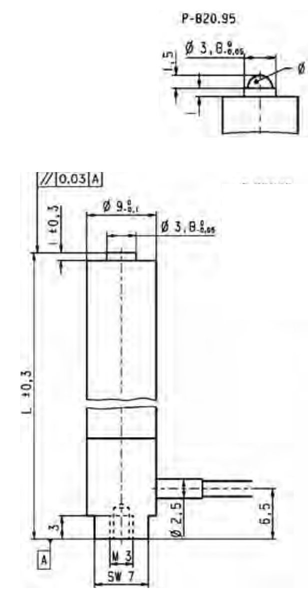
- Static and dynamic precision positioning
- Fiber positioning
- Laser tuning
- Nanotechnology

Ordering Information

Preloaded Piezo Actuator, 50/10 N

P-820.□□

- **1** 15 µm Travel Range
- **2** 30 µm Travel Range
- **0** without Ball Tip
- **B** with Ball Tip



P-820 dimensions in mm.
Length L: see table

Technical Data

Model	P-820.10 P-820.1B	P-820.20 P-820.2B	P-820.30 P-820.3B	Units
Displacement at 0 to 100 V	15	30	45	µm ±20 %
*Resolution	0.15	0.3	0.45	nm
**Static large-signal stiffness	13	7	4	N/µm ±20 %
Push/pull force capacity	50 / 10	50 / 10	50 / 10	N
Max. torque limit (on tip)	0.08	0.08	0.08	Nm
Electrical capacitance	0.3	0.7	1.0	µF ±20 %
Dynamic operating current coefficient (DOCC)	3.0	3.0	3.0	µA / (Hz • µm)
Unloaded resonant frequency f_0	22	15	12	kHz ±20 %
Operating temperature	-20 to +80	-20 to +80	-20 to +80	°C
Mass	8	11	14	g ±5 %
Material: case, end pieces	N-S	N-S	N-S	
Length L	26	44	62	mm ±0.3

*The resolution of piezo actuators is not limited by stiction or friction. Value given is noise equivalent motion with E-503 amplifier (p. 2-146)
**Dynamic small-signal stiffness is ~ 30 % higher
Voltage connection: LEMO FFA.00.250. Coaxial cable, RG 178, 1 m.
Recommended amplifiers / controllers
One channel: E-610 controller / amplifier (p. 2-110)
Modular system E-500 (p. 2-142) with amplifier module E-503 (multi-channel) (p. 2-146)
Multi-channel: E-663 amplifier (p. 2-136)

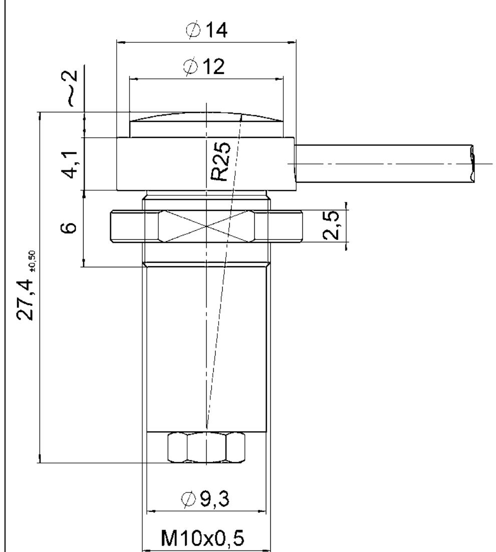
P-855 Miniature Piezo Actuator

Micrometer-Mountable Open-Loop Piezo Translator

P-855.20 piezo translator

Ordering Information

P-855.20
Piezo Actuator for Micrometer Drive



P-855 dimensions in mm, cable length 1 m

- **Displacement 20 µm**
- **Mounts Inside Micrometer Tip**
- **Sub-msec Response**
- **Sub-nm Resolution**

P-855 piezo translators are high-resolution linear actuators specially designed for integration in micrometer tips. They fit the M-227 DC-Mike motorized actuators (see p. 1-42), the M-168 Stepper Mike (see p. 1-55) motorized actuators and the M-631 to M-633 manual micrometers (see p. 1-56).

The piezo translators consist of a monolithic PICMA® piezo ceramic integrated in a stainless steel housing.

P-855 actuators provide sub-millisecond response and sub-nanometer resolution.

Application Examples

- Laser tuning
- Static and dynamic positioning of small parts
- Fiber positioning

Superior Lifetime with Ceramic-Encapsulated Piezos

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only ceramic-encapsulated PZT actuators on the market, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Accessories

Extension cables, adapters & connectors: see in "Accessories" in the "Piezo Drivers / Servo Controllers" (see p. 2-168 *ff*) section.

Notes

See the "Piezo Drivers / Servo Controllers" (see p. 2-99 *ff*) section for our comprehensive line of low-noise modular and OEM control electronics for computer and manual control.

Read details in Mounting and Handling Guidelines (p. 1-67).

Technical Data

Model	P-855.20	Tolerance
Open-loop travel @ -20 to 120 V	20 µm	±20 %
*Open-loop resolution	0.2 nm	
**Static large-signal stiffness	48 N/µm	±20 %
Push / pull force capacity	100 / 5 N	
Operating voltage range	-20 to 120 V	
Piezo ceramic type	PICMA®	
Electrical capacitance	1.5 µF	±20 %
Dynamic operating current coefficient (DOCC)	12.5 µA/(Hz • µm)	
Unloaded resonant frequency	18 kHz	±20 %
Operating temperature range	-40 bis +80 °C	
Voltage connection	VL	
Mass	28 g	±5 %
Recommended amplifier	E-610 (p. 2-110) E-500 System (p. 2-142)	

*Resolution of piezo actuators is not limited by friction or stiction. Noise equivalent motion with E-505 amplifier
**Dynamic small-signal stiffness ~50 % higher

P-840 · P-841 Preloaded Piezo Actuators

Optional with Integrated Position Sensor

P-840, P-841 piezo translators (DIP switch for size comparison)

Ordering Information

Preloaded Piezo Actuator, 1000/50 N

P-84☐.☐☐**(V)**

First box:
- **0** No Sensor
- **1** SGS Sensor

Second box:
- **1** 15 µm Travel Range
- **2** 30 µm Travel Range
- **3** 45 µm Travel Range
- **4** 60 µm Travel Range
- **6** 90 µm Travel Range

Third box:
- **0** without Ball Tip
- **B** with Ball Tip

V: Vacuum Compatible to 10^{-6} hPa

- **Outstanding Lifetime Due to PICMA® Piezo Ceramic Stacks**
- **Travel Range to 90 µm**
- **Compact Case**
- **Pushing Forces to 1000 N**
- **Pulling Forces to 50 N**
- **Sub-Millisecond Response, Sub-Nanometer Resolution**
- **Versions: with Ball Tip, Vacuum Versions**

The P-840 and P-841 series translators are high-resolution linear actuators for static and dynamic applications. They provide sub-millisecond response and sub-nanometer resolution.

Application Examples

- Static and dynamic Precision positioning
- Disc-drive-testing
- Adaptronics
- Smart structures
- Active vibration control
- Switches
- Laser tuning
- Patch-Clamp
- Nanotechnology

Design

These translators are equipped with highly reliable multilayer piezo ceramic stacks protected by a non-magnetic stainless steel case with internal spring preload. The preload makes them ideal for dynamic applications and for tensile loads as well.

Ceramic Insulated Piezo Actuators Provide Long Lifetime

The highest possible reliability is assured by employing the award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with a ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Optimum UHV Compatibility – Minimum Outgassing

The lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (no outgassing / high bakeout temperatures, up to 150 °C).

Mounting

Mounting is at the foot, with push/pull forces of less than 5 N, the actuator can be held by clamping the case. The versions with ball tip decouple torque and off-center forces from the piezoceramic.
To provide magnetic coupling, the P-176.20 magnetic adapter can be screwed into the top piece (only for versions without ball tip).

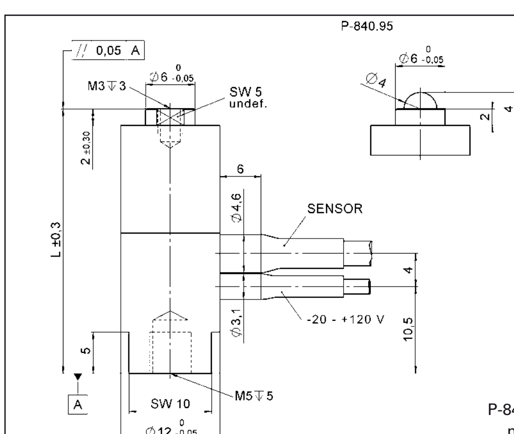
Read details in Mounting and Handling Guidelines (p. 1-67).

High Accuracy in Closed-Loop Operation

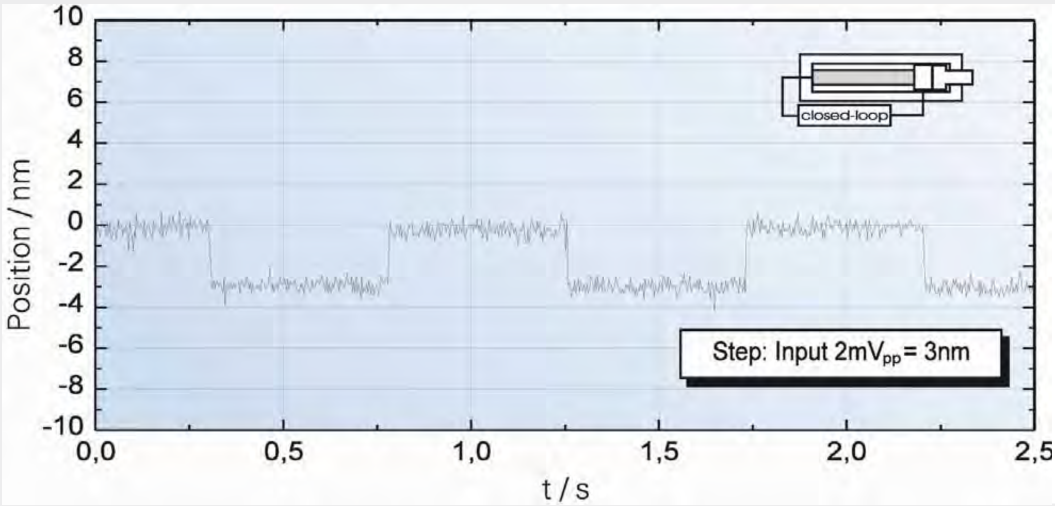
The standard model P-840 is designed for open-loop positioning. Version P-841 with integrated high-resolution strain gauge position sensors provides high precision for closed-loop operation (further details see p. 2-199).

Piezo Drivers, Controllers & Amplifiers

High-resolution amplifiers and servo-control electronics, both digital and analog, are described in the "Piezo Drivers / Servo Controllers" (see p. 2-99) section.



P-840, P-841 dimensions in mm. Length L: See table



Response of a P-841.10 to a 3 nm peak-to-peak square wave control input signal, measured with servo-control bandwidth set to 240 Hz and 2 msec setting time.

Technical Data

Model	P-841.1 P-840.1	P-841.2 P-840.2	P-841.3 P-840.3	P-841.4 P-840.4	P-841.6 P-840.6	Units
Open-loop travel @ 0 to 100 V	15	30	45	60	90	µm ±20 %
Closed-loop travel	15 / –	30 / –	45 / –	60 / –	90 / –	µm
Integrated feedback sensor*	SGS / –	SGS / –	SGS / –	SGS / –	SGS / –	
Closed-loop / open-loop resolution**	0.3 / 0.15	0.6 / 0.3	0.9 / 0.45	1.2 / 0.6	1.8 / 0.9	nm
Static large-signal stiffness***	57	27	19	15	10	N/µm ±20 %
Pushing forces to 1000 N	1000	1000	1000	1000	1000	N
Pulling forces to 50 N	50	50	50	50	50	N
Max. torque limit (on tip)	0.35	0.35	0.35	0.35	0.35	Nm
Electrical capacitance	1.5	3.0	4.5	6.0	9.0	µF ±20 %
Dynamic operating current coefficient (DOCC)	12.5	12.5	12.5	12.5	12.5	µA / (Hz • µm)
Unloaded resonant frequency fo	18	14	10	8.5	6	kHz ±20 %
Operating temperature	-20 to +80	-20 to +80	-20 to +80	-20 to +80	-20 to +80	°C
Mass without cables	20	28	46	54	62	g ±5 %
Material: case, end pieces	N-S	N-S	N-S	N-S	N-S	
Length L	32	50	68	86	122	mm ±0.3

*Closed-loop models can attain linearity up to 0.15 % and are shipped with performance reports.
**Resolution of piezo actuators is not limited by stiction or friction. Value given is noise equivalent motion with E-503 amplifier. (p. 2-146)
***Dynamic small-signal stiffness is ~ 30 % higher.
Voltage connection: LEMO FFA.00.250. Coaxial cable, RG 178, 1 m.
Sensor connector: LEMO FFA.0S.304. Coaxial cable, 1 m.
Recommended amplifiers / controllers
Single-channel: E-610 servo-controller / amplifier (p. 2-110), E-625 servo-controller, bench-top (p. 2-114), E-621 controller module (p. 2-160)
Modular piezo controller system E-500 (p. 2-142) with amplifier module E-505 (high-power) (p. 2-147) and E-509 controller (p. 2-152) (optional)
Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152) (optional)

PI

P-842 – P-845 Preloaded Piezo Actuators

For High Loads and Force Generation, Optional with Integrated Position Sensors

P-844 piezo actuators
(battery for size comparison)

- **Outstanding Lifetime Due to PICMA® Piezo Ceramic Stacks**
- **Travel Range to 90 µm**
- **Pushing Forces to 3000 N**
- **Pulling Forces to 700 N**
- **Sub-Millisecond Response, Sub-Nanometer Resolution**
- **Vacuum Version, Optional Water-Resistant Case**

The P-842 / P-843 and P-844 / P-845 series piezo translators are high-resolution linear actuators for static and dynamic applications. They provide sub-millisecond response and sub-nanometer resolution.

Design

These translators are equipped with PICMA® multilayer piezo ceramic stacks protected by a non-magnetic stainless steel case with internal spring preload. The preload makes them ideal for dynamic applications (such as precision machining, active damping etc.) and for tensile loads as well.

High Accuracy in Closed-Loop Operation

P-842 and P-844 are designed for open-loop positioning or use with external feedback. Versions P-843 and P-845 are equipped with integrated high-resolution SGS-position sensors for high precision in closed-loop operation (for further notes see the nanopositioning tutorial, see p. 2-199).

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actua-

Application Examples

- Static and dynamic precision positioning
- Disc-drive-testing
- Optics
- Metrology / interferometry
- Smart structures / adaptronics
- Precision mechanics / machining
- Active vibration control
- Switches
- Laser tuning

Technical Data and Product Order Numbers

Model	Open-loop travel for 0 to 100 V [µm] ±20 %	Closed-loop travel [µm]*	Integrated feedback sensor**	Closed-loop / Open-loop resolution [nm]***	Static large-signal stiffness [N/µm] ±20 %	Push/pull force capacity [N]	Electrical capacitance [µF] ±20 %
P-842.10 (V)	15	–	–	- / 0.15	57	800 / 300	1.5
P-842.20 (V)	30	–	–	- / 0.3	27	800 / 300	3.0
P-842.30 (V)	45	–	–	- / 0.45	19	800 / 300	4.5
P-842.40 (V)	60	–	–	- / 0.6	15	800 / 300	6.0
P-842.60 (V)	90	–	–	- / 0.9	10	800 / 300	9.0
P-843.10 (V)	15	15	SGS	0.3 / 0.15	57	800 / 300	1.5
P-843.20 (V)	30	30	SGS	0.6 / 0.3	27	800 / 300	3.0
P-843.30 (V)	45	45	SGS	0.9 / 0.45	19	800 / 300	4.5
P-843.40 (V)	60	60	SGS	1.2 / 0.6	15	800 / 300	6.0
P-843.60 (V)	90	90	SGS	1.8 / 0.9	10	800 / 300	9.0
P-844.10 (V)	15	–	–	- / 0.15	225	3000 / 700	6.0
P-844.20 (V)	30	–	–	- / 0.3	107	3000 / 700	12.0
P-844.30 (V)	45	–	–	- / 0.45	75	3000 / 700	18.0
P-844.40 (V)	60	–	–	- / 0.6	57	3000 / 700	24.0
P-844.60 (V)	90	–	–	- / 0.9	38	3000 / 700	36.0
P-845.10 (V)	15	15	SGS	0.3 / 0.15	225	3000 / 700	6.0
P-845.20 (V)	30	30	SGS	0.6 / 0.3	107	3000 / 700	12.0
P-845.30 (V)	45	45	SGS	0.9 / 0.45	75	3000 / 700	18.0
P-845.40 (V)	60	60	SGS	1.2 / 0.6	57	3000 / 700	24.0
P-845.60 (V)	90	90	SGS	1.8 / 0.9	38	3000 / 700	36.0

tors are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Optimum UHV Compatibility - Minimum Outgassing

The lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (no outgassing / high bakeout temperatures, up to 150 °C).

Mounting

Mounting is at the foot, with push/pull forces of less than 100 N, the actuator can be held by clamping the case. Read details in Mounting and Handling Guidelines (p. 1-67).

Accessories

The flexible tips P-176.50 / P-176.60 can be applied for protection of the ceramics from shearing forces (only for versions without ball tip).

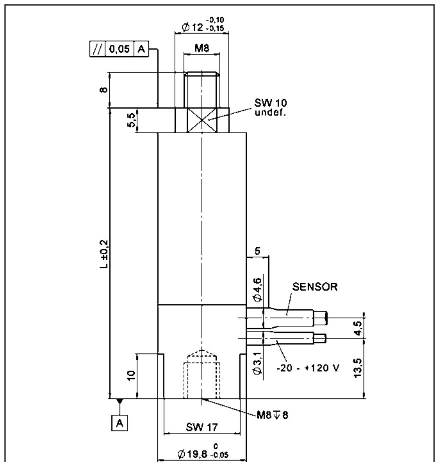
P-176.50
Flexible tip for P-842 / P-843 (see p. 1-103 *ff*)

P-176.60
Flexible tip for P-844 / P-845 (see p. 1-103 *ff*)

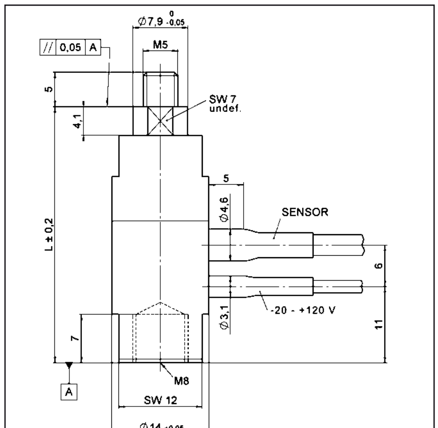
For extensions, adapter cables and connectors, see "Accessories" in the Piezo Actuators & Components section (p. 2-168 *ff*).

Piezo Drivers, Controllers & Amplifiers

High-resolution amplifiers and servo-control electronics, both digital and analog, are described in the "Piezo Drivers / Servo Controllers" section.



P-844, P-845 dimensions in mm. Length L: see table. Max. torque at top piece: 1 Nm



P-842, P-843 dimensions in mm. Length L: see table. Max. torque at top piece: 0.35 Nm

Dynamic operating current coefficient [µA / (Hz • µm)]	Resonant frequency (unloaded) [kHz] ±20 %	Mass without cable [g] ±5 %	Length L [mm]
12.5	18	31	37
12.5	14	42	55
12.5	10	53	73
12.5	8.5	64	91
12.5	6	86	127
12.5	18	31	37
12.5	14	42	55
12.5	10	53	73
12.5	8.5	64	91
12.5	6	86	127
50	16	84	47
50	12	108	65
50	9	132	83
500	7.5	156	0101
50	5.5	204	137
50	16	84	47
50	12	108	65
50	9	132	83
50	7.5	156	101
50	5.5	204	137

Voltage Connection:
LEMO FFA.00.250. Coaxial Cable, RG 178, 1 m.

Sensor Connector:
LEMO FFA.0S.304. Coaxial Cable, 1 m.

Temperature range: -40 to 80 °C; Case / end pieces: non-magnetic steel.

*Closed-loop models can attain linearity up to 0.15 % and are shipped with performance reports.
**Resolution of piezo actuators is not limited by stiction or friction. Noise equivalent motion with E-503 amplifier (see p. 2-146).
***Dynamic small-signal stiffness is ~ 30 % higher.
Recommended amplifiers / controllers
Single-channel: E-610 servo-controller / amplifier (p. 2-110), E-625 servo-controller, bench-top(p. 2-114), E-621 controller module (p. 2-160)
Single channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-505 (high-power) (p. 2-147) and E-509 controller (p. 2-152) (optional)
Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power, see p. 2-147) and E-509 controller (p. 2-152) (optional)

P-212, P-216 PICA™ Power Piezo Stack Actuators

Preloaded Piezo Actuators (HVPZT) w/ Sensor Option

From left:
P-212.1S and .8S, P-216.9S,
.4S and .1S piezo actuators
(CD for size comparison)

Ordering Information

P-21☐.☐☐☐

- **2** Preloaded Piezo Actuator, 1000 V, 2000 N
- **6** Preloaded Piezo Actuator, 1000 V, 4500 N
- **0** w/o Sensor
- **S** w/SGS Position Sensor
- **T** modified for Low Temperature
- **V** modified for High Temperature/Vacuum
- **1** Travel Range 15 µm
- **2** Travel Range 30 µm
- **4** Travel Range 60 µm
- **8** Travel Range 120 µm
- **9** Travel Range 180 µm (P-216 only)

Please read "Options and Accessories" (page 1-102 *ff*) for further information.
Extensions cables, adapters & connectors: see in "Accessories" in the "Piezo Drivers / Servo Controllers" (see p. 2-168 *ff*) section.

Option:

P-177.50
Dynamic applications (with E-481): temperature sensor and protective air for PICA™ HVPZT

- **Travel Range to 180 µm**
- **Pushing Forces to 4500 N**
- **Pulling Forces to 500 N**
- **Sub-millisecond Response**
- **Sub-nanometer Resolution**
- **Options: Vacuum, High- and Low-Temperature**

The P-212 and P-216 series are high-resolution linear piezo actuators (translators) for static and dynamic applications. They provide sub-millisecond response and sub-nanometer resolution.

Application Examples

- Optics
- Metrology / interferometry
- Adaptronics
- Precision engineering / micromechanics
- Adaptive mechanics
- Active vibration damping
- Switches
- Laser tuning
- Force generation / materials testing
- Nanotechnology

These actuators have the friction-free, preloaded PICA™ Power actuators inside. The preload makes them ideal for dynamic applications like precision machining or active damping.

High Displacement with Ultra-High Reliability

PICA™ Power actuators are optimized for high-temperature working conditions and high-duty-cycle dynamic applications.

All PICA™ piezo ceramics are specifically designed for high-duty-cycle applications. With PI's extensive applications knowledge, gained over several decades, performance does not come at the price of reliability. All materials used are specifically matched for robustness and lifetime. Endurance tests on PICA™ actuators prove consistent performance, even after billions (1,000,000,000) of cycles.

Open- and Closed-Loop Models for Optimum Dynamics and Linearity

The standard models are ideal for open loop positioning applications. In this mode the actuator displacement is roughly proportional to the applied voltage.

Open-loop operation is ideal for applications where fast response and very high resolution with maximum bandwidth are essential. Here, commanding and reading the target position in absolute values is either not important or carried out by external position sensors (see p. 2-104).

For highest positioning accuracy and repeatability, select the factory installed closed-loop option with integrated ultra-high-resolution strain gauge position sensors and operate with PI servo-control electronics. For more information, read the tutorial "Piezo-electrics in Positioning" (see p. 2-169 *ff*).

Mechanical Mounting

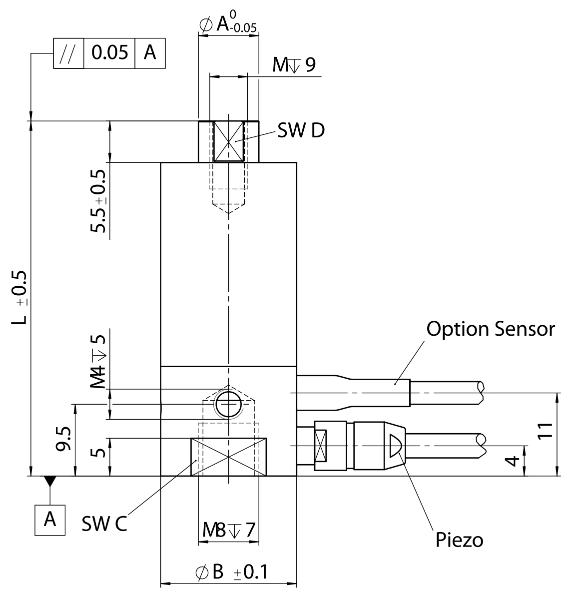
Mounting is at the foot, with push/pull forces of less than 5 N, the actuator can be held by clamping the case. The optional ball tip is intended to decouple torque and off-center forces from the translator. Read details in Mounting and Handling Guidelines (p. 1-67).

High Flexibility with PI Amplifiers, Drivers & Controllers

PI offers a wide range of control electronics for piezo actuators from low-power drivers to the high-performance amplifier / controller E-481.

For closed-loop operation PI offers a wide variety of analog and digital controllers. The E-500 modular system can be easily upgraded from an amplifier to a servo controller, including different interface / display modules.

High-resolution amplifiers and servo-control electronics, both digital and analog, see selection guide in the „Piezo Drivers / Servo Controllers" section (see p. 2-97 *ff*).



	L [mm]	∅A [mm]	∅B [mm]	C	D	M
P-212.1x	47	8	18	15	7	5
P-212.2x	60	8	18	15	7	5
P-212.4x	86	8	18	15	7	5
P-212.8x	139	8	18	15	7	5
P-216.1x	47	10	25	22	8	6
P-216.2x	60	10	25	22	8	6
P-216.4x	86	10	25	22	8	6
P-216.8x	139	10	25	22	8	6
P-216.9x	191	10	25	22	8	6

P-212 and P-216, dimensions in mm.
End pieces and case of stainless steel. Sensor connection: LEMO FFA.0S.304; 1 m coaxial cable with PUR insulation.
Input voltage connection: LEMO FGG.0B.701.CJA.1173, PUR cable, 2-conductor, shielded

Technical Data

	P-212.10	P-212.20	P-212.40	P-212.80	P-216.10	P-216.20	P-216.40	P-216.80	P-216.90	Unit	Tolerance
Operating voltage	0 to1000	0 to1000	0 to 1000	0 to 1000	0 to 1000	0 to 1000	0 to 1000	0 to 1000	0 to 1000	V	
Motion and positioning											
Closed-loop travel*	15	30	60	120	15	30	60	120	180	µm	
Closed-loop resolution*/**	0.3	0.6	1.2	2.4	0.3	0.6	1.2	2.4	3.6	nm	typ.
Open-open resolution**	0.15	0.3	0.6	1.2	0.15	0.3	0.6	1.2	1.8	nm	typ.
Linearity*	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	%	typ.
Mechanical properties											
Static large-signal stiffness***	90	60	34	18	210	140	80	50	32	N/µm	±20%
Unloaded resonant frequency	17	12	7	4.5	17	12	7	4.5	3	kHz	±20%
Push/pull force capacity	2000/300	2000/300	2000/300	2000/300	4500/500	4500/500	4500/500	4500/500	4500/500	N	Max.
Shear force limit	15	10	10	10	60	36	23	23	23	N	
Torque limit (on tip)	0.5	0.5	0.5	0.5	1	1	1	1	1	Nm	
Drive properties											
Electrical capacitance	47	90	180	370	130	250	500	1000	1500	nF	±20%
Dynamic operating current coefficient	5	5	5	5	13	13	13	13	13	µA/(Hz • µm)	±20%
Miscellaneous											
Mass (with cable)	110	120	150	210	170	200	250	370	480	g	±5%

* Requires SGS sensor. SGS versions are shipped with performance reports
** Measured with an Interferometer. The resolution of piezo actuators is not limited by stiction or friction
*** Dynamic small-signal stiffness is ~50% higher
Piezo ceramic type: PICA™ Power
Operating temperature range: -40 to +80 °C
Recommended controller/driver see p. 2-100 *ff*
For maximum lifetime, voltages in excess of 750 V should be applied only for short durations
See Notes (Technical Data) for further information (p. 1-106 *ff*)

P-225, P-235 PICA™ Power Piezo Stack Actuators

Preloaded High-Load Piezo Actuators (HVPZT) w/ Sensor Option

High-load piezo actuators P-235.1S, .4S and .9S, P-225.8S and .1S (from left) with CD for size comparison

- **Extremely High Stiffness**
- **Pushing Forces to 30,000 N**
- **Pulling Forces to 3500 N**
- **Travel Ranges to 180 µm**
- **Options: Versions for Vacuum, High- and Low-Temperatures and with Water-Resistant Case**

Ordering Information

P-2_5 . _ _ _

- **2** Preloaded High-Load Piezo Actuator, 1000 V, 12500 N
- **3** Preloaded High-Load Piezo Actuator, 1000 V, 30000 N
- **0** w/o Sensor
- **S** w/SGS Position Sensor
- **T** modified for Low Temperature
- **V** modified for High Temperature/Vacuum
- **1** Travel Range 15 µm
- **2** Travel Range 30 µm
- **4** Travel Range 60 µm
- **8** Travel Range 120 µm
- **9** Travel Range 180 µm (P-235 only)

Please read "Options and Accessories" (page 1-102 *ff*) for further information.
Extensions cables, adapters & connectors: "Accessories" in the "Piezo Drivers / Servo Controllers" (see p. 2-168 *ff*) section.

Option:

P-177.50
Dynamic applications (with E-481): temperature sensor and protective air for PICA™ HVPZT

P-706.00
Water-resistant case

P-225 and P-235 are preloaded, high-load piezo actuators (translators) for static and dynamic applications. They provide sub-millisecond re-sponse and sub-nanometer resolution.

These ultra-high-force linear actuators consist of PICA™ Power piezoelectric ceramic-stacks encapsulated in a stainless steel case with stainless steel end pieces and a frictionless internal spring preload. The high load capacity and preload makes them ideal for machining applications and active vibration cancellation.

Aplication Examples

- Precision engineering / micromechanics
- Adaptive mechanics
- Active vibration damping
- Adaptronics
- Static and dynamic precision positioning
- Force generation / materials testing

High Displacement with Ultra-High Reliability

PICA™ Power actuators are optimized for high-temperature working conditions and high-duty-cycle dynamic applications.

All PICA ™ piezo ceramics are specifically designed for high-dutycycle applications. With PI's extensive applications knowledge, gained over several decades, performance does not come at the price of reliability. All materials used are specifically matched for robustness and lifetime. Endurance tests on PICA™ actuators prove consistent performance, even after billions (1,000,000,000) of cycles.

Open- and Closed-Loop Models for Optimum Dynamics and Linearity

The standard models are ideal for open loop positioning applications. In this mode the actuator displacement is roughly proportional to the applied voltage.

Open-loop operation is ideal for applications where the fastest response and the highest bandwidth are essential. Here, commanding and reading the target position in absolute values is either not important or carried out by an external feedback loop.

For highest positioning accuracy and repeatability , select the factory installed closed-loop option with integrated ultra-high- resolution strain gauge position sensors and operate with PI servo-control electronics. For more information, read the tutorial "Piezo electrics in Positioning" (see p. 2-169 *ff*).

High Flexibility with PI Amplifiers, Drivers & Controllers

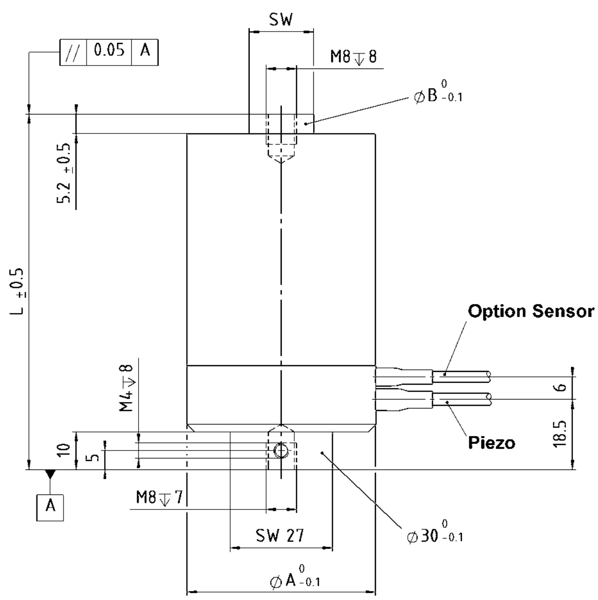
PI offers a wide range of control electronics for piezo actuators from economical, low-power piezo drivers to the E-481 high-performance amplifier / controller providing 2000 W of dynamic power.

For closed-loop operation a wide variety of analog and digital controllers is available. The E-500 modular system can be easily upgraded from an amplifier to a servo controller, including different interface / display modules.

Read details in Mounting and Handling Guidelines (p. 1-67).

High-resolution amplifiers and servo-control electronics, both digital and analog, see selection guide in the "Piezo Drivers / Servo Controllers" section (see p. 2-99 *ff*).

PI



	L [mm]	ØA [mm]	ØB [mm]	SW
P-225.1x	55	39.8	16	13
P-225.2x	68	39.8	16	13
P-225.4x	94	39.8	16	13
P-225.8x	147	39.8	16	13
P-235.1x	55	49.8	20	17
P-235.2x	68	49.8	20	17
P-235.4x	94	49.8	20	17
P-235.8x	147	49.8	20	17
P-235.9x	199	49.8	20	17

P-225 and P-235, dimensions in mm. End pieces and case of stainless steel.
Sensor connection: LEMO FFA.0S.304; 1 m coaxial cable with PUR insulation.
Voltage connection: LEMO FGG.0B.701.CJA.1173, 1 m cable with PUR insultaion, 2-conductor, shielded

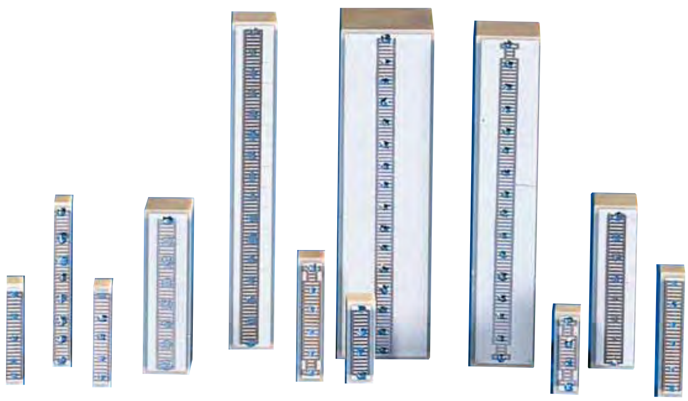
Technical Data

Model	P-225.10	P-225.20	P-225.40	P-225.80	P-235.10	P-235.20	P-235.40	P-235.80	P-235.90	Unit	Tolerance
Operating voltage	0 to 1000	0 to 1000	0 to 1000	0 to 1000	0 to 1000	0 to 1000	0 to 1000	0 to 1000	0 to 1000	V	
Motion and positioning											
Closed-loop travel*	15	30	60	120	15	30	60	120	180	µm	
Closed-loop resolution*/**	0.3	0.6	1.2	2.4	0.3	0.6	1.2	2.4	3.6	nm	typ.
Open-loop resolution**	0.15	0.3	0.6	1.2	0.15	0.3	0.6	1.2	1.8	nm	typ.
Linearity*	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	%	typ.
Mechanical properies											
Static large-signal stiffness***	480	330	200	110	860	600	380	210	150	N/µm	±20
Unloaded resonant frequency	14	10	7	4	14	10	7	3,9	2,8	kHz	±20 %
Push/pull force capacity	12500 / 2000	12500 / 2000	12500 / 2000	12500 / 2000	30000 / 3500	30000 / 3500	30000 / 3500	30000 / 3500	30000 / 3500	N	Max.
Shear force limit	255	152	84	73	707	420	232	147	147	N	
Torque limit (on tip)	1,5	1,5	1,5	1,5	2	2	2	2	2	Nm	
Drive properties											
El. capacitance	320	630	1300	2600	550	1100	2400	5100	7800	nF	±20 %
Dynamic operating current coefficient	33	33	33	33	65	65	65	65	65	µA/(Hz • µm)	±20 %
Miscellaneous											
Mass (with cable)	410	470	610	900	580	690	940	1400	1900	g	±5 %

*Requires SGS sensor. SGS versions are shipped with performance reports
**Measured with an interferometer. The resolution of piezo actuators is not limited by stiction or friction
***Dynamic small-signal stiffness is ~50 % higher
Piezo ceramic type: PICA™ Power
Operating temperature range: -40 to +80 °C
Recommended controller/driver see p. 2-100 *ff*
For maximum lifetime, voltages in excess of 750 V should be applied only for short durations
See Notes (Technical Data) for further information (see p. 1-106 *ff*)

P-882 · P-888 PICMA® Multilayer Piezo Stack Actuators

Ceramic-Insulated High-Power Actuators



PICMA® piezo actuators are available with cross-sections of 2 x 3, 3 x 3, 5 x 5, 7 x 7 and 10 x 10 mm²

- **Superior Lifetime Even Under Extreme Conditions**
- **Very Large Operating Temperature Range**
- **High Humidity Resistance**
- **Excellent Temperature Stability**
- **High Stiffness**
- **Peak Current up to 20 A**
- **UHV Compatible to 10^{-9} hPa**
- **Sub-Millisecond Response / Sub-Nanometer Resolution**
- **Ideal for Dynamic Operation**

PICMA® (PI Ceramic Monolithic Multilayer Actuator) piezo stack actuators are characterized by their high performance and reliability, even in extremely harsh environments. They are superior to conventional multilayer actuators in industrial applications and high-endurance situations, where they show substantially longer lifetimes both in static and dynamic operation.

Application Examples

- Precision mechanics / -machining
- High-speed switching
- Active and adaptive Optics
- Active vibration damping
- Pneumatic & hydraulic valves
- Metrology / Interferometry
- Life science, Biotechnology
- Nanotechnology

New Production Process, Optimized Piezo Ceramics

PICMA® piezo actuators are made from a ceramic material in which the piezoceramic properties such as stiffness, capacitance, displacement, temperature stability and lifetime are optimally combined. Thus the actuators accomplish sub-nanometer resolution in positioning and sub-millisecond response!

Increased Lifetime Through Humidity Resistance

The monolithic ceramic-encapsulated design provides better humidity protection than polymer-film insulation. Diffusion of water molecules into the insulation layer is greatly reduced by the use of cofired, outer ceramic encapsulation. Due to their high resonant frequency the actuators are suitable for highly dynamic applications with small loads; depending on the load an external preload for dynamic applications is recommended. The high Curie temperature of 320 °C gives PICMA® actuators a usable temperature range extending up to 150 °C, far beyond 80 °C as is common for conventional multilayer actuators. With conventional multilayer actuators, heat generation - which is proportional to operating frequency - either limits the operating frequency or duty cycle in dynamic operation, or makes ungainly cooling provisions necessary. At the low end, operation down to a few Kelvin is possible (with reduction in performance specifications).

Optimum UHV Compatibility - Minimum Outgassing

The lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (high bakeout temperatures, up to 150 °C).

PICMA® actuator with optional 0.1 m PTFE insulated wire leads and optional rounded top piece for decoupling lateral forces

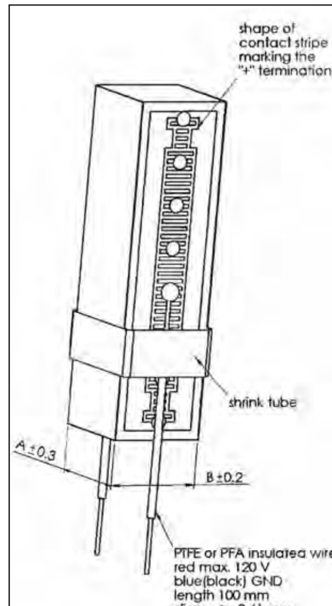
Ideal for Closed-Loop Operation

The ceramic surface of the actuators is extremely well suited for use with resistive or optical fiber strain gauge sensors. Such sensors can be easily applied to the actuator surface and exhibit significantly higher stability and linearity than with conventional polymer-insulated actuators.

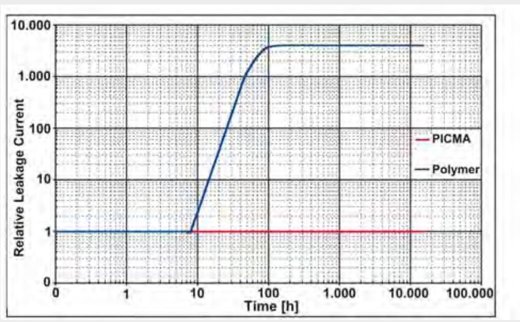
Piezo Drivers, Controllers & High-Voltage Amplifiers

High-resolution amplifiers and servo-control electronics, both digital and analog, are described in the "Piezo Drivers / Servo Controllers" section.

Read more on PICMA® reliability on page 1-65 *ff.*

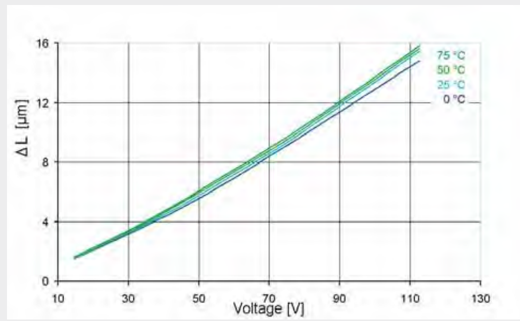


PICMA® actuators, dimensions in mm



PICMA® piezo actuators (bottom curve) compared with conventional multilayer actuators with polymer insulation (top curve). PICMA® actuators are not affected by the high-humidity test conditions. Conventional piezo actuators exhibit increased leakage current after only a few hours. Leakage current is an indicator quality and expected lifetime.

Test conditions: U = 100 VDC, T = 25 °C, Relative Humidity = 70 %



The displacement of PICMA® actuators exhibits very low temperature dependence. This, in combination with their low heat generation, makes PICMA® actuators optimal for dynamic operation

Technical Data / Product Order Numbers

Order number*	Dimensions A x B x L [mm]	Nominal displacement [µm @ 100 V]	Max. displacement [µm @ 120 V]	Blocking force [N @ 120 V]	Stiffness [N/µm]	Electrical capacitance [µF] ±20 %	Resonant frequency [kHz] ±20 %
P-882.11	3 x 2 x 9	6.5 ±20 %	8 ±20 %	190	24	0.15	135
P-882.31	3 x 2 x 13.5	11 ±20 %	13 ±20 %	210	16	0.22	90
P-882.51	3 x 2 x 18	15 ±10 %	18 ±10 %	210	12	0.31	70
P-883.11	3 x 3 x 9	6.5 ±20 %	8 ±20 %	290	36	0.21	135
P-883.31	3 x 3 x 13.5	11 ±20 %	13 ±20 %	310	24	0.35	90
P-883.51	3 x 3 x 18	15 ±10 %	18 ±10 %	310	18	0.48	70
P-885.11	5 x 5 x 9	6.5 ±20 %	8 ±20 %	800	100	0.6	135
P-885.31	5 x 5 x 13.5	11 ±20 %	13 ±20 %	870	67	1.1	90
P-885.51	5 x 5 x 18	15 ±10 %	18 ±10 %	900	50	1.5	70
P-885.91	5 x 5 x 36	32 ±10 %	38 ±10 %	950	25	3.1	40
P-887.31	7 x 7 x 13.5	11 ±20 %	13 ±20 %	1700	130	2.2	90
P-887.51	7 x 7 x 18	15 ±10 %	18 ±10 %	1750	100	3.1	70
P-887.91	7 x 7 x 36	32 ±10 %	38 ±10 %	1850	50	6.4	40
P-888.31	10 x 10 x 13.5	11 ±20 %	13 ±20 %	3500	267	4.3	90
P-888.51	10 x 10 x 18	15 ±10 %	18 ±10 %	3600	200	6.0	70
P-888.91	10 x 10 x 36	32 ±10 %	38 ±10 %	3800	100	13.0	40

Standard piezo ceramic type: 252
Standard electrical interfaces: 100 mm wire leads
*For optional solderable contacts, change order number extension to .x0 (e. g. P-882.10).
Recommended preload for dynamic operation: 15 MPa
Maximum preload for constant force: 30 MPa
Resonant frequency at 1 V_{pp}, unloaded, free at both sides. The value is halved for unilateral clamping
Capacitance at 1 V_{pp}, 1 kHz
Operating voltage: -30 to +130 V; the lifetime depends on the voltage applied
Operating temperature range: -40 to +150 °C
Standard Mechanical Interfaces: Ceramics
Available Options: strain gauge sensors, special mechanical interfaces, etc.
Other specifications on request.

P-007 – P-056 PICA™ Stack Actuator

Piezo actuator for highly dynamic applications

Variety of standard and custom PICA™ Stack piezo actuators

- **High Load Capacity to 100 kN**
- **High Force Generation to 80 kN**
- **Large Cross Sections to 56 mm Diameter**
- **A selection of Variety of Shapes**
- **Extreme Reliability >10⁹ Cycles**
- **Sub-Millisecond Response, Sub-Nanometer Resolution**
- **Vacuum-Compatible Versions**

PICA™ Stack piezo ceramic actuators are offered in a large variety of standard shapes and sizes with additional custom designs to suit any application.

Ultra-High Reliability, High Displacement, Low Power Requirements

PICA™ piezo actuators are specifically designed for high-duty-cycle applications. With our extensive applications knowledge, gained over several decades, we know how to build performance that does not come at the price of reliability. All materials used are specifically matched for robustness and lifetime. Endurance tests on PICA™ actuators prove consistent performance, even after billions (1,000,000,000) of cycles. The combination of high displacement and low electrical capacitance provides for excellent dynamic behavior with reduced driving power requirements.

Application Examples

- Nanopositioning
- High-load positioning
- Precision mechanics / -machining
- Semiconductor technology / test systems
- Laser tuning
- Switches
- Smart structures (Adaptronics)

Flexibility / Short Leadtimes

All manufacturing processes at PI Ceramic are set up for flexibility. Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

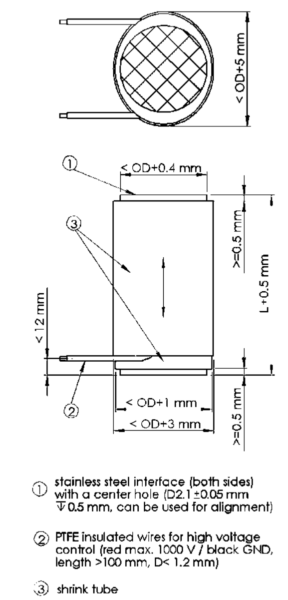
- Custom Materials
- Custom Voltage Ranges
- Custom Geometries (Circular, Rectangular, Triangular, Layer Thickness ...)
- Custom Load / Force Ranges
- Custom Flat or Spherical Endplates (Alumina, Glass, Sapphire, ...)
- Extra-Tight Length Tolerances
- Integrated Piezoelectric Sensor Discs
- Special High / Low Temperature Versions
- Vacuum Compatible Versions

Because all piezoelectric materials used in PICA™ actuators are manufactured at PI Ceramic, leadtimes are short and quality is outstanding. All standard and custom actuators are delivered with performance test sheets.

Piezo Drivers, Controllers & High-Voltage Amplifiers

High-resolution amplifiers and servo-control electronics, both digital and analog, are described in the "Piezo Drivers / Servo Controllers" (see p. 2-99 *ff*) section.

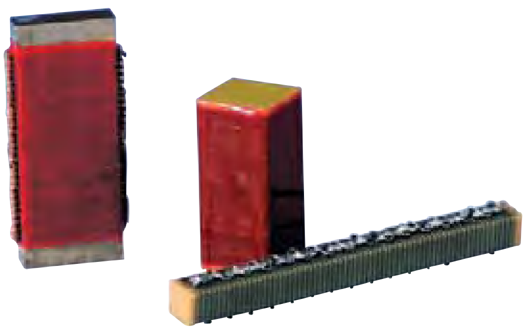
Custom PICA™-Stack actuator with 350 µm displacement



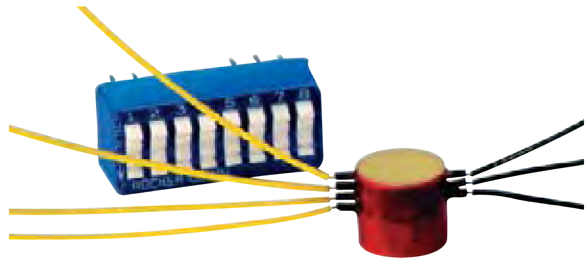
PICA™-Stack dimensions, see technical data table for further information

PICA™ Stack piezo actuators are delivered with metal endcaps for improved robustness and reliability.
For preloaded versions with steel casings (see p. 1-78, p. 1-80).

Standard actuators are covered with heat-shrink tube, shown here is the model P-025.40



Custom PICA™-Stack actuators with rectangular cross-sections.



Custom PICA™-Stack actuator, each layer wired individually.

Technical Data / Product Order Numbers

Order number	Displacement [µm] -10/+20%	Diameter D [mm]	Length L [mm] ±0.5	Blocking force [N]	Stiffness [N/µm]	Capacitance [nF] ±20%	Resonant frequency [kHz]
P-007.00	5	7	8	650	130	11	126
P-007.10	15	7	17	850	59	33	59
P-007.20	30	7	29	1000	35	64	36
P-007.40	60	7	54	1150	19	130	20
P-010.00	5	10	8	1400	270	21	126
P-010.10	15	10	17	1800	120	64	59
P-010.20	30	10	30	2100	71	130	35
P-010.40	60	10	56	2200	38	260	20
P-010.80	120	10	107	2400	20	510	10
P-016.10	15	16	17	4600	320	180	59
P-016.20	30	16	29	5500	190	340	36
P-016.40	60	16	54	6000	100	680	20
P-016.80	120	16	101	6500	54	1300	11
P-016.90	180	16	150	6500	36	2000	7
P-025.10	15	25	18	11000	740	400	56
P-025.20	30	25	30	13000	440	820	35
P-025.40	60	25	53	15000	250	1700	21
P-025.80	120	25	101	16000	130	3400	11
P-025.90	180	25	149	16000	89	5100	7
P-025.150	250	25	204	16000	65	7100	5
P-025.200	300	25	244	16000	54	8500	5
P-035.10	15	35	20	20000	1300	700	51
P-035.20	30	35	32	24000	810	1600	33
P-035.40	60	35	57	28000	460	3300	19
P-035.80	120	35	104	30000	250	6700	11
P-035.90	180	35	153	31000	170	10000	7
P-045.20	30	45	33	39000	1300	2800	32
P-045.40	60	45	58	44000	740	5700	19
P-045.80	120	45	105	49000	410	11000	10
P-045.90	180	45	154	50000	280	17000	7
P-050.20	30	50	33	48000	1600	3400	32
P-050.40	60	50	58	55000	910	7000	19
P-050.80	120	50	105	60000	500	14000	10
P-050.90	180	50	154	61000	340	22000	7
P-056.20	30	56	33	60000	2000	4300	32
P-056.40	60	56	58	66000	1100	8900	19
P-056.80	120	56	105	76000	630	18000	10
P-056.90	180	56	154	78000	430	27000	7

Standard piezo ceramic type: PIC 151
Recommended preload for dynamic operation: 15 MPa
Maximum preload for constant force: 30 MPa
Resonant frequency at 1 V_{pp}, unloaded, free at both sides. The value is halved for unilateral clamping
Capacitance at 1 V_{pp}, 1 kHz
blocking force at 1000 V
Operating voltage: 0 to 1000 V
Operating temperature range: -20 to +85 °C
Standard mechanical interfaces: steel plates, 0.5 to 2 mm thick (depends on model)
Standard electrical interfaces: two PTFE-insulated wires, pigtail length 100 mm
Available options: integrated piezo force sensor or strain gauge sensors, non magnetic, vacuum compatible, etc.
Other specifications on request.

P-010.xxP – P-056.xxP PICA™ Power Actuator

Piezo Stack Actuators for High-Level Dynamic Applications

Variety of PICA™ Power piezo stack actuators from 5 µm to 180 µm travel range

- **Operating Temperature to 150 °C**
- **High Load Capacity to 80 kN**
- **High Force Generation to 70 kN**
- **Large Cross Sections to 56 mm Diameter**
- **Extreme Reliability >10^9 Cycles**
- **Sub-Millisecond Response, Sub-Nanometer Resolution**
- **UHV Versions to 10^{-9} hPa**
- **Non-Magnetic Versions**
- **Temperature Sensor PT1000 Applied**

PICA™ Power piezoceramic stack actuators are offered in a large variety of standard shapes and sizes, with additional custom designs to suit any application. Based on the PIC 255 material, PICA™ Stack Power actuators are optimized for high-temperature working conditions and high-duty-cycle dynamic applications.

Application Examples

- Nanopositioning
- Active vibration damping
- High-load positioning
- Precision mechanics / -machining
- Semiconductor technology / test systems
- Laser tuning
- Switches
- Smart structures (Adaptronics)
- Nanotechnology

High Displacement with Ultra-High Reliability

PICA™ Power actuators are optimized for high-temperature working conditions and high-duty-cycle dynamic applications.

All PICA™ piezo ceramics are specifically designed for high-duty-cycle applications. With PI's extensive applications knowledge, gained over several decades, performance does not come at the price of reliability. All materials used are specifically matched for robustness and lifetime. Endurance tests on PICA™ actuators prove consistent performance, even after billions (1,000,000,000) of cycles.

Flexibility / Short Leadtimes

All manufacturing processes at PI Ceramic are set up for flexibility. Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

- Custom Materials
- Custom Voltage Ranges
- Custom Geometries (Circular, Rectangular, Triangular, Layer Thickness ...)
- Custom Load / Force Ranges
- Custom Flat or Spherical Endplates (Alumina, Glass, Sapphire, ...)
- Extra-Tight Length Tolerances
- Integrated Piezoelectric Sensor Discs
- Special High / Low Temperature Versions
- Vacuum Compatible Versions

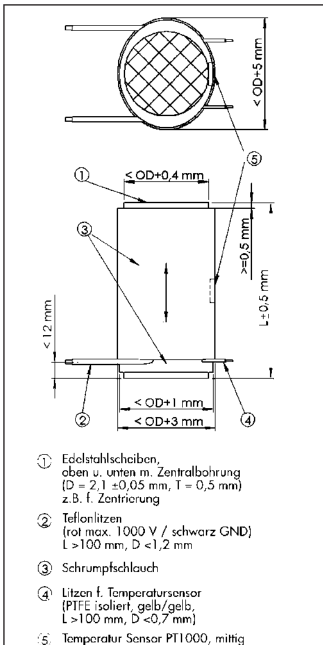
Because all piezoelectric materials used in PICA™ actuators are manufactured at PI Ceramic, leadtimes are short and quality is outstanding. All standard and custom actuators are delivered with performance test sheets.

Piezo Drivers, Controllers & High-Voltage Amplifiers

PI offers a wide range of piezo control electronics, from low-power drivers to the ultra-high-performance E-481 power amplifier delivering 2000 W of dynamic power . For closed-loop positioning applications, a variety of analog and digital controllers is also available. The modular E-500 system can be upgraded from an amplifier to a servo-controller and offers a variety of computer interfaces. Of course, PI also designs custom amplifiers and controllers (see p. 2-98 *ff*).

OEM-PICA™ Power piezo actuators are available with cross sections to 56 mm

Custom preloaded PICA™ Power piezo actuator with forced-air cooling



PICA™ Power dimensions in mm, see technical data table for further information

Technical Data / Product Order Numbers

Order number	Displacement [µm] -10/+20%	Diameter D [mm]	Length L [mm] ±0.5	Blocking force [N]	Stiffness [N/µm]	Capacitance [nF] ±20%	Resonant frequency [kHz]
P-010.00P	5	10	9	1200	240	17	129
P-010.10P	15	10	18	1800	120	46	64
P-010.20P	30	10	31	2100	68	90	37
P-010.40P	60	10	58	2200	37	180	20
P-010.80P	120	10	111	2300	19	370	10
P-016.10P	15	16	18	4500	300	130	64
P-016.20P	30	16	31	5400	180	250	37
P-016.40P	60	16	58	5600	94	510	20
P-016.80P	120	16	111	5900	49	1000	10
P-016.90P	180	16	163	6000	33	1600	7
P-025.10P	15	25	20	9900	660	320	58
P-025.20P	30	25	33	12000	400	630	35
P-025.40P	60	25	60	13000	220	1300	19
P-025.80P	120	25	113	14000	120	2600	10
P-025.90P	180	25	165	14000	80	4000	7
P-035.10P	15	35	21	18000	1200	530	55
P-035.20P	30	35	34	23000	760	1200	34
P-035.40P	60	35	61	26000	430	2500	19
P-035.80P	120	35	114	28000	230	5200	10
P-035.90P	180	35	166	29000	160	7800	7
P-045.20P	30	45	36	36000	1200	2100	32
P-045.40P	60	45	63	41000	680	4300	18
P-045.80P	120	45	116	44000	370	8800	10
P-045.90P	180	45	169	45000	250	13000	7
P-056.20P	30	56	36	54000	1800	3300	32
P-056.40P	60	56	63	66000	1100	6700	18
P-056.80P	120	56	116	68000	570	14000	10
P-056.90P	180	56	169	70000	390	21000	7

Standard piezo ceramic type: PIC 255
Recommended preload for dynamic operation: 15 MPa
Maximum preload for constant force: 30 MPa
Resonant frequency at 1 V_{pp}, unloaded. The value is halved for unilateral clamping
Capacitance at 1 V_{pp}, 1 kHz
blocking force at 1000 V
Operating voltage: 0 to 1000 V
Operating temperature range: -20 to +150 °C
Standard mechanical interfaces: steel plates, 0.5 to 2 mm thick (depends on model)
Standard electrical interfaces: two PTFE-insulated wires, pigtail length 100 mm
Available options: integrated piezo sensor or strain gauge sensors, non magnetic, vacuum compatible, etc.
Other specifications on request.

P-010.xxH – P-025.xxH PICA™ Thru Actuator

High-Load Piezo Stack Actuators with Aperture

PICA™ Thru piezo stack actuators with clear aperture

- **Clear Aperture for Transmitted-Light Applications for Mechanical Preloading**
- **Extreme Reliability >10⁹ Cycles**
- **Large Cross Sections to 56 mm Diameter**
- **Variety of Shapes**
- **Sub-Millisecond Response, Sub-Nanometer Resolution**
- **Vacuum-Compatible Versions**

PICA™ Thru actuators are hollow piezo stack actuators, offered in a large variety of standard shapes and sizes with additional custom designs to meet all customer requirements. They combine the advantage of a clear aperture with the strength and force generation of stack actuators. These tubular devices are high-resolution linear actuators for static and dynamic applications. The clear aperture facilitates transmitted-light applications. Furthermore the electrical consumption is reduced due to the decreased electrical capacitance.

Application Examples

- Optics
- Image stabilization
- Laser tuning
- Laser treatment
- Precision mechanics / -machining
- Confocal microscopy
- Nanopositioning

Ultra-High Reliability, High Displacement, Low Power Requirements

PICA™ piezo actuators are specifically designed for high-duty-cycle applications. With our extensive applications knowledge, gained over several decades, we know how to build performance that does not come at the price of reliability. All materials used are specifically matched for robustness and lifetime. Endurance tests on PICA™ actuators prove consistent performance, even after billions (1,000,000,000) of cycles. The combination of high displacement and low electrical capacitance provides for excellent dynamic behavior with reduced driving power requirements.

Flexibility / Short Leadtimes

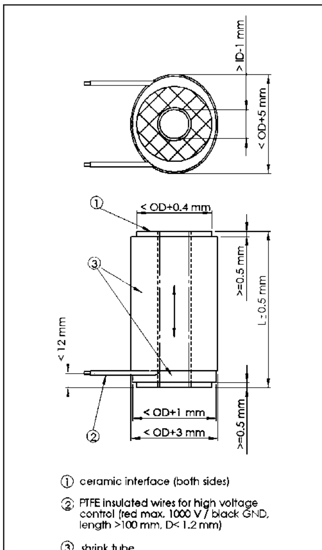
All manufacturing processes at PI Ceramic are set up for flexibility. Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

- Custom Materials
- Custom Voltage Ranges
- Custom Geometries (Circular, Rectangular, Tri-angular, Layer Thickness ...)
- Custom Load / Force Ranges
- Custom Flat or Spherical Endplates (Alumina, Glass, Sapphire, ...)
- Extra-Tight Length Tolerances
- Integrated Piezoelectric Sensor Discs
- Special High / Low Temperature Versions
- Vacuum Compatible Versions

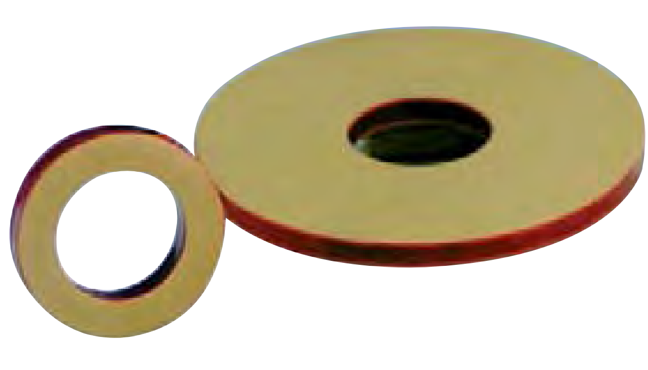
Because all piezoelectric materials used in PICA™ actuators are manufactured at PI Ceramic, leadtimes are short and quality is outstanding. All standard and custom actuators are delivered with performance test sheets.

Piezo Drivers, Controllers & High-Voltage Amplifiers

High-resolution amplifiers and servo-control electronics, both digital and analog, are described in the “Piezo Drivers / Servo Controllers” section.



PICA™ Thru dimensions in mm, see technical data table for further information



Customized PICA™ Thru actuator discs

Custom PICA™ Thru piezo actuator with 56 mm outside diameter, 8 mm inner diameter, 250 µm displacement. Pen for size comparison

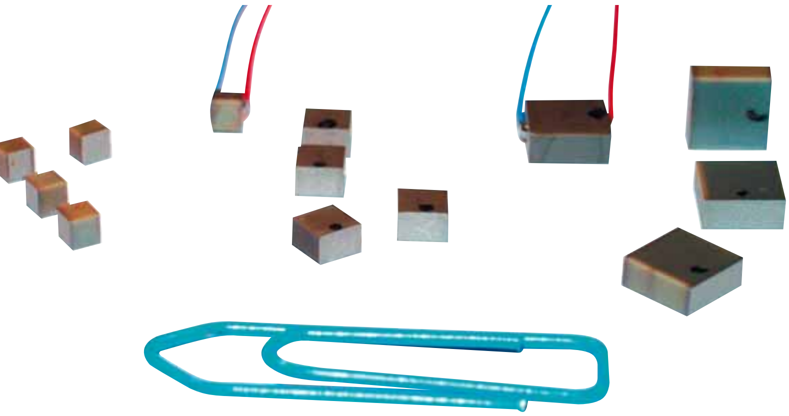
Technical Data / Product Order Numbers

Order numbers	Displacement [µm] -10/+20 %	Diameter OD [mm]	Diameter ID [mm]	Length L [mm] ±0.5	Blocking force [N]	Stiffness [N/µm]	Capacitance [nF] ±20 %	Resonant frequency [kHz]
P-010.00H	5	10	5	7	1200	230	15	144
P-010.05H	10	10	5	12	1300	130	29	84
P-010.10H	15	10	5	15	1700	110	40	67
P-010.15H	20	10	5	21	1500	76	59	48
P-010.20H	30	10	5	27	1800	59	82	39
P-010.30H	40	10	5	40	1600	40	120	28
P-010.40H	60	10	5	54	1800	29	180	21
P-016.00H	5	16	8	7	2900	580	42	144
P-016.05H	10	16	8	12	3400	340	83	84
P-016.10H	15	16	8	15	4100	270	120	67
P-016.15H	20	16	8	21	3800	190	170	48
P-016.20H	30	16	8	27	4500	150	230	39
P-016.30H	40	16	8	40	4000	100	340	28
P-016.40H	60	16	8	52	4700	78	490	21
P-025.10H	15	25	16	16	7400	490	220	63
P-025.20H	30	25	16	27	8700	290	430	39
P-025.40H	60	25	16	51	9000	150	920	22
P-025.50H	80	25	16	66	9600	120	1200	17

Piezo ceramic type PIC 151
Recommended preload for dynamic operation: 15 MPa
Maximum preload for constant force: 30 MPa
Resonant frequency at 1 V_{pp}, unloaded, free at both sides. The value is halved for unilateral clamping
Capacitance at 1 V_{pp}, 1 kHz
Blocking force at 1000 V
Operating voltage range: 0 to 1000 V
Operating temperature range: -20 to +85 °C
Standard mechanical interface (top & bottom): ceramic, 0.5–2 mm thick (depends on model)
Standard electrical interface: two PTFE-insulated wires, pigtail length 100 mm
Available options: integrated force piezo sensor or strain gauge sensors, non-magnetic, vacuum compatible, etc.
Ask about custom designs and further specifications.

PL022 · PL033 · PL055 PICMA® Chip Actuators

Miniature Multilayer Piezo Stack Actuators



PICMA® chip miniature piezo actuators are the smallest ceramic encapsulated multilayer piezo actuators available, paper clip for size comparison

- **Superior Lifetime Even Under Extreme Conditions**
- **Ultra-Compact: from 2 x 2 x 2 mm**
- **Ideal for Dynamic Operation**
- **Sub-Millisecond Response**
- **Sub-Nanometer Resolution**
- **Vacuum Compatible to 10⁹ hPa**
- **High Humidity Resistance**

Smallest Dimensions – High Performance

PICMA® Chip actuators sized from 2 x 2 x 2 mm are the smallest monolithic multilayer piezo stack actuators available. Providing sub-nanometer resolution and sub-millisecond re-s-ponse, they are ideally suited to high-level dynamic applications.

New Production Process, Optimized Piezo Ceramics

PICMA® actuators are made from a ceramic material in which the piezoceramic properties such as stiffness, capacitance, displacement, temperature stability and lifetime are optimally combined. Thus the actuators accomplish sub-nanometer resolution in positioning and sub-millisecond response!

Application Examples

- Static and dynamic precision positioning
- Laser tuning
- Micro-dispensing
- Metrology / Interferometry
- Life science, Biotechnology
- Photonics

Increased Lifetime Through Humidity Resistance

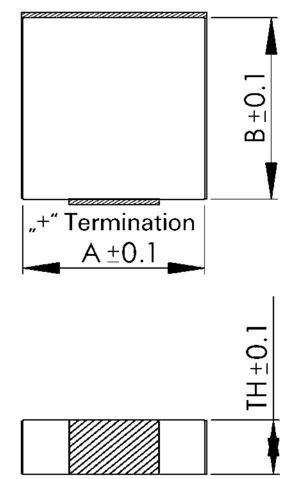
The monolithic ceramic-encapsulated design provides better humidity protection than polymer-film insulation. Diffusion of water molecules into the insulation layer is greatly reduced by the use of cofired, outer ceramic encapsulation. Due to their high resonant frequency the actuators are suitable for highly dynamic applications with small loads; depending on the load an external preload for dynamic applications is recommended. The high Curie temperature of 320 °C gives PICMA® actuators a usable temperature range extending up to 150 °C, far beyond 80 °C as is common for conventional multilayer actuators. With conventional multilayer actuators, heat generation – which is proportional to operating frequency – either limits the operating frequency or duty cycle in dynamic operation, or makes ungainly cooling provisions necessary. At the low end, operation down to a few Kelvin is possible (with reduction in performance specifications).

Optimum UHV Compatibility – Minimum Outgassing

The lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (high bakeout temperatures, up to 150 °C).

Piezo Drivers, Controllers & High-Voltage Amplifiers

High-resolution amplifiers and servo-control electronics, both digital and analog, are described in the “Piezo Drivers / Servo Controllers” section.



PICMA® chip miniature piezo actuator, dimensions in mm. See technical data table for A, B, TH. Lateral tolerances for PL055 0.15 mm

Technical Data / Product Order Numbers

Order number*	Dimensions A x B x TH in mm	Nominal displacement [µm @ 100 V] ±20 %	Blocking force [N]	Electrical capacitance [nF] ±20 %	Resonant frequency [kHz]
PL022.30	2 x 2 x 2	2.2	>120	25	>300
PL033.30	3 x 3 x 2	2.2	>300	80	>300
PL055.30	5 x 5 x 2	2.2	>500	250	>300

* For optional PTFE insulated wire leads change order number extension to .x1 (e. g. PL022.31)

Resonant frequency at 1 V_{pp}, unloaded, free at both sides. The value is halved for unilateral clamping

Capacitance at 1 V_{pp}, 1 kHz

Operating voltage: -20 to +100 V

Operating temperature range: 150 °C

Standard electrical interfaces: Solderable pads

Other specifications on request.

Recommended preload for dynamic operation: 15 MPa

Maximum preload for constant force: 30 MPa

Piezoelectric Actuators & Components from PI Ceramic—Leading in Piezo Technology

PI Ceramic—a PI Subsidiary—is a long-standing, world-class supplier of high-performance piezoelectric actuator and transducer components and subassemblies. The award-winning PICMA® actuator technology is a result of PI Ceramic's research and development, and innovative drive solutions such as PILine® ultrasonic ceramic motors and NEXLINE® high-force ceramic motors are based on piezoelectric actuators from PIC.

PI Ceramic provides a wide range of standard piezoelectric actuator components and develops and produces all piezo ceramic drive systems employed in PI's precision positioning systems. Apart from the standard types a multitude of application-specific and custom-engineered modifications can be delivered.


Piezoceramic rings, plates, tubes

Piezoceramic Materials & Components

Variety of materials:
- lead zirconate titanate (PZT); barium titanate

Variety of shapes:
- discs (rod, block, custom design)
- rings, tubes
- shear elements (plates, rings)

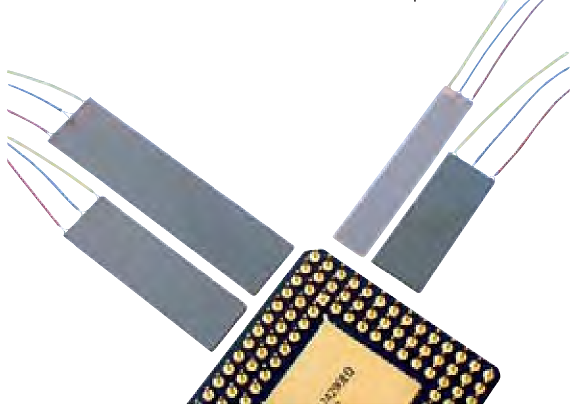
Custom electrodes (material, shape)

Patch transducers, piezo composite materials

For more information on piezoceramic materials and components, see the PI Ceramic catalogs and Website (www.piceramic.de).

PL112 · PL140 PICMA® Bender Actuators

Multilayer Piezo Bender Actuators with High Travel and Low Operating Voltage



Bender actuators with optional wire leads (order number extension .x1); micro processor for size comparison

- **Ceramic Encapsulation for Better Protection and Longer Lifetime**
- **Positioning Range up to 2 mm**
- **Fast Response (10 msec)**
- **Nanometer-Range Resolution**
- **Low Operating Voltage**
- **Vacuum-Compatible Versions to 10^{-9} hPa**
- **Available with Integrated Position Sensor**
- **Special OEM- and Bench-Top Amplifiers Available**

PICMA® multilayer bender piezo actuators provide a deflection of up to 2 mm, forces up to 2 N and response times in the millisecond range. These multilayer piezoelectric components are manufactured from ceramic layers of only about 50 µm thickness. They feature internal silver-palladium electrodes and ceramic insulation applied in a cofiring process. The benders have two outer active areas and one central electrode network dividing the actuator in two segments of equal capacitance, similar to a classical parallel bimorph.

Application Examples

- Wire bonding
- Pneumatic valves
- Fiber optic switches
- (Laser)-Beam steering
- Micropositioning
- Acceleration sensors

Advantages

PICMA® Bender piezo actuators offer several advantages over classic bimorph components manufactured by gluing together two ceramic plates (0.1 to 1 mm thick): faster response time and higher stiffness. The main advantage, however, is the drastically reduced (by a factor of 3 to 10) operating voltage of only 60 V. The reduced voltage allows smaller drive electronics and new applications, such as in medical equipment. Additionally, these devices offer improved humidity resistance due to the ceramic encapsulation.

Increased Lifetime Through Humidity Resistance

The monolithic ceramic-encapsulated design provides better humidity protection than polymer-film insulation. Diffusion of water molecules into the insulation layer is greatly reduced by the use of cofired, outer ceramic encapsulation. Due to their high resonant frequency the actuators are suitable for highly dynamic applications with small loads; depending on the load an external preload for dynamic applications is recommended. The high Curie temperature of 320 °C gives PICMA® actuators a usable temperature range extending up to 150 °C, far beyond 80 °C as is common for conventional multilayer actuators. With conventional multilayer actuators, heat generation – which is proportional to operating frequency – either limits the operating frequency or duty cycle in dynamic operation, or makes ungainly cooling provisions necessary. At the low end, operation down to a few Kelvin is possible (with reduction in performance specifications).

Optimum UHV Compatibility – Minimum Outgassing

The lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (high bakeout temperatures, up to 150 °C).

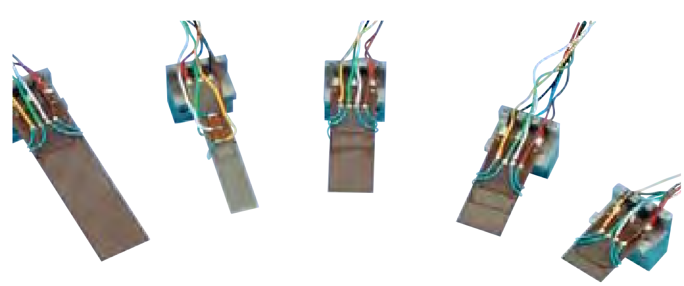
Closed-Loop Version

For closed-loop positioning the versions P-871 with integrated strain gauge sensors are available (see p. 1-84).

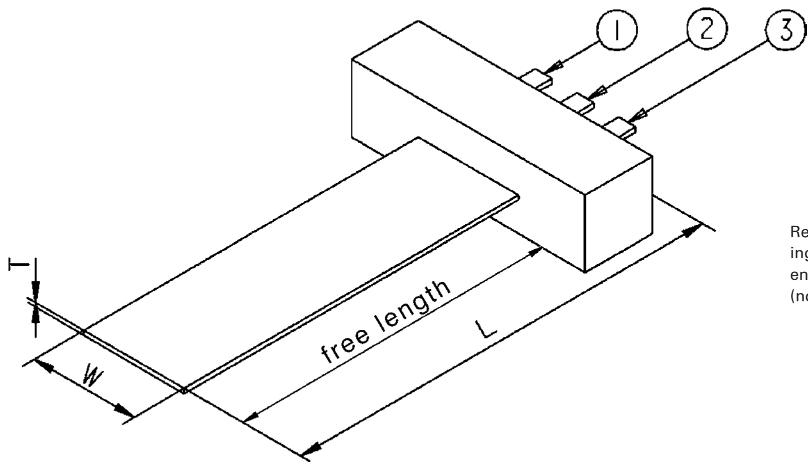
Drivers and Controllers

PI offers a wide selection of low noise amplifiers and controllers for piezo actuators (see section „Piezo Electronics“). Customized piezo electronics are developed on request.

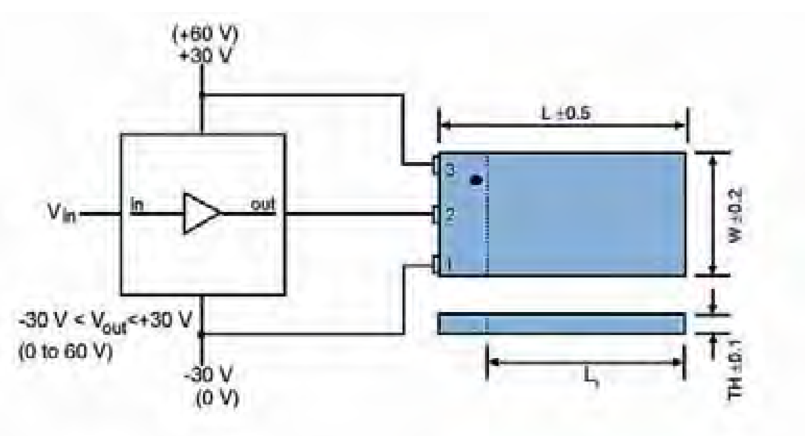
The E-650.00 and E-650.0E piezo amplifiers (see p. 2-122) are especially designed for operating the PICMA® bender actuators.



Bender actuators with strain gauge positioning sensors are available with product number P-871



Recommended clamping: non-conducting material with rounded clamping end face for protection of ceramics (not included). See table for dimensions



Differential control of PICMA® bender actuators
Pin Assignments:
1: -30 V [or GND]
2: -30 V to +30 V [or 0 to 60 V]
3: +30 V [or +60 V]
Dimensions in mm

Technical Data / Product Order Numbers

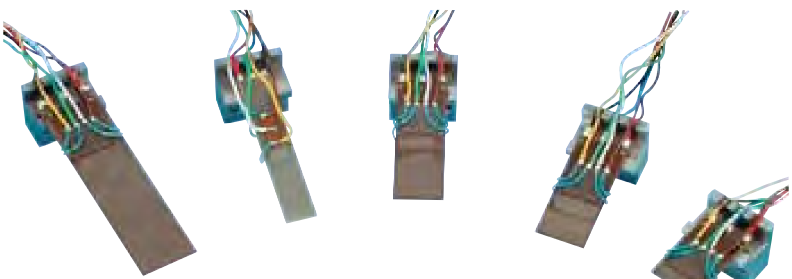
Order number*	Operating voltage [V]	Nominal displacement [µm] ±20 %	Free length [mm]	Dimensions L x W x T [mm]	Blocking force [N]	Electrical capacitance [µF] ±20 %	Resonant frequency [Hz] ±20 %
PL112.10**	0 - 60 (±30)	±80	12	17.8 x 9.6 x 0.65	±2.0	2 x 1.1	>1000
PL122.10	0 - 60 (±30)	±250	22	25.0 x 9.6 x 0.65	±1.1	2 x 2.4	660
PL127.10	0 - 60 (±30)	±450	27	31.0 x 9.6 x 0.65	±1.0	2 x 3.4	380
PL128.10**	0 - 60 (±30)	±450	28	35.5 x 6.3 x 0.75	±0.5	2 x 1.2	360
PL140.10	0 - 60 (±30)	±1000	40	45.0 x 11.0 x 0.60	±0.5	2 x 4.0	160

*For optional PTFE insulated wire leads change order number extension to .x 1 (e. g. PL112.11)
Operating temperature range: -20 to +85 °C;
**to +150 °C Resonant frequency at 1 V_{pp}, capacitance at 1 V_{pp}, 1 kHz

All parameters depend on actual clamping conditions and applied load.
Ask about custom designs and further specifications.

P-871 PICMA® Piezo Bender Actuators

Low-Voltage Multilayer Piezo Bender Actuators with Position Sensor



P-871.140, P-871.128, P-871.122 and P-871.112 closed-loop bender actuators (from left to right)

- **Closed-Loop Operation for Superior Accuracy**
- **Nanometer-Resolution**
- **Displacement to 1.6 mm**
- **Ceramic Encapsulation for Extended Lifetime**
- **Ideal for Scanning Applications**
- **Vacuum-Compatible Versions**
- **Low Operating Voltage**
- **Mounting Hardware Included**
- **Special OEM- and Bench-Top Amplifiers Available**

P-871 transducers are unique closed-loop piezo benders based on the open-loop PL 122 to PL 140 PICMA® -series multilayer actuators p. 1-94. Equipped with high-resolution position feedback sensors they provide better linearity, accuracy and repeatability than other piezo benders on the market. P-871 bender actuators achieve longer positioning ranges than typical piezo stack actuators, up to 1.6 mm, while still providing fast response times in the millisecond range.

Application Examples

- Wire bonders
- Pneumatic valves
- Fiber optic positioning & switches
- (Laser)- Beam steering
- Micropositioning
- Acceleration sensors
- Nanotechnology

Design

These multilayer piezoelectric components are manufactured from ceramic layers of only about 50 µm thickness. They feature internal silver-palladium electrodes and ceramic insulation applied in a cofiring process. Due to the thin layers the operating voltage is significantly lower than for classical parallel bimorph bender elements. For ease of installation, the units come complete with the mounting hardware, cables and connectors.

Closed-Loop Position Control for Higher Accuracy

P-871s are ideal devices for scanning, positioning and beam deflection applications and provide much better accuracy, stability and repeatability than conventional open-loop actuators. The special bender design allows the direct application of a strain gauge sensor to the surface without the need for a polymer insulation layer in between. The advantages are faster response, reduced phase lag and precise position control with non-linearity of <0.5 %. The settling time for a small-signal step (up to 1 % nominal travel) to an accuracy of better than 1 % is between 10 ms (P-871.112) and 30 ms (P-871.140).

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Optimum UHV Compatibility - Minimum Outgassing

The lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (no outgassing / high bakeout temperatures, up to 150 °C).

Amplifiers, Drivers & Controllers

PI offers a wide range of standard amplifiers and controllers for piezo actuators. The E-651.1S and E-651.2S desktop controllers and the OEM board E-614.2BS (see p. 2-121) are specifically designed to operate P-871 bender actuators.

Ordering Information

P-871.112
PICMA® Multilayer Piezo Bender Actuator, 160 µm, 9.6 mm Width, SGS-Sensor

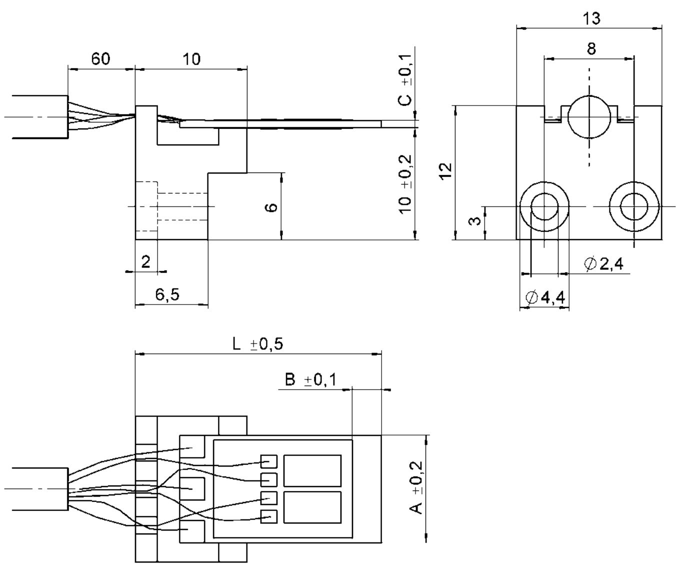
P-871.122
PICMA® Multilayer Piezo Bender Actuator, 400 µm, 9.6 mm Width, SGS-Sensor

P-871.127
PICMA® Multilayer Piezo Bender Actuator, 720 µm, 9.6 mm Width, SGS-Sensor

P-871.128
PICMA® Multilayer Piezo Bender Actuator, 720 µm, 6.3 mm Width, SGS-Sensor

P-871.140
PICMA® Multilayer Piezo Bender Actuator, 1600 µm, 11 mm Width, SGS-Sensor

Ask about custom designs



	L	A	B	C
P-871.112	22	9,6	2,6	0,65
P-871.122	29	9,6	9,6	0,65
P-871.127	35	9,6	15,6	0,65
P-871.128	40	6,25	17	0,75
P-871.140	49	11	29,1	0,60

P-871 dimensions in mm, cable length >1 m

Technical Data

Model	P-871.112*	P-871.122	P-871.127	P-871.128*	P-871.140	Units
Closed-loop travel	±80	±200	±360	±360	±800	µm
Integrated feedback sensor	SGS	SGS	SGS	SGS	SGS	
Closed-loop linearity	0.5	0.5	0.5	0.5	0.5	%
Static large-signal stiffness	0.02	0.01	0.003	0.002	0.0007	N/µm
Blocking force	±2.0	±1.1	±1.0	±0.5	±0.5	N ±20 %
Electrical capacitance	2 x 1.1	2 x 2.4	2 x 3.4	2 x 1.2	2 x 4.0	µF ±20 %
Unloaded resonant frequency	2540	1010	560	340	195	Hz ±20 %
Resonant frequency @ 6.5 g load	480	220	145	100	60	Hz ±20 %

Operating voltage: 0 to 60 V (±30 V)
Recommended driver / controller: E-651 bench top / E-614 PCI card (p. 2-123)
Connector: 1 LEMO connector for both sensor and voltage supply
Operating temperature range: -20 to +85 °C; ** to +150 °C
Resonant frequency at 1 Vpp, capacitance at 1 Vpp, 1 kHz
All specifications depend on the real clamping conditions and on the applied mechanical load.
Other specifications on request.

P-876 DuraAct™

Piezoelectric Patch Transducers

The small-sized P-876.SP1 DuraAct™ transducers (left) are designed for applications where space is at a premium. On the right, the P-876.A12 series transducer (golf ball for size comparison)

- **Actuator, Sensor or Energy Source**
- **Highly Formable Ceramics**
- **Can be Applied to Curved Surfaces**
- **Customized Solutions on Request**
- **Cost-Effective**

P-876 DuraAct™ patch transducers combine the functionality of piezoceramic materials as sensors and actuators as well as for electrical charge generation and storage. Used as a bender actuator, they allow high deflection with high force and precision. Other possible operation modes of DuraAct™ transducers are as high-dynamics sensor (e. g. for structural health monitoring) or for energy harvesting.

Application Examples

- High-dynamics actuators
- Adaptive systems
- Vibration and noise cancellation
- Deformation control and stabilization
- Damage monitoring
- Energy harvesting

Integration into Adaptive Systems

With their compact design, DuraAct™ transducers can be applied to structure areas where deformations are to be generated or detected. For this purpose the transducers can be affixed to the surface of structures or they can be integrated as structural elements. Whole areas are monitored effectively by applying an array of several DuraAct™ on a surface.

DuraAct™ patch transducers are ideally suited for active and adaptive systems. Embedded in a servo-control loop, vibrations can be reduced and structures can be controlled in the nanometer range.

Robust and Cost-Effective Design for Industrial Applications

The laminated design consisting of a piezoceramic plate and polymers provides a mechanically preloaded and electrically insulated device for easy handling. P-876 patch transducers feature a rugged design with the mechanical stability of a structural material.

Energy Harvesting: Self-Sustaining Systems in a Small Package

Another operation mode of DuraAct™ patch transducers is the application as energy harvester. The transformation of mechanical vibrations up to some kilohertz may yield electrical power in the milliwatt range. This power supplies miniature electronic devices like LEDs, sensors or even transmitters for remote data control.

Notes

DuraAct™ Transducers can be offered in highly customized versions:

- Flexible choice of dimensions
- Flexible choice of thickness and bending properties
- Flexible choice of piezoceramic materials and operating temperature
- Various electrical connection designs

Combining sensor and actuator functions (multiple ceramic layers)

Ordering Information

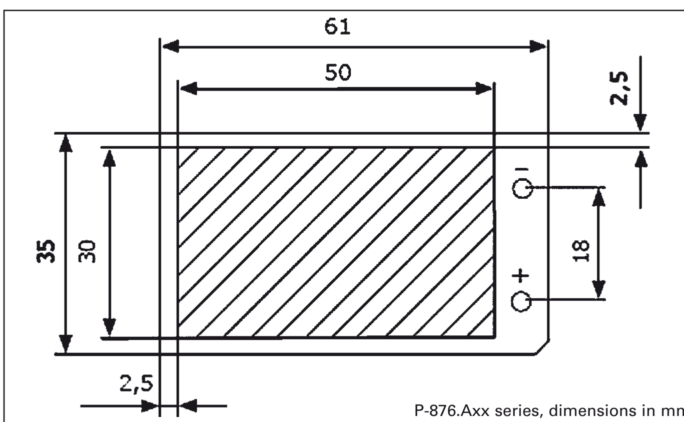
P-876.A11
DuraAct™ Patch Transducer, 61 x 35 x 0,4 mm

P-876.A12
DuraAct™ Patch Transducer, 61 x 35 x 0,5 mm

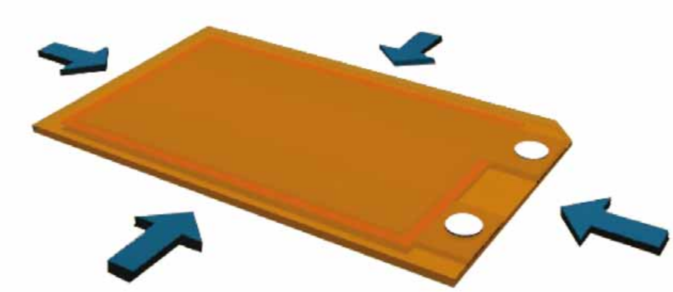
P-876.A15
DuraAct™ Patch Transducer, 61 x 35 x 0,8 mm

P-876.SP1
DuraAct™ Patch Transducer, 16 x 13 x 0.5 mm

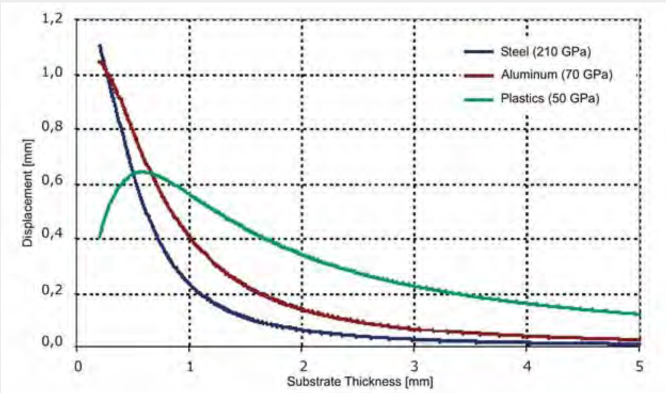
Ask about custom designs!



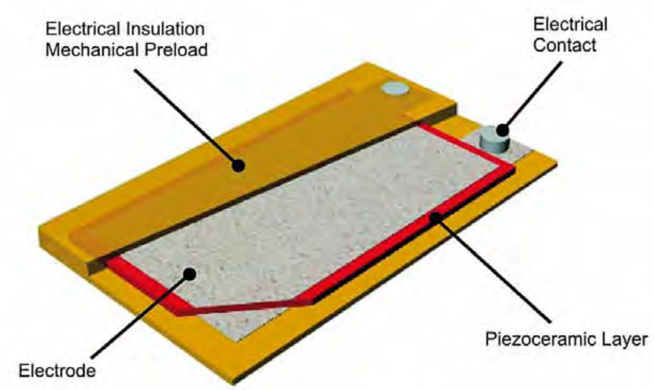
P-876.Axx series, dimensions in mm



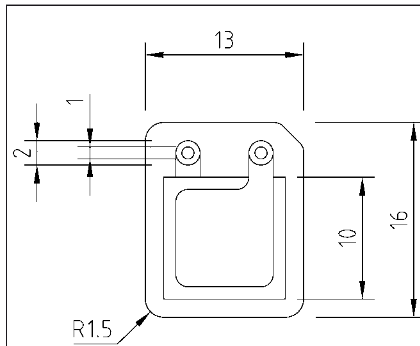
Lateral contraction of a DuraAct™ patch transducer when voltage is applied



Deflection of a bending transducer as a function of the substrate thickness for different materials. A bending transducer consists of a substrate with a P-876 actuator (here: P-876.A15) glued to one side. A contraction of the actuator effects a deflection W



Design principle of the transducer



P-876.SP1, dimensions in mm

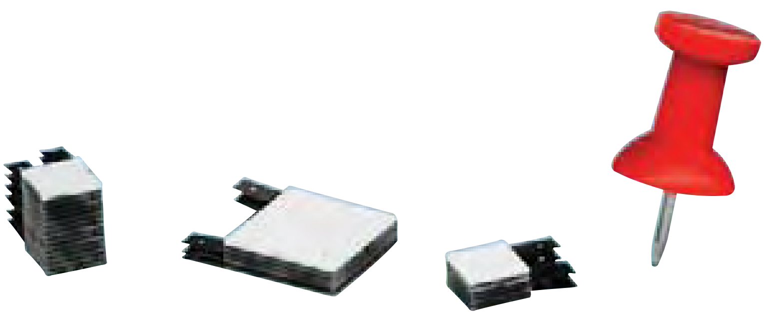
Technical Data

Model	P-876.A11	P-876.A12	P-876.A15	P-876.SP1	Tolerances
Operating voltage	-50 to +200 V	-100 to +400 V	-250 to +1000 V	-100 to +400 V	
Motion and positioning					
Lateral contraction, open-loop	400 µm/m 1.6 µm/m/V	650 µm/m 1.3 µm/m/V	800 µm/m 0.64 µm/m/V	650 µm/m 1.3 µm/m/V	min. (+20 %/-0) min. (+20 %/-0)
Mechanical properties					
Blocking force	90 N	265 N	775 N	280 N	
Length	61 mm	61 mm	61 mm	16 mm	±0.5 mm
Width	35 mm	35 mm	35 mm	13 mm	±0.5 mm
Thickness	0.4 mm	0.5 mm	0.8 mm	0.5 mm	±0.5 mm
Bending radius	12 mm	20 mm	70 mm	–	max.
Drive properties					
Ceramic type	PIC 252 Layer thickness: 100 µm	PIC 255 Layer thickness: 200 µm	PIC 255 Layer thickness: 500 µm	PIC 255 Layer thickness: 200 µm	
Electrical Capacitance	150 nF	90 nF	45 nF	8 nF	±20 %
Miscellaneous					
Operating temperature range*	-20 to +150 °C	-20 to +150 °C	-20 to +150 °C	-20 to +150 °C	
Mass	2.1 g	3.5 g	7.2 g	0.3 g	±10 %
Voltage connection	Soldering pads	Soldering pads	Soldering pads	Soldering pads	
Recommended controller / amplifier (actuator mode)	E-413.D2 (s. p. 2-120) E-835 (s. p. 2-166)	E-413.D2 (s. p. 2-120) E-835 (s. p. 2-166)	E-508 (s. p. 2-150) E-835 (s. p. 2-166)	E-413.D2 (s. p. 2-120) E-835 (s. p. 2-166)	

* Short-term operation up to 180 °C

P-111 · P-151 PICA™ Shear Actuators

Compact Multi-Axis Actuators Based on the Piezo Shear Effect



PICA™ Shear actuators are available in cross-sections from 3 x 3 mm to 16 x 16 mm

- **Compact Single- and Multi-Axis Actuators**
- **X-, XY-, XZ- and XYZ-Versions**
- **High Resonant Frequencies**
- **Extreme Reliability >10^9 Cycles**
- **Picometer-Resolution / Sub-Millisecond Response**
- **UHV Versions to 10^{-9} hPa**
- **Non-Magnetic and Clear Aperture Versions**

The unique PICA™ Shear piezo actuator series are exclusively available from PI. These devices are extremely compact and feature sub-nanometer resolution and ultra-fast response. They come in a variety of geometries providing displacements to 10 µm. Possible applications for these devices are e.g. scanning microscopy, or in motor drives.

Application Examples

- Nanopositioning
- Precision mechanics / -machining
- Active vibration damping
- Semiconductor technology / test systems
- Laser tuning
- Atomic force microscopy
- Switches
- Scanning applications
- Linear motors
- Nanotechnology

High Stiffness and High Displacement

PICA™ Shear actuators exhibit high stiffness, both parallel and perpendicular to the motion direction. Based on the piezoelectric shear effect, the PICA™ Shear X and XY actuators show almost twice the displacement amplitudes of conventional piezo actuators at the same electric field. Consequently they can be made smaller and have higher resonant frequencies. This results in reduced power requirements for a given induced displacement in dynamic X- and Y-axis operation.

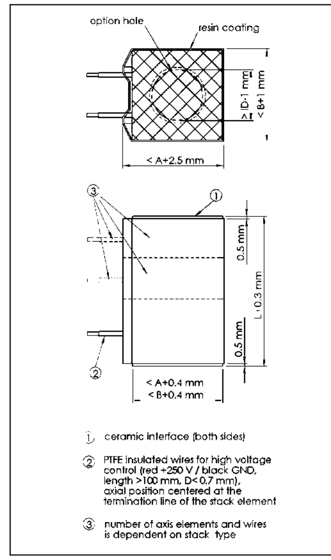
High Reliability under High Duty Cycles, Low Power Requirements

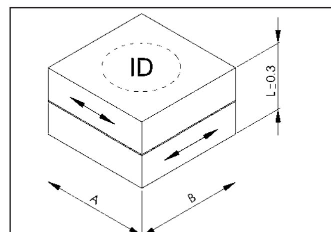
PICA™ Shear actuators are specifically designed for high-duty-cycle applications. All materials used are specifically matched for robustness and lifetime. Endurance tests proved consistent performance, even after billions (1,000,000,000) of cycles. The combination of high displacement and low electrical capacitance provides for excellent dynamic behavior with reduced driving power requirements.

Short Leadtime for Standard & Custom Designs

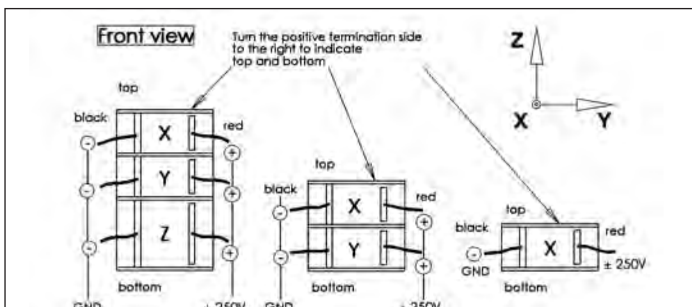
All manufacturing processes at PI Ceramic are set up for maximum flexibility . Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

- Custom Materials
- Custom Voltage Range / Custom Displacement
- Clear Aperture
- Custom Load / Force Ranges
- Custom Flat or Spherical Endplates (Metal, Ceramics, Glass, Sapphire, ...) / Optical Surface Quality

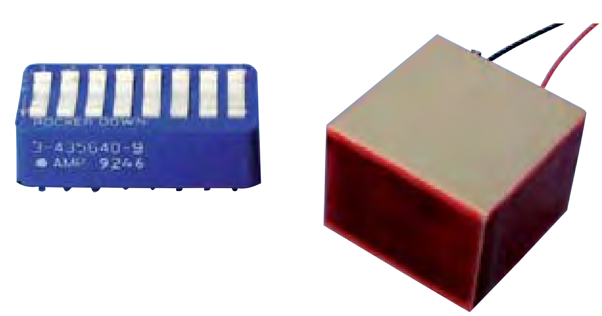




PICA™ Shear dimensions, see technical data table for A, B, L



Axis and lead assignment for PICA™ Shear actuators



The standard actuator P-151.10 is delivered with a 10 cm lead

PI

- Extra-Tight Length Tolerances
- Combination with Piezoelectric Shear Sensors (no Pyroelectric Effect)
- Low-Temperature Designs, Down to Liquid-He
- Vacuum Compatible and Non-Magnetic Versions

Because all piezoelectric materials used in these actuators are manufactured at PI Cera m-ic, leadtimes are short and quality is outstanding. All standard and custom actuators are delivered with performance test sheets.

Amplifiers and Controllers

The E-413.OE bipolar piezo driver is recommended for operating these actuators.

Other high-resolution amplifiers and servo-control electronics, both digital and analog, are described in the "Piezo Drivers / Servo Controllers" section.

Technical Data / Product Order Numbers

Order number	Active axes	Displacement [µm] -10/+20% for -250 to 250 V	Cross section A x B / ID [mm]	Length L [mm] ±0.3	Max. shear load [N]	Axial Stiffness [N/µm]	Capacitance [nF] ±20%	Resonant frequency [kHz]
P-111.01	X	1*	3 x 3	3.5	20	70	0.5	330
P-111.03	X	3*	3 x 3	5.5	20	45	1.5	210
P-111.05	X	5	3 x 3	7.5	20	30	2.5	155
P-121.01	X	1*	5 x 5	3.5	50	190	1.4	330
P-121.03	X	3*	5 x 5	5.5	50	120	4.2	210
P-121.05	X	5	5 x 5	7.5	40	90	7	155
P-141.03	X	3*	10 x 10	5.5	200	490	17	210
P-141.05	X	5	10 x 10	7.5	200	360	28	155
P-141.10	X	10	10 x 10	12	200	230	50	100
P-151.03	X	3*	16 x 16	5.5	300	1300	43	210
P-151.05	X	5	16 x 16	7.5	300	920	71	155
P-151.10	X	10	16 x 16	12	300	580	130	100
P-112.01	XY	1 x 1*	3 x 3	5	20	50	0.5 / 0.5	230
P-112.03	XY	3 x 3*	3 x 3	9.5	10	25	1.5 / 1.5	120
P-122.01	XY	1 x 1*	5 x 5	5	50	140	1.4 / 1.4	230
P-122.03	XY	3 x 3*	5 x 5	9.5	40	70	4.2 / 4.2	120
P-122.05	XY	5 x 5	5 x 5	14	30	50	7 / 7	85
P-142.03	XY	3 x 3*	10 x 10	9.5	200	280	17 / 17	120
P-142.05	XY	5 x 5	10 x 10	14	100	190	28 / 28	85
P-142.10	XY	10 x 10	10 x 10	23	50	120	50 / 50	50
P-152.03	XY	3 x 3*	16 x 16	9.5	300	730	43 / 43	120
P-152.05	XY	5 x 5	16 x 16	14	300	490	71 / 71	85
P-152.10	XY	10 x 10	16 x 16	23	100	300	130 / 130	50
P-123.01	XYZ	1 x 1 x 1*	5 x 5	7.5	40	90	1.4 / 1.4 / 2.9	155
P-123.03	XYZ	3 x 3 x 3*	5 x 5	15.5	10	45	4.2 / 4.2 / 7.3	75
P-143.01	XYZ	1 x 1 x 1*	10 x 10	7.5	200	360	5.6 / 5.6 / 11	155
P-143.03	XYZ	3 x 3 x 3*	10 x 10	15.5	100	170	17 / 17 / 29	75
P-143.05	XYZ	5 x 5 x 5	10 x 10	23	50	120	28 / 28 / 47	50
P-153.03	XYZ	3 x 3 x 3*	16 x 16	15.5	300	450	43 / 43 / 73	75
P-153.05	XYZ	5 x 5 x 5	16 x 16	23	100	300	71 / 71 / 120	50
P-153.10	XYZ	10 x 10 x 10	16 x 16	40	60	170	130 / 130 / 230	30
P-153.10H	XYZ	10 x 10 x 10	16 x 16 / 10	40	20	120	89 / 89 / 160	30
P-151.03H	X	3*	16 x 16 / 10	5.5	200	870	30	210
P-151.05H	X	5	16 x 16 / 10	7.5	200	640	49	155
P-151.10H	X	10	16 x 16 / 10	12	200	460	89	100

Standard piezo ceramic type: 255
* Tolerances ±30 %
Unloaded (longitudinal) resonant frequency measured at 1 V_{pp}, capacitance at 1 V_{pp}, 1 kHz, unloaded, free at both sides
Capacitance at 1 V_{pp}, 1 kHz
Operating voltage: -250 V to +250 V
Operating temperature range: -20 to +85 °C
Standard mechanical interfaces: Ceramics
PTFE-insulated wires, pigtail length 100 mm
Available options: integrated piezo force sensors, non magnetic, vacuum compatible, free aperture etc.
Other specifications on request.

PT120 · PT140 PT Piezo Tube Actuators

Piezoceramic Tube Actuators with Small Tolerances and Various Options

A selection of PT piezoceramic tubes

- **Standard & Custom Sizes**
- **Optional Quartered Electrodes for XYZ-Positioning & Scanning**
- **Sub-Nanometer Resolution**
- **Ideal for OEM-Applications**

PT-series piezoceramic tubes are used in a wide range of applications from microdispensing to scanning microscopy. These monolithic components contract laterally (radially) and longitudinally when a voltage is applied between their inner and outer electrodes. Multi-electrode tubes are available to provide XYZ motion for use in manipulation and scanning microscopy applications. PI also provides ultra-high linearity, closed-loop scanning stages for SPM and nanomanipulation.

Application Examples

- Micropositioning
- Scanning microscopy (AFM, STM, etc.)
- Fiber stretching / modulation
- Micropumps
- Micromanipulation
- Ultrasonic and sonar applications

Precision and Flexibility

PT piezo tubes are manufactured to the tightest tolerances. We can provide tubes with diameters as small as 0.8 mm and tolerances as tight as 0.05 mm. All manufacturing processes at PI Ceramic are set up for maximum flexibility. Should our standard actuators not fit your application, let us provide you with a custom design. Our engineers will work with you to find the optimum solution at a very attractive price, even for small quantities. Some of our custom capabilities are listed below:

- Custom Materials
- Custom Voltage Ranges / Displacement
- Custom Geometries
- Extra-Tight Tolerances
- Applied Sensors
- Special High / Low Temperature Versions

Short Leadtime

Because all piezoelectric materials used in PT tube actuators are manufactured at PI Ceramic, leadtimes are short and quality is outstanding.

Dimensions

max. L: 50 mm
max. OD: 80 mm
min. d: 0.30 mm

Electrodes

Fired silver -plated inside and outside as standard; thin film electrodes (e. g. copper -nickel or gold) as outer electrodes optional.

Options

Single or double wrapped, circumferential bands or quartered outer electrodes.

Polarization

Inner electrode positive potential

Tube actuators are not designed to withstand large forces (see PICA™ Thru actuators p. 1-90), but their high resonant frequencies make them especially suitable for dynamic operation with light loads.

Application examples are micro pumps, scanning microscopy, ink-jet printing, ultrasonic and sonar applications.

Piezo Drivers, Controllers & High-Voltage Amplifiers

High-resolution amplifiers and servo-control electronics, both digital and analog, are described in the "Piezo Drivers / Servo Controllers" section.

Equations

The axial contraction and radial displacement of piezo tubes can be calculated as follows:

(Equation 1)

$$\Delta L \approx d_{31} \cdot L \cdot \frac{U}{d}$$

where:

d_{31} = strain coefficient (displacement normal to polarization direction) [m/V]
L = length of ceramic tube [m]
U = operating voltage [V]
d = wall thickness [m]

(Equation 2)

$$\Delta d \approx d_{33} \cdot U$$

where:

d = change in wall thickness [m]
d_{33} = strain coefficient (field and displacement in polarization direction) [m/V]
U = operating voltage [V]

Typical values for d_{31} and d_{33} are -200 pm/V and 500 pm/V, respectively.

The radial contraction is the superposition of the increase in wall thickness and the tangential contraction; it can be estimated by the following equation:

(Equation 3)

$$\frac{\Delta r}{r} \approx d_{31} \frac{U}{d}$$

where:

r = *radius of piezo tube*
d_{31} = *strain coefficient (displacement normal to polarization direction) [m/V]*
U = *operating voltage [V]*
d = *wall thickness [m]*

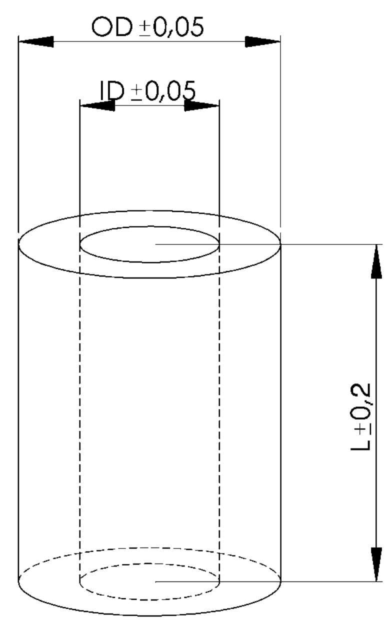
For a given division of the outer electrode of a piezo tube into four 90° sections the differential control (±U) of opposing electrodes results in bending of one of the ends, due to superposition of radial and axial contraction. Such tubes are applied as XY scanner in scanning-probe microscopes such as atomic force microscopes. The scanning range can be evaluated as follows:

(Equation 4)

$$\Delta x \approx \frac{2\sqrt{2} \cdot d_{31} \cdot L^2 \cdot U}{\pi \cdot ID \cdot d}$$

where:

Δx = *scanning range in X and Y (for symmetrical electrodes) [m]*
d_{31} = *strain coefficient (displacement normal to polarization direction) [m/V]*
U = *operating voltage [V]*
L = *length [m]*
ID = *inner diameter [m]*
d = *wall thickness [m]*



PT Tube dimensions, in mm
(see table for further information)

Technical Data / Product Order Numbers

Order number	Dimensions [mm] L x OD x ID**	Max. operating voltage [V]	Electrical capacitance [nF] ±20%	Axial contraction [µm] @ max. V	Radial contraction [µm] @ max. voltage	XY deflection [µm] @ ±200 V
PT120.00	20 x 2.2 x 1.0	500	3	5	0.7	-
PT130.00	30 x 3.2 x 2.2	500	10	9	0.9	-
PT130.90	30 x 3.2 x 2.2	500	12	9	0.9	-
PT130.94*	30 x 3.2 x 2.2	±200	4 x 2.4	9	0.9	±35
PT130.10	30 x 6.35 x 5.35	500	18	9	1.8	-
PT130.14*	30 x 6.35 x 5.35	±200	4 x 3.8	9	1.8	±16
PT130.20	30 x 10.0 x 9.0	500	36	9	3	-
PT130.24*	30 x 10.0 x 9.0	±200	4 x 8.5	9	3	±10
PT130.30	30 x 10.0 x 8.0	1000	18	9	3	-
PT130.40	30 x 20.0 x 18.0	1000	35	9	6	-
PT140.70	40 x 40.0 x 38.0	1000	70	15	12	-

*Quartered electrodes for XY deflection
**OD (outer diameter), ID (inner diameter) ±0.05 mm. PT120 / PT130.00: ID ±0.1 mm

Other specifications on request.

Options and Accessories

Factory Installed Options

Notes

The following options must be installed in the piezo translators during the manufacturing process. They must be ordered with the piezo actuator and cannot be added later. If necessary contact your local PI office for details on how to order modified translators.

Strain Gauge Position Sensor for HVPZT Stack Actuators

For positioning requiring high repeatability and accuracy , the strain gauge position sensor is available. See page 2-187 *ff.* and page 2-199 *ff.*, for more information on position sensors and closed-loop operation of piezos. Piezos with strain gauge sensors are equipped with a 1 m PUR cable with FFA.0S.304.CLAC32 LEMO connector in addition to the voltage cable.

This option includes factory calibration of any PI servo-controller (see "Piezo Drivers & Nanopositioning Controllers" section) delivered along with the sensor -equipped piezo translator.

P-177.50 Dynamic applications (with E-481): temperature sensor and protective air for PICA™ HVPZT

The option for dynamic applications is recommended fort he operation with the E-481 HVPZT Piezo Amplifier / Controller with energy recovery. Protective air and integrated temperature sensor prevent damage to the piezo ceramic by overtemperature.

P-706.00 Water-Resistant Case

The water-resistant case is recommended if PZTs are used in applications where spray of coolants, oil, water , etc. might damage the piezo ceramics. It consists of a specially sealed steel case with integrated flexure zones. Please call for dimensions and further details. The following translators are available with water -resistant cases:
P-844.xx, P-845.xx, P-225.xx, P-235.xx.

P-176.30 Magnetic Adapter

To attach P-820 translators to various positioning units the P-176.30 magnetic adapters are available. The P-176.30 can be glued on the top piece of the P-820.

Cables and Cable Adapters

A variety of cables, extension cables and adapters are available. See "Accessories" page 2-168 *ff.* in the "Piezo Drivers / Servo Controllers" section for further details.

Vacuum Options

All PI piezo translators can be safely used in a vacuum outside the range from 100 to 0.1 hPa (100 to 0.1 torr). See the tutorial "Piezoelectrics in Positioning" section, page 2-205 for discussion. For applications that require reduced outgassing, the P-703.10 and P-703.20 high-vacuum options are available.

P-703.10 High Vacuum (for non-preloaded PZTs)

The translators are delivered as bare ceramic stacks without a case. The PZT s can be baked up to 150 °C. The electrical connection is via two 50 cm long Teflon leads without connector . The nominal displacement of the PZT is reduced by about 20% (due to the stiff insulation materials). P-703.10 includes high-temperature range if ordered with HVPZTs.

P-703.20 High Vacuum (for preloaded PZTs)

The piezo ceramics are enclosed in a stainless steel case with vent holes. The PZTs can be baked to 150 °C. The electrical connection is via two 50 cm T eflon leads without connector. The nominal displacement of the PZT is reduced by about 20% (due to the stiff insulation materials).

Extended Temperature Range

Standard HVPZTs work in the temperature range from -40 °C to 80 °C (-40 °F to +176 °F). For applications requiring an extended temperature range the following options are available:

High-Temperature Range and High Vacuum (only for HVPZTs)

-40 °C to +150 °C /
-40 °F to +302 °F /
233 K to 423 K

The piezo ceramics are enclosed in a stainless steel case with vent holes. Special electrical insulation materials are used. The nominal displacement of the PZT is reduced by about 20% (due to the stiff insulation materials). The electrical connection is via two 1,5 m Kapton leads with LEMO connector.

Low-Temperature Range

-273 °C to +80 °C /
-459 °F to +176 °F /
0 K to 353 K

Generally all PZT ceramics function down to zero kelvin. However, piezo translators are constructed of a combination of materials (ceramics, metal, insulating materials...) which makes the situation more complex.

To qualify the piezoelectric translators for cryogenic temperatures, special insulation material and adhesives must be used. The low-temperature translators are delivered as bare ceramic stacks without case and mechanical preload. The electrical connection is via two 50 cm T eflon leads without connectors.

P-176.30 magnetic adapter

P-176.10 magnetic adapter

P-176.60 flexible tip

Accessories

Accessories can be installed after manufacture.

P-176.Bxx Ball Tips

To avoid bending moments and shear forces on the PZT ceramics, a ball tip is available that can be screwed into the top piece of the individual translators.
P-176.B12 Ball tip for P-212
P-176.B16 Ball tip for P-216
P-176.B25 Ball tip for P-225 and P-235

P-176.Fxx Flat Tips

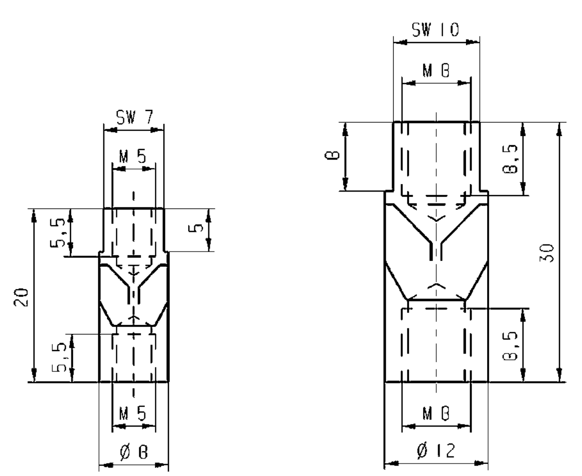
Flat Tips are available and can be screwed into the top piece of the individual translators.
P-176.F12 Flat tip for P-212
P-176.F16 Flat tip for P-216
P-176.F25 Flat tip for P-225
P-176.F35 Flat tip for P-235

P-176.10/20 Magnetic Adapter

To attach P-840/1 and P-212 translators to various positioning units the P-176.10/20 magnetic adapters are available. The P-176.20 can be screwed into the top piece of the P-840/1. The P-176.10 can be screwed into the top piece of the P-212.

P-176.50/60 Flexible Tip

PZT ceramic stacks cannot withstand bending forces. The P-176.50/60 flexible tips are available for applications where it is not possible to avoid those forces. They can be screwed into the standard top pieces of the P-842/3 and P-844/5 translators. See drawing.



P-176.50, P-176.60 flexible tips (dimensions in mm)

Technical Data

Model	P-176.50	P-176.60
Thread	M5/M5	M8/M8
Ø [mm]	8	12
L [mm]	20	30
Tilting angle [deg]	±0.5	±0.5
Axial stiffness [N/µm]	100	200
Bending stiffness [Nm/rad]	22	40

Accessories (cont.)

Cables, Connectors & Adapters for PICA™ HVPZT Piezo Translators and Nanopositioning Systems

Notes

Unless stated otherwise, PI's preloaded PICA™ HVPZT piezo translators and nanopositioners are equipped with LEMO connectors and 1 m PVC cables. The voltage connector is an FGG.0B.701.CJL.1173. With integrated P-177.10 strain gauge, an additional sensor cable is installed. The length of the sensor cable is 1 m, the material PUR and the connector a LEMO FFA.0S.304.CLAC32 as shown on the P-892 cable.

P-202 PICA™ HVPZT cable

P-202.xx PICA™ HVPZT Cable LEMO plug / solderable end

Plug: FGG.0B.701.CJL.1173 (fits PICA™ HVPZT amplifiers, e.g. E-508.00)

Cable with PUR insulation, 2-conductor, shielded

This cable can be soldered to PZTs with pigtails

P-202.06 0.6 m
P-202.10 1 m
P-202.12 2 m
P-202.13 3 m
P-202.15 5 m

P-203 extension cable for PICA™ HVPZTs

P-203.xx PICA™ HVPZT Extension Cable

Plug: FGG.0B.701.CJL.1173
Socket: PHG.0B.701.CJL.1173
Cable: PUR-insulation, 2-conductor, shielded

P-203.01 1 m
P-203.02 2 m
P-203.03 3 m
P-203.05 5 m
P-203.10 10 m
P-203.15 15 m

Sensor Extension Cables

P-892.xx Sensor extension cables for LVDTs and strain gauges

P-892.xx Sensor Extension Cable

For strain gauge sensors or LVDTs.
Plug (right):
FFA.0S.304.CLAC32
Socket (left):
PCA.0S.304.CLLC32
Cable: 4 wires; ≈ Ø 0.20 mm;
#32 AWG (American)
≈ #35 SWG (British)
PVC-Isolation

P-892.01 1	m
P-892.02 2	m
P-892.03 3	m
P-892.05 5	m
P-892.10 10	m

D-892.xx capacitve sensor extension cables

D-892 Sensor Extension Cable Set

For capacitive sensors.
Set of two.
Plug (e.g., far left)
FFA.00.250.CTLC20

Socket (e.g., far right)
PCA.00.250.CTAC22
Cable: LSM 75 (Teflon)

D-892.01 1	m
D-892.02 2	m
D-892.03 3	m

Notes on Specifications for Piezo Actuators and Components

Operating voltage

For PICMA® ceramic equipped piezo actuators: 0 to 100 V typ. Max. recommended operating voltage range is -20 to +120 V (extremes for short durations only).

For PICA™ ceramic equipped piezo actuators: 0 to 1000 V typ. Voltages in excess of +750 V should not be applied for long durations. Operation in the range of -200 to +750 V is recommended for maximum lifetime and displacement.

For shear and bender type piezo actuators, bipolar voltage is applied, ranging from ±30 V up to ±250 V typ.

Motion and Positioning

Performance specifications are valid for room temperature (22 ±3 °C) and closed-loop systems are calibrated at this temperature (specifications for different operating temperatures on request). Recalibration is recommended for operation at a significantly higher or lower temperature. Custom designs for ultra-low or ultra-high temperatures on request.

Integrated feedback sensor

Absolute measuring capacitive and SGS sensors are used to provide position information to the controller . For details see the tutorial "Piezoelectrics in Positioning" Section (see p. 2-187 *ff*).

Open-loop travel for PICMA® Ceramic Equipped Piezo Stages and Actuators

Minimum open-loop travel at 0 to 100 V operating voltage.

Open-loop travel for PICA™ Ceramic Equipped Piezo Actuators

Minimum open-loop travel of high-voltage piezo actuators at 0 to +1000 V operating voltage.

Closed-loop travel for PICMA® Ceramic Equipped Piezo Stages and Actuators

Travel provided in closed-loop operation. PI piezo amplifiers have an output voltage range of -20 to +120 V or -30 to +135 V to provide enough margin for the servo-controller to compensate for load changes, etc.

Open-loop / closed-loop resolution

Resolution of piezo actuators is basically infinitesimal because it is not limited by stiction or friction. Instead of resolution, the noise-equivalent motion is specified. V alues are typical results (RMS, 1 σ), measured with E-503/E-508 amplifier module in E-500/501 chassis.

Mechanical Properties

Static large-signal stiffness

Typical tolerance ±20 %. Static large-signal stiffness of the stage in operating direction at room temperature. Small-signal stiffness and dynamic stiffness may differ because of effects caused by the active nature of piezoelectric material, compound effects, etc. For details see the tutorial "Piezoelectrics in Positioning" Section (see p. 2-189 *ff*)

Unloaded resonant frequency

Typical tolerance ±20%. Lowest resonant frequency in operating direction (does not specify the maximum operating frequency). For details see the tutorial "Piezoelectrics in Positioning" Section (see p. 2-192 *ff*)

Push/pull force capacity (in operating direction)

Specifies the maximum forces that can be applied to the system along the active axis. Limited by the piezo ceramic material and the flexure design. If larger forces are applied, damage to the piezo ceramic, the flexures or the sensor can occur. The force limit must also be considered in dynamic applications.

Example: the dynamic forces generated by sinusoidal operation at 500 Hz, 20 µm peak-to-peak, 1 kg moved mass, are approximately ±100 N. For details see the tutorial "Piezoelectrics in Positioning" Section (see p. 2-192 *ff*)

Shear force limit

Maximum lateral force orthogonal to the operating direction. Limited by the piezo ceramics.

Torque limit (on tip)

Maximum torque that can be applied before damage occurs. Limited by the piezo ceramics.

Drive Properties

Electrical capacitance
Typical tolerance ±20%. The piezo capacitance values indicated in the technical data tables are typical small-signal values (measured at 1 V , 1000 Hz, 20 °C, no load). Large-signal values at room temperature are 30 to 50 % higher. The capacitance of piezo ceramics changes with amplitude, temperature, and load, up to 200 % of the unloaded, small-signal capacitance at room temperature. For detailed information on power requirements, refer to the amplifier frequency-response graphs in the Piezo Drivers / Servo Controllers (p. 2-99 *ff*) Section of this catalog.

Dynamic Operating Current Coefficient (DOCC)
Typical tolerance ±20 %. Average electrical current (supplied by the amplifier) required to drive a piezo actuator per unit frequency and unit displacement (sine-wave operation). For example to find out if a selected amplifier can drive a given piezo stage at 50 Hz with 30 µm amplitude, multiply DOC coefficient by 50 x 30 and check if the result is smaller or equal to the output current of the selected amplifier . For details see the tutorial "Piezoelectrics in Positioning" Section (p. 2-195 *ff*).

Miscellaneous

Operating temperature range

The temperature range indicates where the piezo actuator may be operated without damage. Nevertheless, recalibration or zero-point-adjustment may be required if the system is operated at different temperatures. Performance specifications are valid for room temperature range.

Material

Housings are usually made of stainless steel. Small amounts of other materials may be used internally (for spring preload, piezo coupling, mounting, thermal compensation, etc.).

Al: Aluminum
N-S: Non-magnetic stainless steel
S: Ferromagnetic stainless steel
I: Invar
T: Titanium

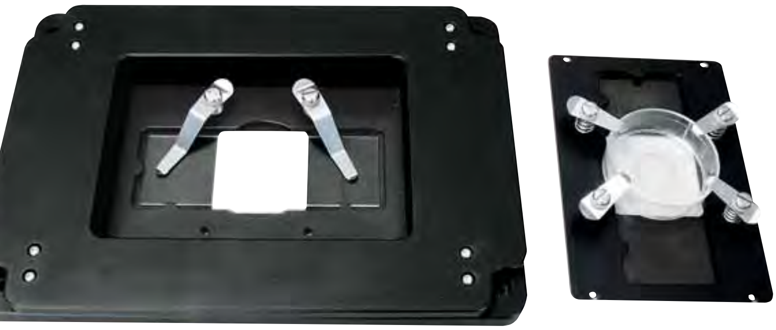
See also "Options and Accessories" (p. 1-102 *ff*).

PI

Piezo-Driven Microscope Stages

PInano™ Z, Scanner for SR-Microscopy

Low-Profile, Low-Cost, Nanopositioning System for Super Resolution Microscopy



PInano™ Z nanopositioning stages (shown with optional slide and Petri dish holder) feature a very low profile of 20 mm (0.8"), a large aperture and deliver highly accurate motion with sub-nanometer resolution

- **Extremely Fast Step & Settle, From 5 msec**
- **Low Profile for Easy Integration: 20 mm (0.8")**
- **100 and 200 µm Travel Ranges**
- **Proprietary Technology: Outstanding Lifetime Due to PICMA® Piezo Ceramic Stacks**
- **Cost-Effective Design due to Piezoresistive Sensors**
- **Compatible w/ Leading Image Acquisition Software Package**
- **Closed-Loop Control for High Repeatability and Accuracy**
- **USB Controller & Software Included**

High-Speed, Low Profile, Optimized for Microscopy

The new PInano™ Z low-profile piezo Z stages are optimized for very fast step and settle and easy integration into high-resolution microscope applications. They feature a very low profile of 0.8" (20 mm), a large aperture, and travel ranges of up to 200 µm with sub-nanometer closed-loop resolution–ideal for leading-edge microscopy and imaging applications.

Application Examples

- 3D Imaging
- Scanning microscopy
- Laser technology
- Interferometry
- Metrology
- Biotechnology
- Micromanipulation

Longest lifetime is guaranteed by the integrated ceramic-encapsulated PICMA® piezo actuators. Due to the significantly higher humidity resistance, the patented PICMA® design provides up to 10 times longer life than conventional piezo actuators (see latest test results at www.pi.ws/picma).

Cost Effective Design, High Performance

PInano™ series piezo positioning stages are designed to provide high performance at minimum cost. For highly-stable, closed loop operation, piezoresistive sensors are applied directly to the moving structure and precisely measure the displacement of the stage platform. The very high sensitivity of these sensors provides optimum position stability and responsiveness as well as nanometer resolution. A proprietary servo controller significantly improves the motion linearity compared to conventional piezoresistive sensor controllers.

Excellent Guiding Accuracy

Flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. FEA techniques are used to give the design the highest possible stiffness in, and perpendicular to, the direction of motion, and to minimize linear and angular runout. Flexures allow extremely high-precision motion, no matter how minute, as they are completely free of play and friction.

Controller & Software Included

The PInano™ Z stage comes complete with a powerful digital closed-loop controller. The controller features two digital interfaces (USB & RS-232) as well as a high-speed analog interface and is compatible with leading image acquisition software packages such as MetaMorph etc.
The controllers are delivered including software for Windows operating systems. DLLs and LabVIEW drivers are available for automated control.
The extensive command set is based on the hardware-independent General Command Set (GCS), which is common to all current PI controllers for both nano- and micropositioning systems. GCS reduces the programming effort in the face of complex multi-axis positioning tasks or when upgrading a system with a different PI controller.

Ordering Information

P-736.ZR1S
PInano™ Z Piezo Slide Scanner System, 100 µm, Slide-Size Aperture, Piezoresistive Sensors, with USB Fully Digital Controller

P-736.ZR2S
PInano™ Z Piezo Slide Scanner System, 200 µm, Slide-Size Aperture, Piezoresistive Sensors, with USB Fully Digital Controller

Accessories

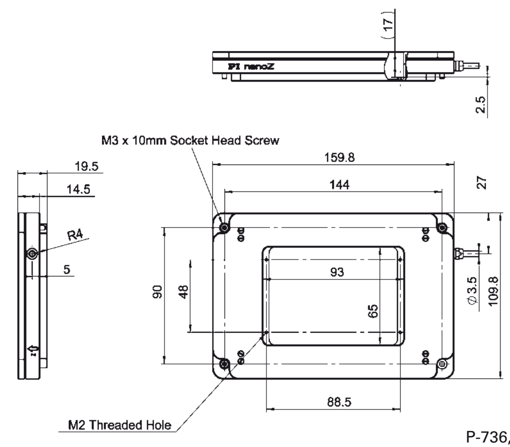
P-545.PD3
35mm Petri Dish Holder for P-545 PInano™ Piezo Stages

P-545.SH3
Microscope Slide Holder for PInano™ Piezo Stages

P-736.AP1
Adapter Plate P-736 PInano™ Piezo Z to M-545 XY Microscope Stages

The PInano™ Z stage can be combined with the M-545 high-st...ty, long-travel manual/motorized microscope stage (25 x 25 mm)

A compact piezo controller with a digital servo, USB, RS-232 and a high–speed analog interface is included



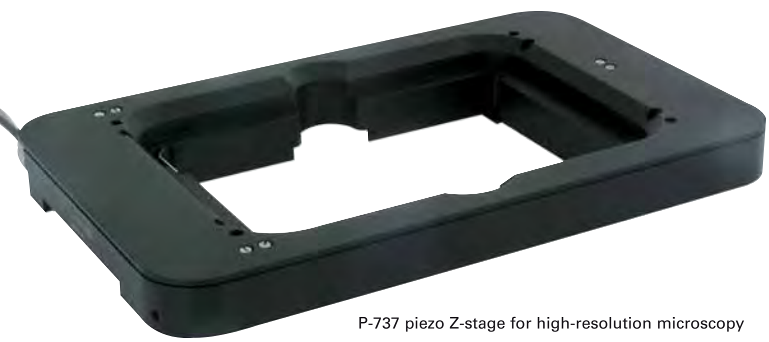
P-736, dimensions in mm

Technical Data

Model	P-736.ZR1S	P-736.ZR2S	Units	Tolerance
Active axes	Z	Z		
Motion and positioning				
Integrated sensor	piezoresistive	piezoresistive		
Closed-loop travel	100	200	µm	
Open-loop resolution	0.2	0.4	nm	typ.
Closed-loop resolution	0.4	0.7	nm	typ.
Linearity	±0.1	±0.1	%	typ.
Repeatability	<4	<5	nm	typ.
Mechanical properties				
Settling time (10% step width)	5	7	ms	
Load	500	500	g	max.
Drive properties				
Ceramic type	PICMA® P-885	PICMA® P-885		
Miscellaneous				
Operating temperature range	15 to 40	15 to 40	°C	
Material	Aluminum	Aluminum		
Mass	550	550	g	±5%
Cable length	1.5	1.5	m	±10 mm

P-737 PIFOC® Specimen-Focusing Z Stage

Low-Profile, Long-Range Piezo Z Nanopositioner for Microscopy Samples



P-737 piezo Z-stage for high-resolution microscopy

- **High-Speed Piezo Z-Motion with Travel Ranges up to 500 µm**
- **Resolution in the Nanometer Range**
- **Clear Aperture to Accomodate Specimen Holders**
- **Perfect Mechanical Fit with XY OEM Manual or Motorized Stages**
- **Sub-Millisecond Response Times**

PIFOC® P-737 high-speed vertical positioning systems are designed for use with XY microscopy stages–OEM manual stages as well as aftermarket motorized stages.

While the XY stage positions the sample, the piezo-actuator-based P-737 moves the sample along the optical axis to quickly and precisely adjust the focus. Vertical stepping with an accuracy in the nanometer range takes only a few milliseconds.

The large aperture is designed to accommodate a variety of specimen holders including slides or multiwell plates.

Application Examples

- Fluorescence microscopy
- Confocal microscopy
- Biotechnology
- Autofocus systems
- 3D Imaging
- Medical technology

High-Speed Z Steps for Fast Focus Control and Z Stack Acquisition

The immediate response of the solid-state piezo drives enables rapid Z-steps with typically 10 to 20 times faster step & settle times than classical stepper motor drives. This leads to higher image acquisition speed and throughput.

Closed-Loop Position Control for High-Precision and Stability

For high stability and repeatability, P-737 stages are equipped with position feedback. High-resolution, fast-responding, strain gauge sensors (SGS) are applied to appropriate locations on the drive train and provide a high-bandwidth, nanometer-precision position feedback signal to the controller. The sensors are connected in a full-bridge configuration to eliminate thermal drift, and assure optimal position stability in the nanometer range.

Excellent Guiding Accuracy

Flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. FEA techniques are used to give the design the highest possible stiffness in, and perpendicular to, the direction of motion, and to minimize linear and angular runout. Flexures allow extremely high-precision motion, no matter how minute, as they are completely free of play and friction.

Ordering Information

P-737.1SL
PIFOC® Nanofocusing Z-Stage for Microscope Sample Holder, 100 µm, SGS, LEMO Connector, for Märzhäuser Microscope Stages

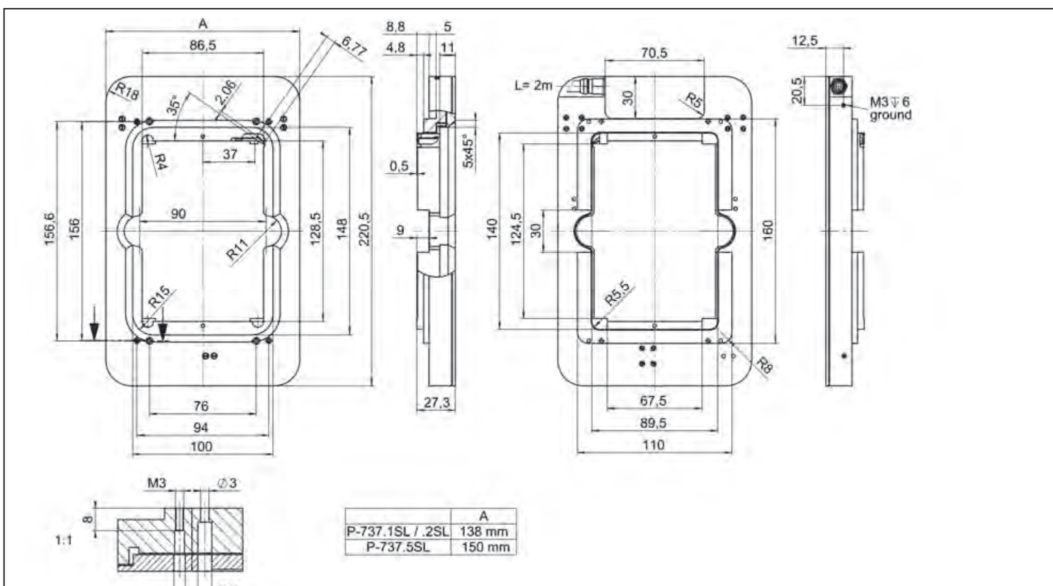
P-737.2SL
PIFOC® Nanofocusing Z-Stage for Microscope Sample Holder, 250 µm, SGS, LEMO Connector, for Märzhäuser Microscope Stages

P-737.5SL
PIFOC® Nanofocusing Z-Stage for Microscope Sample Holder, 500 µm, SGS, LEMO Connector, for Märzhäuser Microscope Stages

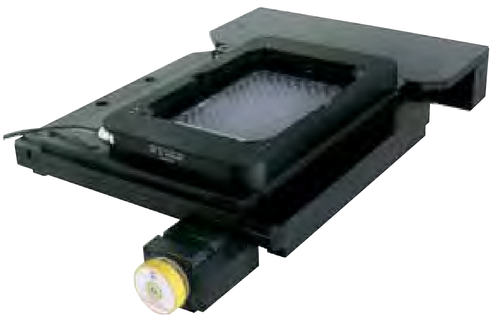
Versions with high-resolution capacitive sensors on request. Ask about custom designs

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.



P-737 dimensions in mm



The P-737 piezo Z-stage (shown with multiwell plate) is compatible with motorized microscope XY stages like the one shown from Märzhäuser

Instead of moving the sample, it is also possible to move the objective. The P-725 PIFOC® Objective Scanner offers travel ranges over 400 µm with nanometer resolution and response times in the millisecond range

Technical Data

Model	P-737.1SL	P-737.2SL	P-737.5SL	Units	Tolerance
Active axes	Z	Z	Z		
Motion and positioning					
Integrated sensor	SGS	SGS	SGS		
Open-loop travel, -20 to +120 V	150	280	550	µm	min. (+20 %/-0 %)
Closed-loop travel	100	250	500	µm	
Open-loop resolution	0.8	1	1.6	nm	typ.
Closed-loop resolution	2.5	4	5	nm	typ.
Linearity, closed-loop	0.2	0.5	0.8	%	typ.
Repeatability	6	12	15	nm	typ.
Rotation around X	±36	±36	±36	µrad	typ.
Rotation around Y	±36	±100	±100	µrad	typ.
Mechanical properties					
Unloaded resonant frequency	270	210	120	Hz	±20 %
Resonant frequency @ 100 g	230	180	115	Hz	±20 %
Resonant frequency @ 200 g	210	155	100	Hz	±20 %
Push/pull force capacity in motion direction	50 / 20	50 / 20	50 / 20	N	Max.
Drive properties					
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical Capacitance	6.3	9.3	13.8	µF	±20 %
Dynamic operating current coefficient	7.9	4.6	3.5	µA/(Hz • µm)	±20 %
Miscellaneous					
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum	Aluminum		
Dimensions	220.5 x 138 x 27.3	220.5 x 138 x 27.3	220.5 x 150 x 27.3	mm	
Mass	0.7	0.7	0.8	kg	±5 %
Cable length	2	2	2	m	±10 mm
Sensor / voltage connection	LEMO	LEMO	LEMO		
System properties					
System configuration	E-500 System with E-503 amplifier (6 W) E-509 servo module	E-500 System with E-503 amplifier (6 W) E-509 servo module	E-665.SR controller/driver (12 W)		
Closed-loop amplifier bandwidth, small signal	60	30	15	Hz	typ.
Settling time (10 % step width)	24	30	50	ms	typ.

Recommended controller / amplifier
Single-channel: E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-665 powerful servo controller, bench-top (p. 2-116)

P-545 PI nano™ XYZ / PI nano™ XY Piezo Stage Systems

Low-Profile, Low-Cost Nanopositioning Systems for Super-Resolution Microscopy

PI nano™ series nanopositioning stages feature a very low profile of 20 mm (0.8), a large aperture for 3 x 1'' slides and deliver highly accurate motion with sub-nanometer resolution in up to 3 axes. Slide / petri dish holders optional

- **Low Profile for Easy Integration: 20 mm (0.8")**
- **Up to 200 x 200 x 200 µm Travel Ranges**
- **Large Clear Aperture for 3 x 1" Slides**
- **Recessed Sample Holders for Maximized Utility Available**
- **Outstanding Lifetime Due to PICMA®Piezo Actuators**
- **Cost-Effective Design due to Piezoresistive Sensors**
- **Compatible w/ Leading Image Acquisition Software Package**
- **Closed-Loop Control for High Repeatability and Accuracy**
- **Millisecond Step Time, Ideal for Super-Resolution Microscopy**
- **24-Bit Controller w/ USB, Ethernet, RS-232 Interface and Analog Control**
- **Available Manual Long-Travel Stage with Motor Upgrade Option**

Long Travel, Low Profile, Optimized for Microscopy

PI nano™ XY and XYZ low-profile piezo scanning stages are optimized for easy integration into high-resolution microscopes. They feature a very low profile of 20 mm (0.8") and a large aperture designed to hold Petri dishes and standard slide holders. The long travel ranges of up to 200 x 200 x 200 µm with nanometer closed-loop resolution are ideal for leading-edge microscopy and imaging applications.

Application Examples

- Super-resolution microscopy
- 3D Imaging
- Laser technology
- Interferometry
- Metrology
- Biotechnology
- Screening
- Micromanipulation

Cost Effective Design, High Performance

PI nano™ series piezo positioning stages are designed to provide high performance at minimum cost. For highly-stable, closed loop operation, piezoresistive sensors are applied directly to the moving structure and precisely measure the displacement of the stage platform. The very high sensitivity of these sensors provides optimum position stability and responsiveness as well as nanometer resolution. A proprietary servo controller significantly improves the motion linearity compared to conventional piezoresistive sensor controllers.

High Reliability and Long Lifetime

The compact P-545 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and provide better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free, not subject to wear and offer extraordinary reliability.

Ordering Information

P-545.2R7
PInano™ XY Piezo Stage, Slide-Size Aperture, 200 x 200 µm, Piezoresistive Sensors, with USB Controller

P-545.3R7
PInano™ XYZ Piezo Stage, Slide-Size Aperture, 200 x 200 x 200 µm, Piezoresistive Sensors, with USB Controller

Controller included

E-545.3RD
PInano™ Multi-Channel Piezo Controller with High-Speed Digital Interface, 3 Channels, Piezoresistive Sensors, Sub-D Connectors

Accessories

M-545.2MO
XY Microscope Stage, 25 x 25 mm, Micrometer-Driven, High Stability, Compatible with PI® Piezo Stages, for Olympus Microscopes

M-545.2MN
XY Microscope Stage, 25 x 25 mm, Micrometer-Driven, High Stability, Compatible with PI® Piezo Stages, for Nikon Microscopes

M-545.2ML
XY Microscope Stage, 25 x 25 mm, Micrometer-Driven, High Stability, Compatible with PI® Piezo Stages, for Leica Microscopes

M-545.2MZ
XY Microscope Stage, 25 x 25 mm, Micrometer-Driven, High Stability, Compatible with PI® Piezo Stages, for Zeiss Microscope

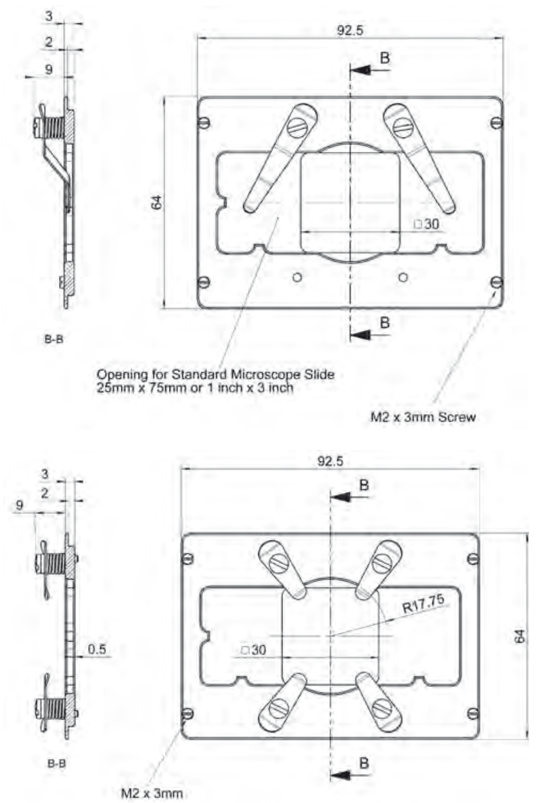
P-545.PD3
35mm Petri Dish Holder for P-545 PInano™ Piezo Stages

P-545.SH3
Microscope Slide Holder for PInano™ Piezo Stages

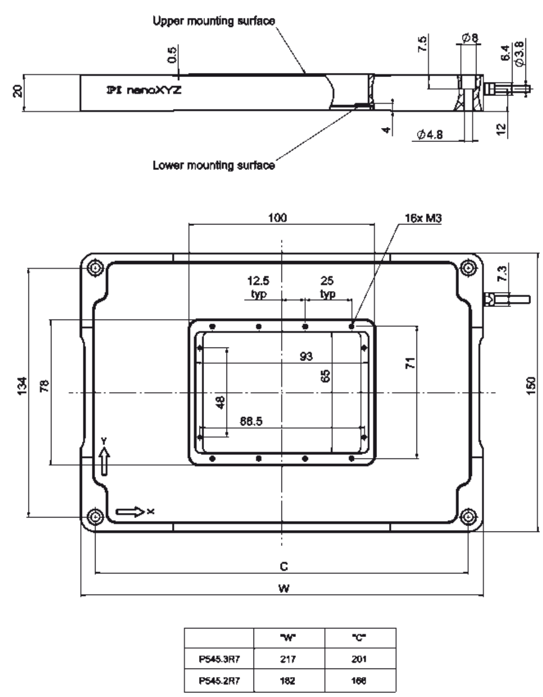
P-545.PP3
Plain Plate for Accessories for PInano™ Piezo Stages

Additional accessories on request.

Background: the piezo controller is included and comes with a 24-bit resolution USB port as well as ethernet, RS-232 and analog interface.
Foreground: The optional M-545 manual XY stage provides a stable platform for the PI nano™ piezo stages.
Custom stage version shown



Accessories: Slide holder (above) and Petri dish holder (below), dimensions in mm



P-545 dimensions in mm

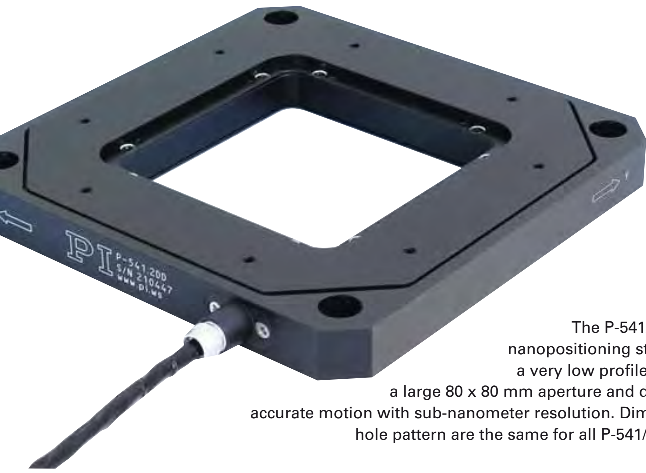
Technical Data

Model	P-545.2R7	P-545.3R7	Unit	Tolerance
Active axes	X, Y	X, Y, Z		
Motion and positioning				
Integrated sensor	piezoresistive	piezoresistive		
Closed-loop travel	200 x 200	200 x 200 x 200	µm	
Closed-loop resolution*	1	1	nm	typ.
Linearity	±0.1	±0.1	%	typ.
Repeatability	< 5	< 5	nm	typ.
Mechanical properties				
Push/pull force capacity	100 / 30	100 / 30	N	max.
Load	50	50	N	max.
Drive properties				
Ceramic type	PICMA® P-885	PICMA® P-885		
Electrical capacitance	6	6 (X, Y), 12 (Z)	µF	±20%
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum		
Mass	1	1.2	kg	±5%
Cable length	1.5	1.5	m	±10 mm
Sensor / voltage connection	Sub-D, 25 pin	Sub-D, 25 pin		
Piezo controller (included in delivery)	E-545	E-545		

* Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion measured with interferometer.

P-541.2 – P-542.2 Piezo XY-Stage

Low-Profile XY Nanopositioning System with Large Aperture



The P-541/P-542-series nanopositioning stages feature a very low profile of 16.5 mm, a large 80 x 80 mm aperture and deliver highly accurate motion with sub-nanometer resolution. Dimensions and hole pattern are the same for all P-541/P-542 stages

- **Low Profile for Easy Integration: 16.5 mm; 80 x 80 mm Clear Aperture**
- **Up to 200 x 200 µm Travel Range**
- **Parallel-Kinematics / Metrology for Enhanced Responsiveness & Multi-Axis Precision**
- **High-Dynamics Direct-Drive Version**
- **Choice of Sensors: Strain Gauge (Lower Cost) or Capacitive Sensors (Higher Performance)**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Combination with Long Travel Microscopy Stages or Longer Stroke**

Low Profile, Optimized for Microscopy Applications

P-541/P-542 nanopositioning and scanning stages are designed for easy integration into high-resolution microscopes. They feature a very low profile of 16.5 mm, a large 80 x 80 mm aperture, and offer highly accurate motion with sub-nanometer resolution.

A variety of Z stages and Z-tip/tilt stages with the same footprint are also offered to suit a wide range of applications (p. 2-44). They are ideal for alignment, nano-focusing or metrology tasks.

Application Examples

- Laser technology
- Scanning microscopy
- Mask / wafer positioning
- Interferometry
- Metrology
- Biotechnology
- Micromanipulation

Choice of Drives: Long Range or High-Speed Direct Drive

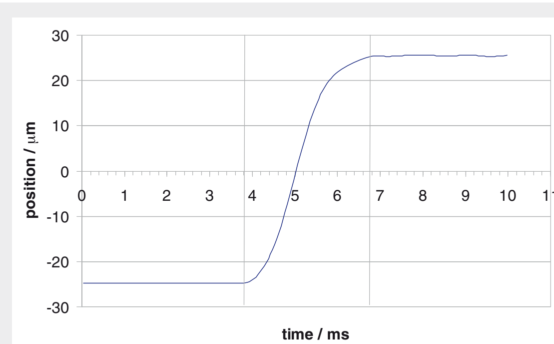
Lever-amplified XY systems with 100 and 200 µm travel and direct-driven XY scanners with 45 µm travel are available. Their high resonant frequencies of 1.5 kHz in both axes allow for faster step response and higher scanning rates, needed for example in single-molecule microscopy, or in other time-critical applications.

Parallel Kinematics for Fast Response

In a parallel kinematics multi-axis system, all actuators act directly on one moving platform. This means that all axes move the same minimized mass and can be designed with identical dynamic properties. Systems with parallel kinematics and metrology have additional advantages over serially stacked or nested systems, including more-compact construction and no cumulative error from the different axes. Parallel kinematics systems can be operated with up to six degrees of freedom with low inertia and excellent dynamic performance. Multi-axis nanopositioning systems equipped with both parallel kinematics and parallel, direct metrology are able to measure platform position in all degrees of freedom against one common fixed reference. In such systems, undesirable motion from one actuator in the direction of another (cross talk) is detected immediately and actively compensated by the servo-loops.

Tailored Position Measurement

Integrated high-resolution position sensors provide fast response and positional stability in the nanometer range. Top-of-the-line models use capacitive sensors. They measure displacement directly and without physical contact (direct metrology) enabling superior linearity. Alternatively, versions with cost-effective strain gauge sensors (SGS) are also available.



The settling time of a P-541.2DD stage is only 3 ms for a 50 µm step

System properties	
System configuration	P-541.2CD and E-500 modular system with E-503 amplifier and E-509 sensor module, 200 g load
Amplifier bandwidth, large signal	35 Hz
Settling time (full travel)	28 ms

Ordering Information

P-541.2DD
XY Nanopositioning System with Large Aperture, High-Speed Direct Drive, 45 x 45 µm, Parallel Kinematics, Capacitive Sensors

P-541.2CD
XY Nanopositioning System with Large Aperture, 100 x 100 µm, Parallel Kinematics, Capacitive Sensors

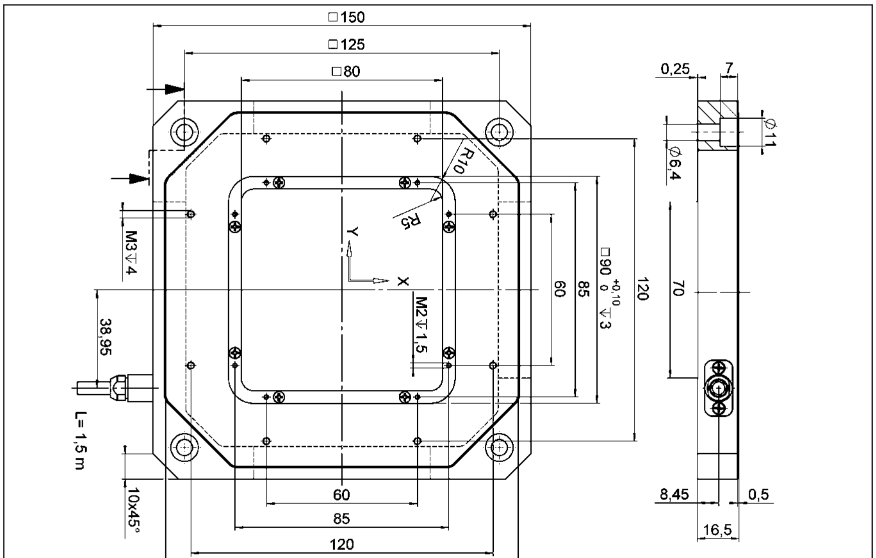
P-542.2CD / P-542.2CL
XY Nanopositioning System with Large Aperture, 200 x 200 µm, Parallel Kinematics, Capacitive Sensors

P-541.2SL
XY Nanopositioning System with Large Aperture, 100 x 100 µm, Strain Gauge Sensors

P-542.2SL
XY Nanopositioning System with Large Aperture, 200 x 200 µm, Strain Gauge Sensors

P-541.20L
XY Nanopositioning System with Large Aperture, 100 x 100 µm, Open Loop

P-542.20L
XY Nanopositioning System with Large Aperture, 200 x 200 µm, Open Loop



P-541.2 and P-542.2, dimensions in mm

Technical Data

Model	P-541.2CD	P-542.2CD P-542.2CL	P-541.2DD	P-541.2SL	P-542.2SL	P-541.20L	P-542.20L	Units	Tolerance
Active axes	X, Y	X, Y	X, Y	X, Y	X, Y	X, Y	X, Y		
Motion and positioning									
Integrated sensor	Capacitive	Capacitive	Capacitive	SGS	SGS	–	–		
Open-loop travel, -20 to +120 V	175 x 175	290 x 290	60 x 60	175 x 175	290 x 290	175 x 175	290 x 290	µm	min. (+20 %/0 %)
Closed-loop travel	100 x 100	200 x 200	45 x 45	100 x 100	200 x 200	–	–	µm	
Open-loop / closed-loop resolution	0.2 / 0.3	0.4 / 0.7	0.1 / 0.3	0.2 / 2.5	0.4 / 4	0.2 / –	0.4 / –	nm	typ.
Linearity	0.03	0.03	0.03*	0.2	0.2	–	–	%	typ.
Repeatability	<5	<5	<5	<10	<10	–	–	nm	typ.
Pitch	<±5	<±5	<±3	<±5	<±5	<±5	<±5	µrad	typ.
Yaw	<±10	<±10	<±3	<±10	<±10	<±10	<±10	µrad	typ.
Mechanical properties									
Stiffness in motion direction	0.47	0.4	10	0.47	0.4	0.47	0.4	N/µm	±20 %
Unloaded resonant frequency	255	230	1550	255	230	255	230	Hz	±20 %
Resonant frequency @ 100 g	200	190	–	200	190	200	190	Hz	±20 %
Resonant frequency @ 200 g	180	–	1230	180	–	180	–	Hz	±20 %
Resonant frequency @ 300 g	150	145	–	150	145	150	145	Hz	±20 %
Push/pull force capacity in motion direction	100 / 30	100 / 30	100 / 30	100 / 30	100 / 30	100 / 30	100 / 30	N	Max.
Load capacity	20	20	20	20	20	20	20	N	Max.
Drive properties									
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical capacitance per axis	4.2	7.5	9	4.2	7.5	4.2	7.5	µF	±20 %
Dynamic operating current coefficient per axis	5.2	4.8	25	5.2	4.8	5.2	4.8	µA/(Hz•µm)	±20 %
Miscellaneous									
Operating temperature range	20 to 80	20 to 80	20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum		
Mass	1100	1150	1210	1050	1100	1050	1100	g	±5 %
Cable length	1.5	1.5	1.5	1.5	1.5	1.5	1.5	m	±10 mm
Sensor connection	Sub-D Special	Sub-D Special / LEMO	Sub-D Special	LEMO	LEMO	–	–		
Voltage connection	Sub-D Special	Sub-D Special / LEMO	Sub-D Special	LEMO	LEMO	LEMO	LEMO		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion with E-503 (p. 2-146) or E-710 controller (p. 2-128).
Dynamic Operating Current Coefficient in µA per Hz and µm. Example: Sinusoidal scan of 10 µm at 10 Hz requires approximately 0.48 mA drive current for the P-542.2CD.
*With digital controller. Non-linearity of direct drive stages measured with analog controllers is up to 0.1 % typ.
Recommended controller / amplifier
Single-channel (1 per axis): E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-621 controller module (p. 2-160)
Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152) (for systems with sensors)
Multi-channel digital controllers: E-710 bench-top (p. 2-128), E-712 modular (p. 2-140), E-725 high-power (p. 2-126), E-761 PCI board (p. 2-130)

P-733.2 · P-733.3 XY(Z) Piezo-Nanopositioning Stage

High-Precision XY(Z) Scanner Family with Aperture

P -733.3 DD (left) and P -733.2 DD, high-speed, direct drive XY(Z) scanning stages are the fastest scanning stages with large aperture currently available (2.2 kHz resonant frequency!). Both units feature a footprint of only 100 x 100 mm. CD for size comparison.

- **Travel Ranges to 100 x 100 µm in X,Y & to 10 µm in Z**
- **Resolution to 0.1 nm with Capacitive Sensors**
- **High-Speed Versions with Direct Drive**
- **Vacuum and Non-Magnetic Versions**
- **Parallel Kinematics for Better Multi-Axis Accuracy and Dynamics**
- **Parallel Metrology for Active Trajectory Control**
- **Frictionless, High-Precision Flexure Guiding System**
- **Clear Aperture 50 x 50 mm for Transmitted-Light Applications**

P-733 XY and XYZ piezo driven stages are fast and highly accurate nanopositioning and scanning systems. They provide a positioning and scanning range of 100 x 100 (x10) µm together with sub-nanometer resolution and are equipped with parallel-metrology capacitive position feedback for superior multi-axis linearity and repeatability. The guiding accuracy minimizes runout to under 10 nm over the whole travel range. In addition, the high-speed Z-axis of the P-733.3CD can actively compensate any out-of-plane Z-axis deviation during XY motion.

Application Examples

- Image processing / stablilization
- Scanning microscopy
- Surface inspection
- Metrology / interferometry
- Biotechnology
- Semiconductor testing
- Mask / wafer positioning
- Micromanipulation
- Nanopositioning with high flatness & straightness

Fastest Multi-Axis Systems / Direct Drive, Low Profile and Large Apertures

P-733.2DD / .3DD multi-axis piezo nanopositioning systems are the fastest ultra-high-precision, open-frame stages for scanning microscopy. They provide a positioning and scanning range of 30 x 30 (x10) µm. P-733 nanopositioning and scanning stages feature very low profiles, as low as 20 mm (0.8 inch). The novel, high-stiffness direct drive gives the systems resonant frequencies as high as 2.2 kHz (4 x that of other comparable systems), enabling millisecond scanning rates with sub-nanometer resolution.

Parallel-Kinematics / Metrology for Enhanced Responsiveness

In a parallel kinematics multi-axis system, all actuators act directly on one moving platform. This means that all axes move the same minimized mass and can be designed with identical dynamic properties. Multi-axis nano positioning systems equipped with both parallel kinematics and parallel, direct metrology are able to measure platform position in all degrees of freedom against one common fixed reference. In such systems, undesirable motion from one actuator in the direction of another (cross talk) is detected immediately and actively compensated by the servo-loops.

Capacitive Sensors for Subnanometer Resolution

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz. The closed-loop resolution is 0.3 nm for the X and Y axes and 0.2 nm for the optional Z-axis. The direct drive versions are rated to 0.1 nm resolution for every axis.

Large Variety of Models for a Broad Range of Applications

For Z-axis scanning applications, the P-733.ZCD (see p. 2-42) version is available with a travel range of 100 µm. For ultra-high-vacuum applications down to 10^{9} hPa, nanopositioning systems as well as comprehensive accessories, such as suitable feedthroughs, are available.

Ordering Information

P-733.2DD
High-Dynamics High-Precision XY Nanopositioning System, 30 x 30 µm, Direct Drive, Capacitive Sensors, Parallel Metrology, Sub-D Connector

P-733.3DD
High-Dynamics Precision XYZ Nanopositioning System, 30 x 30 x 10 µm, Direct Drive, Capacitive Sensors, Parallel Metrology, Sub-D Connector

P-733.2CD* / P-733.2CL*
High-Precision XY Nanopositioning System, 100 x 100 µm, Capacitive Sensors, Parallel Metrology

P-733.3CD* / P-733.3CL*
Precision XYZ Nanopositioning System, 100 x 100 x 10 µm, Capacitive Sensors, Parallel Metrology

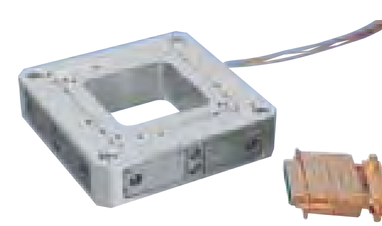
P-733.2VL* / P-733.2VD*
High-Precision XY Nanopositioning System, 100 x 100 µm, Capacitive Sensors, Parallel Metrology, Vacuum Compatible to 10-6 hPa

P-733.2UD
High-Precision XY Nanopositioning System, 100 x 100 µm, Capacitive Sensors, parallel metrology, Sub-D Connector, Vacuum Compatible to 10-9 hPa

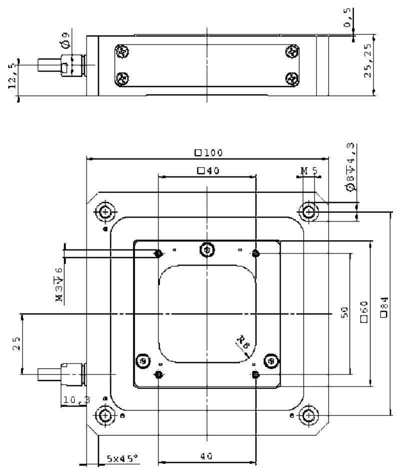
*.xxD with Sub-D Connector

*.xxL with LEMO Connector

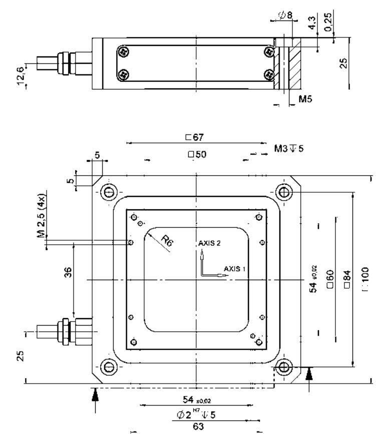
Ask about custom designs



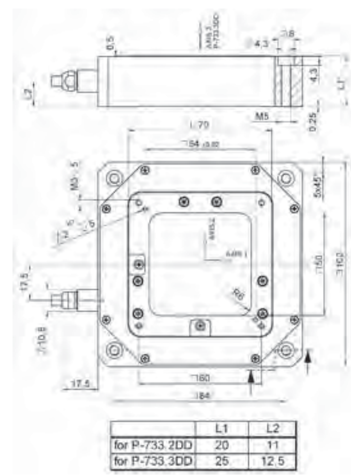
P-733.2UD non-magnetic XY scanning stage for UHV to 10^{-9} hPa



P-733.3 dimensions in mm



P-733.2 dimensions in mm



P-733.xDD dimensions in mm

Technical Data

Model	P-733.2CD P-733.2CL	P-733.3CD P-733.3CL	P-733.2DD	P-733.3DD	Units	Tolerance
Active axes	X, Y	X, Y, Z	X, Y	X, Y, Z		
Motion and positioning						
Integrated sensor	Capacitive	Capacitive	Capacitive	Capacitive		
Open-loop travel, -20 to +120 V	115 x 115	115 x 115 x 12	33 x 33	33 x 33 x 14	µm	min. (+20 %/-0 %)
Closed-loop travel	100 x 100	100 x 100 x 10	30 x 30	30 x 30 x 10	µm	
Open-loop resolution	0.2	0.2 (0.1 in Z)	0.1	0.1	nm	typ.
Closed-loop resolution	0.3	0.3 (0.2 in Z)	0.1	0.1	nm	typ.
Linearity (X, Y)	0.03	0.03	0.03*	0.03*	%	typ.
Linearity (Z)	–	0.03	–	0.03*	%	typ.
Repeatability (X, Y)	<2	<2	<2	<2	nm	typ.
Repeatability (Z)	–	<1	–	<1	nm	typ.
Pitch (X,Y)	<±3	<±3	<±5	<±5	µrad	typ.
Yaw (X, Y)	<±10	<±10	<±10	<±10	µrad	typ.
Runout θZ (motion in Z)		<±5		<±5	µrad	typ.
Mechanical properties						
Stiffness	1.5	1.4 (9 in Z)	20	4 (10 in Z)	N/µm	±20 %
Unloaded resonant frequency	500	460 (1400 in Z)	2230	1200 (1100 in Z)	Hz	±20 %
Resonant frequency @ 120 g	370	340 (1060 in Z)	-	-	Hz	±20 %
Resonant frequency @ 200 g	340	295 (650 in Z)	1550	530 (635 in Z)	Hz	±20 %
Push/pull force capacity in motion direction	50/20	50/20	50/20	50/20	N	Max.
Drive properties						
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical capacitance	6	6 (2.4 in Z)	6.2	6.2 (3.3 in Z)	µF	±20 %
Dynamic operating current coefficient	7.5	7.5 (30 in Z)	25	25 (41 in Z)	µA	(Hz • µm) ±20 %
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminum		
Mass	0.58	0.675	0.58	0.675	kg	±5 %
Cable length	1.5	1.5	1.5	1.5	m	±10 mm
Sensor/ voltage connection	Sub-D special (CD-version) LEMO LEMO (CL-version)	Sub-D special (CD-version) (CL-version)	Sub-D special	Sub-D special		

*With digital controller. Non-linearity of direct drive stages measured with analog controllers is up to 0.1 % typ.

Recommended controller:
Single-channel (1 per axis): E-610 servo controller / amplifier (p. 2-110), E -625 servo controller, bench-top (p. 2-114), E-621 controller module (p. 2-160)
Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152)
Multi-channel digital controllers: E-710 bench-top (p. 2-128), E-712 modular (p. 2-140), E-725 high-power (p. 2-126), E-761 PCI board (p. 2-130)

P-734 XY Piezo Scanner

High-Dynamics System with Minimum Runout & Clear Aper ture

P-734 low-bow flexure nanopositioning stage with ultra-precise trajectory control

- **Ultra-Precision Trajectory Control, Ideal for Surface Analysis and Scanning Microscopy**
- **Parallel-Kinematics / Metrology for Enhanced Responsiveness / Multi-Axis Precision**
- **Travel Range 100 x 100 µm, Clear Aper ture 56 x 56 mm**
- **Capacitive Sensors for Resolution <0,4 nm**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**

P-734 high-dynamics, XY piezo nanopositioning stages feature linear travel ranges to 100 x 100 µm with sub-nanometer resolution and maximum flatness of motion.

Flatness in the Low Nanometer Range

P-734 open-frame XY nanopositioning and scanning stages are ideal for nanometrology tasks that require extreme flatness of scanning. These stages feature an ultra-precise, flexure guiding system which confines motion to the XY plane and reduces runout in Z to a few nanometers or less. This unsurpassed trajectory precision is fundamental for highest-precision surface metrology applications. These stages provide a positioning and scanning range of 100 x 100 µm with accuracy and resolution in the nanometer and sub-nanometer range.

Application Examples

- Scanning microscopy
- Metrology / interferometry
- Semiconductor testing
- Mask/wafer positioning
- Image processing / stablilization
- Biotechnology
- Micromanipulation
- Nanopositioning

Excellent Guiding Accuracy

Flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. FEA techniques are used to give the design the highest possible stiffness in, and perpendicular to, the direction of motion, and to minimize linear and angular runout. Flexures allow extremely high-precision motion, no matter how minute, as they are completely free of play and friction.

Higher Precision in Periodic Motion

The highest dynamic accuracy in scanning applications is made possible by the DDL algorithm, which is available in PI's modern digital controllers. DDL eliminates tracking errors, improving dynamic linearity and usable bandwidth by up to three orders of magnitude!

Direct Position Measurement with Sub-Nanometer Accuracy

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

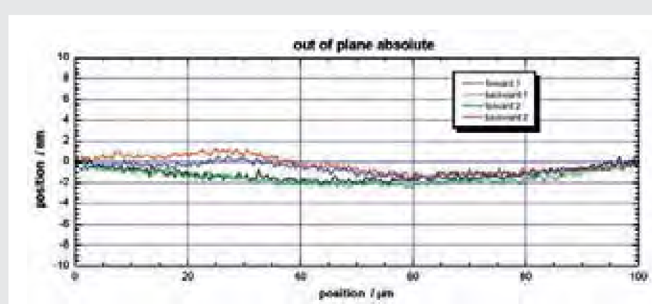
Parallel Kinematics and Metrology with Capacitive Sensors for High Trajectory Fidelity

In a parallel kinematics multi-axis system, all actuators act directly on one moving platform. This means that all axes move the same minimized mass and can be designed with identical dynamic properties. Systems with parallel kinematics and metrology have additional advantages over serially stacked or nested systems, including more-compact construction and no cumulative error from the different axes. Parallel kinematics systems can be operated with up to six degrees of freedom with low inertia and excellent dynamic performance. Multi-axis nanopositioning systems equipped with both parallel kinematics and parallel, direct metrology are able to measure platform position in all degrees of freedom against one common fixed reference. In such systems, undesirable motion from one actuator in the direction of another (cross talk) is detected immediately and actively compensated by the servo-loops. This Active Trajectory Control Concept can keep deviation from a trajectory to under a few nanometers, even in dynamic operation.

Ordering Information

P-734.2CD
High-Precision XY Nanopositioning System with Minimum Runout, 100 x 100 µm, Capacitive Sensors, Parallel Metrology, Sub-D Connector

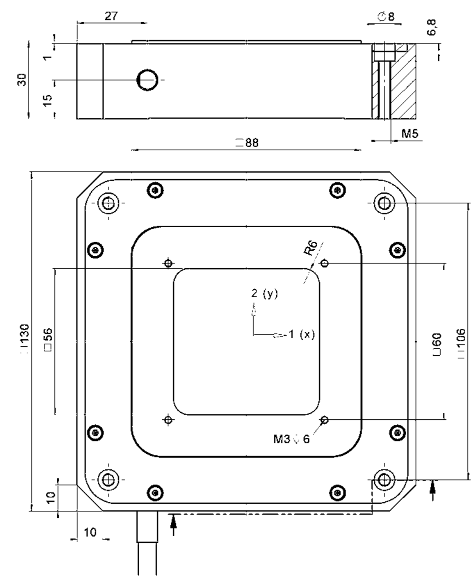
P-734.2CL
High-Precision XY Nanopositioning System with Minimum Runout, 100 x 100 µm, Capacitive Sensors, Parallel Metrology, LEMO Connector



Typical flatness of P-734 motion is in the low nanometer range

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.



P-734 dimensions in mm

Technical Data

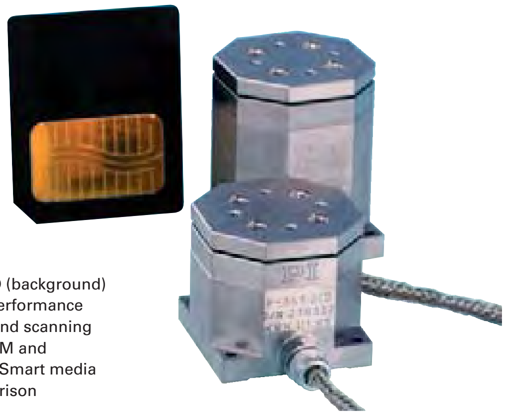
Models	P-734.2CL	P-734.2CD	Units	Tolerance
Active axes	X, Y	X, Y		
Motion and positioning				
Integrated sensor	Capacitive	Capacitive		
Open-loop travel, -20 to +120 V	110 x 110	110 x 110	µm	min. (+20 %/-0 %)
Closed-loop travel	100 x 100	100 x 100	µm	
Open-loop resolution	0.2	0.2	nm	typ.
Closed-loop resolution	0.3	0.3	nm	typ.
Linearity	0.03	0.03	%	typ.
Repeatability	<2.5	<2.5	nm	typ.
Pitch	<3	<3	µrad	typ.
Yaw	<10	<10	µrad	typ.
Flatness	typ. <5, max. <10	typ. <5, max. <10	nm	typ.
Mechanical properties				
Stiffness	3	3	N/µm	±20 %
Unloaded resonant frequency	500	500	Hz	±20 %
Resonant frequency @ 200 g	350	350	Hz	±20 %
Resonant frequency @ 500 g	250	250	Hz	±20 %
Push/pull force capacity in motion direction	300 / 100	300 / 100	N	Max.
Load capacity	20	20	N	Max.
Drive properties				
Ceramic type	PICMA® P-885	PICMA® P-885		
Electrical Capacitance	6.2	6.2	µF	±20%
Dynamic operating current coefficient	7.8	7.8	µA/(Hz • µm)	±20%
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum		
Mass (with cables)	1.04	1.04	kg	±5 %
Cable length	1.5	1.5	m	±10 mm
Sensor connection	2x LEMO	Sub-D Special		
Voltage connection	4x LEMO	Sub-D Special		

Dynamic Operating Current Coefficient in µA per Hz and µm. Example: Sinusoidal scan of 10 µm at 10 Hz requires approximately 7.8 mA drive current.

Recommended controller / amplifier
P-734.2CL (p. 2-64): E-500 modular piezo controller system (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high performance) (p. 2-147) and E-509 controller (p. 2-152)
P-734.2CD (p. 2-64):
Multi-channel digital controllers: E-710/E-725 bench-top (p. 2-128, p. 2-126), E-712 modular (p. 2-140), E-761 PCI board (p. 2-130)

P-363 PicoCube™ XY(Z) Piezo Scanner

High-Dynamics Nanoscanner for Scanning Probe Microscopy



P-363.2CD and .3CD (background) PicoCube™, high-performance piezo positioning- and scanning systems or AFM/STM and nanomanipulation. Smart media card for size comparison

- **Ultra-High-Performance Closed-Loop Scanner for AFM/SPM**
- **Compact Manipulation Tool for Bio/Nanotechnology**
- **Resonant Frequency 9.8 kHz**
- **Capacitive Sensors for Highest Accuracy**
- **Parallel-Motion Metrology for Automated Compensation of Guiding Errors**
- **50 Picometer Resolution**
- **5 x 5 x 5 µm Travel Range**
- **Vacuum-Compatible Versions**

The P-363 PicoCube™ XY/XYZ is an ultra-high-performance closed-loop piezo scanning system. Designed for AFM, SPM and nanomanipulation applications, it combines an ultra-low inertia, high-speed XY/XYZ piezo scanner with non-contact, direct-measuring, parallel-metrology capacitive feedback capable of 50 picometers resolution. On top of being extremely precise, the PicoCube™ system is also very small and rugged. Measuring only 30 x 30 x 40 mm (with removable top plate, 30 x 30 x 28 mm for XY version), it is easy to integrate in any scanning apparatus.

Application Examples

- Scanning microscopy (SPM)
- Biotechnology
- Micromanipulation
- Nanopositioning
- Nano-imprinting
- Nanometrology
- Nanolithography

SPM, AFM, STM, Nanolithography, Nanoimprinting, Nanometrology

The PicoCube™ was specifically developed to overcome the limitations of the open-loop scanners currently available for SPM, AFM and STM. In addition to these applications, the PicoCube™ is also the ideal scanning and manipulation tool for nanoimprinting, nanolithography, ultra-high-resolution, near-field, scanning optical microscopy and nanosurface-metrology applications.

Higher Precision Through Parallel-Motion Metrology w/ Capacitive Sensors

The PicoCube™ is based on a proprietary, ultra-fast, piezo-driven scanner design equipped with direct-measuring, capacitive position sensors (parallel metrology). Unlike conventional sensors, they measure the actual distance between the fixed frame and the moving part of the stage. This results in higher-motion linearity, long-term stability, phase fidelity, and—because external disturbances are seen by the sensor immediately—a stiffer, faster-responding servo-loop.

Multi-axis nanopositioning systems equipped with parallel direct metrology are able to measure the platform position in all degrees of freedom against one fixed reference. In such systems, undesirable motion from one actuator in the direction of another (cross-talk) is detected immediately and actively compensated by the servo-loops. This Active Trajectory Control Concept can keep deviation from a trajectory to under a few nanometers, even in dynamic operation.

Ordering Information

P-363.3CD
PicoCube™ High-Precision XYZ Nanopositioning System, 5 x 5 x 5 µm, Parallel Metrology, Capacitive Sensors, Sub-D Connector

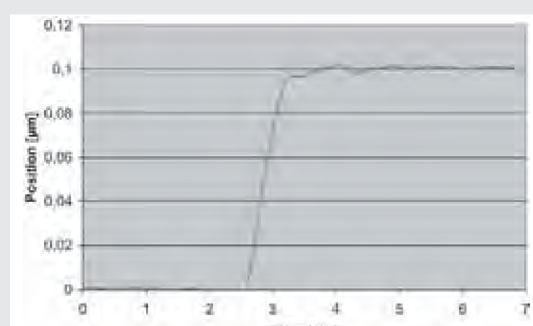
P-363.3UD
PicoCube™ High-Precision XYZ Nanopositioning System, 5 x 5 x 5 µm, Parallel Metrology, Capacitive Sensors, Sub-D Connector, Vacuum Compatible to 10^{-9} hPa

P-363.2CD
PicoCube™ High-Precision XY Nanopositioning System, 5 x 5 µm, Parallel Metrology, Capacitive Sensors, Sub-D Connector

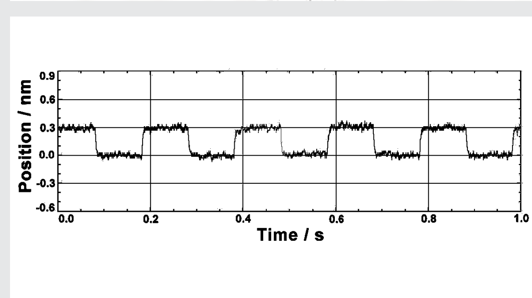
P-363.2UD
PicoCube™ High-Precision XY Nanopositioning System, 5 x 5 µm, Parallel Metrology, Capacitive Sensors, Sub-D Connector, Vacuum Compatible to 10^{-9} hPa

P-363.3CL
PicoCube™ High-Precision XYZ Nanopositioning System, 5 x 5 x 5 µm, Parallel Metrology, Capacitive Sensors, LEMO Connector

P-363.2CL
PicoCube™ High-Precision XY Nanopositioning System, 5 x 5 µm, Parallel Metrology, Capacitive Sensors, LEMO Connector



The P-363 settles to within 1 nm in 1 ms (100 nm step, X and Y motion; faster response in Z)



300 picometer steps (0.3 nm) performed with the P-363, measured with an external high-resolution, capacitive measurement system

Nanometer Accuracy in 1 Millisecond with 30-Picometer Resolution

PicoCube™ systems provide resolution of 30 picometers and below. The ultra-fast XY/XYZ piezo drives offer resonant frequencies of 9.8 kHz in Z and >3 kHz in X and Y! The high resonant frequency and high-bandwidth capacitive feedback allow step and settle to 1% accuracy in as little as one millisecond.

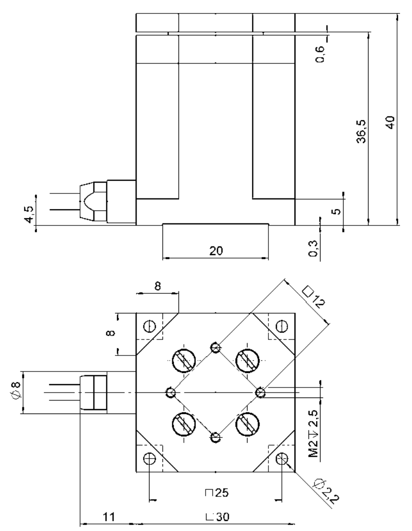
Rugged Design

In spite of its ability to move and position on an atomic scale, the PicoCube™ boasts a rugged design for real-world applications. For extra-high stability and reduced mass, the body is precision machined from heat-treated and stress-relieved titanium. The sophisticated frictionless design also ensures that the (moving) top plate protects the internal actuator/sensor unit from contamination.

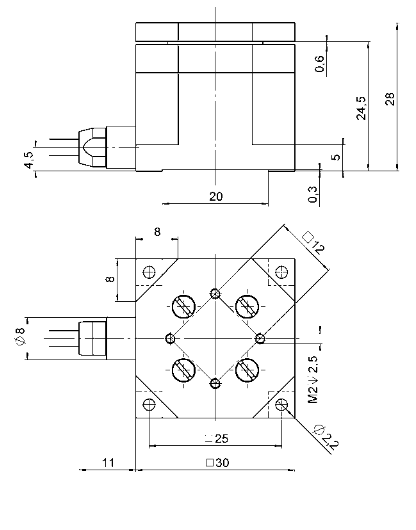
Controller

For dynamic scanning operation the E-725.3CM high-power digital controller offers advanced linearization algorithms for sub-nanometer precision (see p. 2-126).

Alternatively the analog E-536 PicoCube™ controller (see p. 2-134) comes in different versions optimized for resolution or power . An optional E-517 24-bit interface module is also available (see p. 2-156).



P-363.3Cx dimensions in mm. Removable top plate



P-363.2Cx dimensions in mm. Removable top plate

Technical Data

Model	P-363.3CD	P-363.2CD	Units
Active axes	X, Y, Z	X, Y	
Motion and positioning			
Integrated sensor	Capacitive	Capacitive	
Open-loop travel X, Y, -250 to +250 V	±3	±3	µm
Open-loop travel, -250 to +250 V	±2.7	–	µm
Closed-loop travel X, Y	±2.5	±2.5	µm
Closed-loop travel	±2.5	–	µm
Open-loop resolution	0.03*	0.03*	nm
Closed-loop resolution	0.1	0.1nm	
Linearity	0.05	0.05	%
Repeatability	1**	1**	nm
Pitch / yaw in X, Y	0.5	0.5	µrad
Runout X, Y (Z motion)	0.2	–	µrad
Straightness in X, Y	3	3	nm
Flatness in X, Y	<10	<10	nm
Crosstalk X, Y (Z motion)	5	–	nm
Mechanical properties			
Unloaded resonant frequency in X, Y	3.1	4.2	kHz
Unloaded resonant frequency (Z)	9.8	–	kHz
Resonant frequency in X, Y	1.5 (20 g)	2.1 (20 g)	kHz
Load capacity	10	10	N
Ceramic type	PICA™, PICA™ Shear	PICA™ Shear	
Miscellaneous			
Operating temperature range	-20 to 80	-20 to 80	°C
Material	Titanium	Titanium	
Dimensions	30 x 30 x 40	30 x 30 x 28	mm
Mass	225	190	g
Cable length	1.5	1.5	m
Sensor / voltage connection***	Sub-D connector PicoCube™	Sub-D connector PicoCube™	
Recommended controller	E-536 PicoCube™ Controller	E-536 PicoCube™ Controller	

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. V alue given is noise equivalent motion with E-536 controller (p. 2-134)

*With E-536.3xH Controller

**for 10% travel in Z; 50 nm for 100 % travel in Z

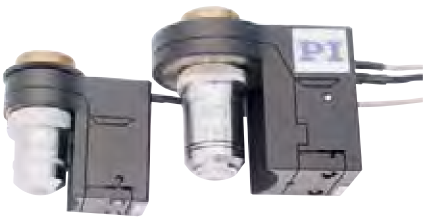
***P-363.xCL versions with LEMO connectors

System properties

System configuration	P-363.3CD (Z-axis) with 20 g load and E-536 servo controller
Settling time	(10 % step width) 1 ms

P-720 PIFOC® Piezo Nanofocusing Systems

Compact High-Dynamics Scanner for Small Objectives



- **Travel Range 100 µm**
- **Rapid Response & Settling Behavior**
- **Scans and Positions Objectives with Sub-nm Resolution**
- **Frictionless, High-Precision Flexure Guiding System**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**

The P-720 objective nanofocusing / scanning drive (objective not included) was designed for small objectives. Similar PIFOC® systems are available for large objectives and with position sensors

Model	Max. objective diameter	Travel	Open-loop, resolution	Stiffness	Push/pull force capacity	Rotation around θ_X, θ_Y
P-720.00	25 mm	100 µm	0.5 nm	0.2 N/µm	100 / 20 N	13 µrad

P-721K PIFOC® Nosepiece Nanopositioner

Compact Design, Sub-Nanometer Resolution

P-721KTPZ Compact Nosepiece Nanopositioner

- **Positioning and Scanning of Microscope Turrets**
- **Direct-Metrology Capacitive Sensors for Highest Linearity, Stability and Control Dynamics**
- **Frictionless, High-Precision Flexure Guiding System for Better Focus Stability**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**

Model	Travel	Closed-loop/ open-loop resolution	Resonant frequency (fully loaded)	Dimensions
P-721KTPZ Turret-PIFOC®	80 µm	10 / 0.5 nm	215 Hz	44.5 x 42 x 53 mm (W x L x H)

P-721K Power-PIFOC® Nosepiece Nanopositioner

For High-Resolution Microscopy. High-Load Capacity, Capacitive Feedback

- **Scans and Positions Objectives with Sub-nm Resolution**
- **Travel Ranges to 150 µm, Millisecond Settling Time**
- **Parallel Flexure Guiding for Minimized Objective Offset**
- **Direct Metrology with Capacitive Sensors for Highest Linearity**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**

The P-721KPTZ high-load PIFOC® allows precision positioning of a complete microscope turret

Model	Load capacity	Closed-loop travel	Resonant frequency	Mass
P-721KPTZ	20 N	to 150 µm	410 Hz (no load)	1.5 kg

P-721 PIFOC® Piezo Flexure Objective Scanner

Fast Nanopositioner and Scanner for Microscope Objectives

P-721.CLQ piezo objective nanopositioning system with P-721.12Q QuickLock option and objective (adapter and objective not included)

- **Scans and Positions Objectives with Sub-nm Resolution**
- **Travel Ranges to 140 µm, Millisecond Settling Time**
- **Significantly Faster Response and Higher Lifetime than Motorized Z-Stages**
- **Parallel Precision Flexure Guiding for Better Focus Stability**
- **Choice of Position Sensors: Capacitive Direct Metrology (Higher Performance) or Strain Gauge (Lower Cost)**
- **Compatible with Metamorph™ Imaging Software**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **QuickLock Adapter for Easy Attachment**
- **Clear Aperture up to 29 mm Ø**

P-721 PIFOCs® are high-speed, piezo-driven microscope objective nanofocusing/scanning devices, providing a positioning and scanning range of 100 µm with sub-nanometer resolution and very high motion of linearity up to 0.03 %. For applications, such as the two-photon spectroscopy wich requires a particulary high resolution, there are versions wich allow a free aperture of up to 29 mm in diameter.

PIFOCs® are also available with up to 460 µm travel (P-725 p. 2-28), and for exceptional dynamic and step performance (models P-726 p. 2-32 and P-725.SDD p. 2-30).

Application Examples

- 3D-Imaging
- Z Stack Acquisition
- Screening
- Interferometry
- Metrology
- Disc-drive-testing
- Autofocus systems
- Confocal microscopy
- Biotechnology
- Semiconductor testing

Superior Accuracy With Direct-Metrology Capacitive Sensors

Capacitive position feedback is used in the top-of-the-line models. PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Alternatively, strain gauge sensor (SGS) models are available. The sensors are connected in a bridge configuration to eliminate thermal drift, and assure optimal position stability in the nanometer range.

Open-loop models are available for applications where fast response and very high resolution are essential. Here, specifying or reporting absolute position values is either not required or is handled by external sensors, such as interferometers, a vision system or photodiode PSD (position sensitive detector). These models retain the inherent piezo advantages such as high resolution and speed.

Ordering Information

P-721.CDQ
Fast PIFOC® Piezo Nanofocusing Z-Drive, 100 µm, Direct Metrology, Capacitive Sensor, Sub-D Connector, for Quick Lock Thread Adapters

P-721.CLQ
Fast PIFOC® Piezo Nanofocusing Z-Drive, 100 µm, Direct Metrology, Capacitive Sensor, LEMO Connector, for Quick Lock Thread Adapters

P-721.SL2
Fast PIFOC® Piezo Nanofocusing Z-Drive, 100 µm, SGS-Sensor, LEMO Connector, for Quick Lock Thread Adapters

P-721.0LQ
Fast PIFOC® Piezo Nanofocusing Z-Drive, 100 µm, No Sensor, LEMO Connector, for Quick Lock Thread Adapters

P-721.CDA
Fast PIFOC® Piezo Nanofocusing Z-Drive, 100 µm, Direct Metrology, Capacitive Sensor, Sub-D Connectors, for Large Aperture QuickLock Thread Adapters

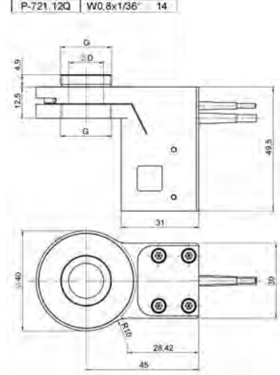
P-721.SDA
Fast PIFOC® Piezo Nanofocusing Z-Drive, 100 µm, SGS Sensor, Sub-D Connectors, for Large Aperture QuickLock Thread Adapters

Accessories

QuickLock Thread Adapter, Large Aperture QuickLock Thread Adapter s. fig.; Extension Tubes for Objectives s. www.pi.ws

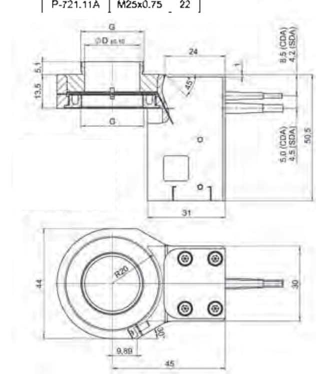
QuickLock Adapter

	G	D
P-721.02Q	M26x0,75	21
P-721.03Q	M27x0,75	21
P-721.04Q	M28x0,75	21
P-721.05Q	M32x0,75	21
P-721.06Q	M26x1/36"	21
P-721.08Q	M19x0,75	14
P-721.11Q	M25x0,75	21
P-721.12Q	W0,8x1/36"	14



P-721.xxQ, .SL2 dimensions in mm (adapter to be ordered separately)

	G	D
P-721.02A	M26x0.75	23
P-721.03A	M27x0,75	24
P-721.04A	M28x0,75	25
P-721.05A	M32x0,75	29
P-721.06A	M26x1/36"	23
P-721.11A	M25x0.75	22



P-721.CDA, .SDA, dimensions in mm (adapter to be ordered separately)

PI

Simple Installation with QuickLock Thread Options

The PIFOC® is mounted between the turret and the objective with the QuickLock thread adapter. After threading the adapter into the turret, the QuickLock is affixed in the desired position. Because the PIFOC® body need not to be rotated, cable wind-up is not an issue.

High Reliability and Long Lifetime

The compact PIFOC® systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and thus offer better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free and not subject to wear, and thus offer an extraordinary reliability.

Choice of Controllers

A large choice of analog and digital piezo controllers as OEM, bench-top and 19-inch-rack-mount versions is available.

Technical Data

Model	P-721.CLQ	P-721.CDQ P-721.CDA	P-721.SL2 P-721.SDA	P-721.0LQ	Units	Tolerance
Active axes	Z	Z	Z	Z		
Motion and positioning						
Integrated sensor	Capacitive	Capacitive	SGS	–		
Open-loop travel, -20 to +120 V	140	140	140	140	µm	min. (+20 %/-0%)
Closed-loop travel	100	100	100	–	µm	calibrated
Open-loop resolution	0.5	0.5	0.5	0.5	nm	typ.
Closed-loop resolution	0.7	0.7	5	–	nm	typ.
Linearity, closed-loop	0.03	0.03	0.2	–	%	typ.
Repeatability	±5	±5	±10	–	nm	typ.
Runout θX, θY	13	13	13	13	µrad	typ.
Crosstalk X, Y	100	100	100	100	nm	typ.
Mechanical properties						
Stiffness in motion direction	0.3	0.3	0.3	0.3	N/µm	±20 %
Unloaded resonant frequency	580	580	580	550	Hz	±20 %
Resonant frequency @ 120 g	235	235	235	235	Hz	±20 %
Resonant frequency @ 200 g	180	180	180	180	Hz	±20 %
Push/pull force capacity in motion direction	100 / 20	100 / 20	100 / 20	100 / 20	N	Max.
Drive properties						
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical capacitance	3.1	3.1	3.1	3.1	µF	±20 %
Dynamic operating current coefficient	3.9	3.9	3.9	3.9	µA/(Hz•µm)	±20 %
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminum		
Mass	0.24	0.24	0.22	0.22	kg	±5 %
Max. objective diameter	39	39	39	39	mm	
Cable length	1	1	1	1	m	±10 mm
Sensor / voltage connection	LEMO	Sub-D Special	LEMO/Sub-D Special	LEMO (no sensor)		
Recommended controller / amplifier	E-610 servo controller/amplifier (p. 2-110), modular piezo controller system E-500 (p. 2-142) with amplifier module E-505 (high performance) (p. 2-147) and E-509 servo controller (p. 2-152)	E-625 servo controller, bench top (p. 2-114), E-665 powerful servo controller, bench-top (p. 2-116), Single-channel digital controller: E-753 (bench-top) (p. 2-108) E-709 single-channel digital controller	SL2 version: E-610 servo controller/amplifier, E-625 servo controller, bench-top, E-665 powerful servo controller, bench-top SDA version: E-709 single-channel digital controller	E-610 servo controller/amplifier		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion with E-503 amplifier (p. 2-144)

N-725 PIFOC® High-Load Objective Scanner

1 mm Travel, Fast Response and Nanometer Precision

N-725 PIFOC® is the first piezo-objective drive with integrated NEXACT® Piezo Linear Motor, combining smooth motion, long travel ranges and fast response with extreme position stability

- **High Force & High-Dynamics for Positioning and Scanning of Large Objectives up to 29 mm Ø**
- **1 mm Travel for Applications with Large Penetration Depth**
- **Ideal for e. g. Two-Photon Microscopy**
- **Very Fast Response: 20 ms Step and Settle Time**
- **Self Locking at Rest, no Heat Generation, no Servojitter**
- **Drive Resolution < 1 nm, 20 nm Encoder Resolution**
- **Two Motion Modes: Continuous Nanostepping and High-Dynamics Analog Mode**
- **Compact Design: Ø 48 mm, 40.5 mm Height**
- **Frictionless, High-Precision Flexure Guiding System for Better Focus Stability**
- **QuickLock Thread Adapter for Simple Installation**

The N-725 PIFOC® is the first piezo objective nanopositioner equipped with a PiezoWalk® linear motor. This drive combines smooth motion, long travel ranges and fast step and settle with extreme position stability. Its exceptional stroke of 1 mm renders stepper motor positioners -often used as range extenders for piezo drives- unnecessary. The focussing plane can be selected in an extended range without any change of the mechanics. Together with a step and settle time of less than 20 ms this allows for higher throughput.
The large travel range is a big advantage for applications that have large optical penetration depth like two-photon microscopy where it allows to make use of the full working range of the objective and quickly scan through z stacks of up to 1 mm.

Application Examples

- 3-D Imaging
- Screening
- Autofocus systems
- Microscopy
- Confocal microscopy
- Surface structure analysis
- Wafer inspection

Simple Installation with QuickLock Thread Options

The PIFOC® is mounted between the turret and the objective with the QuickLock thread adapter. After threading the adapter into the turret, the QuickLock is affixed in the desired position. Because the PIFOC® body need not to be rotated, cable wind-up is not an issue.

PiezoWalk® – the Multi-Functional Piezo Linear Motor

A great advantage characteristic of the NEXACT® drive principle is its dual-mode operating principle combining the best features of piezo motor designs, such as high resolution, high force and high speed into one compact unit. At the target position the drive requires no current and generates no heat while providing long-term, nanometer stability. This autolocking feature also completely eliminates servo jitter as it occurs with other closed-loop motors. Since motion is solely caused by the nanometer precise motion of clamped piezo actuators, there is no wear to limit the lifetime. When operated in closed-loop, excellent velocity control is achieved.
See p. 1-12 for further information on NEXACT® PiezoWalk® technology.

Controller and Drive Electronics Optimized for the Application

NEXACT® actuators require special drive electronics to control the complex stepping sequences. The E-861 includes complete NEXACT® servo controller with low-noise drivers and a powerful DSP. It also comes with ample software for easy integration and highly effective computer control. For applications which do not require the highest resolution, the E-862 lower-priced drive electronics can be ordered.
The products described in this document are in part protected by the following patents:
German Patent No. P4408618.0

Ordering Information

N-725.1A
PIFOC® Piezo Nanofocusing Z-Drive with NEXACT® Linear Motor, 1 mm, Linear Encoder, 20 nm Resolution, for QuickLock Thread Adapters

Accessories

QuickLock Thread Adapters: see figure

P-721.90Q
Extens. Tube, 12.5 mm, Thread W0.8 x 1/36''

P-721.91Q
Extens. Tube, 12.5 mm, Thread M25 x 0.75

P-721.92Q
Extens. Tube, 12.5 mm, Thread M26 x 0.75

P-721.93Q
Extens. Tube, 12.5 mm, Thread M27 x 0.75

P-721.94Q
Extens. Tube, 12.5 mm, Thread M28 x 0.75

P-721.95Q
Extens. Tube, 12.5 mm, Thread M32 x 0.75

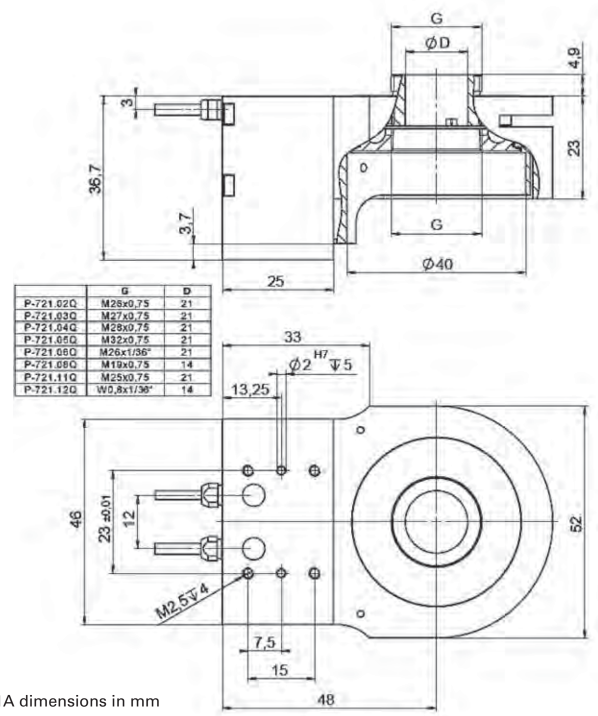
P-721.96Q
Extens. Tube, 12.5 mm, Thread M26 x 1/36''

P-721.98Q
Extens. Tube, 12.5 mm, Thread M19 x 0.75

Ask about custom designs!

Scanner for Higher Resolution and Higher Loads

PI offers a range of related PIFOC® objective scanners with different specifications. The P-725 models e. g. (s. p. 2-28) offer resolutions of less than one nanometer. For larger loads and dynamic scanning applications the models P-726 (s. p. 2-32) and P-725.DD (s. p. 2-30) are also available with travel ranges of up to 100 µm.



N-725.1A dimensions in mm

Technical Data

Model	N-725.1A
Active axes	Z
Motion and positioning	
Travel range	1 mm
Integrated sensor	Linear encoder
Sensor resolution	20 nm *
Travel range in analog mode	7 µm
Closed-loop resolution	20 nm *
Linearity, closed-loop	0.1%
Bidirectional repeatability	50 nm
Rotation (X, Y) typ.	15 µrad / 100 µm
Step and Settle (200 nm), typ.	20 ms
Max. velocity	10 mm/s*
Mechanical properties	
Stiffness in motion direction	0.5 N/µm
Max. push / pull force (active)	10 N
Drive properties	
Drive type	NEXACT® linear drive
Operating voltage	-10 V to +45 V
Miscellaneous	
Operating temperature range	0 to 50°C
Material	Aluminium
Mass	440 g
Cable length	1.5 m
Connector	HD sub-D connector, 15-pin
Recommended controller	E-861.1A1 Controller for NEXACT® Linear Drives and Positioners

* With E-861. Depending on drive electronics.

P-725 PIFOC® Long-Travel Objective Scanner

High-Precision Positioner / Scanner for Microscope Objectives

P-725.2CL with QuickLock option
P-721.12Q for W0.8 x 1/36” threads
and objective (QuickLock adapter
and objective not included)

- **Travel Ranges to 460 µm**
- **Significantly Faster Response and Higher Lifetime than Motorized Z-Stages**
- **Scans and Positions Objectives with Sub-nm Resolution**
- **Direct Metrology with Capacitive Sensors for Highest Linearity**
- **Parallel Precision Flexure Guiding for Better Focus Stability**
- **Compatible with Metamorph™ Imaging Software**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **QuickLock Adapter for Easy Attachment**
- **Clear Aperture up to 29 mm Ø**

P-725 PIFOC® nanofocus systems are long-travel (up to 460 µm), high-speed, piezo-driven microscope objective nanofocusing/scanning devices. The innovative, frictionless, flexure guiding system provides enhanced precision for superior focus stability with fast response for rapid settling and scanning. Despite the larger travel range, they are 20 % shorter than P-721 units (p. 2-25) while providing sub-nanometer resolution. For applications which require a particularly high resolution, such as the two photon spectroscopy, there are versions which allow a free aperture of up to 29 mm in diameter.

Application Examples

- 3D-Imaging
- Screening
- Interferometry
- Metrology
- Disc-drive-testing
- Autofocus systems
- Confocal microscopy
- Biotechnology
- Semiconductor testing

Superior Accuracy With Direct-Metrology Capacitive Sensors

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. Further advantages of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.
Open-loop models are available for applications where fast response and very high resolution are essential. Here, specifying or reporting absolute position values is either not required or is handled by external sensors, such as interferometers, a vision system or photodiode PSD (position sensitive detector). These models retain the inherent piezo advantages such as high resolution and speed.

Open-loop models are available for applications where fast response and very high resolution are essential. Here, specifying or reporting absolute position values is either not required or is handled by external sensors, such as interferometers, vision system or photodiode PSD (position sensitive detector). These models retain the inherent piezo advantages as high resolution and speed.

Ordering Information

P-725 PIFOC® Piezo Nanofocusing Z-Drive for Long Scanning Ranges

P-725. □ □□

- **1** Travel Range 100 µm (closed-loop)
- **2** Travel Range 250 µm (closed-loop)
- **4** Travel Range 400 µm (closed-loop)

- **CA** Capacitive Sensor, Sub-D Connectors, for Large Aperture QuickLock Thread Adapters
- **CD** Capacitive Sensor, Sub-D Connectors, for QuickLock Thread Adapters
- **CL** Capacitive Sensor, LEMO Connector, for QuickLock Thread Adapters
- **0L** No Sensor, Sub-D Connectors, for QuickLock Thread Adapters, Travel Range see Data Table

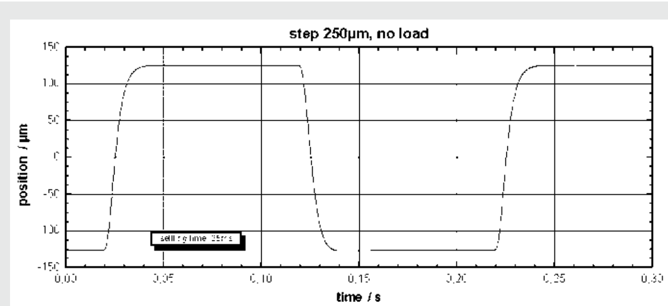
Accessories
QuickLock Thread Adapters s. fig.,
Extension Tubes for Objectives s. www.pi.ws

Simple Installation with QuickLock Thread Options

The PIFOC® is mounted between the turret and the objective with the QuickLock thread adapter. After threading the adapter into the turret, the QuickLock is affixed in the desired position. Because the PIFOC® body need not to be rotated, cable wind-up is not an issue.

High Reliability and Long Lifetime

The compact PIFOC® systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature

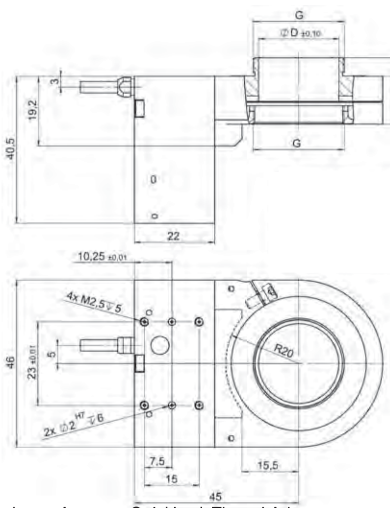


Fastest step and settle: The P-725.2CL can perform a 250 µm step to 1 % accuracy in only 25 ms (no load; 50 ms with a load of 150 g. With E-665.CR controller) cofired ceramic encapsulation and thus offer better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free and not subject to wear, and thus offer an extraordinary reliability.

Scanner for Higher Dynamics and Higher Loads

PI offers a series of related PIFOC® objective scanners with different specifications. For higher loads and dynamic scanning applications the models P-726 (s. p. 2-32) and P-725.DD (s. p. 2-30) featuring a stroke of up to 100 µm are available.

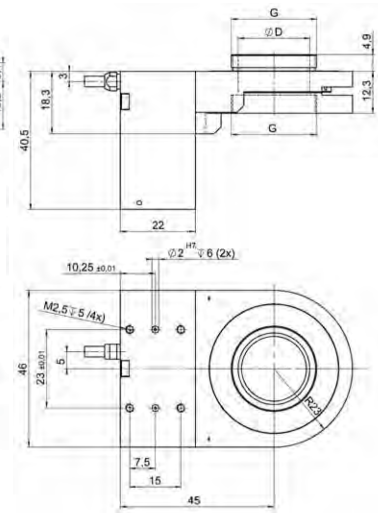
Alternatively, the sample can be moved into focus: The P-737 piezo Z-nanopositioner features a large aperture to hold a variety of sample holders.



Large Aperture QuickLock Thread Adapter

	G	D
P-721.02A	M26x0,75	23
P-721.03A	M27x0,75	24
P-721.04A	M28x0,75	25
P-721.05A	M32x0,75	29
P-721.06A	M26x1/36"	23
P-721.11A	M25x0,75	22

P-725.xCA dimensions in mm
(thread adapter ordered separately)



QuickLock Thread Adapter

	G	D
P-721.02Q	M26x0,75	21
P-721.03Q	M27x0,75	21
P-721.04Q	M28x0,75	21
P-721.05Q	M32x0,75	21
P-721.06Q	M26x1/36"	21
P-721.08Q	M19x0,75	14
P-721.11Q	M25x0,75	21
P-721.12Q	W0,8x1/36"	14

P-725.xCD, .xCL dimensions in mm
(thread adapter ordered separately)

Technical Data

Model	P-725.1CL P-725.1CD P-725.1CA	P-725.2CL P-725.2CD P-725.2CA	P-725.4CL P-725.4CD P-725.4CA	P-725.x0L closed-loop version	Units	Tolerance
Active axes	Z	Z	Z	Z		
Motion and positioning						
Integrated sensor	Capacitive	Capacitive	Capacitive	-		
Open-loop travel, -20 to +120 V	150	330	460	as P-725.xCL	µm	min. (+20 %/-0 %)
Closed-loop travel	100	250	400	-	µm	calibrated
Open-loop resolution	0.3	0.4	0.5	as P-725.xCL	nm	typ.
Closed-loop resolution	0.65	0.75	1.25	-	nm	typ.
Linearity, closed-loop	0.03	0.03	0.03	-	%	typ.
Repeatability	±5	±5	±5	-	nm	typ.
Runout Θ_X	1	6	10	as P-725.xCL	µrad	typ.
Runout Θ_Y	20	45	45	as P-725.xCL	µrad	typ.
Crosstalk in X	20	20	60	as P-725.xCL	nm	typ.
Crosstalk in Y	20	40	60	as P-725.xCL	nm	typ.
Mechanical properties						
Stiffness in motion direction	0.23	0.17	0.12	as P-725.xCL	N/µm	±20 %
Unloaded resonant frequency	470	330	230	as P-725.xCL	Hz	±20 %
Resonant frequency @ 150 g	185	140	120	as P-725.xCL	Hz	±20 %
Push/pull force capacity in motion direction	100 / 20	100 / 20	100 / 20	as P-725.xCL	N	Max.
Drive properties						
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	as P-725.xCL		
Electrical capacitance	4.2	6.2	6.2	as P-725.xCL	µF	±20 %
Dynamic operating current coefficient	5.2	3.1	1.9	as P-725.xCL	µA/(Hz • µm)	±20 %
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminium		
Max. objective diameter	39	39	39	39	mm	
Mass	0.215	0.23	0.23	as P-725.xCL	kg	±5 %
Sensor / voltage connection	CL-version: LEMO others: Sub-D special	CL-version: LEMO others: Sub-D special	CL-version: LEMO others: Sub-D special	LEMO (no sensor)		

P-721.12Q QuickLock thread adapter, exploded view with microscope objective and PIFOC® (mounting tools are included, QuickLock adapter and objective not included)

Recommended controller / amplifier
CL-versions:
E-610 servo controller / amplifier (p. 2-110); E-500 modular piezo controller system (p. 2-142) with E-505 high-performance amplifier module (p. 2-147) and E-509 controller (p. 2-152)
CD/CA-versions:
E-621 controller module (p. 2-160), E-625 servo controller, bench-top (p. 2-114), E-665 display servo controller, with digital interface, bench-top (p. 2-116)
Single-channel digital controller: E-753 (bench-top) (p. 2-108), E-709

P-725.xDD PIFOC® High-Dynamics Piezo Scanner

Nanopositioning and Scanning System for Microscope Objectives

P-725.CDD direct-drive version for high-dynamics focusing

- **Fastest Settling Time under 5 ms with Microscope Objective**
- **18 µm Travel Range**
- **Scans and Positions Objectives with Sub-nm Resolution**
- **Parallel Flexure Guiding for Minimized Objective Offset**
- **Choice of Position Sensors: Capacitive Direct Metrology (Higher Performance) or Strain Gauges (Lower Cost)**
- **Compatible with Metamorph™ Imaging Software**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **QuickLock Adapter for Easy Attachment**

Direct Drive for Ultra-Fast Scanning and Positioning

The P-725.xDD objective positioners were designed for extremely fast motion over relatively short travel ranges up to 18 µm. Their ultra-stiff direct piezo drive (1.2 kHz resonant frequency) enables the highest scanning rates and response times of only 5 msecs – essential for time-critical tasks.

Application Exampels

- 3D-Imaging
- Screening
- Interferometry
- Metrology
- Disc-drive-testing
- Autofocus systems
- Confocal microscopy
- Biotechnology
- Semiconductor testing

Superior Accuracy With Direct-Metrology Capacitive Sensors

Capacitive position feedback is used in the top-of-the-line model. PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Alternatively compact, more cost-efficient strain gauge sensors (SGS) featuring nanometer resolution are implemented. Absolute-measuring SGS-sensors are applied to appropriate places on the drive train and thus measure the displacement of the moving part of the stage relative to the base.

Simple Installation with QuickLock Thread Options

The PIFOC® is mounted between the turret and the objective with the QuickLock thread adapter. After threading the adapter into the turret, the QuickLock is affixed in the desired position. Because the PIFOC® body need not to be rotated, cable wind-up is not an issue.

High Reliability and Long Lifetime

The compact PIFOC® systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and thus offer better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free and not subject to wear, and thus offer an extraordinary reliability.

Ordering Information

P-725.CDD
Fast PIFOC® Piezo Nanofocusing Z-Drive, 18 µm, Capacitive Sensor, Sub-D Connector, for QuickLock Thread Adapters

P-725.SDD
Fast PIFOC® Piezo Nanofocusing Z-Drive, 18 µm, SGS-Sensor, LEMO Connector, for QuickLock Thread Adapters

Accessories
QuickLock Thread Adapters

P-721.11Q
QuickLock Thread Adapter M25 x 0.75

P-721.12Q
QuickLock Thread Adapter W0.8 x 1/36"

P-721.02Q
QuickLock Thread Adapter M26 x 0.75

P-721.03Q
QuickLock Thread Adapter M27 x 0.75

P-721.04Q
QuickLock Thread Adapter M28 x 0.75

P-721.05Q
QuickLock Thread Adapter M32 x 0.75

P-721.06Q
QuickLock Thread Adapter M26 x 1/36 "

P-721.08Q
QuickLock Thread Adapter M19 x 0.75

Extension Tubes for Objectives

P-721.90Q
Extension Tube, 12.5 mm, Thread W0.8 x 1/36"

P-721.91Q
Extens. Tube, 12.5 mm, Thread M25 x 0.75

P-721.92Q
Extension Tube, 12.5 mm, Thread M26 x 0.75

P-721.93Q
Extension Tube, 12.5 mm, Thread M27 x 0.75

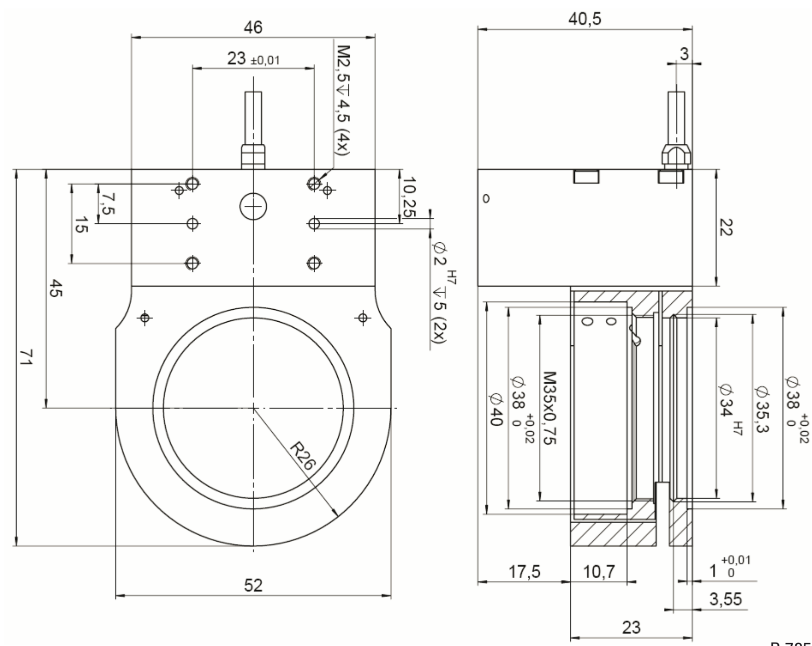
P-721.94Q
Extension Tube, 12.5 mm, Thread M28 x 0.75

P-721.95Q
Extension Tube, 12.5 mm, Thread M32 x 0.75

P-721.96Q
Extension Tube, 12.5 mm, Thread M26 x 1/36"

P-721.98Q
Extension Tube, 12.5 mm, Thread M19 x 0.75

Ask about custom designs!



P-725.xDD dimensions in mm

Technical Data

Model	P-725.CDD	P-725.SDD	Units	Tolerance
Active axes	Z	Z		
Motion and positioning				
Integrated sensor	Capacitive	SGS		
Open-loop travel, -20 to +120 V	18	18	µm	min. (+20 %/-0 %)
Closed-loop travel	18	18	µm	calibrated
Open-loop resolution	0.2	0.2	nm	typ.
Closed-loop resolution	0.2	0.2	nm	typ.
Linearity, closed-loop	0.04*	0.5	%	typ.
Repeatability	±1.5	±5	nm	typ.
Runout θ_X, θ_Y	2	2	µrad	typ.
Crosstalk in X, Y	150	150	nm	typ.
Mechanical properties				
Stiffness in motion direction	1.5	1.5	N/µm	±20 %
Unloaded resonant frequency	1180	1180	Hz	±20 %
Resonant frequency @ 200 g	450	450	Hz	±20 %
Push/pull force capacity in motion direction	100 / 20	100 / 20	N	Max.
Drive properties				
Ceramic type	PICMA® P-887	PICMA® P-887		
Electrical capacitance	3.1	3.1	µF	±20 %
Dynamic operating current coefficient	19.4	19.4	µA/(Hz • µm)	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum		
Mass	0.21	0.2	kg	±5 %
Cable length	1.5	1.5	m	±10 mm
Sensor / voltage connection	Sub-D Special	LEMO		

Recommended controller
E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-665 high-power servo controller, bench-top (p. 2-116)
Single-channel digital controller: E-753 (bench-top) (p. 2-108)
* With E-753 digital controller. Non-linearity of direct drive stages measured with analog controllers is up to 0.1 % typ.

P-726 PIFOC® High-Load Objective Scanner

High-Dynamic Piezo Z Scanner for Heavy Objectives

High-dynamics P-726 PIFOC® for large microscope objectives over 60 mm in length

- **High-Dynamics Positioning and Scanning for Large Objectives**
- **1120 Hz Resonant Frequency, 560 Hz with 210 g Load**
- **Typical Settling Time about 6 ms**
- **Travel Range 100 µm**
- **Direct-Metrology Capacitive Sensors for Best Linearity, Stability and Control Dynamics**
- **Resolution to 0.3 nm**
- **Frictionless, High-Precision Flexure Guiding System for Better Focus Stability**

The P-726 PIFOC® Nanofocusing system was developed to achieve the fastest possible stepping time with the heavy, high-numerical-aperture objectives used in many of today's high-resolution microscopy applications. Its extremely stiff design offers excellent settling time and scanning frequency values even when objectives of several hundred grams are moved. High stiffness is achieved with the rotationally symmetric arrangement of multiple piezo drives and the optimized design of the flexure and lever elements, which assure the excellent guiding accuracy and dynamics.

Furthermore, like other members of the PIFOC® family, the P-726 is equipped with direct metrology capacitive position sensors that allow resolutions far below one nanometer.

Application Examples

- 3-D Imaging
- Screening
- Autofocus systems
- Microscopy
- Confocal microscopy
- Surface analysis
- Wafer inspection

Direct Metrology with Capacitive Sensors for Highest Stability and Accuracy

PI's proprietary capacitive position sensors measure the actual motion of the moving part relative to the stationary base (direct metrology). Errors in the drive train, actuator, lever arm or in guiding system do not influence the measurements. The result is exceptional motion linearity, higher long-term stability and a stiffer, more-responsive servo loop, because external influences are immediately recognized by the sensor. Due to this sensor principle, the P-726 features a resolution of under 0.4 nm in closed-loop and a linearity of 0.02 %.

Simple Installation with QuickLock Thread Options

The PIFOC® is mounted between the turret and the objective with the QuickLock thread adapter. After threading the adapter into the turret, the QuickLock is affixed in the desired position. Because the PIFOC® body need not to be rotated, cable wind-up is not an issue.

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Ordering Information

P-726.1CD
High-Dynamics PIFOC® Piezo Nanofocusing Z-Drive, 100 µm, Capacitive Sensor

QuickLock Thread Adapter as Accessories:

P-726.04
P-726 PIFOC® Thread Adapter M28 x 0.75

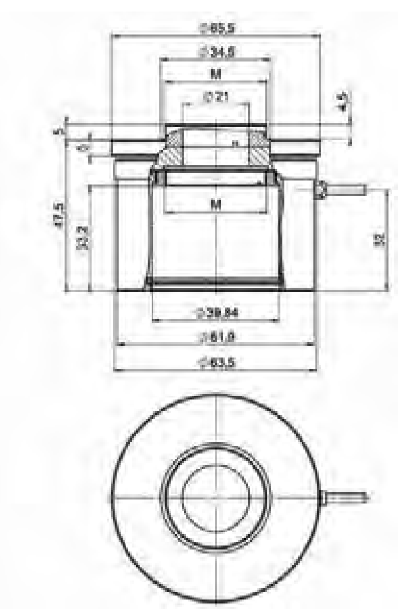
P-726.05
P-726 PIFOC® Thread Adapter M32 x 0.75

P-726.06
P-726 PIFOC® Thread Adapter M26 x 1/36"

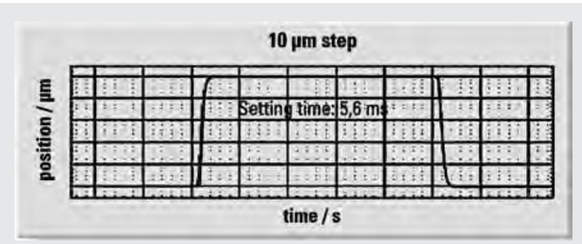
P-726.11
P-726 PIFOC® Thread Adapter M25 x 0.75

P-726.12
P-726 PIFOC® Thread Adapter W0.8 x 1/36"

Ask about custom designs!



P-726 dimensions in mm with P-726.05 M32 QuickLock adapter



P-726 settling time under load

Technical Data

	P-726.1CD	Tolerance
Active axes	Z	
Motion and positioning		
Integrated sensor	Capacitive, direct metrology	
Closed-loop travel	100 µm	calibrated
Closed-loop resolution	0.4 nm	typ.
Open-loop resolution	0.3 nm	typ.
Linearity, closed-loop	0.02 %	typ.
Repeatability	±3 nm	typ.
Runout θ_X, θ_Y	±5 µrad	typ.
Crosstalk X, Y	50 nm	typ.
Mechanical properties		
Stiffness in motion direction	3.4 N/µm	±20 %
Unloaded resonant frequency	1120 Hz	±20 %
Resonant frequency under load	560 Hz @ 210 g	±20 %
Resonant frequency under load	480 Hz @ 310 g	±20 %
Push/pull force capacity in motion direction	100 / 50 N	Max.
Drive properties		
Piezo ceramic type	PICMA® P-885	
Electrical capacitance	6 µF	±20 %
Dynamic operating current coefficient	7.5 µA/(Hz • µm)	±20 %
Miscellaneous		
Operating temperature range	-20 to 80 °C	
Material	Aluminum, steel	
Dimensions	Diameter: 65 mm, Height: 50.7 mm	
Max. objective diameter	M32	
Mass	575 g	±5 %
Cable length	1.5 m	±10 mm
Sensor / voltage connection	Sub-D Special	
Recommended controller / amplifier	Single-channel digital controller: E-753 (bench-top) (p. 2-108) E-625 bench-top controller (p. 2-114), E-665 high-power bench-top controller (p. 2-116) E-500 modular piezo controller system (p. 2-142) with E-505 high-power amplifier module (p. 2-147) and E-509 servo-controller (p. 2-152)	
System properties		
System configuration	E-500 modular piezo controller system with E-505 high-power amplifier module and E-509 servo-controller 310 g load (objective mass)	
Closed-loop amplifier bandwidth, small signal, 10 µm	130 Hz	
Closed-loop amplifier bandwidth, large signal	70 Hz	

P-726 QuickLock thread adapter exploded view with P-726 PIFOC® (mounting tools included)

N-725 PIFOC® High-Load Objective Scanner

1 mm Travel, Fast Response and Nanometer Precision

N-725 PIFOC® is the first piezo-objective drive with integrated NEXACT® Piezo Linear Motor, combining smooth motion, long travel ranges and fast response with extreme position stability

- **High Force & High-Dynamics for Positioning and Scanning of Large Objectives up to 29 mm Ø**
- **1 mm Travel for Applications with Large Penetration Depth**
- **Ideal for e. g. Two-Photon Microscopy**
- **Very Fast Response: 20 ms Step and Settle Time**
- **Self Locking at Rest, no Heat Generation, no Servojitter**
- **Drive Resolution < 1 nm, 20 nm Encoder Resolution**
- **Two Motion Modes: Continuous Nanostepping and High-Dynamics Analog Mode**
- **Compact Design: Ø 48 mm, 40.5 mm Height**
- **Frictionless, High-Precision Flexure Guiding System for Better Focus Stability**
- **QuickLock Thread Adapter for Simple Installation**

The N-725 PIFOC® is the first piezo objective nanopositioner equipped with a PiezoWalk® linear motor. This drive combines smooth motion, long travel ranges and fast step and settle with extreme position stability. Its exceptional stroke of 1 mm renders stepper motor positioners -often used as range extenders for piezo drives- unnecessary. The focussing plane can be selected in an extended range without any change of the mechanics. Together with a step and settle time of less than 20 ms this allows for higher throughput.

The large travel range is a big advantage for applications that have large optical penetration depth like two-photon microscopy where it allows to make use of the full working range of the objective and quickly scan through z stacks of up to 1 mm.

Application Examples

- 3-D Imaging
- Screening
- Autofocus systems
- Microscopy
- Confocal microscopy
- Surface structure analysis
- Wafer inspection

Simple Installation with QuickLock Thread Options

The PIFOC® is mounted between the turret and the objective with the QuickLock thread adapter. After threading the adapter into the turret, the QuickLock is affixed in the desired position. Because the PIFOC® body need not to be rotated, cable wind-up is not an issue.

PiezoWalk® – the Multi-Functional Piezo Linear Motor

A great advantage characteristic of the NEXACT® drive principle is its dual-mode operating principle combining the best features of piezo motor designs, such as high resolution, high force and high speed into one compact unit. At the target position the drive requires no current and generates no heat while providing long-term, nanometer stability. This autolocking feature also completely eliminates servo jitter as it occurs with other closed-loop motors. Since motion is solely caused by the nanometer precise motion of clamped piezo actuators, there is no wear to limit the lifetime. When operated in closed-loop, excellent velocity control is achieved.

See p. 1-12 for further information on NEXACT® PiezoWalk® technology.

Controller and Drive Electronics Optimized for the Application

NEXACT® actuators require special drive electronics to control the complex stepping sequences. The E-861 includes complete NEXACT® servo controller with low-noise drivers and a powerful DSP. It also comes with ample software for easy integration and highly effective computer control. For applications which do not require the highest resolution, the E-862 lower-priced drive electronics can be ordered.

The products described in this document are in part protected by the following patents:
German Patent No. P4408618.0

Ordering Information

N-725.1A
PIFOC® Piezo Nanofocusing Z-Drive with NEXACT® Linear Motor, 1 mm, Linear Encoder, 20 nm Resolution, for QuickLock Thread Adapters

Accessories

QuickLock Thread Adapters:
see figure

P-721.90Q
Extens. Tube, 12.5 mm, Thread W0.8 x 1/36''

P-721.91Q
Extens. Tube, 12.5 mm, Thread M25 x 0.75

P-721.92Q
Extens. Tube, 12.5 mm, Thread M26 x 0.75

P-721.93Q
Extens. Tube, 12.5 mm, Thread M27 x 0.75

P-721.94Q
Extens. Tube, 12.5 mm, Thread M28 x 0.75

P-721.95Q
Extens. Tube, 12.5 mm, Thread M32 x 0.75

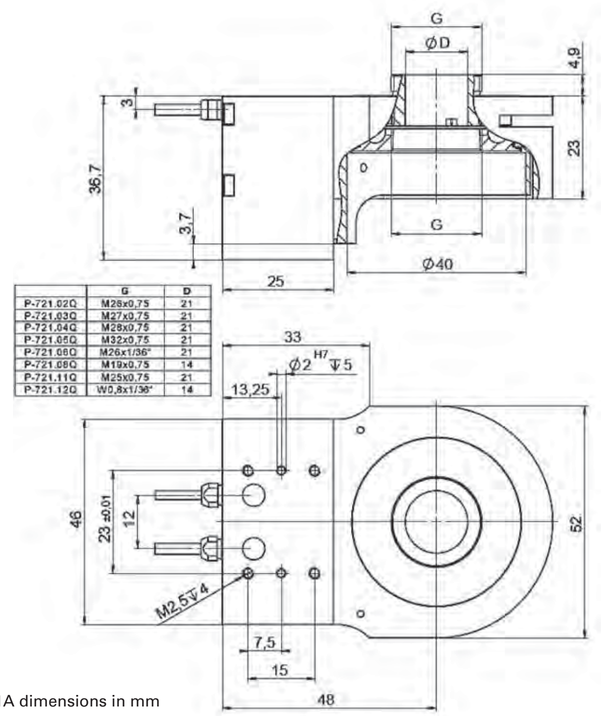
P-721.96Q
Extens. Tube, 12.5 mm, Thread M26 x 1/36''

P-721.98Q
Extens. Tube, 12.5 mm, Thread M19 x 0.75

Ask about custom designs!

Scanner for Higher Resolution and Higher Loads

PI offers a range of related PIFOC® objective scanners with different specifications. The P-725 models e. g. (s. p. 2-28) offer resolutions of less than one nanometer. For larger loads and dynamic scanning applications the models P-726 (s. p. 2-32) and P-725.DD (s. p. 2-30) are also available with travel ranges of up to 100 µm.



	G	D
P-721.02Q	M26x0,75	21
P-721.03Q	M27x0,75	21
P-721.04Q	M28x0,75	21
P-721.05Q	M32x0,75	21
P-721.06Q	M26x1/36"	21
P-721.08Q	M19x0,75	14
P-721.11Q	M25x0,75	21
P-721.12Q	W0,8x1/36"	14

N-725.1A dimensions in mm

Technical Data

Model	N-725.1A
Active axes	Z
Motion and positioning	
Travel range	1 mm
Integrated sensor	Linear encoder
Sensor resolution	20 nm *
Travel range in analog mode	7 µm
Closed-loop resolution	20 nm *
Linearity, closed-loop	0.1%
Bidirectional repeatability	50 nm
Rotation (X, Y) typ.	15 µrad / 100 µm
Step and Settle (200 nm), typ.	20 ms
Max. velocity	10 mm/s*
Mechanical properties	
Stiffness in motion direction	0.5 N/µm
Max. push / pull force (active)	10 N
Drive properties	
Drive type	NEXACT® linear drive
Operating voltage	-10 V to +45 V
Miscellaneous	
Operating temperature range	0 to 50°C
Material	Aluminium
Mass	440 g
Cable length	1.5 m
Connector	HD sub-D connector, 15-pin
Recommended controller	E-861.1A1 Controller for NEXACT® Linear Drives and Positioners

* With E-861. Depending on drive electronics.

PI

P-611.Z Piezo Z-Stage

Compact Nanopositioner

P-611 Z-axis nanopositioning stage,
100 µm closed-loop travel, resolution to 0.2 nm

- **Compact: Footprint Only 44 x 44 mm**
- **Travel Range to 120 µm**
- **Resolution to 0.2 nm**
- **Cost-Effective Mechanics/Electronics System Configurations**
- **Frictionless, High-Precision Flexure Guiding System**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **X, XY, XZ and XYZ Versions also Available**

P-611 Z stages are piezo-based nanopositioning systems with 100 µm closed-loop travel range featuring a compact footprint of only 44 x 44 mm. The stages described here are part of the P-611 family of positioners available in 1- to 3-axis configurations. Equipped with ceramic-encapsulated piezo drives and a stiff, zero-stiction, zero-friction flexure guiding system, all P-611 piezo stages combine millisecond responsiveness with nanometric precision and extreme reliability.

The P-611.Z versions described here are ideally suited for use in applications such as microscopy, auto-focusing and photonics packaging.

Application Examples

- Photonics / integrated optics
- Micromachining
- Micromanipulation
- Semiconductor testing

Closed-Loop and Open-Loop Versions

High-resolution, fast-responding, strain gauge sensors (SGS) are applied to appropriate locations on the drive train and provide a high-bandwidth, nanometer-precision position feedback signal to the controller. The sensors are connected in a full-bridge configuration to eliminate thermal drift, and assure optimal position stability in the nanometer range.

The open-loop models are ideal for applications where fast response and very high resolution are essential, but absolute positioning is not important. They can also be used when the position is controlled by an external feedback system such as an interferometer, a PSD (position sensitive diode), CCD chip / image processing system, or the eyes and hands of an operator.

Versatility & Combination with Motorized Stages

The P-611 family of piezo stages comprises a variety of single- and multi-axis versions (X, XY, Z, XZ and XYZ) that can be easily combined with a number of very compact manual or motorized micropositioning systems to form coarse/fine positioners with longer travel ranges (see p. 2-20, p. 2-50 *ff*).

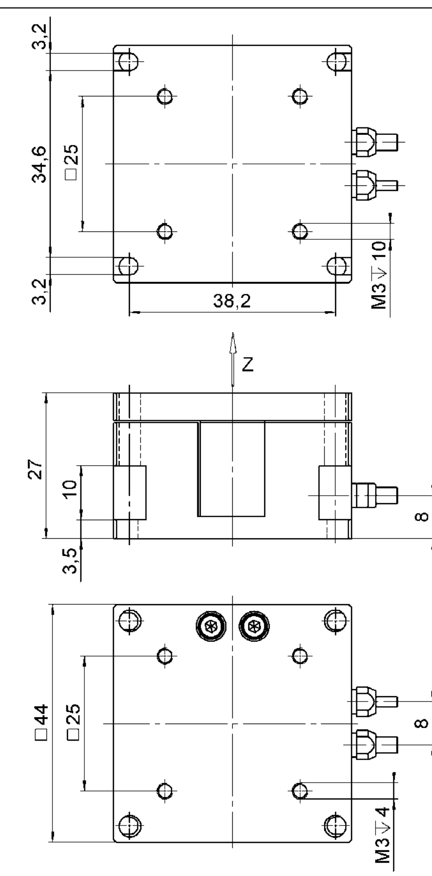
High Reliability and Long Lifetime

The compact P-611 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and thus offer better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free and not subject to wear, and thus offer an extraordinary reliability.

Ordering Information

P-611.Z0
Vertical Nanopositioning Stage, 120 µm, No Sensor

P-611.ZS
Vertical Nanopositioning Stage, 100 µm, SGS-Sensor



P-611.ZS dimensions in mm

Nanopositioning / Piezoelectric Positioners

Piezo Systems

Precision Flexure-Guided Nanopositioners and Scanners


Drive, sensors, mechanics and control electronics with software – components of PI's positioning systems

From Piezo Actuators to Piezo Nanopositioning and Scanning Systems

Piezo ceramic actuators are at the heart of most PI nanopositioning systems. These actuators provide sub-nanometer resolution and sub-millisecond response time by frictionless motion based on molecular effects. To form a high performance nanopositioning system, the intrinsic advantages of the piezo drive have to be complemented by a frictionless, stiff guidance system and highly linear, responsive nanometrology sensors for position feedback. Sophisticated digital servo systems, low noise drivers and control algorithms are necessary to support the mechanical part of the nanopositioning system.

Flexures – the Main Mechanical Component

Flexure motion is based on the elastic deformation (flexing) of a solid material. Friction and stiction are entirely eliminated, and flexures exhibit high stiffness, load capacity and resistance to shock and vibration. Flexures are maintenance free and not subject to wear. They are vacuum compatible, operate over a wide temperature range and require neither lubricants nor compressed air for operation. PI flexures are optimized for highest possible stiffness and straightness / flatness in the nanometer realm combined in many cases with integrated motion amplifiers. This allows for extended travel up to the millimeter range.

Excellent Guiding Accuracy

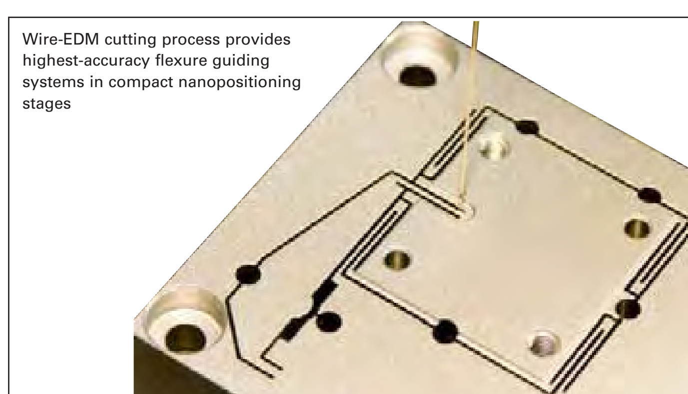
The multilink flexure guiding systems employed in most PI piezo nanopositioners eliminate cosine errors and provide bidirectional flatness and straightness in the nanometer or microradian range. This high precision means that even the most demanding positioning tasks can be run bidirectionally for higher throughput.

Lifetime / PICMA® Piezo Actuators

PI nanopositioning systems employ the award-winning PICMA® piezo actuators, the only actuators with co-fired ceramic encapsulation. The PICMA® piezo technology was specifically developed by PI's piezo ceramic division to provide higher performance and lifetime in nanopositioning applications.

Multilayer piezo actuators are similar to ceramic capacitors and are not affected by wear and tear. Read p. 2-12 *ff* for details.


P-733 low-profile XY and XYZ scanning stages


Wire-EDM cutting process provides highest-accuracy flexure guiding systems in compact nanopositioning stages

CE & RoHS Compliance

All standard PI nanopositioning systems are fully CE and RoHS compliant.

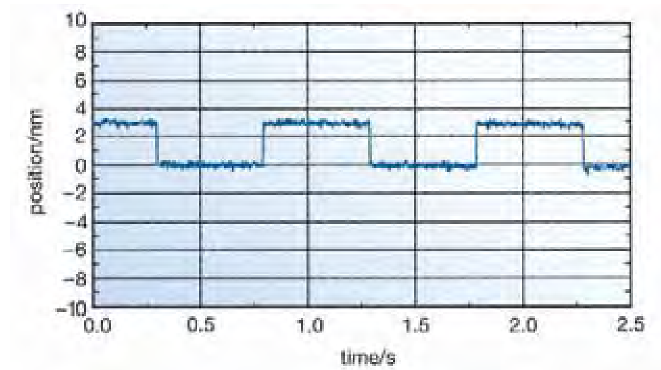
Measuring Nanometers: Stage Metrology Selection

Achieving nanometer and subnanometer precision requires a stage internal metrology system, capable of measuring motion on the nanometer scale. The five primary characteristics to consider when selecting a stage metrology system are linearity, sensitivity (resolution), stability, bandwidth, and cost. Other factors include the ability to measure the moving platform directly and contact vs. noncontact measurement. Three types of sensors are typically used in piezo nanopositioning applications—capacitive, strain, and LVDT. Table 1 summarizes the characteristics of each sensor type. For long travel ranges of 1mm and above, classical piezo multilayer or stack drives are replaced by PiezoWalk® motors. These unique drives are complemented by special optical linear sensors to achieve nanometer precision and linearities of 0.001%.

PI capacitive sensors measure the gap between two plates or one plate and a planar, conducting surface based on electrical capacitance. These sensors can be designed to become an integral part of a nanopositioning system, with virtually no effect on size and mass (inertia). Capacitive sensors offer the highest resolution, stability, and bandwidth. They enable direct measurement of the moving platform and are noncontact. Capacitive sensors also offer the highest linearity (accuracy). PI's capacitive sensors / control electronics use a high-frequency AC excitation signal for enhanced bandwidth and drift-free measurement stability (subnanometer stability over several hours, see p. 3-17 *ff*). PI's exclusive ILS linearization system further improves system linearity. If used with PI's digital controllers, digital polynomial linearization of mechanics and electronics makes possible an overall system linearity of better than 0.01 %. Capacitive sensors are the metrology system of choice for the most demanding applications.

A strain gauge sensor is a resistive metal or semiconductor film bonded to a piezo stack or—for enhanced precision—to the guiding system of a flexure stage. It offers high resolution and bandwidth and is typically chosen for cost-sensitive applications. As a contact type sensor, it measures indirectly, in that the position of the moving platform is inferred from a measurement at the lever, flexure or stack. PI employs full-bridge implementations with multiple strain gauges per axis for enhanced thermal stability. PI's PICMA® drive technology also enables higher performance of actuator-applied strain gauge sensors.

LVDT sensors measure magnetic energy in a coil. A magnetic core attached to the moving platform moves within a coil attached to the frame producing a change in the inductance equivalent to the position change. LVDT sensors provide noncontact, direct measurements of position. They are cost-effective and offer high stability and repeatability.



Response of a PI Nanopositioning stage to a square wave control signal clearly shows the true sub-nm positional stability, incremental motion and bidirectional repeatability. Measured with external capacitive gauge, 20 pm resolution.

Table 1

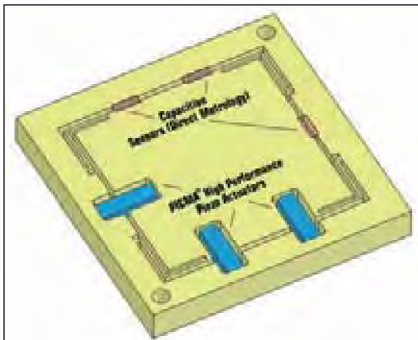
Sensor Type	Sensitivity* (Resolution)	Linearity*	Sability* / Repeatability	Bandwidth*	Metrology Type	Excitation Signal
Capacitive	Best	Best	Best	Best	Direct / Noncontact	AC
Strain	Better	Good	Good	Better	Inferred** (Indirect) / Contact	DC
LVDT	Good	Good	Better	Good	Direct / Noncontact	AC
Linear Encoder	Best***	Best***	Best***	Better	Direct / Noncontact	DC

*The ratings describe the influence of the sensor on the performance of the whole nanopositioning system. Resolution, linearity, repeatability, etc. specifications in the PI product data sheets indicate the performance of the complete system and include the controller, mechanics and sensor. They are verified using external nanometrology equipment (Zygo Interferometers). It is important not to confuse these figures with the theoretical performance of the sensor alone.
**Strain type sensors (metal foil, semiconductor, or piezoresistive) infer position information from strain.
***for travel ranges >1mm

Parallel and Serial Designs

There are two ways to achieve multi-axis motion: parallel and serial kinematics. Serial kinematics (nested or stacked systems) are simpler and less costly to implement, but they have some limitations compared to parallel kinematics systems.

In a multi-axis serial kinematics system, each actuator (and usually each sensor) is assigned to exactly one degree of freedom. In a parallel kinematics multi-axis system, all actuators act directly on the same moving platform (relative to ground), enabling reduced size and inertia, and the elimination of microfriction caused by moving cables. This way, the same resonant frequency and dynamic behavior can be obtained for both the X and Y axes. The advantages are higher dynamics and scanning rates, better trajectory guidance as well as better reproducibility and stability.

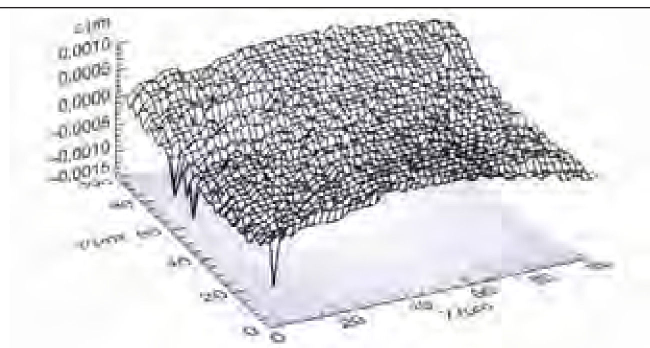


Principle of a PI XY-Theta-Z, minimum-inertial-mass, monolithic, parallel kinematics nanopositioning system. Accuracy, responsiveness and straightness/flatness are much better than in stacked multi-axis (serial kinematics) systems.

Direct Parallel Metrology: Multi-Axis Measurements Relative to a Fixed Reference

Parallel kinematics facilitates implementation of Direct Parallel Metrology—measurement of all controlled degrees of freedom relative to ground. This is a more difficult design to build but it leads to clear performance advantages.

A parallel metrology sensor sees all motion in its measurement direction, not just that of one actuator. This means that all motion is inside the servo-loop, no matter which actuator may have caused it, resulting in superior multi-axis precision, repeatability and flatness, as shown in the figure below. Direct parallel metrology also allows stiffer servo settings for faster response. Off-axis disturbances—external or internal, such as induced vibration caused by a fast step of one axis—can be damped by the servo.



Flatness of an active-trajectory-controlled nanopositioning stage over 100 x 100 µm scanning range is about 1 nm

PI

Analog and Digital Controllers

PI offers the largest selection of digital and analog piezo drivers / linear amplifiers and piezo motion controllers worldwide.

The electronics play a key role for maximum performance of piezoelectric nanopositioning stages, tip/tilt mirrors and actuators. Ultra-low-noise, high-stability servo-controllers and linear amplifiers are essential, because piezoelectric actuators respond to even microvolt changes of the control voltage with motion.

For industrial applications, where maximum throughput is crucial, PI offers digital control algorithms for dynamic linearization and reduced settling times. For dynamic high-power applications, PI's unique energy-recovery power amplifiers provide up to 2000 W of peak power!

State-of-the-art PI digital control systems offer several advantages over analog control systems: coordinate transformation, real-time linearity compensation and elimination of some types of drift. Digital controllers also allow virtually instant changes of servo parameters for different load conditions, etc. However, not all digital controllers are created equal. Poor implementations can add noise and lack certain capabilities of a well-designed analog implementation, such as fast settling time, compatibility with advanced feed-forward techniques, stability and robust operation.

PI digital controllers can download device-specific parameters from ID-chip-equipped nanopositioning stages, facilitating interchangeability of nanomechanisms and controllers.

All PI nanopositioning controllers (analog and digital) are equipped with one or more user-tunable notch filters. A controller with notch filter can be tuned to provide higher bandwidth because side-effects of system resonances can be suppressed before they affect system stability. For the most demanding step-and-settle applications, PI's exclusive Mach™ InputShaping® implementation is available as an option.

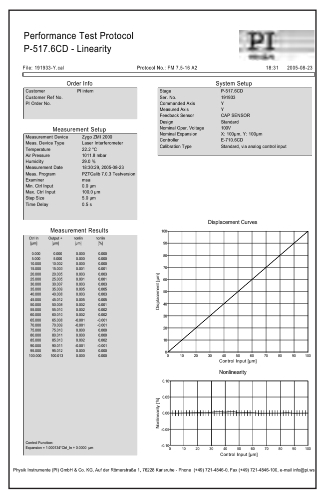
See page 2-100 *ff* Section for a complete overview on PI's piezo drivers and controllers.

Test & Metrology Protocol for Piezo Systems
Getting What You Bargained For

Piezo nanopositioning systems are significant investments and PI believes in optimizing the performance of every customer's system. PI individually tests every stage and optimizes the static and dynamic performance for the customer's application. The metrology test protocol is part of the system's delivery package. It shows the customer what the performance of the system was at the time of delivery and which system components belong together. For PI every metrology procedure and its recording is a quality assurance instrument, and only nanopositioning systems which meet their specifications will leave the premises.

Furthermore, PI makes significant continuing investments in improved-quality, higher-performance nanometrology equipment so that we can deliver better value to our customers.

Because a nanomechanism can only be as accurate as the equipment it was tuned and tested with, PI closed-loop stages are measured exclusively with prestigious Zygo interferometers. PI's nanometrology metrology laboratories are seismically, electromagnetically and thermally isolated, with temperatures controlled to better than 0.25 °C / 24 hrs. We are confident that our metrology capabilities and procedures are the benchmark for the industry.



Performance Test Protocol
P-517.6CD - Linearity

File: 191933-Y.cal | Protocol No.: FM 7.5-16 A2 | 18:31 2005-08-23

Order Info

Customer	PI intern
Customer Ref No.	
PI Order No.	

Measurement Setup

Measurement Device	Zygo ZMI 2000
Meas. Device Type	Laser Interferometer
Temperature	22.2 °C
Air Pressure	1011.8 mbar
Humidity	29.0 %
Measurement Date	18:30:29, 2005-08-23
Meas. Program	PZTCalib 7.0.3 Testversion
Examiner	msa
Min. Ctrl Input	0.0 µm
Max. Ctrl Input	100.0 µm
Step Size	5.0 µm
Time Delay	0.5 s

System Setup

Stage	P-517.6CD
Ser. No.	191933
Commanded Axis	Y
Measured Axis	Y
Feedback Sensor	CAP SENSOR
Design	Standard
Nominal Oper. Voltage	100V
Nominal Expansion	X: 100µm, Y: 100µm
Controller	E-710.6CD
Calibration Type	Standard, via analog control input

Measurement Results

Ctrl In [µm]	Output + [µm]	nonlin [µm]	nonlin [%]
0.000	0.000	0.000	0.000
5.000	5.000	0.000	0.000
10.000	10.002	0.000	0.000
15.000	15.003	0.001	0.001
20.000	20.005	0.003	0.003
25.000	25.005	0.001	0.001
30.000	30.007	0.003	0.003
35.000	35.009	0.005	0.005
40.000	40.008	0.003	0.003
45.000	45.012	0.005	0.005
50.000	50.008	0.002	0.001
55.000	55.010	0.002	0.002
60.000	60.010	0.002	0.002
65.000	65.008	-0.001	-0.001
70.000	70.009	-0.001	-0.001
75.000	75.010	0.000	0.000
80.000	80.011	0.000	0.000
85.000	85.013	0.002	0.002
90.000	90.011	-0.001	-0.001
95.000	95.012	0.000	0.000
100.000	100.013	0.000	0.000

Control Function:
Expansion = 1.000134*Ctrl_In + 0.0000 µm

Physik Instrumente (PI) GmbH & Co. KG, Auf der Römerstraße 1, 76228 Karlsruhe - Phone (+49) 721-4846-0, Fax (+49) 721-4846-100, e-mail info@pi.ws

All PI nanopositioning systems come with extensive system performance documentation

An S-334 long-range 2-axis fast steering mirror measured with a Moeller Wedel autocollimator

An S-340 2-axis fast steering mirror platform measured with a Zygo interferometer

PI

PICMA® Piezo Actuators—Extreme Lifetime, for Industrial Reliability Requirements

Full-Ceramic Encapsulation & Patented Design

PICMA® award-winning multilayer piezo actuators feature full-ceramic insulation

PI has 4 decades of experience with piezo ceramic actuators in motion control applications in industry and research. Currently PI employs more than 100 people fully dedicated to piezo ceramic research, development and production. Extensive know-how and the most modern equipment make for the unique flexibility and worldwide leadership in piezo matters.

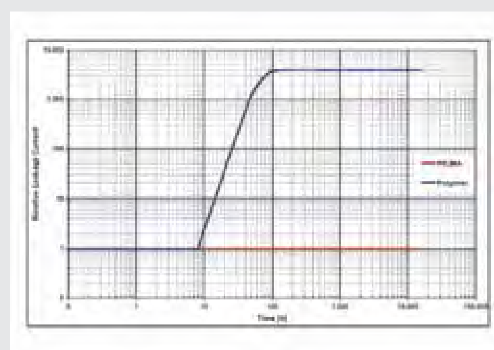
PI piezo actuators not only show an optimal combination of travel and stiffness, but are also designed for maximum lifetime under actual operating conditions in industrial environments.

Maximum lifetime means highest possible reliability. PI's award-winning, patented PICMA® actuators are based upon the newest technology which reduces the failure rate by a factor 10 compared to conventionally designed multilayer actuators.

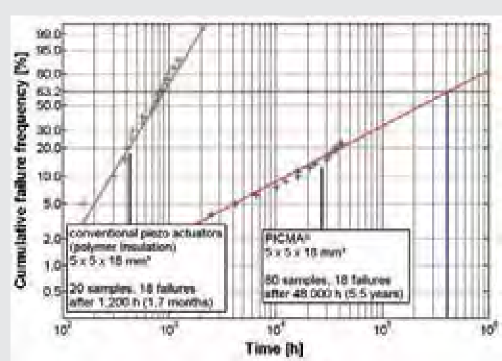
Long Term Tests Prove DC Reliability

PI's monolithic ceramic-encapsulated design provides better humidity protection than conventional polymer-film insulation. Diffusion of water molecules into the insulation layer is greatly reduced by the use of co-fired, outer ceramic encapsulation. Humidity is the main influence on the long-term reliability in low-dynamics or quasi-static operation modes, where the piezo actuator is supplied with a DC voltage to maintain a position for a long time.

Comparative tests with both PICMA® and conventional multilayer piezo actuators have proven the positive effects of the ceramic encapsulation. While polymer-coated piezos typically only survive 30 days of continuous operation - PICMA® actuators are still working after more than 4 years!



PICMA® piezo actuators (lower curve) compared with polymer-insulated multilayer piezo actuators. PICMA® actuators are insensitive to high humidity in this test. In conventional actuators, the leakage current begins to rise after only a few hours—an indication of degradation of the insulation and reduced lifetime.



Results of an accelerated DC-lifetime-test of PICMA® actuators compared to conventional actuators (100 V DC, room temperature, 90% R.H.). The expected MTTF (Mean Time To Failure) for PICMA® is 80 years (700 000 hrs of continuous operation). All of the polymer-insulated samples have failed after 1,600 hrs (MTTF 805 hrs = 1 month)

Continuous Dynamic Operation

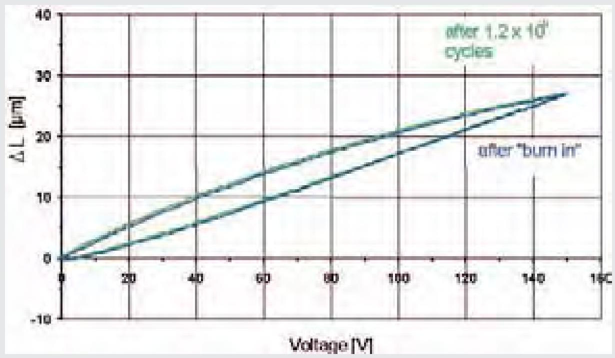
Here, the well-known lifetime-limiting factors of conventional designs are humidity, crack formation inside the ceramic leading to rising leakage currents and delamination of electrodes under extreme dynamic conditions.

PI reduces the cracking probability by a special patented design where segmented slots take care of excessive tensional stresses. Furthermore, the special electrode design ensures excellent, stable, electric contact even after billions of cycles.

PICMA® multilayer piezo actuators show no significant decrease in displacement even after many billions of cycles.

Long-Term Test under Cryogenic Conditions

To suit an application requiring 10 years minimum lifetime under cryogenic conditions, accelerated lifetime tests with PICMA® piezo actuators have been successfully performed. Inserted in a cryogenic bath of liquid nitrogen (75 K), the piezo is placed in a vacuum chamber (2 • 10^{-3} mbar) and subjected to dynamic operation at 90 % of the maximum voltage range (>105 V) with an operating frequency up to 1000 Hz. After one month of continuous operation there were no degradations in piezo performance to be measured, neither mechanic concerning the displacement, nor electrical concerning electrical capacitance or resonant frequency (Dr. Bosotti et al., University of Milano, Italy, 2005).



AC tests were performed for 4.0 x 109 cycles at 8 samples PICMA® 5x5x18 using a 116 Hz-sine wave excitation (1.0 x 107 cycles per day) at a unipolar operating voltage of 100 V, 15 MPa preload. Control measurements were taken every 109 cycles. There was no significant decrease in displacement.

Large Operating Temperature Range , Optimum UHV Compatibility—Minimum Outgassing

Another advantage of fully ceramic-encapsulation PICMA® actuators is the extended operating temperature range, up to 150 °C, a huge improvement over the 80 °C limit common for other, polymer-insulated, monolithic actuators. The heat generation in dynamic operation is proportional to the operating frequency. Thus, a higher operating temperature allows for higher operating frequencies and duty cycles. Additionally, the lack of polymer insulation and the high Curie temperature make for optimal ultra-high-vacuum compatibility (no outgassing / high bake-out temperatures, up to 150 °C).

P-712 Low-Profile Piezo Scanner

Compact OEM System

P-712 piezo scanner with up to 40 µm travel range

- **High Dynamic, to 5 ms Settling Time**
- **Travel Range up to 40 µm**
- **Resolution to 0.2 nm**
- **Compact Design with Low Profile, 40 x 40 x 6 mm**
- **Clear Aperture 25 x 15 mm**
- **PICMA® High-Power Actuators**

P -712 piezo scanners are ideal for applications where limited space requires small-sized equipment. The high resonant frequency allows for fast linear scanning with 30 µm travel in one axis and provides settling times of about 5 ms. The P-712 linear scanner is offered in two versions, one with SGS position sensors for closed-loop operation, and one without sensors for open-loop.

Application Examples

- Optical path tuning
- Biotechnology
- Medical technology
- Image processing / stablilization
- CCD / CMOS camera technology

A similar XY version is available with product number P-713 / P-714 (see p. 2-56).

Excellent Guiding Accuracy

Flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. FEA techniques are used to give the design the highest possible stiffness in, and perpendicular to, the direction of motion, and to minimize linear and angular runout. Flexures allow extremely high-precision motion, no matter how minute, as they are completely free of play and friction.

Electric discharge machining (EDM) with fine cutting wires is used to obtain the required precision for the flexures which make up the guidance system and determine the stiffness.

Optional Position Control

High-resolution, broadband, strain gauge sensors (SGS) are applied to appropriate locations on the drive train and measure the displacement of the moving part of the stage relative to the base indirectly. The SGS sensors assure optimum position stability in the nanometer range and fast response.

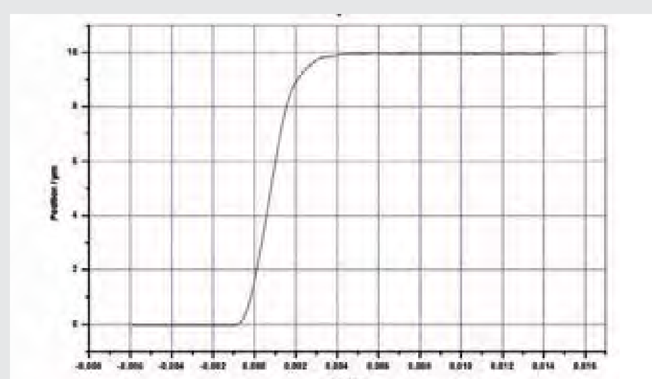
Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

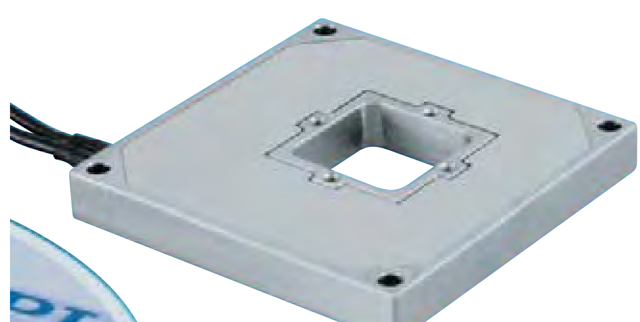
Ordering Information

P-712.10L
Low-Profile OEM Nanoscanner, 40 µm, Open-Loop

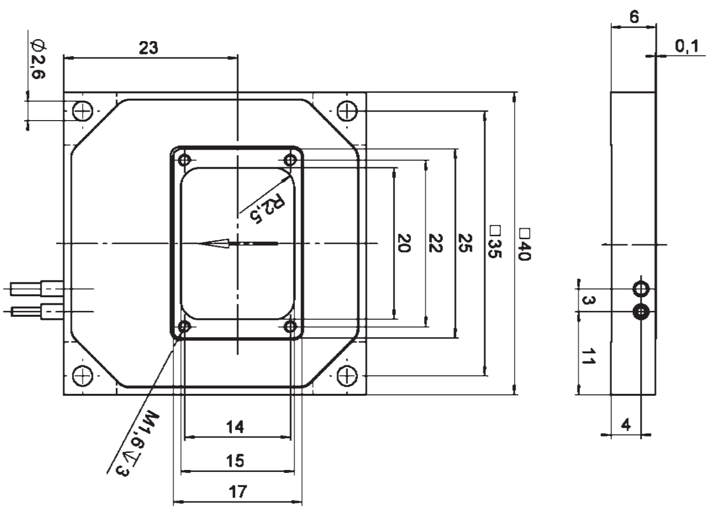
P-712.1SL
Low-Profile OEM Nanoscanner, 30 µm, SGS-Sensor



Settling time for the P -712 at 30 µm is in the 5 ms range



The P -713 XY-scanner is based on the same principle as the P -712 offering a travel range of 15 x 15 µm and a very high resonant frequency of over 2 kHz



P-712 dimensions in mm

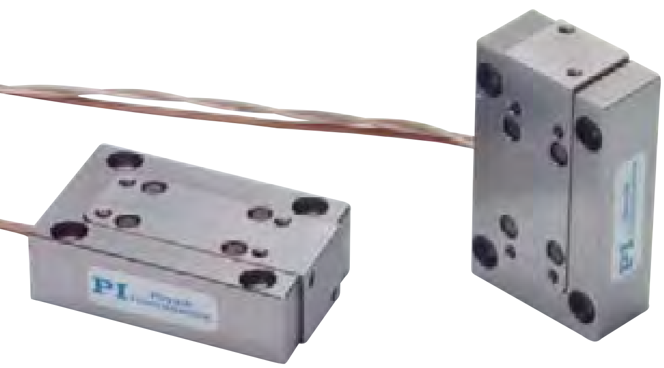
Technical Data

Model	P-712.1SL	P-712.10L	Units	Tolerance
Active axes	X	X		
Motion and positioning				
Integrated sensor	SGS	–		
Open-loop travel, -20 to +120 V	40	40	µm	min. (+20 %/0 %)
Closed-loop travel	30	–	µm	calibrated
Closed-loop resolution	2	–	nm	typ.
Open-loop resolution	0.2	0.2	nm	typ.
Linearity, closed-loop	0.3	–	%	typ.
Repeatability	±5	–	nm	typ.
Pitch	±5	±5	µrad	typ.
Yaw	±20	±20	µrad	typ.
Mechanical properties				
Stiffness in motion direction	0.6	0.6	N/µm	±20 %
Unloaded resonant frequency	1550	1550	Hz	±20 %
Resonant frequency under load	1090 (20 g)	1090 (20 g)	Hz	±20 %
Push/pull force capacity in motion direction	6	6	N	Max.
Load capacity	5	5	N	Max.
Lateral Force	6	6	N	Max.
Drive properties				
Ceramic type	PICMA® P-882	PICMA® P-882		
Electrical capacitance	0.3	0.3	µF	±20 %
Dynamic operating current coefficient	1.3	1.3	µA/(Hz • µm)	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80		
Material	Stainless steel	Stainless steel		
Dimensions	40 x 40 x 6	40 x 40 x 6	mm	
Mass	0.095	0.095	kg	±5 %
Cable length	1.5	1.5	m	±10 mm
Voltage connection	LEMO	LEMO		
Sensor connector	LEMO	–		

Recommended controller / amplifier
Single-channel (1 per axis): E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114)

P-753 LISA Linear Actuator & Stage

High-Dynamics, Very Stable Piezo Nanopositioner



P-753.11C LISA nano-precision actuators / positioning stages

- **Versatile Design: Flexure Stage or Actuator**
- **Resolution 0.05 nm, Rapid Response**
- **Capacitive Sensors for Highest Linearity**
- **Frictionless Precision Flexure Guidance for Frictionless, Ultra-Straight Motion**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Vacuum-Compatible and Nonmagnetic Versions Available**

The P-753 LISA (Linear Stage Actuators) high-speed nanopositioners can be used both as linear actuators or as translation stages. They are equipped with capacitive feedback sensors, frictionless, flexure guiding systems and high-performance piezo drives providing a positioning and scanning range of up to 38 µm with very fast settling time and extremely low tip/tilt error.

Application Examples

- Disc-drive-testing
- Metrology
- Nanopositioning
- Scanning microscopy
- Photonics / integrated optics
- Interferometry
- Biotechnology
- Micromanipulation

Direct-Drive Design for Fastest Response

The direct-drive design, together with careful attention to mass minimization, results in significant reduction in inertial recoil forces applied to the supporting structures, enhancing overall system response, throughput and stability with settling times in the millisecond range.

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Automatic Configuration

The „.CD“ versions are equipped with an ID-chip that stores all individual stage data and servo-control parameters. This data is read out automatically by the AutoCalibration Function of PI's digital piezo controllers. Thus, digital controllers and nanopositioning stages with ID-chip can be operated in any combination.

High Reliability and Long Lifetime

The compact P-753 LISA systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and thus offer better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free and not subject to wear, and thus offer an extraordinary reliability.

Ordering Information

P-753.11C
LISA High-Dynamics Nanopositioning System, 12 µm, Direct Metrology, Capacitive Sensor, LEMO Connector

P-753.21C
LISA High-Dynamics Nanopositioning System, 25 µm, Direct Metrology, Capacitive Sensor, LEMO Connector

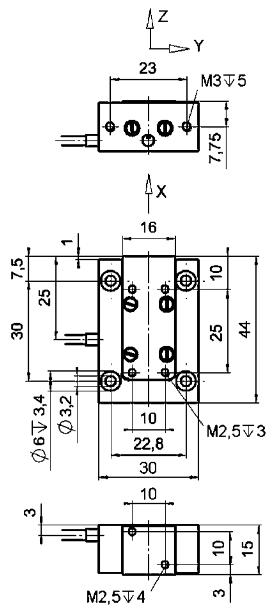
P-753.31C
LISA High-Dynamics Nanopositioning System, 38 µm, Direct Metrology, Capacitive Sensor, LEMO Connector

P-753.1CD*
LISA High-Dynamics Nanopositioning System, 12 µm, Direct Metrology, Capacitive Sensor, Sub-D Connector

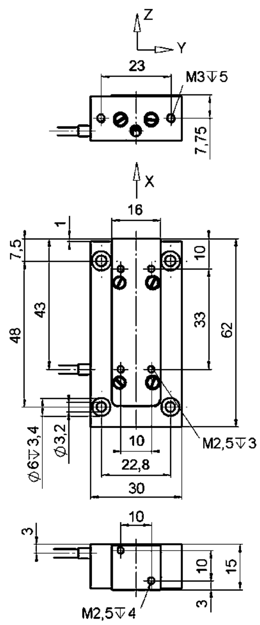
P-753.2CD*
LISA High-Dynamics Nanopositioning System, 25 µm, Direct Metrology, Capacitive Sensor, Sub-D Connector

P-753.3CD*
LISA High-Dynamics Nanopositioning System, 38 µm, Direct Metrology, Capacitive Sensor, Sub-D Connector

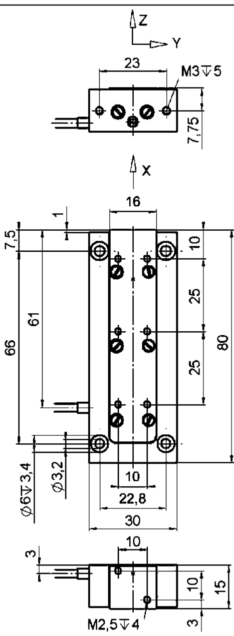
*Vacuum versions to 10^{-9} hPa are available as P-753.xUD, non-magnetic vacuum versions can be ordered as P-753.xND.



P-753.1 dimensions in mm, max. torque at M2.5 threads: 30 Ncm



Picture sub text 03
P-753.2 dimensions in mm, max. torque at M2.5 threads: 30 Ncm



P-753.3 dimensions in mm, max. torque at M2.5 threads: 30 Ncm

Technical Data

Model	P-753.11C	P-753.21C	P-753.31C	P-753.1CD	P-753.2CD	P-753.3CD	Units	Tolerance
Active axes	X	X	X	X	X	X		
Motion and positioning								
Integrated sensor	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive		
Closed-loop travel	12	25	38	12	25	38	µm	calibrated
Closed-loop / open-loop resolution	0.05	0.1	0.2	0.05	0.1	0.2	nm	typ., full travel
Linearity, closed-loop	0.03	0.03	0.03	0.03	0.03	0.03	%	typ.
Repeatability	±1	±2	±3	±1	±2	±3	nm	typ.
Pitch / yaw	±5	±7	±10	±5	±7	±10	µrad	typ.
Mechanical properties								
Stiffness in motion direction	45	24	16	45	24	16	N/µm	±20 %
Unloaded resonant frequency	5.6	3.7	2.9	5.6	3.7	2.9	kHz	±20 %
Resonant frequency @ 200 g	2.5	1.7	1.4	2.5	1.7	1.4	kHz	±20 %
Push/pull force capacity in motion direction	100 / 20	100 / 20	100 / 20	100 / 20	100 / 20	100 / 20	N	Max.
Load capacity (vertical/horizontal mounting)	10 / 2	10 / 2	10 / 2	10 / 2	10 / 2	10 / 2	kg	Max.
Drive properties								
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical capacitance	1.5	3.1	4.6	1.5	3.1	4.6	µF	±20 %
Dynamic operating current coefficient	12	15	15	12	15	15	µA/(Hz • µm)	±20 %
Miscellaneous								
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel		
Dimensions	44 x 30 x 15	44 x 30 x 62	44 x 30 x 80	44 x 30 x 15	44 x 30 x 62	44 x 30 x 80	mm	
Mass	0.15	0.205	0.25	0.16	0.215	0.26	kg	±5 %
Cable length	1.5	1.5	1.5	1.5	1.5	1.5	m	±10 mm
Sensor / voltage connection	LEMO	LEMO	LEMO	Sub-D Special	Sub-D Special	Sub-D Special		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion with E-503 (p. 2-146) amplifier.
Recommended controller / amplifier
LEMO connector: E-500 (p. 2-142) piezo controller system with E-505 high-power amplifier (p. 2-147) and E-509 servo module (p. 2-152)
Sub-D special connector: E-610 servo controller / amplifier card (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-665 high-power display controller, bench-top (p. 2-116), E-753 digital controller (p. 2-108)

P-752 High Precision Nanopositioning Stage

High-Dynamics, Very Stable Piezo Scanner with Extreme Guiding Accuracy

P-752.11C piezo nanopositioning system

- **0.1 nm Resolution, Fast Response**
- **Travel to 35 µm**
- **Capacitive Sensors for Highest Linearity**
- **Flexure Guidance for Frictionless, Ultra-Straight Motion**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**

P-752 series high-speed nanopositioning stages are extremely precise devices, providing a positioning and scanning range up to 30 µm with very rapid settling and extremely low tip/tilt errors. These stages were specially designed for high-speed dithering and disk drive testing applications.

Application Examples

- Disc-drive-testing
- Metrology
- Nanopositioning
- Scanning microscopy
- Photonics / integrated optics
- Interferometry
- Biotechnology
- Micromanipulation

Direct-Drive Design for Fastest Response

The direct-drive design, together with careful attention to mass minimization, results in significant reduction in inertial recoil forces applied to the supporting structures, enhancing overall system response, throughput and stability. In combination with the E-500 controller system the P-752.11C stage with 300 g load settles to better than 1 % with less 10 msec.

P-752 stages are equipped with capacitive sensors providing sub-nanometer resolution and stability. PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. Further advantages of direct metrology with capacitive sensors are the high phase fidelity and the high bandwidth of up to 10 kHz.

Automatic Configuration

The ".CD" versions are equipped with an ID-chip that stores all individual stage data and servo-control parameters. This data is read out automatically by the AutoCalibration function of PI's digital piezo controllers. Thus, digital controllers and nanopositioning stages with ID-chip can be operated in any combination.

Higher Precision in Periodic Motion

The highest dynamic accuracy in scanning applications is made possible by the DDL algorithm, which is available in most of PI's modern digital controllers. DDL eliminates tracking errors, improving dynamic linearity and usable bandwidth by up to three orders of magnitude!

High Reliability and Long Lifetime

The compact P-752 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and thus offer better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free and not subject to wear, and thus offer an extraordinary reliability.

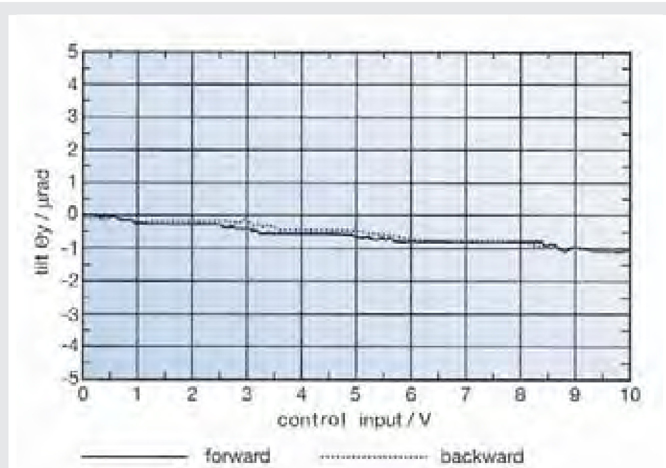
Ordering Information

P-752.11C
High-Dynamics Piezo Nanopositioning System, 15 µm, Direct Metrology, Capacitive Sensor, LEMO Connector

P-752.21C
High-Dynamics Piezo Nanopositioning System, 30 µm, Direct Metrology, Capacitive Sensor, LEMO Connector

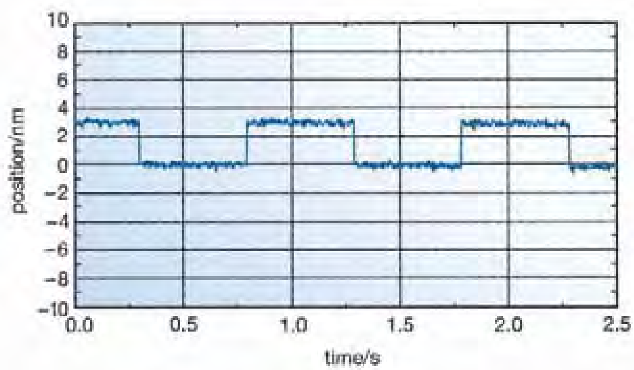
P-752.1CD
High-Dynamics Piezo Nanopositioning System, 15 µm, Direct Metrology, Capacitive Sensor, Sub-D Connector

P-752.2CD
High-Dynamics Piezo Nanopositioning System, 30 µm, Direct Metrology, Capacitive Sensor, Sub-D Connector



Typical 0.5 µrad bidirectional trajectory repeatability (P-752.11C stage) means processes may be performed bidirectionally for twice the productivity

PI



Response of a P-752.11C to a square wave control signal with 3 nm amplitude shows true sub-nm positional stability, incremental motion and bidirectional repeatability (measured with E-501 & E-503.00 & E-509.C1 controller, bandwidth set to 240 Hz)

Technical Data

Model	P-752.11C	P-752.1CD	P-752.21C	P-752.2CD	Units	Tolerance
Active axes	X	X	X	X		
Motion and positioning						
Integrated sensor	Capacitive	Capacitive	Capacitive	Capacitive		
Open-loop travel, -20 to +120 V	20	20	35	35	µm	min. (+20 %/-0 %)
Closed-loop travel	15	15	30	30	µm	calibrated
Closed-loop / open-loop resolution	0.1	0.1	0.2	0.2	nm	typ.
Linearity, closed-loop	0.03	0.03	0.03	0.03	%	typ.
Repeatability	±1	±1	±2	±2	nm	typ., full travel
Pitch / yaw	±1	±1	±1	±1	µrad	typ.
Mechanical properties						
Stiffness in motion direction	30	30	20	20	N/µm	±20 %
Unloaded resonant frequency	3200	3200	2100	2100	Hz	±20 %
Resonant frequency @ 300 g	980	980	600	600	Hz	±20 %
Push/pull force capacity in motion direction	100 / 10	100 / 10	100 / 10	100 / 10	N	Max.
Load capacity	30	30	30	30	N	Max.
Drive properties						
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical capacitance	2.1	2.1	3.7	3.7	µF	±20 %
Dynamic operating current coefficient	17	17	15	15	µA/(Hz • µm)	±20 %
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Stainless steel	Stainless steel	Stainless steel	Stainless steel		
Dimensions	66 x 40 x 13.5	66 x 40 x 13.5	84 x 40 x 13.5	84 x 40 x 13.5	mm	
Mass	0.25	0.25	0.35	0.35	kg	±5 %
Cable length	1.5	1.5	1.5	1.5	m	±10 mm
Sensor / voltage connection	LEMO	Sub-D Special	LEMO	Sub-D Special		

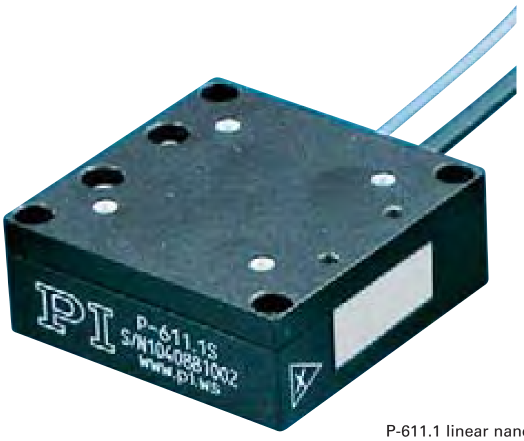
Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion with E-503 (p. 2-146) amplifier.

Recommended controller / amplifier
LEMO connector: E-500 piezo controller system (p. 2-142) with E-505 high-power amplifier (p. 2-147) and E-509 servo module (p. 2-152)
Sub-D special connector: E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-665 high-power display controller, bench-top (p. 2-116), E-753 digital controller (p. 2-108)

PI

P-611.1 Piezo Nanopositioner

Cost-Effective, Compact Linear Positioning System



P-611.1 linear nanopositioning system, 100 µm travel, resolution of 0.2 nm

- **Compact Design: Footprint 44 x 44 mm**
- **Travel Range to 120 µm**
- **Resolution to 0.2 nm**
- **Cost-Effective Mechanics/Electronics System Configurations**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Z Stage, XY, XZ and XYZ Versions Available**

P-611.1 piezo stages are flexure-guided nanopositioning systems featuring a compact footprint of only 44 x 44 mm. The linear stages described here are part of the P-611 family of positioners available in 1 to 3 axis configurations. Despite their small dimensions, the systems provide up to 120 µm travel with sub-nanometer resolution. They are ideally suited for positioning tasks such as optical-path length correction in interferometry, sample positioning in microscopy or scanning applications. Equipped with ceramic-encapsulated piezo drives and a stiff zero-stiction, zero-friction flexure guiding system, all P-611 piezo stages combine millisecond responsiveness with nanometric precision and extreme reliability.

Application Examples

- Micromachining
- Microscopy
- Micromanipulation
- Semiconductor testing

Closed-Loop and Open-Loop Versions

High-resolution, fast-responding, strain gauge sensors (SGS) are applied to appropriate locations on the drive train and provide a high-bandwidth, nanometer-precision position feedback signal to the controller. The sensors are connected in a full-bridge configuration to eliminate thermal drift, and assure optimal position stability in the nanometer range.

The open-loop models are ideal for applications where fast response and very high resolution are essential, but absolute positioning is not important. They can also be used when the position is controlled by an external feedback system such as an interferometer, a PSD (position sensitive diode), CCD chip / image processing system, or the eyes and hands of an operator.

Versatility & Combination with Motorized Stages

The P-611 family of piezo stages comprises a variety of single- and multi-axis versions (X, XY, Z, XZ and XYZ) that can be easily combined with a number of very compact manual or motorized micropositioning systems to form coarse/fine positioners with longer travel ranges (see p. 2-36, 2-50 *ff*).

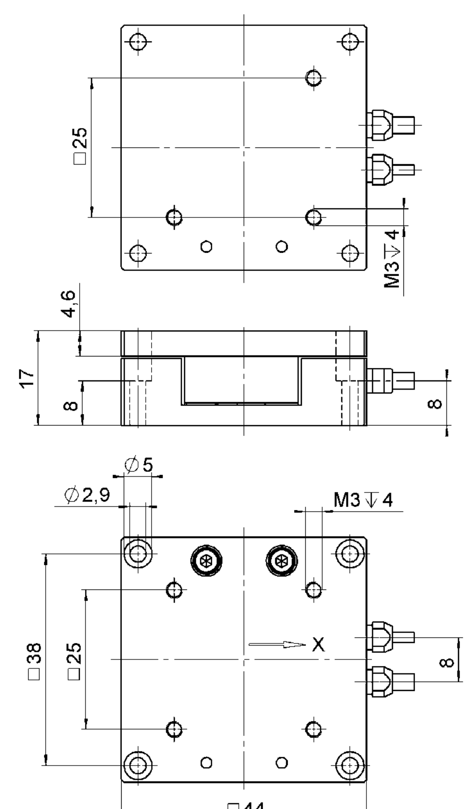
High Reliability and Long Lifetime

The compact P-611 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and thus offer better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free and not subject to wear, and thus offer an extraordinary reliability.

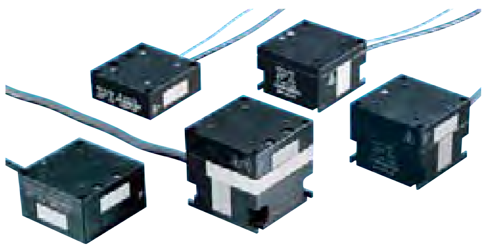
Ordering Information

P-611.10
Linear Nanopositioning System, 120 µm, No Sensor

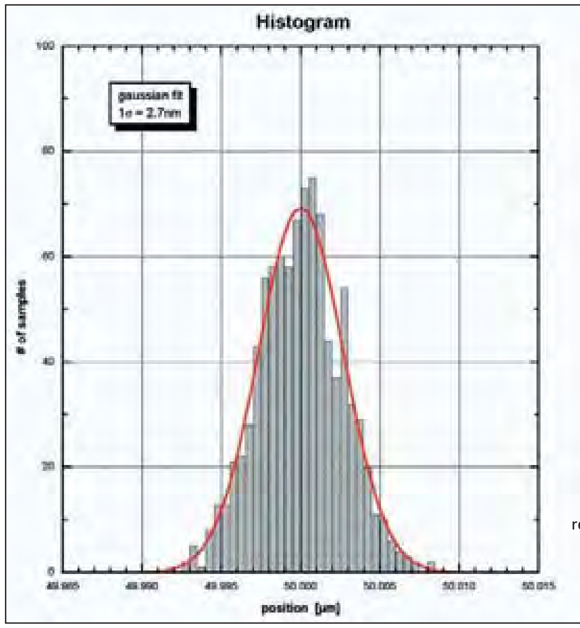
P-611.1S
Linear Nanopositioning System, 100 µm, SGS-Sensor



P-611.1S dimensions in mm



The whole P-611 family: X, Z, XY, XZ and XYZ stages



P-611.1S repeatability equals 2.7 nm

System properties	
System configuration	P-611.1S and E-665.SR controller, 30 g load
Closed-loop amplifier bandwidth, small signal	45 Hz
Settling time (10 % step width)	18 ms

Technical Data

Model	P-611.1S	P-611.10	Unit	Tolerance
Active axes	X	X		
Motion and positioning				
Integrated sensor	SGS	–		
Open-loop travel, -20 to 120 V	120	120	µm	min. (+20 %/0 %)
Closed-loop travel	100	–	µm	calibrated
Open-loop resolution	0.2	0.2	nm	typ.
Closed-loop resolution	2	–	nm	typ.
Linearity, closed-loop	0.1	–	%	typ.
Repeatability	<10	–	nm	typ.
Pitch	±5	±5	µrad	typ.
Yaw	±20	±20	µrad	typ.
Flatness	10	10	nm	typ.
Mechanical properties				
Stiffness in motion direction	0.2	0.2	N/µm	±20 %
Unloaded resonant frequency	400	400	Hz	±20 %
Resonant frequency @ 30 g	300	300	Hz	±20 %
Resonant frequency @ 100 g	195	195	Hz	±20 %
Push/pull force capacity in motion direction	15 / 10	15 / 10	N	Max.
Load capacity	15	15	N	Max.
Drive properties				
Ceramic type	PICMA® P-885	PICMA® P-885		
Electrical capacitance	1.5	1.5	µF	±20 %
Dynamic operating current coefficient	1.9	1.9	µA/(Hz • µm)	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material	Aluminum, steel	Aluminum, steel		
Dimensions	44 x 44 x 17	44 x 44 x 17	mm	
Mass	0.135	0.135	kg	±5 %
Cable length	1.5	1.5	m	±10 mm
Voltage connection	LEMO	LEMO		
Sensor connector	LEMO	–		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Noise equivalent motion with E-503 amplifier (p. 2-146).
Dynamic Operating Current Coefficient in µA per Hz and µm. Example: Sinusoidal scan of 50 µm at 10 Hz requires approximately 0.9 mA drive current.

Recommended controller / amplifier
E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-665 powerful servo controller, bench-top (p. 2-116), for open-loop systems:
E-660 bench-top (p. 2-119) for multiple independent axes:
E-621 controller module (p. 2-160)

P-620.1 – P-629.1 PIHera® Piezo Linear Stage

Compact Nanopositioning System Family with Long Travel Ranges

PIHera® piezo nanopositioning systems feature travel ranges from 50 to 1800 µm

- **Travel Ranges 50 to 1800 µm**
- **High-Precision, Cost-Efficient**
- **Resolution to 0.1 nm**
- **Direct Metrology with Capacitive Sensors**
- **0.02 % Positioning Accuracy**
- **Frictionless, High-Precision Flexure Guiding System**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **X-, XY-, Z-, XYZ Versions**
- **Vacuum-Compatible Versions Available**

Single-axis PIHera® systems are piezo-nanopositioning stages featuring travel ranges from 50 to 1800 µm. Despite the increased travel ranges, the units are extremely compact and provide rapid response and high guiding precision. This and the long travel range is achieved with a friction-free and extremely stiff flexure system.

Application Examples

- Interferometry
- Microscopy
- Nanopositioning
- Biotechnology
- Quality assurance testing
- Semiconductor technology

The PIHera® piezo nanopositioning series also includes Z- and XY-stages (see p. 2-40, p. 2-54).

Nanometer Precision in Milliseconds

One of the advantages of PIHera® stages over motor-driven positioning stages is the rapid response to input changes and the fast and precise settling behavior. The P-622.1CD, for example, can settle to an accuracy of 10 nm in only 30 msec (other PI stages provide even faster response)!

Superior Accuracy With Direct-Metrology Capacitive Sensors

A choice of tasks such as optical path adjustment in interferometry, sample positioning in microscopy, precision alignment or optical tracking require the relatively long scanning ranges and nanometer precision offered by PIHera® nanopositioning stages.

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Designed for Precision

High stiffness is achieved with the FEA-optimized design of the frictionless flexure elements, which assure excellent guiding accuracy and dynamics. A straightness and flatness in the nanometer range is achieved.

Ordering Information

P-620.1CD* / P-620.1CL*
PIHera® Precision Piezo Linear Nanopositioning System, 50 µm, Direct Metrology, Capacitive Sensor

P-621.1CD* / P-621.1CL*
PIHera® Precision Piezo Linear Nanopositioning System, 100 µm, Direct Metrology, Capacitive Sensor

P-622.1CD* / P-622.1CL*
PIHera® Precision Piezo Linear Nanopositioning System, 250 µm, Direct Metrology, Capacitive Sensor

P-625.1CD* / P-625.1CL*
PIHera® Precision Piezo Linear Nanopositioning System, 500 µm, Direct Metrology, Capacitive Sensor

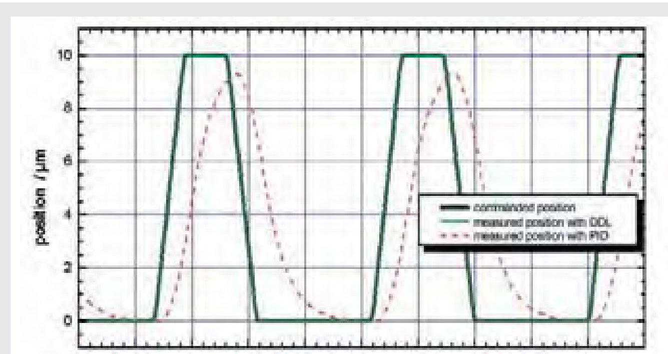
P-628.1CD* / P-628.1CL*
PIHera® Precision Piezo Linear Nanopositioning System, 800 µm, Direct Metrology, Capacitive Sensor

P-629.1CD* / P-629.1CL*
PIHera® Precision Piezo Linear Nanopositioning System, 1500 µm, Direct Metrology, Capacitive Sensor

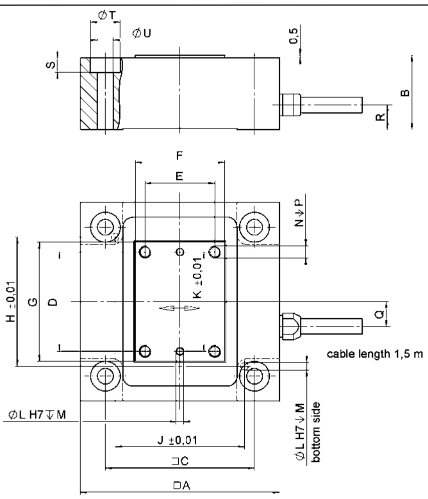
*.1CD with Sub-D Connector
*.1CL with LEMO Connector

Open-loop versions are available as P-62x.10L.
Vacuum versions to 10^{-9} hPa are available as P-62x.1UD.

System properties	
System configuration	P-625.1CD and E-500 modular piezo controller system with E-505.00F amplifier and E-509.C1A servo controller; 250 g load
Closed-loop amplifier bandwidth, large signal	30 Hz
Settling time (full travel)	31 ms



Rapid scanning motion of a P-621.1CD (commanded rise time 5 ms) with the E-710 controller ##600300 and Digital Dynamic Linearization (DDL) option. DDL virtually eliminates the tracking error (<20 nm) during the scan. The improvement over a classical PI controller is up to 3 orders of magnitude, and increases with the scanning frequency



	A	B	C	D	E	F	G	H	J	K	ØL	M	N	P	Q	R	S	ØT	ØU
P-620.1CD / 10L	30	12	24	15	12	15	18	19	24	15	1,01	1,5	M2	4	4,5	6	2	4,4	2,2
P-621.1CD / 10L	40	15	30	20	14	18	24	26	26	20	1,51	2,5	M2,5	5	5	5	3	6	3,2
P-622.1CD / 10L	50	15	40	24	20	25	30	35	35	24	1,51	2,5	M2,5	5	5,5	5	3	6	3,2
P-625.1CD / 10L	60	15	50	40	27	32	44,5	46	46	40	1,51	2,5	M2,5	5	5,5	5	3	6	3,2
P-628.1CD / 10L	80	17	70	58	41	45	63	66	66	58	1,51	2,5	M2,5	5	5,5	5	3	6	3,2

P-62x.1CD/.1CL/.10L dimensions in mm

PIHera® XYZ combination, P-62x.2 XY piezo stage (see p. 2-54), P-62x.Z vertical stage (see p. 2-40)

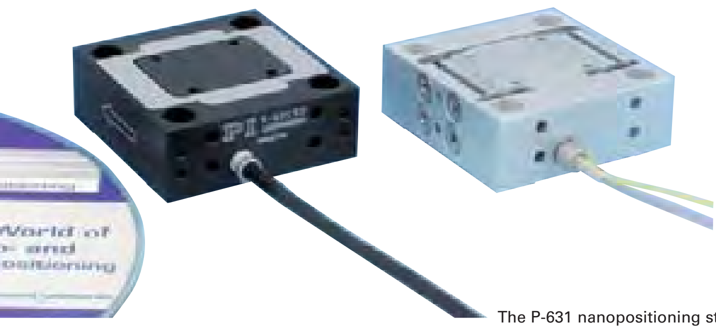
Technical Data

Model	P-620.1CD/ P-620.1CL	P-621.1CD/ P-621.1CL	P-622.1CD/ P-622.1CL	P-625.1CD/ P-625.1CL	P-628.1CD/ P-628.1CL	P-629.1CD/ P-629.1CL/	P-62x.10L open-loop version	Units	Tolerance
Active axes	X	X	X	X	X	X	X		
Motion and positioning									
Integrated sensor	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive	–		
Open-loop travel, -20 to +120 V	60	120	300	600	950	1800	as P-62x.1CD	µm	min. (+20 %/-0 %)
Closed-loop travel	50	100	250	500	800	1500	–	µm	calibrated
Closed-loop / open-loop resolution	0.1 / 0.2	0.2 / 0.4	0.4 / 0.7	0.5 / 1.4	0.5 / 1.8	2 / 3	as P-62x.1CD	nm	typ.
Linearity, closed-loop	0.02	0.02	0.02	0.02	0.03*	0.03**	–	%	typ.
Repeatability	±1	±1	±1	±5	±10	±14	–	nm	typ.
Pitch / yaw	±3	±3	±3	±6	±6	±10	as P-62x.1CD	µrad	typ.
Mechanical properties									
Stiffness in motion direction	0.42	0.35	0.2	0.1	0.12	0.13	as P-62x.1CD	N/µm	±20 %
Unloaded resonant frequency	1100	800	400	215	125	125	as P-62x.1CD	Hz	±20 %
Resonant frequency @ 20 g	550	520	340	180	115	120	as P-62x.1CD	Hz	±20 %
Resonant frequency @ 120 g	260	240	185	110	90	110	as P-62x.1CD	Hz	±20 %
Push/pull force capacity in motion direction	10	10	10	10	10	10	as P-62x.1CD	N	Max.
Load capacity	10	10	10	10	10	10	as P-62x.1CD	N	Max.
Lateral Force	10	10	10	10	10	8	as P-62x.1CD	N	Max.
Drive properties									
Ceramic type	PICMA® P-883	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-887	PICMA® P-888	as P-62x.1CD		
Electrical capacitance	0.35	1.5	3.1	6.2	19	52	as P-62x.1CD	µF	±20 %
Dynamic operating current coefficient	0.9	1.9	1.9	1.6	3	4.3	as P-62x.1CD	µA/(Hz • µm)	±20 %
Miscellaneous									
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 150	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum		
Dimensions	30 x 30 x 12	40 x 40 x 15	50 x 50 x 15	60 x 60 x 15	80 x 80 x 17	100 x 100 x 22.5	as P-62x.1CD	mm	
Mass	0.11	0.16	0.2	0.24	0.38	0.72	as P-62x.1CD	kg	±5 %
Cable length	1.5	1.5	1.5	1.5	1.5	1.5	1.5 m	±10 mm	
Sensor / voltage connection	CD version: Sub-D special CL version: LEMO	CD version: Sub-D special CL version: LEMO	CD version: Sub-D special CL version: LEMO	CD version: Sub-D special CL version: LEMO	CD version: Sub-D special CL version: LEMO	CD version: Sub-D special CL version: LEMO	LEMO (no sensor)		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. The value given is noise equivalent motion with E-710 controller (p. 2-128).
*With digital controller. For analog controller 0.05 %.
**With digital controller. For analog controller 0.07 %.
Recommended controller / amplifier
CD version: E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-665 powerful servo controller, bench-top (p. 2-116)
Single-channel digital controller: E-753 (bench-top) (p. 2-108)
CL version: E-500 modular piezo controller system (p. 2-142) with E-505 amplifier module (high power) p. 2-147 and E-509 controller (p. 2-152)
Open-loop version: E-500 modular piezo controller system (p. 2-142) with E-505 amplifier module (high power) (p. 2-147)

P-631 Compact Piezo Nanopositioning System

Cost-Effective, Scalable Design for High-Volume Applications



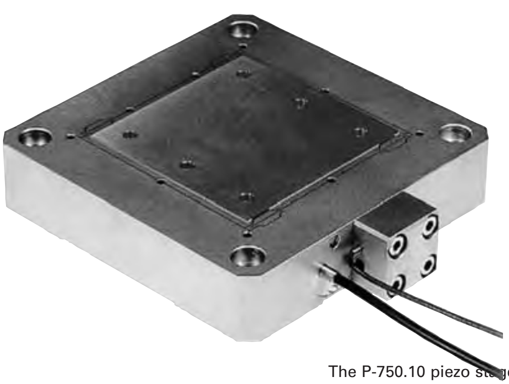
The P-631 nanopositioning stage with 100 µm travel range is also available as vacuum version

- Cost-Effective, Compact Design for High-Volume Applications
- Travel Range 100 µm, Longer Ranges on Request
- Direct Metrology with Capacitive Sensors
- Resolution to 0,2 nm
- Outstanding Lifetime Due to PICMA® Piezo Actuators
- Mechanically Compatible to P-621 PIHera® Nanopositioning Stages

Model	Closed-loop / open-loop travel @ -20 to +120 V	Closed-loop / openloop resolution	Linearity	Pitch / yaw	Load capacity
P-631.1CD	120 / 100 µm	0.2 / 0.4 nm	0.02 %	25 µrad	10 N

P-750 Piezo Nanopositioning System

Dynamic High-Load Nanopositioning Stages with Direct Metrology



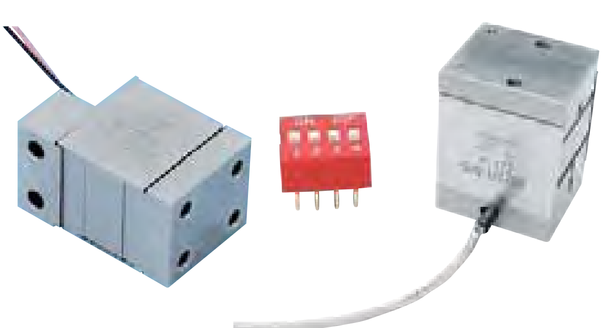
The P-750.10 piezo stage is equipped with high-precision capacitive position sensors

- 1 nm Lateral Guiding Accuracy
- Frictionless, High-Precision Flexure Guiding System
- Load Capacity 10 kg
- Resolution <1 nm
- Superior Accuracy With Direct-Metrology Capacitive Sensors
- Direct Drive for Faster Response
- 75 µm Travel Range
- Outstanding Lifetime Due to PICMA® Piezo Actuators

Model	Closed-loop / open-loop travel	Closed-loop / open-loop resolution	Load capacity	Rotation around θ_X, θ_Y	Unloaded resonant frequency
P-750.00	– /75 µm	– / 0.4 nm	100 N	±10 µrad	600 Hz
P-750.20 with capacitive sensor	75 / 75 µm	1 / 0.4 nm	100 N	±10 µrad	600 Hz

P-772 Miniature Nanopositioning System

High Dynamics and Direct Position Measurement

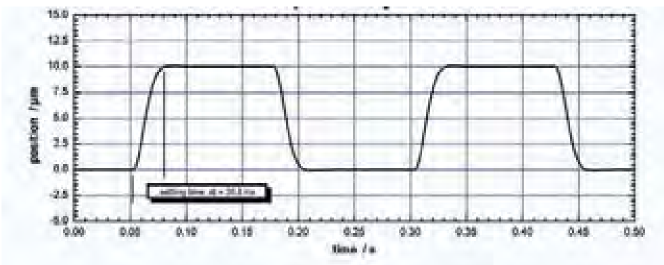


The P-772 piezo nanopositioning system is available with capacitive sensors for closed-loop operation (left) or as open-loop version (right). DIP switch for size comparison.

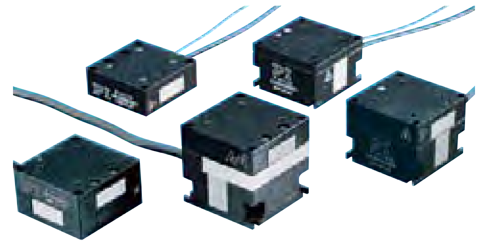
- Smallest Stage with Direct Metrology
- Frictionless, High-Precision Flexure Guiding System
- Resolution <0.1 nm
- Travel Range to 12 µm
- Closed-Loop and Open-Loop Versions
- Rapid Response and Settling
- Outstanding Lifetime Due to PICMA® Piezo Actuators

Modell	Closed-loop / open-loop travel @ 0 to +100 V	Closed-loop / open-loop resolution	Linearity	Unloaded resonant frequency	Load capacity
P-772.1CD / P-772.1CL	10 / 12 µm	0.05 / 0.05 nm	0.03 %	1.7 kHz	5 N
P-772.0L	– />10 µm	– / 0.05 nm	–	1.7 kHz	5 N

PI



The settling time of a P-611.Z with a load of 30 g is 26 ms for a 10 µm step. Measured with interferometer



The whole P-611 family: X, Z, XY, XZ and XYZ stages

Technical Data

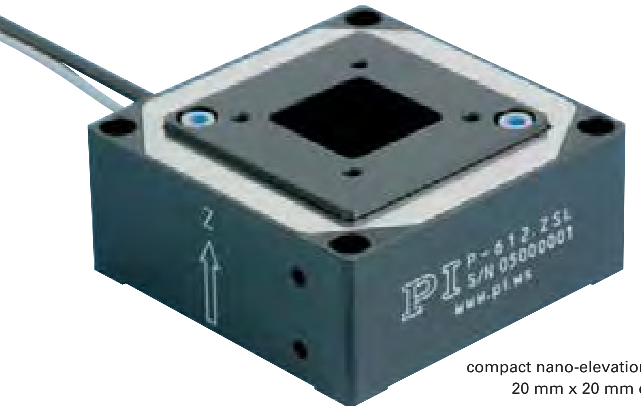
Model	P-611.ZS	P-611. Z0	Unit	Tolerance
Active axes	Z	Z		
Motion and positioning				
Integrated sensor	SGS	-		
Open-loop travel, -20 to +120 V	120	120	µm	min. (+20 %/0 %)
Closed-loop travel	100	-	µm	
Open-loop resolution	0.2	0.2	nm	typ.
Closed-loop resolution	2	-	nm	typ.
Linearity 0.1		-	%	typ.
Repeatability	<10	-	nm	typ.
Runout θZ (Z motion)	±5	±5	µrad	typ.
Runout θX (Z motion)	±20	±20	µrad	typ.
Runout θY (Z motion)	±5	±5	µrad	typ.
Mechanical properties				
Stiffness	0.45	0.45	N/µm	±20 %
Unloaded resonant frequency	460	460	Hz	±20 %
Resonant frequency @ 30 g	375	375	Hz	±20 %
Resonant frequency @ 100 g	265	265	Hz	±20 %
Push/pull force capacity	15 / 10	15 / 10	N	Max.
Drive properties				
Ceramic type	PICMA® P-885	PICMA® P-885		
Electrical capacitance	1.5	1.5	µF	±20 %
Dynamic operating current coefficient	1.9	1.9	µA/(Hz • µm)	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material	Aluminum, steel	Aluminum, steel		
Dimensions	44 x 44 x 27	44 x 44 x 27	mm	
Mass	176	176	g	±5 %
Cable length	1.5	1.5	m	±10 mm
Sensor connector	LEMO	LEMO		
Voltage connection	LEMO	LEMO		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion with E -503 amplifier (p. 2-146)
Recommended controller / amplifier
E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-665 powerful servo controller, bench-top (p. 2-116), E-660 bench-top for open-loop systems (p. 2-119)

System properties	
System Configuration	P-611.1S and E-665.SR controller, 30 g load
Amplifier bandwidth, small signal	40 Hz
Settling time (10 % step width)	25 ms

P-612.Z Piezo Z Stage

Compact Nanopositioning Stage with Aperture



P-612.ZSL
compact nano-elevation stage with a
20 mm x 20 mm clear aperture

- **Travel Range 100 µm**
- **Resolution to 0.2 nm**
- **Linearity 0.2 %**
- **Compact: Footprint 60 x 60 mm**
- **Very Cost-Effective Controller/Piezomechanics Systems**
- **Frictionless, High-Precision Flexure Guiding System**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**

These elevation stages are cost-effective, compact, piezo-based positioning systems with travel ranges of 100 µm. The space-saving design features a footprint of only 60 x 60 mm. The 20 x 20 mm clear aperture makes them ideally suited for sample positioning in microscopy. Equipped with PICMA® piezo drives and zero-stiction, zero-friction flexure guiding system, the series provides nanometer-range resolution and millisecond response time.

Application Examples

- Interferometry
- Scanning microscopy
- Nanopositioning
- Biotechnology
- Quality assurance testing
- Semiconductor fabrication

Position Servo-Control with Nanometer Resolution

High-resolution, broadband, strain gauge sensors (SGS) are applied to appropriate locations on the drive train and measure the displacement of the moving part of the stage relative to the base. The SGS sensors assure optimum position stability in the nanometer range and fast response.

The open-loop models are ideal for applications where fast response and very high resolution are essential, but absolute positioning is not important. They can also be used when the position is controlled by an external sensor such as an interferometer, a PSD (position sensitive detector), CCD chip / image processing system, or the eyes and hands of an operator.

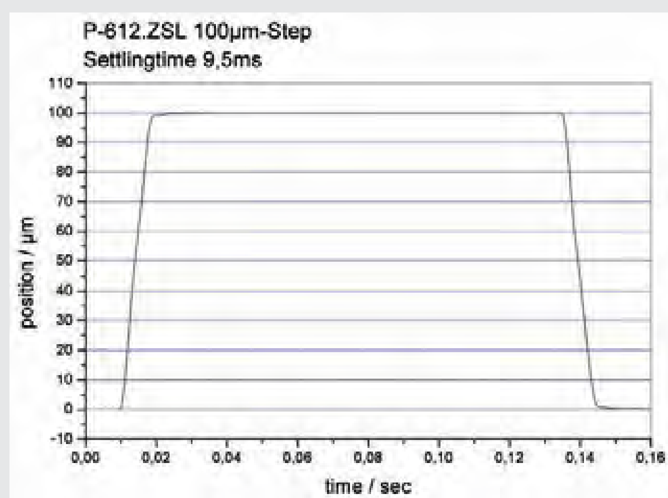
High Reliability and Long Lifetime

The compact P-612 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and thus provide better performance and reliability than conventional piezo actuators. Actuators, guiding system and sensors are maintenance-free, not subject to wear and offer an extraordinary reliability.

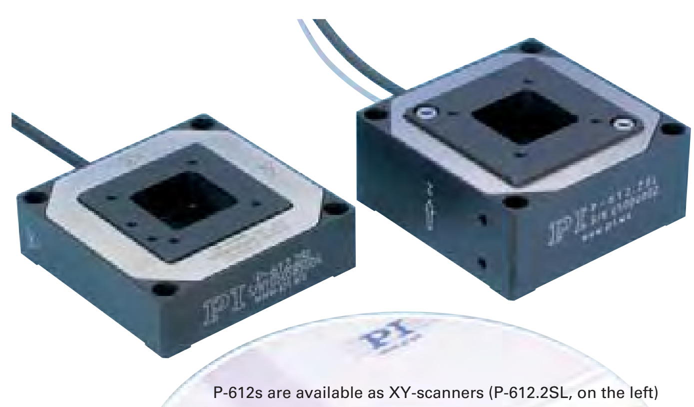
Ordering Information

P-612.ZSL
Vertical Nanopositioning Stage, 100 µm, 20 x 20 mm Aperture, SGS-Sensor

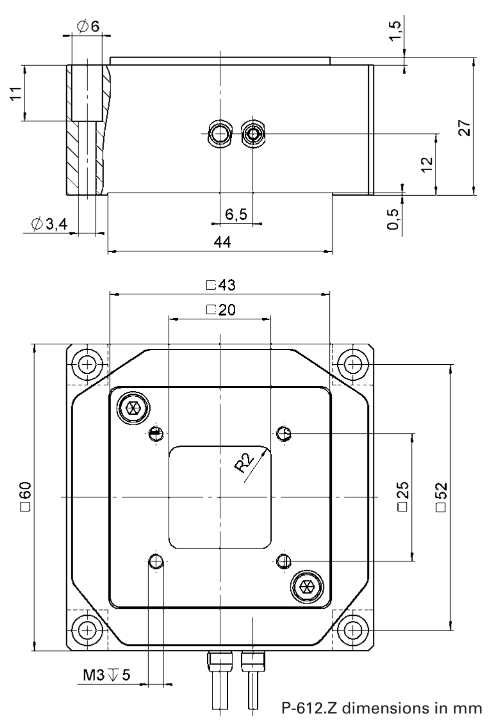
P-612.Z0L
Vertical Nanopositioning Stage, 100 µm, 20 x 20 mm Aperture, No Sensor



Settling takes less than 10 ms over the entire travel range in closed-loop operation



P-612s are available as XY-scanners (P-612.2SL, on the left) and vertical stages (P-612.ZSL, on the right) providing a travel range of 100 µm per axis



P-612.Z dimensions in mm

System properties	
System configuration	P-612.ZSL and E-625.SR controller, 30 g load
Closed-loop amplifier small signal bandwidth	110 Hz
Closed-loop amplifier large signal bandwidth	80 Hz
Settling time (10 % step width)	8 ms

Technical Data

Model	P-612.ZSL	P-612.Z0L	Units	Tolerance
Active axes	Z	Z		
Motion and positioning				
Integrated sensor	SGS	–		
Open-loop travel, -20 to +120 V	110	110	µm	min. (+20 %/-0 %)
Closed-loop travel	100	–	µm	calibrated
Open-loop resolution	0.2	0.2	nm	typ.
Closed-loop resolution	1.5	–	nm	typ.
Linearity, closed-loop	0.2	–	%	typ.
Repeatability	±4	–	nm	typ.
Runout θ_X, θ_Y	±10	±10	µrad	typ.
Crosstalk X, Y	±20	±20	µm	typ.
Mechanical properties				
Stiffness in motion direction	0.63	0.63	N/µm	±20 %
Unloaded resonant frequency	490	490	Hz	±20 %
Resonant frequency under load	420 (30 g)	420 (30 g)	Hz	±20 %
Load capacity	15 / 10	15 / 10	N	Max.
Drive properties				
Ceramic type	PICMA® P-885	PICMA® P-885		
Electrical capacitance	3	3	µF	±20 %
Dynamic operating current coefficient	3.8	3.8	µA/(Hz • µm)	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum		
Mass	0.28	0.275	kg	±5 %
Cable length	1.5	1.5	m	±10 mm
Sensor / voltage connection	LEMO	LEMO (no sensor)		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion with E-503 amplifier. (p. 2-146)
Recommended controller / amplifier
E-610 servo controller / amplifier card (p. 2-110), E-625 servo-controller, bench-top (p. 2-114), E-665 high-power servo-controller with display, bench-top (p. 2-116), E-660 bench-top for open-loop systems (p. 2-119)

P-620.Z – P-622.Z PIHera® Precision Z-Stage

Nanopositioning System Family with Direct Metrology and Long Travel Ranges

P-620.ZCL, P-621.ZCL and P-622.ZCL (from left) PIHera® piezo nano-elevation stages, 50 to 400 µm (CD for size comparison)

- **Vertical Travel Range 50 to 400 µm**
- **High-Precision, Cost-Efficient**
- **Resolution to 0.1 nm**
- **Direct Metrology with Capacitive Sensors**
- **0,02 % Positioning Accuracy**
- **Frictionless, High-Precision Flexure Guiding System**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **X-, XY-, Z- XYZ-Versionen**
- **Vacuum-Compatible Versions Available**

Z-axis PIHera® systems are cost-efficient piezo nanopositioning stages featuring travel ranges up to 400 µm and provide sub-nanometer reso - lution. Despite the increased travel ranges, the units are extremely compact and pro - vide sub-nanometer reso - lution. The long travel range is achieved with a friction-free and extremely stiff flexure system, which also offers rapid response and excellent guiding accuracy.

Application Examples

- Interferometry
- Microscopy
- Nanopositioning
- Biotechnology
- Quality assurance testing
- Semiconductor technology

PIHera® piezo nanopositioning stages are also available as X- and XY-stages (see p. 2-22 and p. 2-54).

Nanometer Precision in Milliseconds

One of the advantages of PIHera® stages over motor -driven positioning stages is the rapid response to input changes and the fast and precise settling behavior . The P-622.1CD, for example, can settle to an accuracy of 10 nm in only 30 msec (other PI stages provide even faster response)!

Superior Accuracy With Direct-Metrology Capacitive Sensors

A choice of tasks such as optical path adjustment in interferometry, sample positioning in microscopy, precision alignment or optical tracking require the relatively long scanning ranges and nanometer precision offered by PIHera® nanopositioning stages.

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Designed for Precision

High stiffness is achieved with the FEA-optimized design of the frictionless flexure elements, which assure excellent guiding accuracy and dynamics. A straightness and flatness in the nanometer range is achieved.

Ordering Information

P-620.ZCD
PIHera® Precision Vertical Nanopositioning Stage, 50 µm, Capacitive Sensor, Sub-D Connector

P-620.ZCL
PIHera® Precision Vertical Nanopositioning Stage, 50 µm, Capacitive Sensor, LEMO Connector

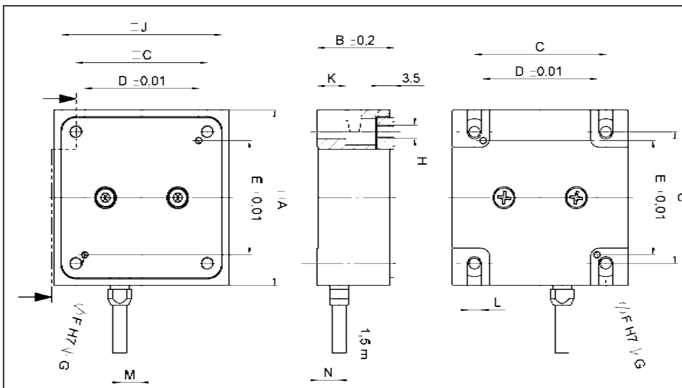
P-621.ZCD
PIHera® Precision Vertical Nanopositioning Stage, 100 µm, Capacitive Sensor, Sub-D Connector

P-621.ZCL
PIHera® Precision Vertical Nanopositioning Stage, 100 µm, Capacitive Sensor, LEMO Connector

P-622.ZCD
PIHera® Precision Vertical Nanopositioning Stage, 250 µm, Capacitive Sensor, Sub-D Connector

P-622.ZCL
PIHera® Precision Vertical Nanopositioning Stage, 250 µm, Capacitive Sensor, LEMO Connector

Open-loop versions are available as P-62x.Z0L



	A	B	C	D	E	ØF
P-620.ZCD / Z0L	30	15	24	19	24	1,01
P-621.ZCD / Z0L	40	17,5	30	26	26	1,51
P-622.ZCD / Z0L	50	17,5	40	35	35	1,51

	G	H	J	K	L	M	N
P-620.ZCD / Z0L	2	M2	28	5	2,2	4,5	6
P-621.ZCD / Z0L	2,5	M3	36,5	6,5	3,2	5	5
P-622.ZCD / Z0L	2,5	M3	46,5	6,5	3,2	5	5

P-62x.ZCD / .ZCL / .Z0L dimensions in mm

System properties	
System configuration	P-621.ZCD with E-753 digital controller and 30 g load
Amplifier bandwidth, small signal	25 Hz
Amplifier bandwidth, large signal	25 Hz
Settling time (full travel)	15 ms

PIHera® XYZ combination

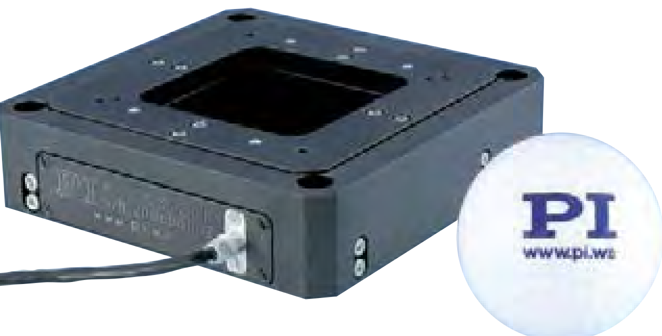
Technical Data

Model	P-620.ZCD P-620.ZCL	P-621.ZCD P-621.ZCL	P-622.ZCD P-622.ZCL	P-62x.Z0L Open-loop versions	Units	Tolerance
Active axes	Z	Z	Z	Z		
Motion and positioning						
Integrated sensor	Capacitive	Capacitive	Capacitive	–		
Open-loop travel, -20 to +120 V	65	140	400	as P-62x.ZCD	µm	min. (+20 %/-0 %)
Closed-loop travel	50	100	250	–	µm	
Open-loop resolution	0.1	0.2	0.5	as P-62x.ZCD	nm	typ.
Closed-loop resolution	0.2	0.3	1	–	nm	typ.
Linearity 0.02		0.02	0.02	–	%	typ.
Repeatability	±1	±1	±1	–	nm	typ.
Runout θ_X, θ_Y)	<20	<20	<80	as P-62x.ZCD	µrad	typ.
Mechanical properties						
Stiffness 0.5		0.6	0.24	as P-62x.ZCD	N/µm	±20 %
Unloaded resonant frequency	1000	790	360	as P-62x.ZCD	Hz	±20 %
Resonant frequency @ 30 g	690	500	270	as P-62x.ZCD	Hz	±20 %
Push/pull force capacity	10 / 5	10 / 8	10 / 8	as P-62x.ZCD	N	Max.
Load capacity	10	10	10	as P-62x.ZCD	N	Max.
Lateral Force	10	10	10	as P-62x.ZCD	N	Max.
Drive properties						
Ceramic type	PICMA® P-883	PICMA® P-885	PICMA® P-885	as P-62x.ZCD		
Electrical capacitance	0.7	3	6.2	as P-62x.ZCD	µF	±20 %
Dynamic operating current coefficient	1.8	3.8	3.1	as P-62x.ZCD	µA/(Hz • µm)	±20 %
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 150	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminum		
Mass	0.12	0.17	0.24	as P-62x.ZCD	g	±5 %
Cable length	1.5	1.5	1.5	as P-62x.ZCD	m	±10 mm
Sensor / voltage connection	Sub-D special (CD-version) CL-version: LEMO	Sub-D special (CD-version) CL-version: LEMO	Sub-D special (CD-version) CL-version: LEMO	LEMO (no sensor)		

Recommended controller
CD-Versions:
E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-665 powerful servo controller, bench-top (p. 2-116)
Single-channel digital controller: E-753 (bench-top) (p. 2-108)
CL-Versions:
Modular piezo controller system E-500 (p. 2-142) with amplifier module E-505 (high performance) (p. 2-147) and E-509 controller (p. 2-152)
Open-loop versions: modular piezo controller system E-500 (p. 2-142) with amplifier module E-505 (high performance) (p. 2-147)

P-733.Z High-Dynamics Z-Nanopositioner / Scanner

Direct Position Metrology and Clear Aperture



P-733.ZCD Piezo Z-Stage

- **Travel Range 100 µm**
- **Direct Metrology with Capacitive Sensors**
- **Resolution to 0.3 nm, Closed-Loop**
- **Clear Aperture 50 x 50 mm**
- **Versions with Additional Degrees of Freedom Available**
- **XY and XYZ Versions Also Available**
- **Vacuum-Compatible Versions Available**

P-733.Z piezo vertical stages offer a positioning and scanning range of 100 µm with sub-nanometer resolution. The 50 x 50 mm clear aperture is ideal for applications such as scanning or confocal microscopy. Their fast settling time of less than 10 ms allows high throughput rates.

Application Examples

- Scanning microscopy
- Confocal microscopy
- Mask / wafer positioning
- Surface measurement technique
- Nano-imprinting
- Micromanipulation
- Image processing / stablilization
- Nanopositioning with high flatness & straightness

Capacitive Sensors for Highest Accuracy

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz. The resolution of the P-733.Z is better than 0.3 nm.

Because of the direct measurement of the actual distance between the fixed frame and the moving part of the stage, errors in the drive train, actuator, lever arm or in guiding system do not influence the measuring accuracy. The result is exceptional motion linearity, higher long-term stability and a stiffer, more-responsive control loop, because external influences are immediately recognized by the sensor. The capacitive sensor non-linearity is typically less than 0.03 %, the repeatability of the P-733.Z is better than 2 nm.

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Large Variety of Models for a Broad Range of Applications

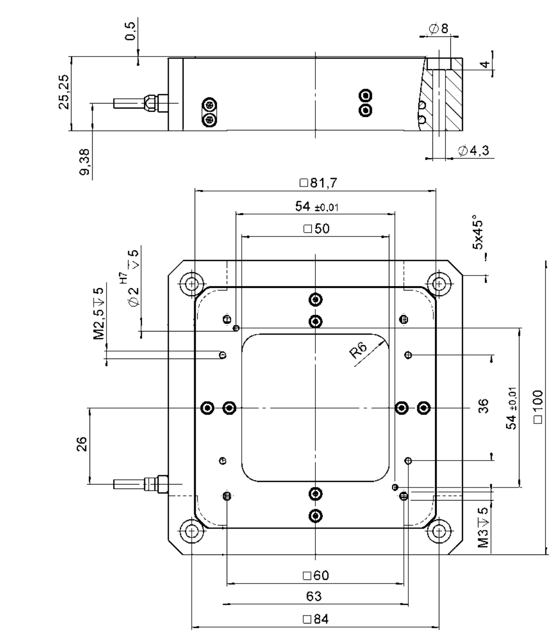
For scanning and positioning tasks in XY, the P-733.2CD and .3CD versions are available with a travel range of 100 x 100 µm. For high-dynamics applications, the P-733.2DD and P-733.3DD models can be offered with direct drive and reduced travel range (see p. 2-62).

For ultra-high-vacuum applications down to 10^{-9} hPa, nanopositioning systems as well as comprehensive accessories, such as suitable feedthroughs, are available.

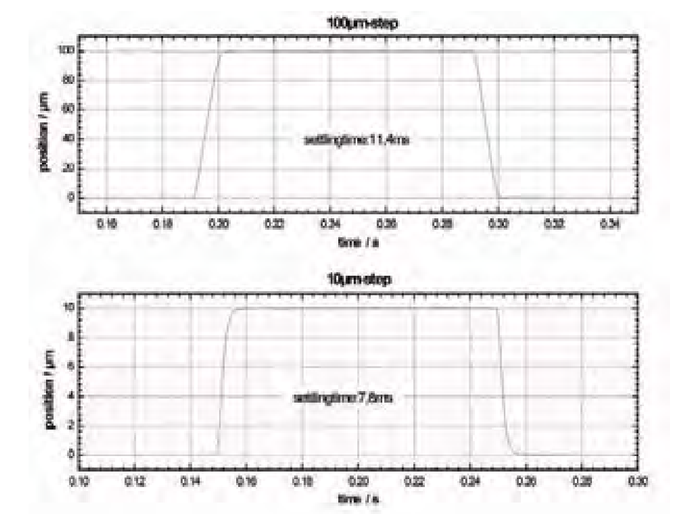
Ordering Information

P-733.ZCD
Compact Precision Nanopositioning Vertical Stage, 100 µm, Capacitive Sensor, Sub-D Connector

P-733.ZCL
Compact Precision Nanopositioning Vertical Stage, 100 µm, Capacitive Sensor, LEMO Connector



P-733.Z dimensions in mm



Step response of the P-733.ZCD. Settling time is in the 10 ms range

System properties	
System configuration	E-500 modular system with E-503 amplifier and E-509 sensor module; 20 g load
Amplifier bandwidth, small signal	96 Hz
Settling time (10 % step width)	8 ms

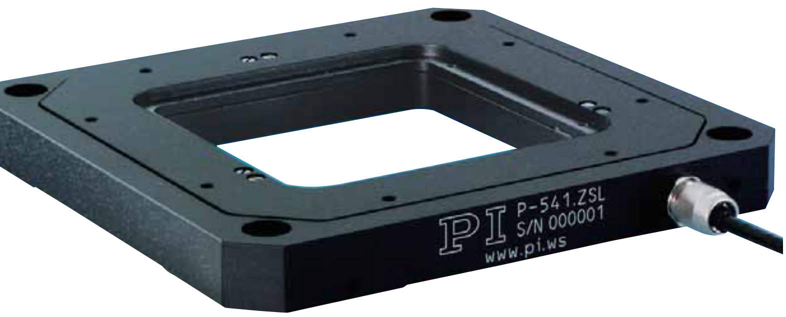
Technical Data

Model	P-733.ZCD P-733.ZCL	Tolerance
Active axes	Z	
Motion and positioning		
Integrated sensor	Capacitive	
Open-loop travel, -20 to +120 V	115 µm	min. (+20 %/-0 %)
Closed-loop travel	100 µm	
Open-loop resolution	0.2 nm	typ.
Closed-loop resolution	0.3 nm	typ.
Linearity	0.03 %	typ.
Repeatability	<2 nm	typ.
Rotation around Z	<10 µrad	typ.
Rotation around X	<5 µrad	typ.
Rotation around Y	<5 µrad	typ.
Mechanical properties		
Stiffness	2.5 N/µm	±20 %
Unloaded resonant frequency	700 Hz	±20 %
Resonant frequency @ 120 g	530 Hz	±20 %
Resonant frequency @ 200 g	415 Hz	±20 %
Push/pull force capacity	50 / 20 N	Max.
Drive properties		
Ceramic type	PICMA® P-885	
Electrical capacitance	6 µF	±20 %
Dynamic operating current coefficient	7.5 µA/(Hz • µm)	±20 %
Miscellaneous		
Operating temperature range	20 to 80 °C	
Material	Aluminum	
Dimensions	100 x 100 x 25 mm	
Mass	580 g	±5 %
Cable length	1,5 m	±10 mm
Sensor connection	Sub-D special (CD-version); 2x LEMO (CL-version)	
Voltage connection	Sub-D special (CD-version); 1 x LEMO (CL-version)	

Dynamic Operating Current Coefficient in µA per Hz and mrad. Example: Sinusoidal scan of 10 µm at 10 Hz requires approximately 3 mA drive current.
Recommended controller
One channel: E-610 controller / amplifier (p. 2-110), E-625 bench-top controller (p. 2-114), E-621 modular controller (p. 2-160)
Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152)
Single-channel digital controller: E-753 (bench-top) (p. 2-108)

P-541.Z Piezo Z and Z/Tip/Tilt Stages

Low Profile, Large Aperture



P-541 series nanopositioning Z-stages and Z-tip/tilt stages offer travel ranges of 100 µm with sub-nanometer resolution. They feature a very low profile of 16.5 mm and a large 80 x 80 mm aperture. Versions with strain gauge and capacitive position feedback sensors are available

- **Low Profile for Easy Integration: 16.5 mm; 80 x 80 mm Clear Aperture**
- **Vertical and Z/Tip/Tilt Stages**
- **100 µm Travel Range, 1 mrad Tilt**
- **Parallel-Kinematics / Metrology for Enhanced Responsiveness / Multi-Axis Precision**
- **Choice of Sensors: Strain Gauge (Lower Cost) or Capacitive Sensors (Higher Performance)**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Combination with Long-Travel M-686 Microscopy Stages**

Low Profile, Optimized for Microscopy Applications

The P-541 Z stages and Z/tip/tilt stages are for ideal alignment, nano-focusing or metrology tasks in the nanometer range. They feature a very low profile of 16.5 mm, a large 80 x 80 mm aperture, and offer highly accurate motion with sub-nanometer resolution.

Application Examples

- Scanning microscopy
- Mask / wafer positioning
- Interferometry
- Metrology
- Biotechnology
- Micromanipulation

A variety of P-541 XY scanning stages with the same footprint are also available (see p. 2-60). Due to the low-profile design, the stages can easily be integrated in high-resolution microscopes.

Choice of Position Sensors

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Alternatively, economical strain gauge sensors are available. PI uses a bridge configuration to eliminate thermal drift, and assure optimal position stability in the nanometer range.

Active and Passive Guidance for Nanometer Flatness and Straightness

Flexures optimized with Finite Element Analysis (FEA) are completely free of play and friction to allow extremely high-precision motion. The FEA techniques also optimize straightness and flatness and provide for the highest possible stiffness in, and perpendicular to, the direction of motion.

Due to the parallel-kinematics design there is only one common moving platform for all axes, minimizing mass, enabling identical dynamic behaviour and eliminiating cumulative errors. Parallel kinematics also allows for a more compact construction and faster response compared to stacked or nested designs.

Ordering Information

P-541.ZCD
Vertical Nanopositioning Stage with Large Aperture, 100 µm, Direct Metrology, Capacitive Sensors

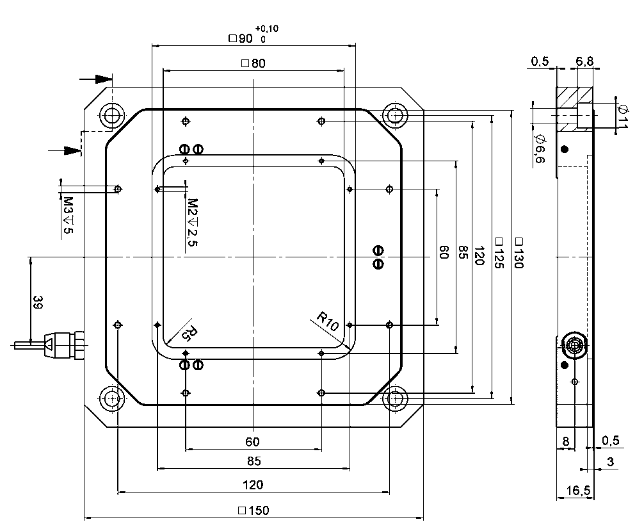
P-541.TCD
Vertical Tip / Tilt Nanopositioning Stage with Large Aperture, 100 µm / 1 mrad, Parallel Metrology, Capacitive Sensors

P-541.ZSL
Vertical Nanopositioning Stage with Large Aperture, 100 µm, Strain Gauge Sensors

P-541.TSL
Vertical Tip / Tilt Nanopositioning Stage with large Aperture, 100 µm, Strain Gauge Sensors

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.



P-541.Z dimensions in mm

M-686 open-frame stage with P-541 piezo scanner on top makes an ideal combination for microscopy tasks. The system height is only 48 mm

System properties	
System configuration	P-541.ZCD and E-500 modular system with E-503 amplifier and E-509 sensor module, 20 g load
Amplifier bandwidth, small signal	60 Hz
Settling time (10 % step width)	9 ms

Technical Data

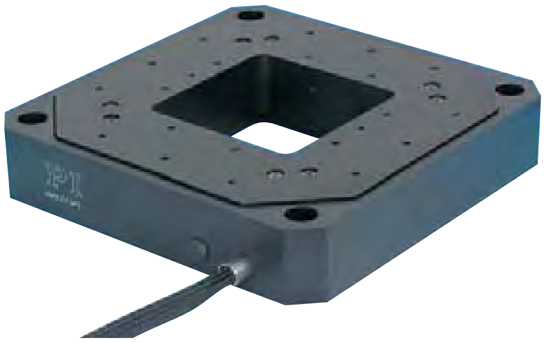
Models	P-541.ZCD	P-541.TCD*	P-541.ZSL	P-541.TSL	P-541.T0L*	P-541.Z0L	Units	Tolerane
Active axes	Z	Z, θ_X, θ_Y	Z	Z, θ_X, θ_Y	Z	Z, θ_X, θ_Y		
Motion and positioning								
Integrated sensor	Capacitive	Capacitive	SGS	SGS	Open-loop	Open-loop		
Open-loop Z-travel, -20 to +120 V	150	150	150	150	150	150	µm	min. (+20 %/0 %)
Open-loop tip/tilt angle, -20 to +120 V	–	±0.6	–	±0.6	–	±0.6	mrad	min. (+20 %/0 %)
Closed-loop Z-travel	100	100	100	100	–	–	µm	
Closed-loop tip/tilt angle	–	±0.4	–	±0.4	–	–	mrad	
Open-loop Z-resolution	0.2	0.2	0.2	0.2	0.2	0.2	nm	typ.
Open-loop tip/tilt angle resolution	–	0.02	–	0.02	–	0.02	µrad	typ.
Closed-loop Z-resolution	0.5	0.5	2.5	2.5	–	–	nm	typ.
Closed-loop tip/tilt resolution	–	0.08	–	0.25	–	–	µrad	typ.
Linearity Z, θ_X, θ_Y	0.03	0.03	0.2	0.2	–	–	%	typ.
Repeatability Z	<2	<2	<10	<10	–	–	nm	typ.
Repeatability θ_X, θ_Y	–	0.01	–	0.05	–	–	µrad	typ.
Runout θ_X, θ_Y	±15	±15	±15	±15	±15	±15	µrad	typ.
Mechanical properties								
Stiffness Z	0.8	0.8	0.8	0.8	0.8	0.8	N/µm	±20 %
Unloaded resonant frequency (Z)	410	410	410	410	410	410	Hz	±20 %
Unloaded resonant frequency (θ_X, θ_Y)	–	330	–	330	–	330	Hz	±20 %
Resonant frequency @ 200 g (Z)	250	250	250	250	250	250	Hz	±20 %
Resonant frequency @ 200 g (θ_X, θ_Y)	–	270	–	270	–	270	Hz	±20 %
Push/pull force capacity	50 / 20	50 / 20	50 / 20	50 / 20	50 / 20	50 / 20	N	Max.
Drive properties								
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical capacitance	6.3	6.3	6.3	6.3	6.3	6.3	µF	±20 %
Dynamic operating current coefficient	7.9	7.9	7.9	7.9	7.9	7.9	µA / (Hz • µm)	±20 %
Miscellaneous								
Operating temperature range	20 to 80	20 to 80	20 to 80	20 to 80	20 to 80	20 to 80	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum		
Mass	750	750	730	730	700	700	g	±5 %
Cable length	1.5	1.5	1.5	1.5	1.5	1.5	m	±10 mm
Sensoranschluss	Sub-D Special	Sub-D Special	LEMO	3 x LEMO	–	–		
Voltage connection	Sub-D Special	Sub-D Special	LEMO	3 x LEMO	LEMO	3 x LEMO		

*Parallel kinematics design; the maximum displacement for translation and tilt motion cannot be achieved at the same time
Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion with E-503 (p. 2-146) or E-710 controller (p. 2-128).
Recommended controller / amplifier
Single-channel (1 per axis): E-610 servo controller / amplifier (p. 2-110), E-625 servo controller, bench-top (p. 2-114), E-621 controller module (p. 2-160)
Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152)
Single-channel digital controller: E-753 (bench-top) (p. 2-108)
Multi-channel digital controllers: E-710 bench-top (p. 2-128), E-712 modular (p. 2-140), E-725 high-power (p. 2-126), E-761 PCI board (p. 2-130)

PI

P-518, P-528, P-558 Piezo Z/Tip/Tilt Stage

High-Dynamics with Large Clear Aperture



P-528 Z/tip/tilt piezo nanopositioning system

- **1- and 3-Axis Versions**
- **Closed-Loop Vertical / Tilt Range to 200 µm / 2 mrad (Open-Loop to 240 / 2.4)**
- **Parallel Kinematics / Metrology for Enhanced Responsiveness & Multi-Axis Precision**
- **Frictionless, High-Precision Flexure Guiding System**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Clear Aperture 66 x 66 mm**
- **Capacitive Sensors for Highest Linearity**

P-5x8 series, Z/tip/tilt nanopositioners / scanners are open-frame, high-resolution, piezo-driven stages providing motion to 240 µm and 2.4 mrad with resolutions of up to 0.5 nm and 50 nrad. The 66 x 66 mm clear aperture is ideal for transmitted-light applications.

XY and XYZ multi-axis versions in the same form factor are also offered as P-517, P-527 (see p. 2-70) models with six degrees of freedom are available upon request.

Application Examples

- Metrology
- Interferometry
- Optics
- Lithography
- Scanning microscopy
- Mass storage device testing
- Laser technology
- Micromachining

Capacitive Position Sensors for Higher Accuracy

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

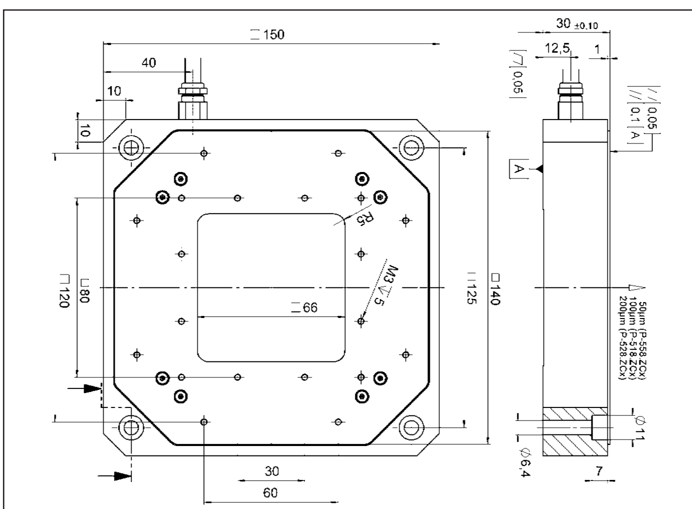
Excellent Guiding Accuracy

Flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. FEA techniques are used to give the design the highest possible stiffness in, and perpendicular to, the direction of motion, and to minimize linear and angular runout. Flexures allow extremely high-precision motion, no matter how minute, as they are completely free of play and friction.

Flatness and Straightness is further enhanced by active trajectory control: Multi-axis nanopositioning systems equipped with both parallel kinematics and parallel direct metrology are able to measure platform position in all degrees of freedom against one common fixed reference. In such systems, undesirable motion from one actuator in the direction of another (cross-talk) is detected immediately and actively compensated by the servo-loops. This Active Trajectory Control Concept can keep deviation from a trajectory to under a few nanometers, even in dynamic operation.

Higher Precision in Periodic Motion

The highest dynamic accuracy in scanning applications is



P-558, P-518, P-528 dimensions in mm

Ordering Information

P-558.ZCD
Precision Nanopositioning Z-Stage, 50 µm, Direct Metrology, Capacitive Sensors, Sub-D Connector

P-558.ZCL
Precision Nanopositioning Z-Stage, 50 µm, Direct Metrology, Capacitive Sensors, LEMO Connector

P-518.ZCD
Precision Nanopositioning Z-Stage, 100 µm, Direct Metrology, Capacitive Sensors, Sub-D Connector

P-518.ZCL
Precision Nanopositioning Z-Stage, 100 µm, Direct Metrology, Capacitive Sensors, LEMO Connector

P-528.ZCD
Precision Nanopositioning Z-Stage, 200 µm, Direct Metrology, Capacitive Sensors, Sub-D Connector

P-528.ZCL
Precision Nanopositioning Z-Stage, 200 µm, Direct Metrology, Capacitive Sensors, LEMO Connector

P-558.TCD
Precision Nanopositioning Z/Tip/Tilt Stage, 50 µm, 0.6 mrad, Parallel Metrology, Capacitive Sensors, Sub-D Connector

P-518.TCD
Precision Nanopositioning Z/Tip/Tilt Stage, 100 µm, 1.4 mrad, Parallel Metrology, Capacitive Sensors, Sub-D Connector

P-528.TCD
Precision Nanopositioning Z/Tip/Tilt Stage, 200 µm, 2.4 mrad, Parallel Metrology, Capacitive Sensors, Sub-D Connector

made possible by the DDL algorithm, which is available in PI's modern digital controllers. DDL eliminates tracking errors, improving dynamic linearity and usable bandwidth by up to three orders of magnitude!

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Technical Data

Model	P-558.ZCD/ P-558.ZCL	P-558.TCD	P-518.ZCD/ P-518.ZCL	P-518.TCD	P-528.ZCD/ P-528.ZCL	P-528.TCD	Units	Tolerance
Active axes	Z	Z, θ_x, θ_y	Z	Z, θ_x, θ_y	Z	Z, θ_x, θ_y		
Motion and positioning								
Integrated sensor	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive		
Open-loop travel, -20 to +120 V	60	60	140	140	240	240	µm	min. (+20 %/-0 %)
Open-loop tip/tilt angle, -20 to +120 V	–	±0.3 mrad	–	±0.7 mrad	–	±1.2 mrad	mrad	min. (+20 %/-0 %)
Closed-loop travel	50	50	100	100	200	200	µm	
Closed-loop tip/tilt angle	–	±0.25 mrad	-	±0.5 mrad	–	±1 mrad	mrad	
Open-loop resolution	0.2	0.2	0.2	0.4	0.6	0.6	nm	typ.
Open-loop tip/tilt angle resolution	–	0.02	–	0.04	–	0.06	µrad	typ.
Closed-loop resolution	0.5	0.5	0.8	0.8	1	1	nm	typ.
Closed-loop tip/tilt resolution	–	0.05	–	0.05	–	0.1	µrad	typ.
Linearity θ_x, θ_y	–	0.03	–	0.03	–	0.03	%	typ.
Repeatability	±5	±5	±5	±5	±10	±10	nm	typ.
Repeatability θ_x, θ_y	–	±0.03	–	±0.05	–	±0.1	µrad	typ.
Runout θ_z (Z motion)	<10	<10	<10	<10	<20	<20	µrad	typ.
Runout θ_x, θ_y (Z motion)	<50	<50	<50	<50	<100	<100	µrad	typ.
Mechanical properties								
Stiffness	4	4	2.7	2.7	1.5	1.5	N/µm	±20 %
Unloaded resonant frequency (Z)	570	570	500	500	350	350	Hz	±20 %
Unloaded resonant frequency (θ_x, θ_y)	-	610	-	530	-	390	Hz	±20 %
Resonant frequency @ 30 g in Z	410	410	350	350	210	210	Hz	±20 %
Resonant frequency @ 500 g in X, Y	-	430	-	370	-	250	Hz	±20 %
Resonant frequency @2500 g in Z	245	245	200	200	130	130	Hz	±20 %
Resonant frequency @ 2500 g θ_x, θ_y	-	240	-	190 -		115	Hz	±20 %
Push/pull force capacity	100 / 50	100 / 50	100 / 50	100 / 50	100 / 50	100 / 50	N	Max.
Drive properties								
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical capacitance	6	6	8.4	8.4	14.8	14.8	µF	±20 %
Dynamic operating current coefficient	15	15	10.5	10.5	9.2	9.2	µA/(Hz•µm)	±20%
Miscellaneous								
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum		
Dimensions	150 x 150 x 30	150 x 150 x 30	150 x 150 x 30	150 x 150 x 30	150 x 150 x 30	150 x 150 x 30	mm	
Mass	1380	1380	1400	1400	1420	1420	g	±5 %
Cable length	1.5	1.5	1.5	1.5	1.5	1.5	m	±10 mm
Sensor / voltage connection	CD-version: Sub-D special CL-version: LEMO	Sub-D Special	CD-version: Sub-D special CL-version: LEMO	Sub-D Special	CD-version: Sub-D special CL-version: LEMO	Sub-D Special		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. V alue given is noise equivalent motion with E-503 (p. 2-146) or E-710 controller (p. 2-128)

Recommended controller

CD-Versions:

Single-channel (1 per axis): E-610 servo controller / amplifier (p. 2-110), E-625 servo controller , bench-top (p. 2-114)

Single-channel digital controller: E-753 (bench-top) (p. 2-108)

CL-Versions:

Single-channel: E-500 modular piezo controller system (p. 2-142) with E-505 (p. 2-147) high-power amplifier module and E-509 servo-controller (p. 2-152)

Multi-channel versions:

Multi-channel digital controllers: E-710 bench-top (p. 2-128), E-712 modular (p. 2-140), E-725 high-power (p. 2-126), E-761 PCI board (p. 2-130)

P-915K Vacuum-Compatible Piezo-Z Stage

High-Load, High Dynamics and Large Clear Aperture

The direct-drive P-915KVPZ stage provides high stiffness for fast operation

- Travel Range 45 µm
- Large Clear Aperture 273 x 273 mm
- Direct Metrology with Capacitive Sensors
- Direct Drive for High Dynamics and Stiffness
- Vacuum Compatible up to 10^{-6} hPa
- Outstanding Lifetime Due to PICMA® Piezo Actuators

Model	Travel	Resolution	Push/ Pull force capacity	Material	Dimensions
P-915KVPZ Z Stage	45 µm	0.3 nm	20 N	Stainless stell	Moving platform: 375 x 375 mm Clear aperture: 273 x 273 mm

P-915K Low-Profile Piezo Objective Scanner

For High Scanning Frequencies

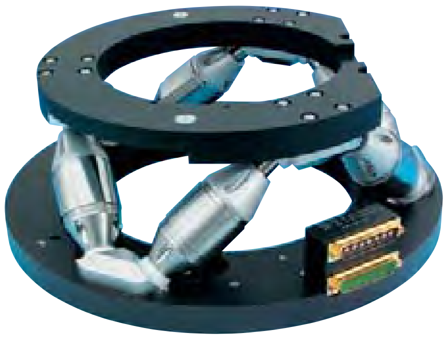
The P-915KLPZ objective scanner allows high scanning frequencies

- Very Low Profile of 15 mm
- Travel Range 75 µm
- Clear Aperture for Objectives with W0.8 x 1/36” Thread
- Frictionless, High-Precision Flexure Guiding System for Better Focus Stability and Minimized Runout
- Very Low Profile
- Outstanding Lifetime Due to PICMA® Piezo Actuators

Model	Active axes	Travel range	Resonant frequency @ 150 g	Dimensions
P-915KLPZ Objective Scanner	Z	75 µm	200 Hz	60 x 60 x 15 mm

N-515K Non-Magnetic Piezo Hexapod

6-Axis Precision Positioning System with NEXLINE® Linear Drives



6-axis parallel kinematics (Hexapod) with integrated N-215 NEXLINE® high-load actuators, suitable for applications in strong magnetic fields

- **Travel Ranges 10 mm Linear, 6° Rotation**
- **Large Clear Aperture Ø 202 mm**
- **Non-Magnetic**
- **Nanometer Resolution**
- **Low-Profile: 140 mm Height Only**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**
- **Up to 500 N Force Generation**
- **Self Locking at Rest, No Heat Generation**

Model	Travel range	Load capacity	Dimensions
N-515KNPH NEXLINE® Piezo Hexapod	X, Y, Z: 10 mm θ_X, θ_Y, θ_Z: 6°	50 kg	Outer Ø baseplate, 380 mm Ø moved platform (top) 300 mm 140 mm height

N-510 High-Force NEXLINE® Z/Tip/Tilt Platform

Nanometer Precision for Semiconductor Industry, Wafer Alignment

Z, tip, tilt nanopositioning platform with 3 integrated drives (tripod design)

- **Self Locking at Rest, No Heat Generation**
- **Vacuum Compatible and Non-Magnetic Designs Feasible**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**
- **NEXLINE® Piezo Walking Drive Free from Wear and Tear**
- **Load Capacity 200 N**
- **High Precision with Integrated 5 nm Incremental Sensors + Picometer Resolution Dithering Mode**

Model	Travel	Load capacity	Linear velocity	Dimensions
N-510 NEXLINE® Z, tip, tilt platform	1,3 mm vertical range 10 mrad tilt angle	200 N	0.2 mm/s	Ø 300 mm (12´´) Clear aperture 250 mm

N-510K High-Stiffness NEXLINE® Z Stage

High-Precision Positioning, with Capacitive Sensors

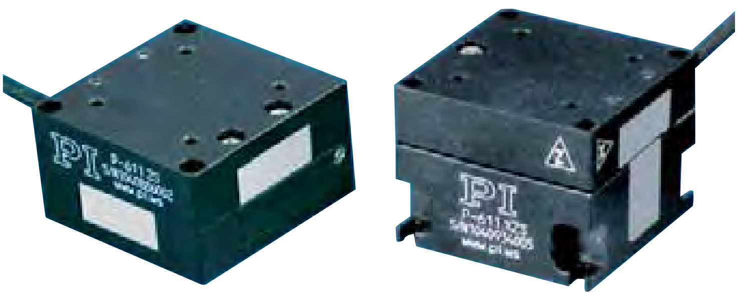
The N-510KHFS hybrid-drive nanopositioner offers maximum accuracy for semiconductor inspection applications

- **Self Locking at Rest, No Heat Generation**
- **Hybrid Drive: PiezoWalk® plus PICMA®**
- **Travel Range: 400 µm Coarse + 40 µm Fine**
- **2 µm Closed-Loop Resolution**
- **Direct Metrology: One Single Control Loop with Capacitive Sensors**
- **High Push and Holding Force to 25 N**
- **Piezo Walking Drive w/o Wear and Tear & Outstanding Lifetime due to PICMA® Piezo Actuators**

Model	Vertical V travel	elocity	Bidirectional repeatability	Load capacity	Dimensions
N-510KHFS Hybrid-Focus System	400 µm coarse 40 µm fine	1 mm/sec	50 nm (full travel)	25 N	Ø 300 mm 68.5 mm height

P-611.XZ · P-611.2 XZ & XY Nanopositioner

Compact 2-Axis Piezo System for Nanopositioning Tasks



P-611 XY- and XZ-nanopositioning systems (from left), 100 µm travel, resolution to 0.2 nm

- **Compact: Footprint 44 x 44 mm**
- **Travel Range to 120 x 120 µm**
- **Resolution to 0.2 nm**
- **Cost-Effective Mechanics/Electronics System Configurations**
- **Frictionless, High-Precision Flexure Guiding System**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **X, Z and XYZ Versions also Available**

P-611 piezo stages are flexure-guided nanopositioning systems featuring a compact footprint of only 44 x 44 mm. The XY- and XZ-versions described here are part of a family of positioners available in 1 to 3 axis configurations. Despite their small dimensions the systems provide up to 120 µm travel with sub-nanometer resolution. They are ideally suited for planar positioning tasks such as optical-path length correction in interferometry, sample positioning in microscopy or scanning applications, for autofocus and photonics applications. Both versions are available with 100 µm travel per axis. Equipped with ceramic-encapsulated piezo drives and a stiff, zero-stiction, zero-friction flexure guiding system, all P-611 piezo stages combine millisecond responsiveness with nanometric precision and extreme reliability.

Application Examples

- Fiber positioning
- Semiconductor testing
- Micromachining
- Micromanipulation
- MEMS fabrication/testing
- Photonics / integrated optics

Closed-Loop and Open-Loop Versions

High-resolution, fast-responding, strain gauge sensors (SGS) are applied to appropriate locations on the drive train and provide a high-bandwidth, nanometer-precision position feedback signal to the controller. The sensors are connected in a full-bridge configuration to eliminate thermal drift, and assure optimal position stability in the nanometer range.

The open-loop models are ideal for applications where fast response and very high resolution are essential, but absolute positioning is not important. They can also be used when the position is controlled by an external linear position sensor such as an interferometer, a PSD (position sensitive diode), CCD chip / image processing system, or the eyes and hands of an operator.

Versatility & Combination with Motorized Stages

The P-611 family of piezo stages comprises a variety of single- and multi-axis versions (X, XY, Z, XZ and XYZ) that can be easily combined with a number of very compact manual or motorized micropositioning systems to form coarse/fine positioners with longer travel ranges (see p. 2-20, p. 2-36 and p. 2-50).

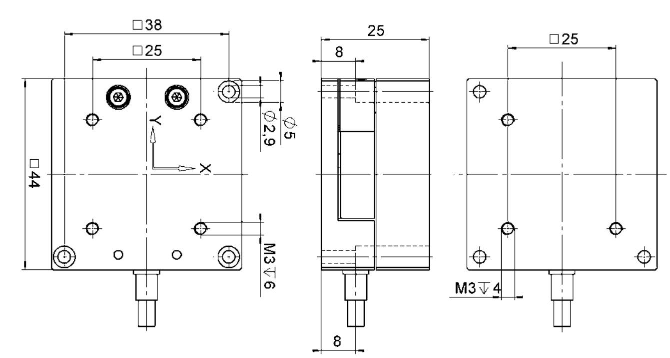
Ordering Information

P-611.2S
XY Nanopositioning System, 100 x 100 µm, SGS-Sensor

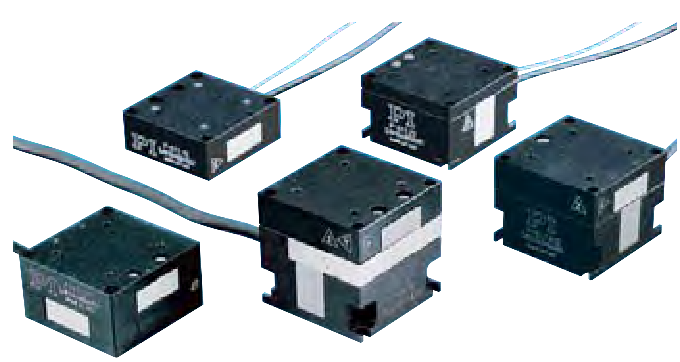
P-611.20
XY Nanopositioning System, 100 x 100 µm, No Sensor

P-611.XZS
XZ Nanopositioning System, 100 x 100 µm, SGS-Sensor

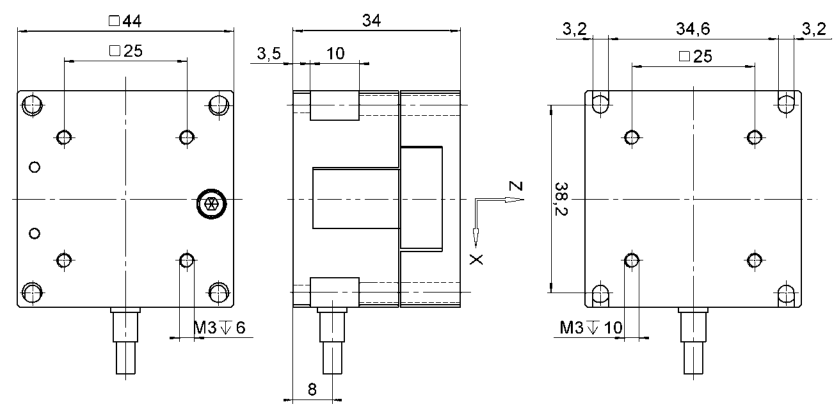
P-611.XZ0
XZ Nanopositioning System, 100 x 100 µm, No Sensor



P-611.2S dimensions in mm



The whole P-611 family: X, Z, XY, XZ and XYZ stages



P-611.XZS dimensions in mm

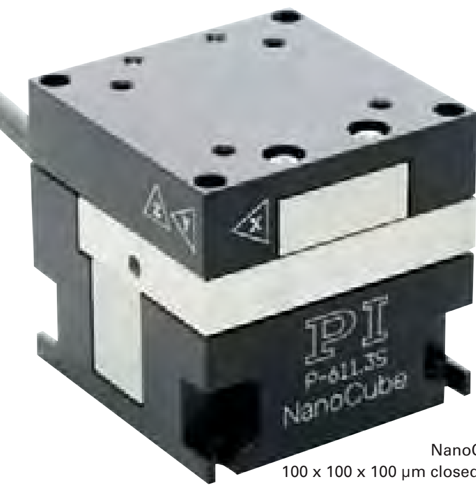
Technical Data

Models	P-611.2S	P-611.20	P-611.XZS	P-611.XZ0	Units	Tolerance
Active axes	X, Y	X, Y	X, Z	X, Z		
Motion and positioning						
Integrated sensor	SGS	–	SGS	–		
Open-loop travel, -20 to +120 V	120	20	120	120	µm	min. (+20 %/0 %)
Closed-loop travel	100	–	100	–	µm	
Open-loop resolution	0.2	0.2	0.2	0.2	nm	typ.
Closed-loop resolution	2	–	2	–	nm	typ.
Linearity	0.1	–	0.1	–	%	typ.
Repeatability	<10	–	<10	–	nm	typ.
Pitch in X,Y	±5	±5	±5	±5	µrad	typ.
Runout θ_X (Z motion)	–	–	±10	±10	µrad	typ.
Yaw in X	±20	±20	±20	±20	µrad	typ.
Yaw in Y	±10	±10	–	–	µrad	typ.
Runout θ_Y (Z motion)	–	–	±10	+/-10	µrad	typ.
Mechanical properties						
Stiffness 0.2		0.2	0.2 Z: 0.35	0.2 Z: 0.35	N/µm	±20 %
Unloaded resonant frequency	X: 345; Y: 270	X: 345; Y: 270	X: 365; Z: 340	X: 365; Z: 340	Hz	±20 %
Resonant frequency @ 30 g	X: 270; Y: 225	X: 270; Y: 225	X: 280; Z: 295	X: 280; Z: 295	Hz	±20 %
Resonant frequency @ 100 g	X: 180; Y: 165	X: 180; Y: 165	X: 185; Z: 230	X: 185; Z: 230	Hz	±20 %
Push/pull force capacity in motion direction	15 / 10	15 / 10	15 / 10	15 / 10	N	Max.
Load capacity	15	15	15	15	N	Max.
Drive properties						
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical capacitance	1.5	1.5	1.5	1.5	µF	±20 %
Dynamic operating current coefficient	1.9	1.9	1.9	1.9	µA/(Hz • µm)	±20 %
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Aluminum, steel	Aluminum, steel	Aluminum, steel	Aluminum, steel		
Dimensions	44 x 44 x 25	44 x 44 x 25	44 x 44 x 34	44 x 44 x 34	mm	
Mass	0.235	0.235	0.27	0.27	kg	±5 %
Cable length	1.5	1.5	1.5	1.5	m	±10 mm
Sensor connection	LEMO	–	LEMO	–		
Voltage connection	LEMO	LEMO	LEMO	LEMO		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. V alue given is noise equivalent motion with E-50 3 amplifier (p. 2-146)
Dynamic Operating Current Coefficient in µA per Hz and µm. Example: Sinusoidal scan of 50 µm at 10 Hz requires approximately 0. 9 mA drive current.
Recommended controller / amplifier
Single-channel (1 per axis): E-610 servo controller / amplifier (p. 2-110), E -625 servo controller , bench-top (p. 2-114), E-62 1 controller module (p. 2-160)
Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152)

P-611.3 NanoCube® XYZ Piezo Stage

Compact Multi-Axis Piezo System for Nanopositioning and Fiber Alignment



NanoCube® XYZ-nanopositioning system, 100 x 100 x 100 µm closed-loop travel range, resolution 1 nm

- **Up to 120 x 120 x 120 µm Travel Range**
- **Very Compact: 44 x 44 x 44 mm**
- **Resolution to 0.2 nm, Rapid Response**
- **Frictionless, High-Precision Flexure Guiding System**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Fast Multi-Axis Scanning**
- **Version with Integrated Fiber Adapter Interface**
- **Cost-Effective Mechanics/Electronics System Configurations**

The P-611 NanoCube® piezo stage is a versatile, multi-axis piezo-nanopositioning system. Its 100 x 100 x 100 µm positioning and scanning range comes in an extremely compact package of only 44 x 44 x 44 mm. Equipped with a stiff, zero-stiction, zero-friction guiding system, this NanoCube® provides motion with ultra-high resolution and settling times of only a few milliseconds. The minimal moved masses and the stiff piezo drive make it ideal for high-throughput applications such as fiber alignment where it enables significantliy faster device characterization than achievable with conventional motorized drives.

Application Examples

- Photonics / integrated optics
- Micromanipulation
- Biotechnology
- Semiconductor testing
- Fiber positioning

Closed-Loop and Open-Loop Versions

High-resolution, fast-responding, strain gauge sensors (SGS) are applied to appropriate locations on the drive train and provide a high-bandwidth, nanometer-precision position feedback signal to the controller. The sensors are connected in a full-bridge configuration to eliminate thermal drift, and assure optimal position stability in the nanometer range.

The open-loop models are ideal for applications where fast response and very high resolution are essential, but absolute positioning is not important, e.g. in tracking or fiber positioning. They can also be used when the position is controlled by an external linear position sensor such as an interferometer, a PSD (position sensitive diode), CCD chip / image processing system, or the eyes and hands of an operator.

Versatility & Combination with Motorized Stages

The P-611 family of piezo stages comprises a variety of single- and multi-axis versions (X, XY, Z, XZ and XYZ) that can be easily combined with a number of very compact manual or motorized micropositioning systems to form coarse/fine positioners with longer travel ranges (see p. 2-20, p. 2-36 and p. 2-50). For fiber positioning tasks, several fiber, waveguide and optics adapters are available for mounting on the NanoCube® P-611.3SF (e.g. for combination with the F-206.S nanoalignment system see p. 4-12).

High Reliability and Long Lifetime

The compact P-611 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and thus offer better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free and not subject to wear, and thus offer an extraordinary reliability.

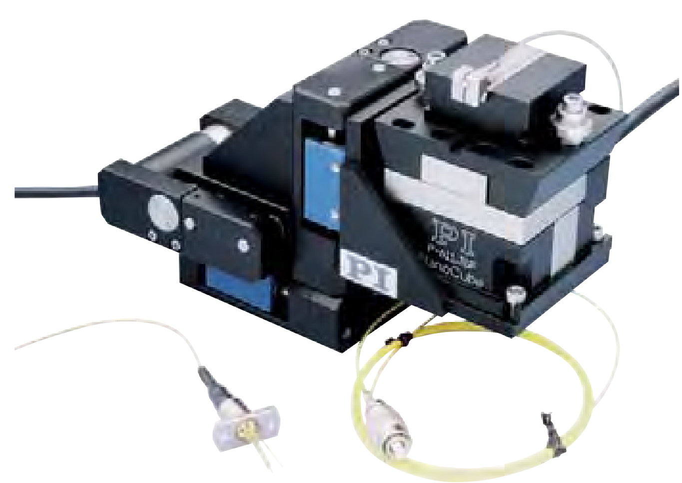
Ordering Information

P-611.3S
NanoCube® XYZ Nanopositioning System, 100 x 100 x 100 µm, Strain Gauge Sensors

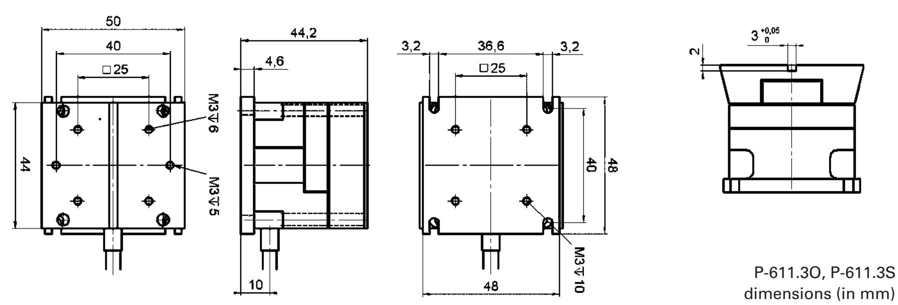
P-611.30
NanoCube® XYZ Nanopositioning System, 100 x 100 x 100 µm, Open-Loop

P-611.3SF
NanoCube® XYZ Nanopositioning System, 100 x 100 x 100 µm, Strain Gauge Sensors, Fiber Adapter Interface

P-611.30F
NanoCube® XYZ Nanopositioning System, 100 x 100 x 100 µm, Open-Loop, Fiber Adapter Interface



Combination of P-611.3SF NanoCube® XYZ Nanopositioning System, 100 x 100 x 100 µm and M-111 XYZ MicroPositioner 15 x 15 x 15 mm



P-611.3O, P-611.3S dimensions (in mm)

Technical Data

Model	P-611.3S P-611.3SF	P-611.3O P-611.3OF	Units	Tolerance
Active axes	X, Y, Z	X, Y, Z		
Motion and positioning				
Integrated sensor	SGS			
Open-loop travel, -20 to +120 V	120 / axis	120 / axis	µm	min. (+20 %/0 %)
Closed-loop travel	100 / axis	–	µm	
Open-loop resolution	0.2	0.2	nm	typ.
Closed-loop resolution	1	–	nm	typ.
Linearity	0.1	–	%	typ.
Repeatability	<10	–	nm	typ.
Pitch in X,Y	±5	±5	µrad	typ.
Runout θ_X (Z motion)	±10	±10	µrad	typ.
Yaw in X	±20	±20	µrad	typ.
Yaw in Y	±10	±10	µrad	typ.
Runout θ_Y (Z motion)	±10	±10	µrad	typ.
Mechanical properties				
Stiffness 0.3		0.3	N/µm	±20 %
Unloaded resonant frequency X / Y / Z	350 / 220 / 250	350 / 220 / 250	Hz	±20 %
Resonant frequency @ 30 g X / Y / Z	270 / 185 / 230	270 / 185 / 230	Hz	±20 %
Resonant frequency @ 100 g X / Y / Z	180 / 135 / 200	180 / 135 / 200	Hz	±20 %
Push/pull force capacity in motion direction	+15 / -10	+15 / -10	N	Max.
Load capacity	15	15	N	Max.
Drive properties				
ceramic type	PICMA® P-885	PICMA® P-885		
Electrical capacitance	1.5	1.5	µF	±20 %
Dynamic operating current coefficient	1.9	1.9	µA/(Hz • µm)	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material	Aluminum, steel	Aluminum, steel		
Dimensions	44 x 44 x 43.2 SF-version: 44 x 50 x 44.2	44 x 44 x 43.2 OF-version: 44 x 50 x 44.2	mm	
Mass	0.32	0.32	kg	±5 %
Cable length	1.5	1.5	m	±10 mm
Sensor connector	Sub-D	–		
Voltage connection	Sub-D	Sub-D		
Recommended controller / amplifier	E-664 Nanocube® Controller (p. 2-137)	3 x E-610.00F OEM amplifier modules (p. 2-110); E-663 3-channel amplifier, bench-top (p. 2-136)		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. V alue given is noise equivalent motion with E-50 3 amplifier (p. 2-146)
Dynamic Operating Current Coefficient in µA per Hz and µm. Example: Sinusoidal scan of 50 µm at 10 Hz requires approximately 0. 8 mA drive current.
Adapter cable with LEMO connectors for sensor and operating voltage available.

P-620.2 - P-629.2 PIHera® XY Piezo Stage

High-Precision Nanopositioner Family – Compact and Long Travel Ranges

PIHera® XY-Nanopositioniersysteme mit Stellwegen von 50 x 50 µm bis 1800 x 1800 µm

- **Travel Ranges 50 to 1800 µm**
- **High-Precision, Cost-Efficient**
- **Resolution to 0.1 nm**
- **Frictionless, High-Precision Flexure Guiding System**
- **0,02 % Positioning Accuracy**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **X-, XY-, Z- and XYZ-Versions**
- **Vacuum-Compatible Versions Available**

Two-axis (XY) PIHera® systems are piezo-nanopositioning stages featuring travel ranges from 50 to 1800 µm. Despite the increased travel ranges, the units are extremely compact and provide rapid response and high guiding precision. This, and the long travel range is achieved with a friction-free and extremely stiff flexure system sub-nanometer resolution. The PIHera® piezo nanopositioning series also includes Z and X stages (see p. 2-22 and p. 2-40).

Application Examples

- Interferometry
- Microscopy
- Nanopositioning
- Biotechnology
- Quality assurance testing
- Semiconductor technology

Nanometer Precision in Milliseconds

One of the advantages of PIHera® stages over motor-driven positioning stages is the rapid response to input changes and the fast and precise settling behavior. The P-622.1CD, for example, can settle to an accuracy of 10 nm in only 30 msec (other PI stages provide even faster response)!

Superior Accuracy With Direct-Metrology Capacitive Sensors

A choice of tasks such as optical path adjustment in interferometry, sample positioning in microscopy, precision alignment or optical tracking require the relatively long scanning ranges and nanometer precision offered by PIHera® nanopositioning stages.
PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Designed for Precision

High stiffness is achieved with the FEA-optimized design of the frictionless flexure elements, which assure excellent guiding accuracy and dynamics. A straightness and flatness in the nanometer range is achieved.

Ordering Information

P-620.2CD* / P-620.2CL*
PIHera® Precision XY Nanopositioning System, 50 x 50 µm, Direct Metrology, Capacitive Sensors

P-621.2CD* / P-621.2CL*
PIHera® Precision XY Nanopositioning System, 100 x 100 µm, Direct Metrology, Capacitive Sensors

P-622.2CD* / P-622.2CL*
PIHera® Precision XY Nanopositioning System, 250 x 250 µm, Direct Metrology, Capacitive Sensors

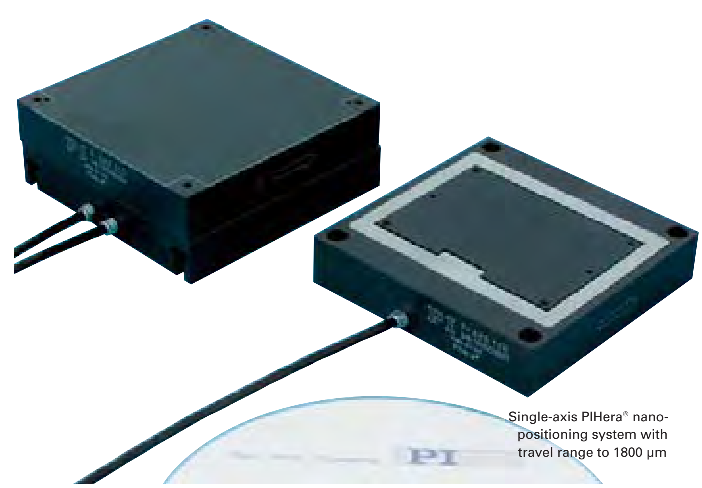
P-625.2CD* / P-625.2CL*
PIHera® Precision XY Nanopositioning System, 500 x 500 µm, Direct Metrology, Capacitive Sensors

P-628.2CD* / P-628.2CL*
PIHera® Precision XY Nanopositioning System, 800 x 800 µm, Direct Metrology, Capacitive Sensors

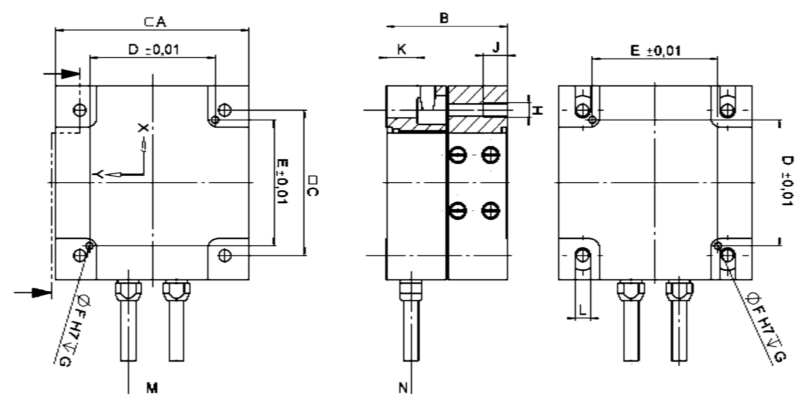
P-629.2CD* / P-629.2CL*
PIHera® Precision XY Nanopositioning System, 1500 x 1500 µm, Direct Metrology, Capacitive Sensors

*.2CD with Sub-D Connector
*.2CL with LEMO Connector

Open-loop versions are available as P-62x.20L.
Vacuum versions to 10^{-9} hPa are available as P-62x.2UD.



Single-axis PIHera® nanopositioning system with travel range to 1800 µm



	A	B	C	D	E	ØF	G
P-620.2CD / .20L	30	21,5	24	24	19	1,01	1,5
P-621.2CD / .20L	40	25	30	26	26	1,51	2,5
P-622.2CD / .20L	50	25	40	35	35	1,51	2,5
P-625.2CD / .20L	60	25	50	46	46	1,51	2,5
P-628.2CD / .20L	80	30	70	66	66	1,51	2,5

	H	J	K	L	M	N
P-620.2CD / .20L	M2	3,5	5,1	2,2	9	6
P-621.2CD / .20L	M3	5	6,25	3,2	10	5
P-622.2CD / .20L	M3	5	6,25	3,2	11	5
P-625.2CD / .20L	M3	6	6,25	3,2	11	5
P-628.2CD / .20L	M3	6	6,75	3,2	11	5

P-62x.2CD/.2CL/.20L Abmessungen in mm

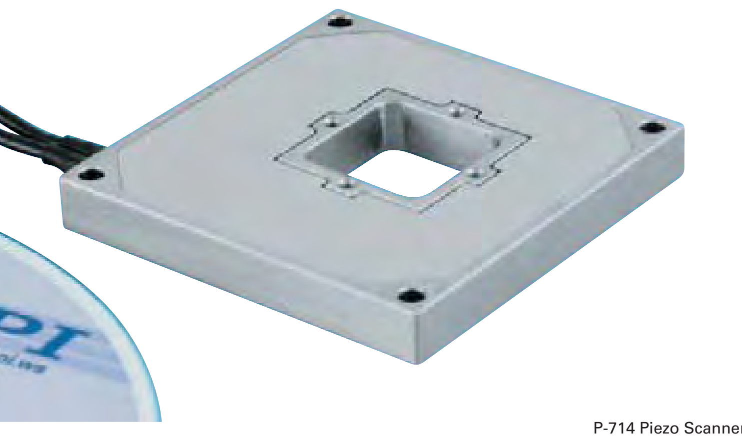
Technical Data

Model	P-620.2CD/ P-620.2CL	P-621.2CD/ P-621.2CL	P-622.2CD/ P-622.2CL	P-625.2CD/ P-625.2CL	P-628.2CD/ P-628.2CL	P-629.2CD P-629.2CL	P-62x.20L open-loop versions	Units T	olerance
Active axes	X, Y	X, Y	X, Y	X, Y	X, Y	X, Y	X, Y		
Motion and positioning									
Integrated sensor	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive	–		
Open-loop travel X, Y, -20 to +120 V	60	120	300	600	950	1800	as P-62x.2CD	µm	min. (+20 %/-0 %)
Closed-loop travel	50	100	250	500	800	1500	–	µm	
Open-loop resolution	0.1	0.2	0.4	0.5	0.5	2	as P-62x.2CD	nm	typ.
Closed-loop resolution	0.2	0.4	0.7	1.4	3.5	3.5	–	nm	typ.
Linearity 0.02		0.02	0.02	0.03	0.03	0.03	–	%	typ.
Repeatability ±2		±2	±2	±5	±10	±14	as P-62x.2CD	nm	typ.
Pitch / yaw	±3	±3	±3	±3	±20	±30	as P-62x.2CD	µrad	typ.
Mechanical properties									
Stiffness	0.22	0.25	0.2	0.1	0.05	0.1	as P-62x.2CD	N/µm	±20 %
Unloaded resonant frequency in X,	575	420	225	135	75	60	as P-62x.2CD	Hz	±20 %
Unloaded resonant frequency in Y	800	535	300	195	105	100	as P-62x.2CD	Hz	±20 %
Resonant frequency in X @ 50 g	270	285	180	120	60	55	as P-62x.2CD	Hz	±20 %
Resonant frequency in Y @ 50 g	395	365	215	150	85	85	as P-62x.2CD	Hz	±20 %
Resonant frequency in X @ 100 g	285	220	160	105	55	50	as P-62x.2CD	Hz	±20 %
Resonant frequency in Y @ 100 g	300	285	175	125	75	80	as P-62x.2CD	Hz	±20 %
Push/pull force capacity in motion direction	10 / 5	10 / 8	10 / 8	10 / 8	10 / 8	10 / 8	as P-62x.2CD	N	Max.
Load capacity	10	10	10	10	10	10	as P-62x.2CD	N	Max.
Lateral Force	10	10	10	10	10	10	as P-62x.2CD	N	Max.
Drive properties									
Ceramic type	PICMA® P-883	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-887	PICMA® P-888	as P-62x.2CD		
Electrical Capacitance	0.35	1.5	3.1	6.2	19	52	as P-62x.2CD	µF	±20 %
Dynamic operating current coefficient	0.9	1.9	1.9	1.6	3	4.3	as P-62x.2CD	µA/(Hz•µm)	±20 %
Miscellaneous									
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 150	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum		
Mass	0.195	0.295	0.348	0.43	0.7	1.37	as P-62x.2CD	kg	±5 %
Cable length	1.5	1.5	1.5	1.5	1.5	1.5	1.5	m	±10 mm
Sensor / voltage connection	CD version: 2x Sub-D special CL version: LEMO	CD version: 2x Sub-D special CL version: LEMO	CD version: 2x Sub-D special CL version: LEMO	CD version: 2x Sub-D special CL version: LEMO	CD version: 2x Sub-D special CL version: LEMO	CD version: 2x Sub-D special CL version: LEMO	2x LEMO (no sensor)		

Lower axis: X; upper axis: Y.
Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. The value given is noise equivalent motion with E-710 controller (p. 2-128)
Recommended controller
CD version: E-610 servo controller / amplifier (p. 2-110), E-625 servo controller , bench-top (p. 2-114), E-665 powerful servo c ontroller, bench-top (p. 2-116)
Multi-channel digital controllers: E-710 bench-top (p. 2-128), E-712 modular (p. 2-140), E-725 high-power (p. 2-126), E-761 PCI board (p. 2-140)
CL version: E-500 modular piezo controller system (p. 2-142) with E-505 amplifier module (1 per axis, high power) (p. 2-147) and E-509 controller (p. 2-152)
Open-loop versions: E-500 modular piezo controller system (p. 2-142) with E-505 amplifier module (1 per axis, high power) (p. 2- 147)

P-713 · P-714 XY Piezo Scanner

Cost-Effective OEM System with Low Profile



P-714 Piezo Scanner

- **Ideal for Pixel Sub-Stepping in Image Enhancement**
- **Small Footprint and Low Profile: 45 x 45 x 6 mm with Clear Aperture**
- **Very Cost-Effective Design**
- **Travel Ranges to 20 x 20 µm**
- **Parallel Kinematics for Better Multi-Axis Accuracy and Dynamics**

P-713 / P-714 family piezo scanners and positioners with travel ranges of 15 x 15 µm feature especially compact designs. Ideal applications for the P-713 and P-714 are high-dynamics scanning or tracking tasks such as sub-stepping methods for enhancing image resolution. Such tasks involve moving to specific positions in a small area (e. g. marked cells or CCD photosites) and from there following or performing motion with an amplitude of a few microns. The resonant frequency of up to over 2 kHz makes for settling times of a few milliseconds, even after a full-range move, all with closed-loop repeatability of under 5 nm.

A single-axis version with similar footprint is available as P-712 (see p. 2-14) and XY versions with longer travel ranges are available on request.

Application Examples

- Pixel dithering / sub-stepping image resolution enhancement
- Quality assurance testing
- Optical Metrology
- Microscopy
- Imaging
- CCD / CMOS camera technology

Flexibility

P-713 and P-714 nanopositioners are offered in different versions for different applications. The lowest-cost, basic version of the P-713 offers guiding accuracy in the motion plane of 50 µrad, a value generally good enough for dithering and interlacing tasks in scanning patterns of a few microns. For more demanding applications, the P-714 offers greater accuracy, typically 5 µrad or <10 nm absolute.

Nanometer Position Servo-Control

If servo-control is required and no external position sensor is available, the P-714.2SL version, equipped with high-resolution strain gauge sensors (SGS) can provide nanometer-range resolution.

High-resolution, broadband, strain gauge sensors (SGS) are applied to appropriate locations on the drive train and measure the displacement of the moving part of the stage relative to the base indirectly. The SGS sensors assure optimum position stability in the nanometer range and fast response.

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

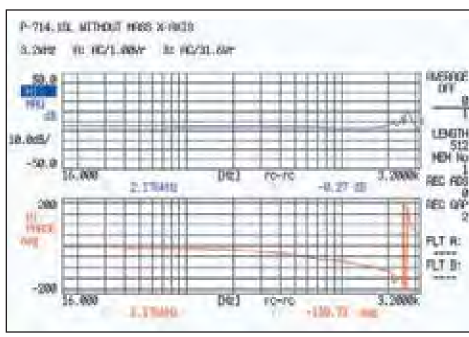
Ordering Information

P-713.20L
Low-Profile OEM XY Nanoscanner, 15 x 15 µm, No Sensor, LEMO Connector

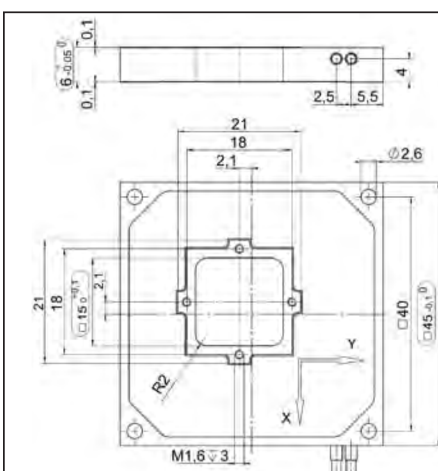
P-714.20L
Low-Profile OEM XY Nanoscanner, 15 x 15 µm, Improved Guiding Accuracy, No Sensor, LEMO Connector

P-713.2SL
Low-Profile OEM XY Nanoscanner, 15 x 15 µm, SGS-Sensor, LEMO Connector

P-714.2SL
Low-Profile OEM XY Nanoscanner, 15 x 15 µm, Improved Guiding Accuracy, SGS-Sensor, LEMO Connector



The resonant frequency of an unloaded P-713 / P-714 scanner is over 2 kHz

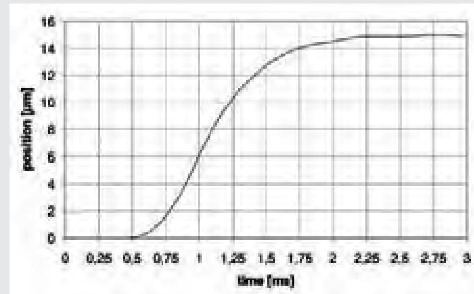


P-713/P-714 dimensions in mm

PI

See the "Selection Guide" for comparison with other nanopositioning systems (see p. 2-4 *ff*).

System properties	
System controller	P-714.2SL with modular system E-500 (E-503 amplifier and E-509 sensor module); 20 g load
Bandwidth, small signal	300 Hz
Bandwidth, large signal	220 Hz
Settling time (10 % step width)	3.1 ms
Settling time (full travel)	4.5 ms



Settling time for the P-713/P-714 at 15 µm is in the 2 ms range

Technical Data

Model	P-713.20L	P-713.2SL	P-714.20L	P-714.2SL	Units	Tolerance
Active axes	X, Y	X, Y	X, Y	X, Y		
Motion and positioning						
Integrated sensor	-	SGS	-	SGS		
Open-loop travel, -20 to +120 V	20	20	20	20	µm	min. (+20 %/0 %)
Closed-loop travel	-	15	-	15	µm	
Open-loop resolution	0.1	0.1	0.1	0.1	nm	typ.
Closed-loop resolution	-	1	-	1	nm	typ.
Linearity	-	0.3	-	0.3	%	typ.
Repeatability	-	<4	-	<4	nm	typ.
Pitch	typ. ±1 max. ±5	typ. ±1 max. ±5	typ. ±1 max. ±5	typ. ±1 max. ±5	µrad	typ.
Yaw	typ. ±40 max. ±50	typ. ±40 max. ±50	typ. ±40 max. ±50	typ. ±40 max. ±50	µrad	µrad
Mechanical properties						
Stiffness	0.8	0.8	0.8	0.8	N/µm	±20 %
Unloaded resonant frequency	2250	2250	2250	2250	Hz	±20 %
Resonant frequency under load	1310 (20 g) 1020 (50 g) 460 (100 g)	1310 (20 g) 1020 (50 g) 460 (100 g)	1310 (20 g) 1020 (50 g) 460 (100 g)	1310 (20 g) 1020 (50 g) 460 (100 g)	Hz	±20 %
Push/pull force capacity in motion direction	5 / 5	5 / 5	5 / 5	5 / 5	N	Max.
Load capacity	2	2	2	2	N	Max.
Drive properties						
Ceramic type	PICMA® P-882	PICMA® P-882	PICMA® P-882	PICMA® P-882		
Electrical capacitance in X , Y	0.31	0.31	0.31	0.31	µF	±20 %
Dynamic operating current coefficient (DOCC) in X, Y	2.5	2.5	2.5	2.5	µA/(Hz • µm)	±20 %
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Stainless steel, ferromagnetic	Stainless steel, ferromagnetic	Stainless steel, ferromagnetic	Stainless steel, ferromagnetic		
Dimensions	45 x 45 x 6	45 x 45 x 6	45 x 45 x 6	45 x 45 x 6		
Mass	0.1	0.1	0.1	0.1	kg	±5 %
Cable length	1.5	1.5	1.5	1.5	m	±10 mm
Sensor connection	-	LEMO	-	LEMO		
Voltage connection	LEMO	LEMO	LEMO	LEMO		

Resolution of PI piezo nanopositioners is not limited by friction or stiction. V alue given is noise equivalent motion with E-50 3 amplifier (p. 2-146)

Dynamic Operating Current Coefficient in µA per Hz and µm. Example: Sinusoidal scan of 10 µm at 100 Hz requires approximately 2 .5 mA drive current.

Recommended controller / amplifier

Single-channel (1 per axis): E-610 servo controller / amplifier (p. 2-110), E-625 servo controller , bench-top (p. 2-114), E-621 controller module (p. 2-160)

Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152)

P-612 XY Piezo Nanopositioning System

Compact, Clear Aperture

P-612.2SL XY piezo stage (CD for size comparison)

- Compact: Footprint 60 x 60 mm
- 100 x 100 µm Closed-Loop Travel Range (130 x 130 Open-Loop)
- For Cost-Sensitive Applications
- Clear Aperture 20 x 20 mm
- Parallel-Kinematics for Enhanced Responsiveness / Multi-Axis Precision
- Outstanding Lifetime Due to PICMA® Piezo Actuators
- Z-Stage Also Available

The P-612.2SL is a piezo-based nanopositioning system featuring a compact footprint of only 60 x 60 mm and a height of 18 mm. Due to the 20 x 20 mm open aperture, the system is excellently suited for sample positioning in microscopy or scanning applications. Equipped with piezo drives and zero-stiction, zero-friction flexure guiding system, the series provides nanometer-range resolution and millisecond response time. A Z stage with the same form factor is available for vertical positioning applications (see P-612.ZSL p. 2-38).

Cost-Effective Design

Flexures optimized with Finite Element Analysis (FEA) are used to guide the compact, low-cost stage. Flexures allow extremely high-precision motion, no matter how minute, as they are completely free of play and friction. They also optimize stiffness in and perpendicular to the direction of motion.

Position Servo-Control with Nanometer Resolution

High-resolution, broadband, strain gauge sensors (SGS) are applied to appropriate locations on the drive train and measure the displacement of the moving part of the stage relative to the base directly. The SGS sensors assure optimum position stability in the nanometer range and fast response.

The open-loop models are ideal for applications where fast response and very high resolution are essential, but absolute positioning is not important. They can also be used in applications where the position is controlled by an external linear position sensor such as an interferometer, a PSD (position sensitive diode), CCD chip / image processing system, or the eyes and hands of an operator.

Ordering Information

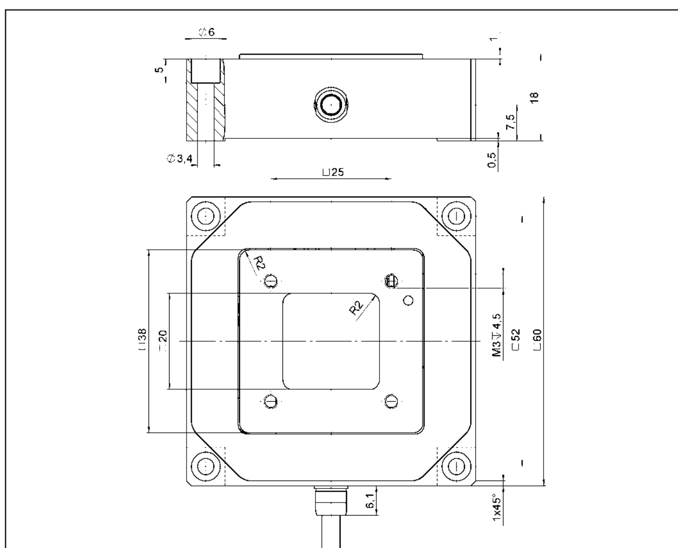
P-612.2SL
XY Nanopositioning System with 20 x 20 mm Aperture, 100 x 100 µm, Strain Gauge Sensors

P-612.20L
XY Nanopositioning System with Aperture 20 x 20 mm, 100 x 100 µm, Open-Loop

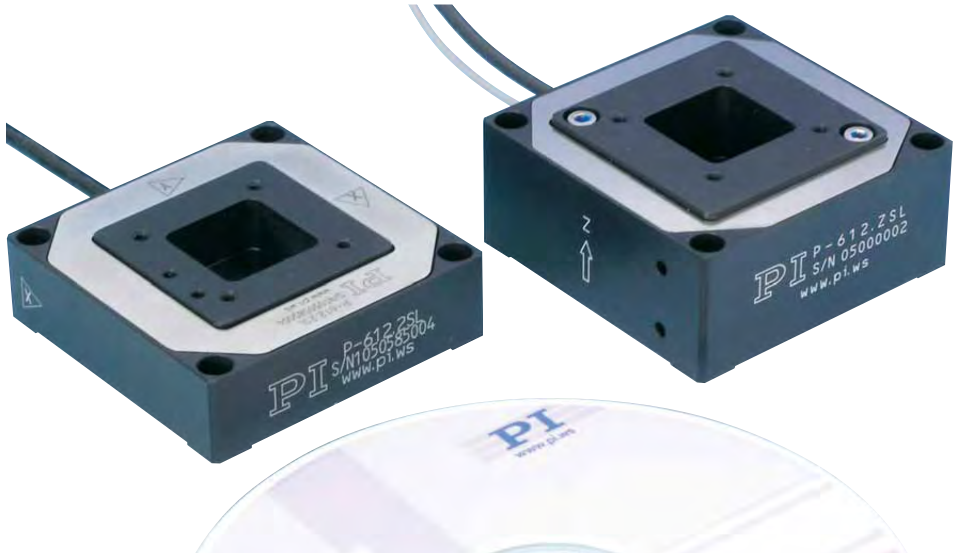
Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

System properties	
System configuration	P-612.2 SL and E-500 modular system with E-503 amplifier and E-509 sensor module, 100 load
Amplifier bandwidth, small signal	45 Hz
Settling time (10 % step width)	15 ms



P-612.2 dimensions in mm



P-612 are available as XY-scanners (P-612.2SL, on the left) and vertical stages (P-612.ZSL, on the right) providing a travel range of 100 µm per axis

Technical Data

Model	P-612.2SL	P-612.20L	Units	Tolerance
Active axes	X, Y	X, Y		
Motion and positioning				
Integrated sensor	SGS	–		
Open-loop travel, -20 to +120 V	130	130	µm	min. (+20 %/-0 %)
Closed-loop travel	100	–		µm
Open-loop resolution	0.8	0.8	nm	typ.
Closed-loop resolution	5	–	nm	typ.
Linearity 0.4		–	%	typ.
Repeatability	<10	–	nm	typ.
Pitch	±10	±10	µrad	typ.
Yaw in X/ Y	±10 / ±50	±10 / ±50	µrad	typ.
Mechanical properties				
Stiffness	0.15	0.15	N/µm	±20 %
Unloaded resonant frequency	400	400	Hz	±20 %
Resonant frequency @ 100 g	200	200	Hz	±20 %
Push/pull force capacity in motion direction	15 / 5	15 / 5	N	Max.
Load capacity	15	15	N	Max.
Drive properties				
Ceramic type	PICMA® P-885	PICMA® P-885		
Electrical capacitance	1.5	1.5	µF	±20 %
Dynamic operating current coefficient	1.9	1.9	µA/(Hz • µm)	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material	Aluminum, steel	Aluminum, steel		
Mass	105	105	g	±5 %
Cable length	1.5	1.5	m	±10 mm
Sensor connector	LEMO connector	–		
Voltage connection	LEMO connector	LEMO connector		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Noise equivalent motion with E-503 amplifier (p. 2-146)
Recommended controller
Single-channel (1 per axis): E-610 servo-controller / amplifier (p. 2-110) , E-625 servo-controller, bench-top (p. 2-114), E-621 controller module (p. 2-160)
Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152)

P-615 NanoCube® XYZ Piezo System

Long-Travel Multi-Axis Piezo Stage for Precision Alignment Applications

P-615NanoCube® XYZ Nanopositioning System provides up to 420 x 420 x 300 µm travel range

- **Up to 420 x 420 x 300 µm Travel Range**
- **Resolution 1 nm**
- **Parallel-Kinematics / Metrology for Enhanced Responsiveness / Multi-Axis Precision**
- **Clear Aperture of 10 mm Ø, Ideal for Alignment and Photonics Packaging Applications**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Open- & Closed-Loop Versions**
- **Vacuum-Compatible Versions to 10^{-9} hPa**
- **Frictionless, High-Precision Flexure Guiding System**

The P-615 NanoCube® is a multi-axis piezo nanopositioning and alignment system. Its 420 x 420 x 300 µm, XYZ positioning and scanning range comes in a compact package. Equipped with a zero-stiction, zero-friction guidance system, this NanoCube® provides motion with ultra-high resolution and settling times of only a few milliseconds.

Fiber Positioning

The P-615 NanoCube® is equipped with a fiber adapter interface similar to the P-611.3SF and accommodates all F-603-series fiber holders and accessories. Fiber optics handling is facilitated by the clear aperture.

Application Examples

- Micromanipulation
- Biotechnology
- Semiconductor testing
- Photonics / integrated optics

Double Stiffness for Fast Response

The P-615's unique flexure design has double the stiffness in the vertical axis than in X and Y, providing faster response and higher operating frequencies under load. For example, the settling time to reach a commanded position with 1% accuracy is only 15 ms in the Z-axis with 100 g load (as opposed to 10 ms without load).

Open-Loop and Closed-Loop Operation

The open-loop basic model P-615.30L is ideal for applications where fast response and very high resolution are essential but specifying or reporting absolute position values is either not required or is handled by external sensors, e. g. in tracking or fiber positioning tasks. In open-loop mode, the piezo displacement is roughly proportional to the applied voltage (see p. 2-184).

Capacitive Sensors for Highest Accuracy

The P-615.3C models are equipped with high-accuracy, capacitive position sensors. PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Active and Passive Guidance for Nanometer Flatness and Straightness

Wire-cut flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. The FEA techniques give the design the highest possible stiffness and minimize linear and angular runout. Further enhancement is achieved by active trajectory control: multi-axis nanopositioning systems equipped with parallel metrology are able to measure platform position in all degrees of freedom against a common, fixed reference. In such systems, undesirable motion from one actuator in the direction of another (cross-talk) is detected immediately and actively compensated by the servo-loops. This can keep deviation from a trajectory to under a few nanometers, even in dynamic operation.

Ordering Information

P-615.3CD
NanoCube® XYZ Nanopositioning System with Long Travel Range, 350 x 350 x 250 µm, Parallel Metrology, Capacitive Sensors, Sub-D Connector

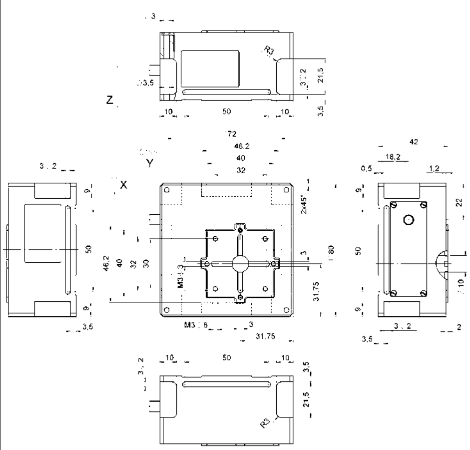
P-615.3CL
NanoCube® XYZ Nanopositioning System with Long Travel Range, 350 x 350 x 250 µm, Parallel Metrology, Capacitive Sensors, LEMO Connector

P-615.30L
NanoCube® XYZ Nanopositioning System with Long Travel Range, 420 x 420 x 300 µm, Parallel Metrology, Open-Loop, LEMO Connector

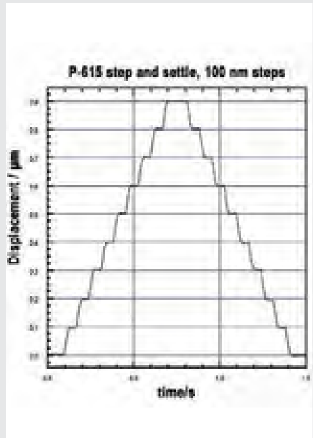
P-615.3UD
NanoCube® XYZ Nanopositioning System with Long Travel Range, 350 x 350 x 250 µm, Parallel Metrology, Capacitive Sensors, Sub-D Connector, Vacuum Compatible to 10^{-9} hPa

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.



P-615 dimensions in mm.
The clear aperture has a diameter of 10 mm.



P-615, X-axis with 100 g load performing 100 nm steps in rapid sequence without overshoot. Settling time for the Z-axis to reach a commanded position with 1 % accuracy is only 15 ms.

P-615 with optional fiber holder F-603.22

Technical Data

Model	P-615.3CD / P-615.3CL	P-615.30L	Units	Tolerance
Active axes	X, Y, Z	X, Y, Z		
Motion and positioning				
Integrated sensor	Capacitive	–		
Open-loop travel in X/Y/Z, -20 to +120 V	420 / 420 / 300	420 / 420 / 300	µm	min. (+20 %/-0 %)
Closed-loop travel X/Y/Z	350 / 350 / 250	–	µm	
Open-loop resolution X/Y/Z	0.5	0.5	nm	typ.
Closed-loop resolution X/Y/Z	1	–	nm	typ.
Linearity X/Y/Z	0.02	–	%	typ.
Repeatability in X, Y, Z	±7.5 / ±7.5 / ±5	–	nm	typ.
Pitch in X,Y	100	100	µrad	typ.
Yaw in X, Y	50	50	µrad	typ.
Runout θ_X, θ_Y (Z motion)	10	10	µrad	typ.
Mechanical properties				
Stiffness X / Y / Z	0.13 / 0.13 / 0.35	0.13 / 0.13 / 0.35	N/µm	±20 %
Unloaded resonant frequency in X / Y / Z	210 / 210 / 250	210 / 210 / 250	Hz	±20 %
Resonant frequency @ 100 g in X / Y / Z	125 / 125 / 200	125 / 125 / 200	Hz	±20 %
Push/pull force capacity in motion direction	20 / 10	20 / 10	N	Max.
Load capacity	20	20	N	Max.
Drive properties				
Ceramic type	PICMA® P-885	PICMA® P-885		
Electrical capacitance in X / Y / Z	3.7 / 3.7 / 6.2	3.7 / 3.7 / 6.2	µF	±20 %
Dynamic operating current coefficient (DOCC) in X / Y / Z	1.3 / 1.3 / 3.1	1.3 / 1.3 / 3.1	µA/(Hz·µm)	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum		
Mass	0.58	0.57	kg	±5 %
Cable length	1.5	1.5	m	±10 mm
Sensor / voltage connection	Sub-D special (CD-version); (no LEMO (CL-version)	LEMO sensor)		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion with E-503 amplifier (p. 2-146).

Recommended controller
Multi-channel digital controllers: E-710 bench-top (p. 2-128), E-712 modular (p. 2-140), E-725 high-power (p. 2-126), E-761 PCI board (p. 2-130)
Multi-channel:
E-500 modular piezo controller system (p. 2-142) with E-509 servo-controller (p. 2-152) (optional) and as amplifier either E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power, p. 2-147) modules P-615.30L (p. 2-68): E-610 controller / amplifier (p. 2-110) (1 per axis)

P-517 · P-527 Multi-Axis Piezo Scanner

High-Dynamics Nanopositioner / Scanner with Direct Position Metrology


P-527.2CL parallel-kinematic nanopositioning system

- **Travel Ranges to 200 µm**
- **Sub-Nanometer Resolution**
- **Frictionless, High-Precision Flexure Guiding System**
- **Capacitive Sensors for Highest Linearity**
- **Parallel-Kinematics / Metrology for Enhanced Responsiveness / Multi-Axis Precision**
- **Clear Aperture 66 x 66 mm**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**

P-517 and P-527 high-dynamics, multi-axis piezo-nanopositioning stages are available in XY ΘZ, XY and XYZ configurations featuring linear travel ranges to 200 x 200 x 20 µm and rotation ranges to 4 mrad. The 66 x 66 mm clear aperture is ideal for transmitted-light applications.
Z/tip/tilt versions in the same form factor are also offered as models P-518, P-528, P-558 (see p. 2-46) and as custom versions with up to six degrees of freedom.

Capacitive Sensors for Highest Accuracy

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Application Examples

- Metrology
- Interferometry
- Optics
- Lithography
- Nanopositioning
- Scanning microscopy
- Mass storage device testing
- Laser technology
- Micromachining

Technical Data

Models	P-517.2CL	P-527.2CL	P-517.3CL/ P-517.3CD	P-527.3CL/ P-527.3CD	P-517.RCD	P-527.RCD
Active axes	X, Y	X, Y	X, Y, Z	X, Y, Z	X, Θ_Y, Θ_Z	Θ_Y, Θ_Z
Motion and positioning						
Integrated sensor	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive	Capacitive
Open-loop travel, -20 to +120 V	130	250	130; Z: 25	250; Z: 25	130; Θ_Z: ±1.3 mrad	250; Θ_Z: ±2.5 mrad
Closed-loop travel	100	200	100; Z: 20	200; Z: 20	100; Θ_Z: ± 1 mrad	200; Θ_Z: ± 2 mrad
Open-loop resolution	0.3	0.5	0.3; Z: 0.1	0.5; Z: 0.1	0.3; Θ_Z: 0.1 µrad	0.5; Θ_ZZ: 0.1 µrad
Closed-loop resolution	1	2	1; Z: 0.1	2; Z: 0.1	1; Θ_Z: 0.3 µrad	2; Θ_Z: 0.3 µrad
Linearity	0.03	0.03	0.03	0.03	0.03	0.03
Repeatability	±5	±10	±5; Z: ±1	±10; Z: ±1	±5; Z: ±0.5 µrad	±10
Mechanical properties						
Stiffness	2	1	2; Z: 15	1; Z: 15	2	1
Unloaded resonant frequency	450	350	450; Z: 1100	350; Z: 1100	450; Z: 400	350; Z: 300
Resonant frequency @ 500 g X, Y	250	190	250	190	250	190
Resonant frequency @ 2500 g X, Y	140	110	140	110	140	110
Push/pull force capacity in motion direction	50 / 30	50 / 30	50 / 30	50 / 30	50 / 30	50 / 30
Drive properties						
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885
Electrical capacitance	9.2	9.2	9; Z: 6	9; Z: 6	9	9
Dynamic operating current coefficient (DOCC)	11.5	5.8	11.5; Z: 37	5.5; Z: 37	11.5	5.5
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80
Material	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum	Aluminum
Mass	0.14	0.14	0.145	0.145	0.14	0.14
Sensor / voltage connection	LEMO	LEMO	Sub-D special (CD-version) LEMO (CL-version)	; Sub-D special (CD-version) LEMO (CL-version)	Sub-D Special	Sub-D Special

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. Value given is noise equivalent motion with E-503 or E-710 controller (p. 2-146 or p. 2-128)
Linear Dynamic Operating Current Coefficient in µA per Hz and µm. Example for P-527.2xx: Sinusoidal scan of 30 µm at 10 Hz requires approximately 1.8 mA drive current (p. 2-70). Electrical capacitance and DOCC of the rotati[...] stated.
Recommended controller
Versions with LEMO connectors: Single-channel (1 per axis): E-610 servo-controller / amplifier (p. 2-110), E-625 servo-controller, bench-top (p. 2-114), E-621 controller module (p. 2-160) Multi-channel: modular piezo controller sy[...] (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152)
Versions with Sub-D connectors: Multi-channel digital controllers: E-710 bench-top (p. 2-128), E-712 modular (p. 2-140), E-725 high-power (p. 2-126), E-761 PCI board (p. 2-130)

Active and Passive Guidance for Nanometer Flatness and Straightness

Flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. The FEA techniques provide for the highest possible stiffness in, and perpendicular to, the direction of motion, and minimize linear and angular runout. Flexures allow extremely high-precision motion, no matter how minute, as they are completely free of play and friction. Due to the parallel kinematics design there is only one common moving platform for all axes, minimizing mass, enabling identical dynamic behavior and eliminating cumulative errors. Parallel kinematics also allows for a more compact construction and faster response compared to stacked or nested designs. The high precision due to flexure guidance is further enhanced by Active T rajectory Control: Multi-axis nanopositioning systems equipped with both parallel kinematics and parallel direct metrology are able to measure platform position in all degrees of freedom against one common fixed reference. In such systems, undesirable motion from one actuator in the direction of another (cross-talk) is detected immediately and actively compensated by the servo-loops. This Active T rajectory Control Concept can keep deviation from a trajectory to under a few nanometers, even in dynamic operation.

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Ordering Information

P-517.2CL
Precision XY Nanopositioning System, 100 x 100 µm, Capacitive Sensors, Parallel Metrology, LEMO Connector

P-527.2CL
Precision XY Nanopositioning System, 200 x 200 µm, Capacitive Sensors, Parallel Metrology, LEMO Connector

P-517.3CL
Precision XYZ Nanopositioning System, 100 x 100 x 20 µm, Capacitive Sensors, Parallel Metrology, LEMO Connector

P-517.3CD
Precision XYZ Nanopositioning System, 100 x 100 x 20 µm, Capacitive Sensors, Parallel Metrology, Sub-D Connector

P-527.2CL
Precision XY Nanopositioning System, 200 x 200 µm, Capacitive Sensors, Parallel Metrology, LEMO Connector

P-527.3CD
Precision XYZ Nanopositioning System, 200 x 200 x 20 µm, Capacitive Sensors, Parallel Metrology, Sub-D Connector

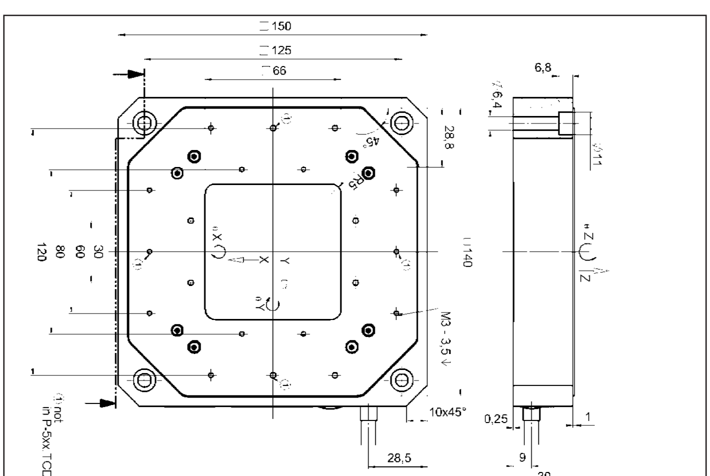
P-517.RCD
Precision XY / rotation nanopositioning system, 100 x 100 µm, 2 mrad, Capacitive Sensors, Parallel Metrology, Sub-D Connector

P-527.RCD
Precision XY / rotation nanopositioning system, 200 x 200 µm, 4 mrad, Capacitive Sensors, Parallel Metrology, Sub-D Connector

Units	Tolerance
µm	min.(+20%/0%)
µm	
nm	typ.
nm	typ.
%	typ.
nm	typ.
N/µm	±20%
Hz	±20%
Hz	±20%
Hz	±20%
N	Max.
µF	±20%
µA/(Hz • µm)	±20%
°C	
kg	±5%

on axes base upon differential motion in X, Y; therefore not

stem E-500 (p. 2-142) with amplifier module E-503



P-517, P-527 dimensions in mm, cable length 1.5 m

P-562.6CD PIMars 6-Axis Piezo Stage System

High-Precision Nanopositioning System with 6 Degrees of Freedom

-562.6CD PIMars six-axis parallel-kinematics nanopositioning stag

- **6 Motion Axes: 3 x Linear, 3 x Rotation**
- **Travel Ranges to 200 µm Linear and 1 mrad Tilt Angle**
- **Enhanced Responsiveness & Multi-Axis Precision: Parallel Kinematics / Metrology**
- **Highest Linearity and Stability with Capacitive Sensors**
- **Frictionless, High-Precision Flexure Guiding System**
- **Excellent Scan-Flatness**
- **Clear Aperture 66 x 66 mm**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **UHV Versions to 10^{-9} hPa**

PIMars open-frame piezo stages are fast and highly accurate multi-axis scanning and nanopositioning systems with flatness and straightness in the nanometer range. Thanks to the parallel-kinematic design, where all piezo drives act on the same moving platform, and sophisticated digital control algorithms it is possible to achieve highly precise motion in all degrees of freedom: three linear axes and three rotary axes. The travel ranges amount to 200 µm in X, Y and Z, and the tilt angles are ±0.5 mrad about the respective axis. Systems with larger travel ranges or faster response are available on request. A six-axis system with 800 µm travel range in the X and Y axis is available as the P-587.6CD s. p. 2-76.

PIMars systems feature a large 66 x 66 mm clear aperture for transmitted-light applications such as near-field scanning or confocal microscopy and mask positioning. PIMars stages for ultra-high vacuum applications are also available. These versions contain vacuum-qualified components only. The integrated ceramic-encapsulated PICMA® actuators allow high bakeout temperatures and assure minimal outgassing rates. A non-magnetizable version is available on request.

Application Examples

- Scanning microscopy (SPM)
- Mask/wafer positioning
- Interferometry
- Metrology
- Biotechnology
- Micromanipulation

Ordering Information

P-562.6CD
PIMars 6-Axis Nanopositioning System, 200 µm, 1 mrad, Parallel Metrology

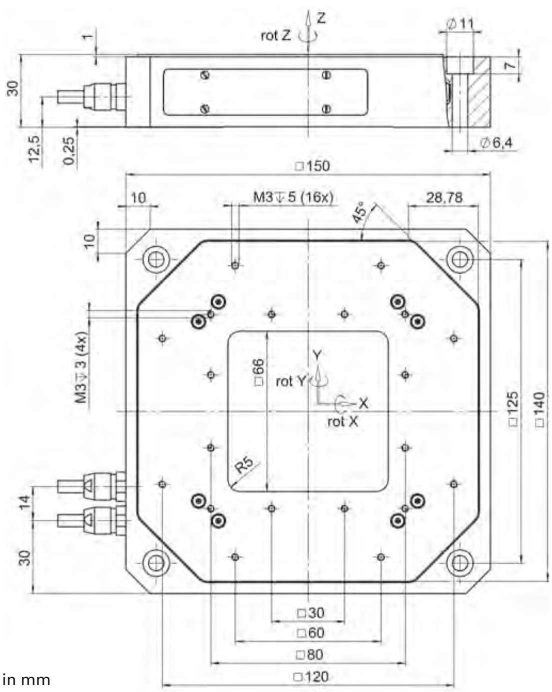
Other travel ranges on request!

Capacitive Sensors for Highest Accuracy and Stability

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. Further advantages of direct metrology with capacitive sensors are the excellent long-term stability, high phase fidelity and the high bandwidth of up to 10 kHz.

Active and Passive Guidance for Nanometer Flatness and Straightness

Wire-cut flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. The FEA techniques give the design the highest possible stiffness and minimize linear and angular runout. Further enhancement is achieved by active trajectory control: multiaxis nanopositioning systems equipped with parallel metrology are able to measure platform position in all degrees of freedom against a common, fixed reference. In such systems, undesirable motion from one actuator in the direction of another (cross-talk) is detected immediately and actively compensated by the servo-loops. This can keep deviation from a trajectory to under a few nanometers, even in dynamic operation.



P-562 dimensions in mm

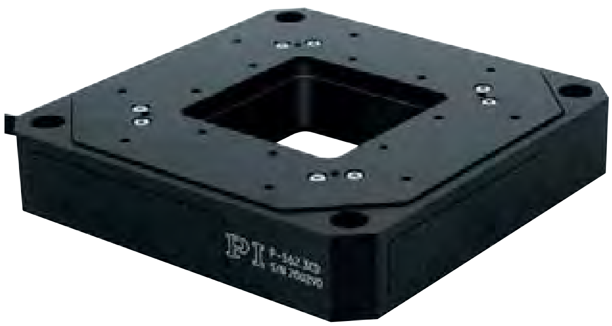
Technical Data

Model	P-562.6CD	Tolerance
Active axes	X, Y, Z, θX, θY, θZ	
Motion and Positioning		
Integrated sensor	Capacitive	
Closed-loop travel X, Y, Z	200 µm	
Closed-loop tip/tilt angle	±0.5 mrad	
Closed-loop resolution X, Y, Z	1 nm	typ.
Closed-loop tip/tilt resolution	0.1 µrad	typ.
Linearity X, Y, Z	0.01 %	typ.
Linearity θX, θY, θZ	0.1 %	typ.
Repeatability in X, Y, Z	±2 / ±2 / ±3 nm	typ.
Repeatability θX / θY / θZ	±0.1 / ±0.1 / ±0.15 µrad	typ.
Flatness	< 15 nm	typ.
Unloaded resonant frequency in X / Y / Z	110 / 110 / 190 Hz	±20%
Load capacity	50 N	max.
Push/pull force capacity in motion direction	120 / 30 N	max.
Drive properties		
Ceramic type	PICMA®	
Electrical capacitance in X / Y / Z	7.4 / 7.4 / 14.8 µF	±20%
Dynamic operating current coefficient in X, Y, Z	4.6 / 4.6 / 9.2 µA/(Hz • µm)	±20%
Miscellaneous		
Operating temperature range	-20 to 80 °C	
Material	Aluminium	
Mass	1.45 kg	±5%
Cable length	1.5 m	±10 mm
Sensor / voltage connection	2 x Sub-D Special	

Recommended controller / amplifier
E-710.6CD s. p. 2-128 or E-712.6CD digital controller s. p. 2-140

P-561 · P-562 · P-563 PIMars™ XYZ Piezo System

High-Precision Nanopositioning Stage, 3 to 6 Axes



P-562 PIMars™ multi-axis, parallel-kinematics nanopositioning stages are available with up to 340 µm travel per axis. Custom versions to 6 DOF are available

- **Parallel-Kinematics / Metrology for Enhanced Responsiveness / Multi-Axis Precision**
- **Travel Ranges to 340 x 340 x 340 µm**
- **Capacitive Sensors for Highest Linearity**
- **Frictionless, High-Precision Flexure Guiding System**
- **Excellent Scanning Flatness**
- **High-Dynamics XYZ Version Available; Custom Versions to 6-DOF**
- **Clear Aperture 66 x 66 mm**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **UHV Versions to 10^{-9} hPa**

PIMars™ open-frame piezo stages are fast and highly accurate multi-axis scanning and nanopositioning systems with flatness and straightness in the nanometer range.

The 66 x 66 mm clear aperture is ideal for transmitted-light applications such as near -field scanning or confocal microscopy and mask positioning.

Large Variety of Models

PIMars™ multi-axis nanopositioners are offered in a large variety of configurations. Standard models include long-travel systems (to 300 x 300 x 300 µm), high-speed and vacuum versions. Custom six-axis designs with rotation to 6 mrad are available on request.

PI offers versions specially designed for applications in ultra-high vacuum with vacuum-qualified components only. The integrated ceramic-encapsulated PICMA® actuators allow high bakeout temperatures and assure minimal outgassing rates. A non-magnetizable version is available on request.

Application Examples

- Scanning microscopy
- Mask/wafer positioning
- Interferometry
- Metrology
- Biotechnology
- Micromanipulation

Direct Drive for Ultra-Fast Scanning and Positioning

The P-561.3DD versions have resonant frequencies to 1.0 kHz, enabling millisecond scanning rates with sub-nanometer resolution.

Capacitive Sensors for Highest Accuracy and Position Stability

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Active and Passive Guidance for Nanometer Flatness and Straightness

Wire-cut flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. The FEA techniques give the design the highest possible stiffness and minimize linear and angular runout. Further enhancement is achieved by active trajectory control: multi

Ordering Information

P-561.3CD
PIMars™ XYZ Piezo-Nanopositioning System, 100 x 100 x 100 µm, Parallel Metrology

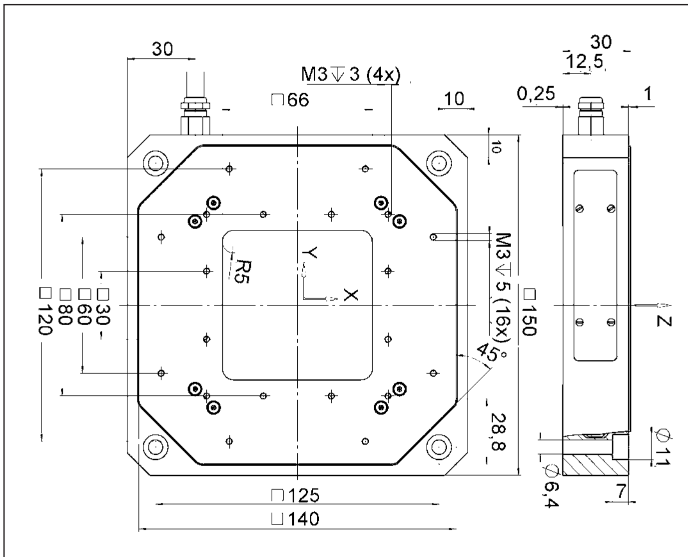
P-562.3CD
PIMars™ XYZ Piezo-Nanopositioning System, 200 x 200 x 200 µm, Parallel Metrology

P-563.3CD
PIMars™ XYZ Piezo-Nanopositioning System, 300 x 300 x 300 µm, Parallel Metrology

P-561.3DD
PIMars™ High-Dynamics XYZ Nanopositioning System, 45 x 45 x 15 µm, Parallel Metrology, Direct Drive

Vacuum-compatible versions to 10^{-6} hPa for the P-561.3CD, P-562.3CD and P-563.3CD models are available as P-561.3VD, P-562.3VD and P-563.3VD; versions to 10^{-9} hPa as P-561.3UD, P-562.3UD and P-563.3UD.

Super-invar & titanium versions are available, 6-DOF versions on request.

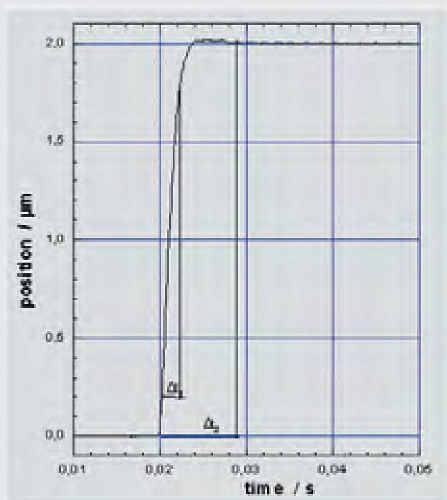


P-561, P-562, P-562 dimensions in mm

System properties

System Configuration	P-561.3CD with E-710 digital controller, 330 g load
Amplifier bandwidth, small signal	25 Hz in X, Y; 35 Hz in Z
Settling time (10 % step)	20 ms

axis nanopositioning systems equipped with parallel metrology are able to measure platform position in all degrees of freedom against a common, fixed reference. In such systems, undesirable motion from one actuator in the direction of another (cross-talk) is detected immediately and actively compensated by the servo-loops. This can keep deviation from a trajectory to under a few nanometers, even in dynamic operation.



P-562.3CD (unloaded) step and settle is faster than 10 ms in X, Y and Z

Technical Data

Model	P-561.3CD	P-562.3CD	P-563.3CD	P-561.3DD	Units	Tolerance
Active axes	X, Y, Z	X, Y, Z	X, Y, Z	X, Y, Z		
Motion and positioning						
Integrated sensor	Capacitive	Capacitive	Capacitive	Capacitive		
Open-loop travel, -20 to +120 V	150 x 150 x 150	300 x 300 x 300	340 x 340 x 340	58 x 58 x 18	µm	min. (+20 %/0 %)
Closed-loop travel	100 x 100 x 100	200 x 200 x 200	300 x 300 x 300	45 x 45 x 15	µm	
Open-loop resolution	0.2	0.4	0.5	0.1	nm	typ.
Closed-loop resolution	0.8	1	2	0.2	nm	typ.
Linearity	0.03	0.03	0.03	0.01*	%	typ.
Repeatability in X, Y, Z	2 / 2 / 2	2 / 2 / 4	2 / 2 / 4	2 / 2 / 2	nm	typ.
Pitch in X,Y	±1	±2	±2	±3	µrad	typ.
Runout θ_x, θ_y (Z motion)	±15	±20	±25	±3	µrad	typ.
Yaw in X, Y	±6	±10	±10	±3	µrad	typ.
Flatness in X, Y	±15	±20	±25	±10	nm	typ.
Crosstalk X, Y (Z motion)	±30	±50	±50	±20	nm	typ.
Mechanical properties						
Unloaded resonant frequency in X / Y / Z	190 / 190 / 380	160 / 160 / 315	140 / 140 / 250	920 / 920 / 1050**	Hz	±20 %
Resonant frequency @ 100 g in X / Y / Z	-	145 / 145 / 275	120 / 120 / 215	860 / 860 / 950	Hz	±20 %
Resonant frequency @330 g in X / Y / Z	140 / 140 / 300	130 / 130 / 195	110 / 110 / 170	500 / 500 / 470	Hz	±20 %
Push force capacity in motion direction in X / Y / Z	200 / 200 / 50	120 / 120 / 50	100 / 100 / 50	200 / 200 / 50	N	Max.
Pull force capacity in motion direction in X / Y / Z	30 / 30 / 30	30 / 30 / 30	30 / 30 / 30	30 / 30 / 30		
Load capacity	50	50	50	50	N	Max.
Drive properties						
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885	PICMA® P-885 in Z, P-888 in XY		
Electrical capacitance in X / Y / Z	5.2 / 5.2 / 10.4	7.4 / 7.4 / 14.8	7.4 / 7.4 / 14.8	38 / 38 / 6	µF	±20 %
Dynamic operating current coefficient (DOCC) in X / Y / Z	6.5 / 6.5 / 13	4.6 / 4.6 / 9.25	3.1 / 3.1 / 6.1	106 / 106 / 50	µA/ (Hz • µm)	±20 %
Miscellaneous						
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Aluminum	Aluminum	Aluminum	Aluminum		
Mass	1.45	1.45	1.45	1.55	kg	±5 %
Cable length	1.5	1.5	1.5	1.5	m	±10 mm
Sensor / voltage connection	Sub-D Special	Sub-D Special	Sub-D Special	Sub-D Special		

Resolution of PI Piezo Nanopositioners is not limited by friction or stiction. V alue given is noise equivalent motion with E-71 0 (p. 2-128) controller.
*With digital controller. Non-linearity of direct drive stages measured with analog controllers is typically up to 0.1 %.

Recommended controller
Multi-channel digital controllers: E-710 bench-top (p. 2-128), E-712 modular (p. 2-140), E-725 high-power (p. 2-126), E-761 PCI board (p. 2-130)

PI

P-915K XY-Theta-Z Piezo Stage

3 Degrees of Freedom in the XY Plane

The P-915KPPS is equipped with FEA-modeled flexures for higher stiffness in all three directions of motion

- **Travel Ranges 250 x 250 µm, 16 mrad**
- **Frictionless, High-Precision Flexure Guiding System**
- **High Stiffness >1 N/µm**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**

Model	Travel	Resolution	Load capacity	Settling (system combination with E-621	Dimensions
P-915KPPS XY-Rot-Z-Piezo Stage	250 x 250 µm ±8 mrad	3 nm 15 µrad	2 kg	45 ms (250 µm) 28 ms (16 mrad)	60 x 60 x 100 mm

P-313 PicoCube™ XY(Z) Piezo Scanner

Picometer Precision, High Bandwidth, No Servo Lag, for Scanning Probe Microscopy

A new drive concept allows high-linearity positioning in open-loop operation

- **Ultra-High-Performance Scanner for AFM/SPM**
- **20 Picometers Resolution, <1 nm Hysteresis**
- **Very High Bandwidth with no Servo Lag Due to New Drive Concept**
- **Compact Manipulation Tool for Bio-/Nanotechnology**
- **Resonant Frequency 4.0 kHz (X, Y), 11 kHz (Z)**
- **1 x 1 x 0.8 µm Travel Range**

Model	Travel range (±250 V)	Resolution	Dimensions
P-313.30 PicoCube™ XYZ Scanner	1 x 1 µm (X,Y) 0.8 µm (Z)	0.02 nm (X, Y) 0.14 nm (Z)	30 x 30 x 29.4 mm Moved platform 20 x 20 mm

P-628K Long-Travel XY Piezo Stage with Nanometer Flatness

Novel Active Z-Axis Design Provides Real Time Runout Compensation

The P-628KHFS with an active Z-axis provides an improved straightness of travel with only 9.5 mm added height compared to an P-628.2 nanopositioning stage

- **Closed-Loop Travel Range 800 x 800 µm (up to 1500 µm Possible)**
- **Improved Straightness of Travel <1nm**
- **High-Precision, Cost-Efficient**
- **Resolution to 0.1 nm, 0.02 % Positioning Accuracy**
- **Frictionless, High-Precision Flexure Guiding System**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**

Model	Travel ranges	Unload resonant frequency	Load capacity	Dimensions
P-628KHFS High Flatness XY Stage	800 x 800 µm (X, Y)	75 Hz (X), 105 Hz (Y)	10 N	80 x 80 x (9.5 + 30) mm

PI

P-915K Fast XY Piezo Scanner

Cost-Effective OEM Slide for Imaging

The fast P-915KXYS open-loop XY scanner is ideally suited for image enhancement e.g. for CCD chips

- **For Pixel Sub-Stepping to Enhance Image Resolution**
- **Compact Design: 40 x 60 x 7 mm**
- **Highly Cost-Efficient Open-Loop Design**
- **Travel Ranges to 4 x 4 µm**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**

Model	Travel Resolution		Load capacity	Dimensions
P-915KXYS XY Scanner	4 x 4 µm	0.4 nm	50 g	40 x 60 x 7 mm

P-915K High-Dynamics XY Piezo Scanner

Cost-Effective OEM Slide with Large Aperture for Imaging Applications

The P-915KHDS XY scanning stage is driven by 4 PICMA® piezo actuators to provide high stiffness, high dynamics and superior lifetime

- **Direct Drive for High Dynamics**
- **Scanning Stage for Pixel Sub-Stepping: Enhances Image Resolution**
- **Cost-Efficient Design**
- **15 x 15 µm Travel Range**
- **Load Capacity to 5 N**
- **Clear Aperture 30 x 45 mm**

Model	Travel range	Resolution	Resonant frequency	Dimensions
P-915KHDS High-Dynamics XY Scanner	15 x 15 µm	0.1 nm	1850 Hz	Baseplate 85 x 54 mm Moved platform 69 x 69 mm Clear aperture 30 x 45 mm

P-915K Vacuum Compatible XYZ Piezo Scanner

Large Clear Aperture, High-Dynamics, High-Load Nanopositioner

The P-915KLVS high-dynamics scanner offers a very large clear aperture of 200 x 200 mm

- **Vacuum Compatible to 10^{-6} hPa**
- **Direct Metrology with Capacitive Sensors**
- **Excellent Straightness: <0.1 µrad Runout**
- **Frictionless, High-Precision Flexure Guiding System**
- **Direct Metrology with Capacitive Sensors**

Model	Travel Re-	solution	Resonant frequency	Load capacity	Dimensions
P-915KLVS Large XYZ Scanner	100 x 100 x 100 µm	1 nm	110 Hz (X,Y) 230 Hz (Z)	50 kg	340 x 340 x 60 mm Clear aperture 200 x 200 mm

P-587 6-Axis Precision Piezo Stage

Long Scanning Range, Direct Position Measurement

P-587 piezo-driven parallel-kinematics nanopositioning / scanning stage with E-710.6CD 6-axis digital controller

- **For Surface Metrology, Scanning and Positioning in all Six Degrees of Freedom**
- **800 x 800 x 200 µm Linear Range**
- **Up to 1 mrad Rotational Range**
- **Parallel-Kinematics / Metrology for Enhanced Responsiveness / Multi-Axis Precision**
- **Direct Metrology with Capacitive Sensors for Highest Linearity**
- **Outstanding Lifetime Due to PICMA® Piezo Actuators**
- **Frictionless, High-Precision Flexure Guiding System**
- **Active Trajectory Control in All 6 Degrees of Freedom**

The P-587.6CD is a unique, highly accurate, 6-axis scanning and positioning system based on piezo flexure drives. It provides a linear travel range of 800 x 800 x 200 µm and rotation ranges up to 1 mrad.

Application Examples

- Interferometry
- Metrology
- Nano-imprinting
- Semiconductor testing
- Semiconductor fabrication

Direct Position Measurement with Sub-Nanometer Accuracy

PI's proprietary capacitive sensors measure position directly and without physical contact. They are free of friction and hysteresis, a fact which, in combination with the positioning resolution of well under 1 nm, makes it possible to achieve very high levels of linearity. A further advantage of direct metrology with capacitive sensors is the high phase fidelity and the high bandwidth of up to 10 kHz.

Excellent Guiding Accuracy

Flexures optimized with Finite Element Analysis (FEA) are used to guide the stage. FEA techniques are used to give the design the highest possible stiffness in, and perpendicular to, the direction of motion, and to minimize linear and angular runout. Flexures allow extremely high-precision motion, no matter how minute, as they are completely free of play and friction. A flatness and straightness in the low nanometer range is achieved, important for surface metrology applications.

Parallel Kinematics and Metrology with Capacitive Sensors for High Trajectory Fidelity

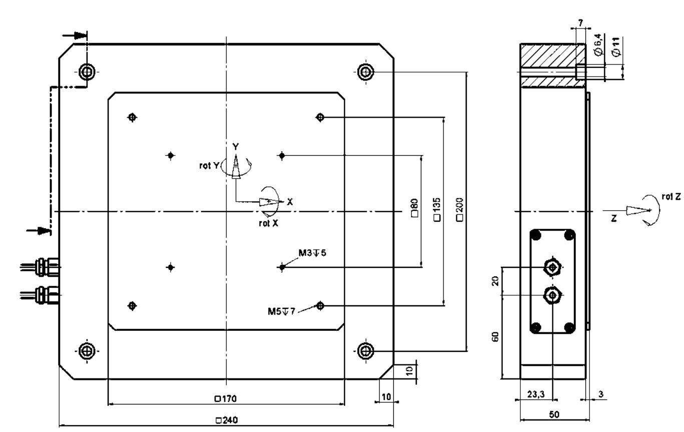
In a parallel kinematics multi-axis system, all actuators act directly on one moving platform. This means that all axes move the same minimized mass and can be designed with identical dynamic properties. Parallel kinematics systems have additional advantages over serially stacked systems, including more-compact construction and no cumulative errors from the individual axes. Multiaxis nanopositioning systems equipped with direct metrology are able to measure platform position in all degrees of freedom against one common reference. In such systems, undesirable motion from one actuator in the direction of another (cross-talk) is detected immediately and actively compensated by the servo-loops. This Active Trajectory Control Concept can keep deviation from a trajectory to under a few nanometers, even in dynamic operation.

Automatic Configuration

PI digital piezo controllers and nanopositioning stages with ID-Chip can be operated in any combination, supported by the AutoCalibration function of the controller. Individual stage data and optimized servo-control parameters are stored in the ID-Chip and are read out automatically by the digital controllers.

Ordering Information

P-587.6CD
6-Axis Nanopositioning System with Long Travel Range, 800 x 800 x 200 µm, ±0.5 mrad, Parallel Metrology, Capacitive Sensors



P-587 dimensions in mm

PI

Technical Data

Model	P-587.6CD	Tolerance
Active axes	X, Y, Z, θ_X, θ_Y, θ_Z	
Motion and positioning		
Integrated sensor	Capacitive	
Closed-loop travel X, Y	800 µm	
Closed-loop travel	200 µm	
Closed-loop tip/tilt angle	±0.5 mrad	
Closed-loop θZ angle	±0.5 mrad	
Closed-loop / open-loop resolution X, Y	2.2 / 0.9 nm	typ.
Closed-loop / open-loop resolution Z	0.7 / 0.4 nm	typ.
Closed-loop / open-loop resolution θ_X, θ_Y	0.1/ 0.05 µrad	typ.
Closed-loop / open-loop resolution θ_Z	0.3 / 0.1 µrad	typ.
Linearity X, Y, Z	0.01 %	typ.
Linearity θ_X, θ_Y, θ_Z	0.1 %	typ.
Repeatability X, Y	±3 nm	typ.
Repeatability	±2 nm	typ.
Repeatability θ_X, θ_Y	±0.1 µrad	typ.
Repeatability θ_Z	±0.15 µrad	typ.
Flatness	<15 nm	typ.
Mechanical properties		
Stiffness X / Y / Z	0.55 / 0.55 / 1.35 N/µm	
Unloaded resonant frequency in X / Y / Z	103 / 103 / 235 Hz	±20 %
Resonant frequency @ 500 g in X / Y / Z	88 / 88 / 175 Hz	±20 %
Resonant frequency @ 2000 g in X / Y / Z	65 / 65 / 118 Hz	±20 %
Push/pull force capacity in motion direction	50 / 10 N	Max.
Drive properties		
Ceramic type	PICMA®	
Electrical capacitance in X / Y / Z	81 / 81 / 18.4 µF	±20 %
Dynamic operating current coefficient (DOCC) in X, Y, θ_Z	12.6 µA/(Hz • µm)	±20 %
Dynamic operating current coefficient (DOCC) Z, θ_X, θ_Y	11.5 µA/(Hz • µm)	±20 %
Miscellaneous		
Operating temperature range	-20 to 80 °C	
Material	Aluminum	
Dimensions	240 x 240 x 50 mm	
Mass	7.2 kg	±5 %
Cable length	1.5 m	±10 mm
Sensor / voltage connection	2 x Sub-D Special	
Recommended controller / amplifier	E-710.6CD (p. 2-128) or E-712.6CD (p. 2-140) digital controller	

The maximum rotational angle in θ_Z is 8 mrad, the tilt angles around X and Y rate 3 mrad.
Due to parallel kinematics linear motion is not possible when the stage is in extreme position.

Notes on Specifications for Piezo Stages, Systems and Actuators

Motion and positioning

Performance specifications are valid for room temperature (22 ±3 °C) and closed-loop systems are calibrated at this temperature (specifications for different operating temperatures on request). Recalibration is recommended for operation at a significantly higher or lower temperature. Custom designs for ultra-low or ultra-high temperatures on request.

Integrated feedback sensor

Absolute measuring capacitive and SGS sensors are used to provide position information to the controller. For details see the tutorial "Piezoelectrics in Positioning" section (see p. 2-188 *ff*).

Open-loop travel for PICMA® Ceramic Equipped Piezo Stages and Actuators

Typical open-loop travel at 0 to 100 V operating voltage. Max. recommended operating voltage range is -20 to +120 V (extremes for short durations only).

Open-loop travel for PICA™ Ceramic Equipped Piezo Actuators

Typical open-loop travel of high-voltage piezo actuators at 0 to +1000 V operating voltage. Voltages in excess of +750 V should not be applied for long durations. Operation in the range of -200 to +750 V is recommended for maximum lifetime and displacement.

Closed-loop travel for PICMA® Ceramic Equipped Piezo Stages and Actuators

Travel provided in closed-loop operation. PI piezo amplifiers have an output voltage range of -20 to +120 V or -30 to +135 V to provide enough margin for the servo-controller to compensate for load changes, etc.

Open-loop / closed-loop resolution

Resolution of piezo flexure stages is basically infinitesimal because it is not limited by stiction or friction. Instead of resolution, the noise-equivalent motion is specified. V alues are typical results (RMS, 1 σ), measured with E-503/E-508) amplifier module in E-500/501 chassis.

Full-range repeatability (typ.)

Typical values in closed-loop mode (RMS, 1 σ). Repeatability is a percentage of the total distance or angle traveled. For small ranges, repeatability is significantly better.

Pitch / Yaw / Roll / Rotational Runout

Typical rotational off-axis error; sometimes associated with a particular motion axis, as in "Rotational runout (Z motion)".

Straightness / Flatness / Crosstalk

Typical linear off-axis error; sometimes associated with a particular motion axis, as in "Crosstalk (Z motion)".

Mechanical properties

Stiffness

Static large-signal stiffness of the stage in operating direction at room temperature. Small-signal stiffness and dynamic stiffness may differ because of effects caused by the active nature of piezoelectric material, compound effects, etc. For details see the tutorial "Piezoelectrics in Positioning" section (see p. 2-171 *ff*).

Unloaded resonant frequency

Lowest resonant frequency in operating direction (does not specify the maximum operating frequency). For details see the tutorial "Piezoelectrics in Positioning" section (see p. 2-171 *ff*).

Resonant frequency with load

Resonant frequency of the loaded system.

Push/pull force capacity (in operating direction)

Specifies the maximum forces that can be applied to the system along the active axis. Limited by the piezoceramic material and the flexure design. If larger forces are applied, damage to the piezoceramic, the flexures or the sensor can occur. The force limit must also be considered in dynamic applications.

Example: the dynamic forces generated by sinusoidal operation at 500 Hz, 20 µm peak-to-peak, 1 kg moved mass, are approximately ±100 N. For details see the tutorial "Piezoelectrics in Positioning" section (see p. 2-171 *ff*).

Load capacity

Maximum vertical load, when the stage is mounted horizontally. Limited by the flexures or the load capacity of the piezo actuators.

Lateral force limit

Maximum lateral force orthogonal to the operating direction. Limited by the piezoceramics and the flexures. For XY stages the push/pull force capacity of the other module (in its operating direction) limits the lateral force that can be tolerated.

Torque limit (θ_X, θ_Y, θ_Z)

Maximum torque that can be applied to the system before damage occurs. Limited by the piezo ceramics and the flexures

PI

Drive properties

Electrical capacitance

The piezo capacitance values indicated in the technical data tables are small-signal values (measured at 1 V, 1000 Hz, 20 °C, no load). Large-signal values at room temperature are 30 to 50 % higher. The capacitance of piezoceramics changes with amplitude, temperature, and load, up to 200 % of the unloaded, small-signal capacitance at room temperature. For detailed information on power requirements, refer to the amplifier frequency-response graphs in the "Piezo Drivers / Servo Controllers" (see p. 2-99 *ff*) section of this catalog.

Dynamic Operating Current Coefficient (DOCC)

Average electrical current (supplied by the amplifier) required to drive a piezo actuator per unit frequency and unit displacement (sine-wave operation). For example to find out if a selected amplifier can drive a given piezo stage at 50 Hz with 30 µm amplitude, multiply DOC coefficient by 50 x 30 and check if the result is smaller or equal to the output current of the selected amplifier. For details see the tutorial "Piezoelectrics in Positioning" section (see p. 2-169 *ff*).

Miscellaneous

Operating temperature range

Typically -20 to +80 °C, the temperature range indicates where the piezo stage may be operated without damage. Nevertheless, recalibration or zero-point-adjustment may be required if the system is operated at different temperatures. Performance specifications are valid for room temperature range.

Material

Flexure stages are usually made of anodized aluminum or stainless steel. Small amounts of other materials may be used internally (for spring preload, piezo coupling, mounting, thermal compensation, etc.).

Al: Aluminum
N-S: Non-magnetic stainless steel
S: Ferromagnetic stainless steel
I: Invar
T: Titanium

Voltage connection

Standard operating voltage connectors are LEMO and sub-D type connectors.

Low-voltage piezos:
LEMO FFA.00.250, male.
Cable: coaxial, RG 178, Teflon coated, 1 m

Sub-D special connectors include lines for stage ID information used by digital controllers with AutoCalibration function

Sensor connection

Standard sensor connectors are LEMO and sub-D type connectors.
Sub-D special connectors contain both piezo voltage and sensor connections.

For extension cables and adapters, see "Accessories" p. 2-89 *ff*, in the "Piezo Drivers / Servo Controllers" section.

Fast Steering Mirrors / Active Optics

Piezo Tip/Tilt Mirrors Fundamentals

Single Axis Designs

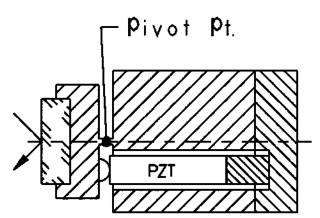


Fig. 1. Single-flexure, single-piezo actuator tilt platform design

Single-Axis Systems / Scanners

Two designs of single-axis (θ_x) tilt platforms are available:

I. Single-Flexure, Single-Actuator Tilt Platform

Examples: S-224 and S-226.

The platform is supported by one flexure and pushed by one linear piezo actuator (see Fig. 1). The flexure determines the pivot point and doubles as a preload for the piezo actuator. The advantages of the single-flexure, single-actuator design are the straightforward construction, low cost and small size. If angular stability over a wide temperature range is a critical issue, the differential piezo drive is recommended.

II. Differential-Piezo-Drive Tilt Platform

This design features two piezo actuators operating in push/pull mode supporting the platform (see Fig. 2). The actuators are wired in a bridge which is supplied with a constant and a variable drive voltage. The case features integrated zero-friction, zero-stiction flexures which assure excellent guiding accuracy.

The differential design exhibits excellent angular stability over a wide temperature range. With this arrangement, temperature changes only affect the vertical position of the platform (piston motion) and have no influence on the angular position. In the closed-loop models, availability of two sensor signals permits better linearity and resolution.

A variety of single- and multi-axis implementations is possible.

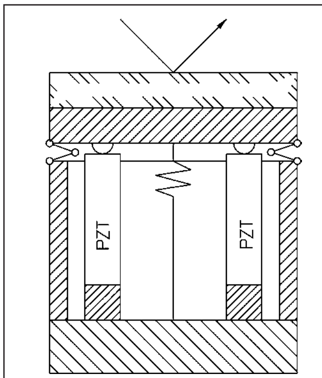


Fig. 2. Design of a differential-piezo-drive tilt platform

Multi-Axis Tip/Tilt Systems / Scanners

PI offers two standard designs, both using parallel kinematics. Parallel kinematics systems have the following advantages over serial systems: only one moving platform, fixed pivot point, better dynamics, smaller form-factor. In addition, the design offers better linearity than attainable with two single-axis systems (e.g. two galvoscanners) in a stacked configuration.

I. Piezo Tripod Z/Tip/Tilt Platform

Examples: S-315 and S-316, S-325.

The platform is supported by three piezo actuators spaced at 120° intervals. Because expansion of an individual actuator affects both θ_x and θ_Y, more complex control algorithms are required.

With coordinate transformation, platform position commands can be resolved into targets for individual actuators (see the equations and Fig. 3 for details). The piezo tripod has one advantage over the differential drive: in addition to tilt motion, it allows active vertical control (piston motion) of the platform—an important feature for applications involving optical path-length adjustment (phase-shifting).

Also, the design allows for a central clear aperture, ideal for transmitted-light applications. As with the differential drives, temperature changes have no effect on the angular stability.

II. Differential-Piezo-Drive Tip/Tilt Platform

Examples:
S-334, S-330, S-340.

The platform is driven by two pairs of piezo actuators arranged at 90° angles. Each pair is controlled as a unit in push-pull mode. The four actuators are connected in a bridge circuit and supplied with one fixed and two variable voltages. Because each actuator pair is parallel to one of the orthogonal tip/tilt axes θ_x and θ_Y, no coordinate transformation is required.

Like the piezo tripod design, the differential drive exhibits excellent angular stability over a wide temperature range. In the closed-loop models, availability of two sensor signals permits better linearity and resolution.

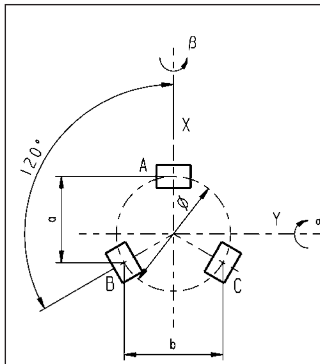


Fig. 3. Piezo tripod drive: A, B, C are the linear displacements of the respective actuators

$$\alpha = \frac{2A - (B+C)}{2a}$$

$$\beta = (B-C) / b$$

$$z = (A+B+C) / 3$$

Example:
S-315 tip/tilt platform (see page 3-16).
Ø = 13.9 mm
a = 10.4 mm
b = 12.0 mm
A, B, C 0 to 12 µm

Dynamic Behavior of Piezo Steering Mirrors

The maximum operating frequency of a tilt platform is heavily dependent on its mechanical resonant frequency. The performance characteristics of the amplifier, servo-controller and sensors are also very important. To estimate the effective resonant frequency of the tilt mirror system (platform + mirror), the moment of inertia of the mirror substrate must first be calculated.

Moment of inertia of a rotationally symmetric mirror:

$$I_M = m\left[\frac{3R^2 + H^2}{12} + \left(\frac{H}{2} + T\right)^2\right]$$

Moment of inertia of a rectangular mirror:

$$I_M = m\left[\frac{L^2 + H^2}{12} + \left(\frac{H}{2} + T\right)^2\right]$$

where:

m = mirror mass [g]

I_M = moment of inertia of the mirror [g · mm²]

L = mirror length perpendicular to the tilt axis [mm]

H = mirror thickness [mm]

T = distance, pivot point to platform surface (see technical data table for individual model) [mm]

R = mirror radius [mm]

Using the resonant frequency of the unloaded platform (see individual technical data table) and the moment of inertia of the mirror substrate, the system resonant frequency is calculated according to the following equation:
Resonant frequency of a tilt platform/mirror system

$$f' = \frac{f_0}{\sqrt{1 + I_M/I_0}}$$

where:

f' = resonant frequency of platform with mirror [Hz]

f_0 = resonant frequency of unloaded platform [Hz]

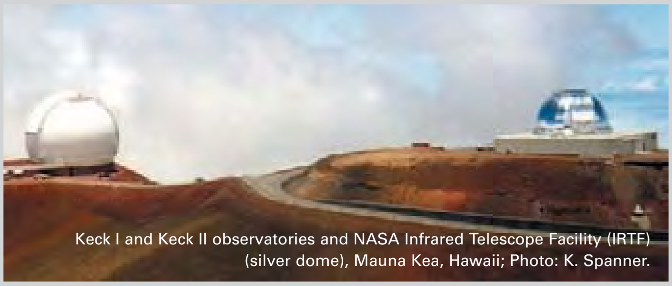
I_0 = moment of inertia of the platform (see technical data table for the individual model) [g · mm²]

I_M = moment of inertia of the mirror [g · mm²]

For more information on static and dynamic behavior of piezo actuators, see pp. 2-196 *ff.*

Custom Systems for Telescopes

PI Steering Mirrors and Alignment Systems in Astronomy


Keck I and Keck II observatories and NASA Infrared Telescope Facility (IRTF) (silver dome), Mauna Kea, Hawaii; Photo: K. Spanner.

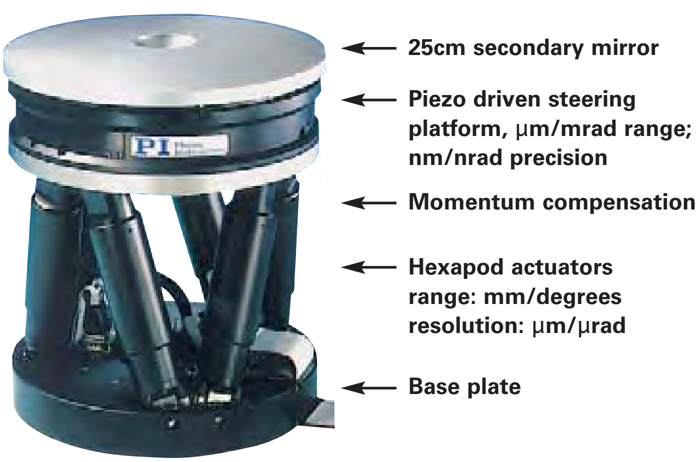

The Horsehead Nebula; Photo: Brian Lula.

Resolution in large earthbound telescopes is limited by atmospheric turbulence and vibrations. During the last 15 years PI has designed several large-aperture tip/tilt systems for image stabilization. Piezoelectrically driven active secondary mirrors can improve the effective resolution up to 1000 % by correcting for these image shifts in real time, especially during long integrations with weak light sources.

Momentum Compensation

Due to the inertia of the large mirrors and the high accelerations required to correct for image fluctuations, significant forces can be induced in the telescope structure, causing unwanted vibrations. PI has developed momentum compensation systems integrated into the tip/tilt platforms which cancel undesirable vibrations and thus offer significantly better stabilization than uncompensated systems.


Active tip/tilt mirror system for the Keck Outrigger telescope in Hawaii. The units are controlled by a high-performance digital controller with a fiber optic interface (not shown).
Mirror diameter: 250 mm
Tip/tilt range: ±150 µrad
Resolution: nanoradian range
Position measurement: capacitive

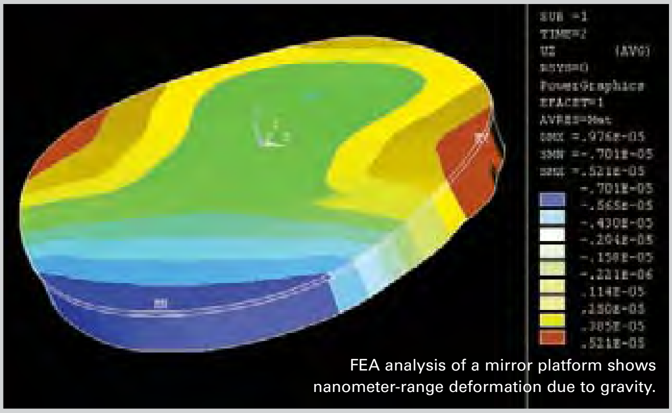


Example of a combined high-speed piezo tip/tilt plaftform with a long range, low-speed 6-axis hexapod alignment system

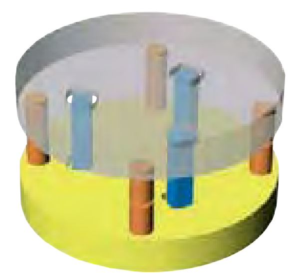
High-Resolution Linear Actuators

273 PI actuators are used for tip/tilt/piston movement of segmented mirror panels in the SALT Telescope.
Features: 16 nm design resolution; 0.15 µm minimum incremental motion; non-rotating tip, compact design.

Active Optics / Steering Mirrors



FEA analysis of a mirror platform shows nanometer-range deformation due to gravity.



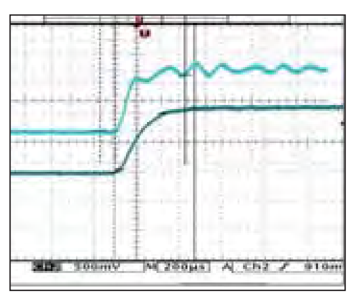
Basic design of a piezo tip/tilt platform featuring three actuators and four sensors. Large platforms handle optics to Ø500 mm

Fast Steering Mirrors: Why Piezo?

- Faster and more precise than conventional actuators
- Better stability through differential drive designs
- Stiff mechanical interface, 1 DOF only
- Tip/tilt & piston movements
- Up to Ø50 cm apertures

Applications of Fast Steering Mirrors

- Fast beam steering, alignment, switching
- Image resolution enhancement (pixel multiplication, dithering)
- Optical path length stabilization
- Vibration cancellation (laser systems, imaging)
- Interferometry, Fabry-Perot filters
- Image stabilization, high speed background subtraction
- Laser beam stabilization (resonators, optical setups)
- Laser beam scanning (lithography, optical setups)
- Laser beam steering and tracking (telecommunication satellites, etc.)
- Bore-sight systems
- Dynamic error correction (e. g. in polygon scanning mirrors)
- Mass storage device testing and manufacture



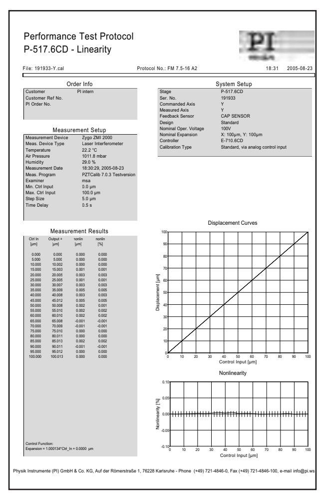
Fast: 200 µs step response. Standard (top), optimized amplifier (bottom), 0.2 µrad steps

Test & Metrology Protocol for Piezo Systems
Getting What You Bargained For

Piezo nanopositioning systems are significant investments and PI believes in optimizing the performance of every customer's system. PI individually tests every stage and optimizes the static and dynamic performance for the customer's application. The metrology test protocol is part of the system's delivery package. It shows the customer what the performance of the system was at the time of delivery and which system components belong together. For PI every metrology procedure and its recording is a quality assurance instrument, and only nanopositioning systems which meet their specifications will leave the premises.

Furthermore, PI makes significant continuing investments in improved-quality, higher-performance nanometrology equipment so that we can deliver better value to our customers.

Because a nanomechanism can only be as accurate as the equipment it was tuned and tested with, PI closed-loop stages are measured exclusively with prestigious Zygo interferometers. PI's nanometrology metrology laboratories are seismically, electromagnetically and thermally isolated, with temperatures controlled to better than 0.25 °C / 24 hrs. We are confident that our metrology capabilities and procedures are the benchmark for the industry.



Performance Test Protocol
P-517.6CD - Linearity

File: 191933-Y.cal   Protocol No.: FM 7.5-16 A2   18:31   2005-08-23

Order Info

Customer	PI intern
Customer Ref No.	
PI Order No.	

System Setup

Stage	P-517.6CD
Ser. No.	191933
Commanded Axis	Y
Measured Axis	Y
Feedback Sensor	CAP SENSOR
Design	Standard
Nominal Oper. Voltage	100V
Nominal Expansion	X: 100µm, Y: 100µm
Controller	E-710.6CD
Calibration Type	Standard, via analog control input

Measurement Setup

Measurement Device	Zygo ZMI 2000
Meas. Device Type	Laser Interferometer
Temperature	22.2 °C
Air Pressure	1011.8 mbar
Humidity	29.0 %
Measurement Date	18:30:29, 2005-08-23
Meas. Program	PZTCalib 7.0.3 Testversion
Examiner	msa
Min. Ctrl Input	0.0 µm
Max. Ctrl Input	100.0 µm
Step Size	5.0 µm
Time Delay	0.5 s

Measurement Results

Ctrl In [µm]	Output + [µm]	nonlin [µm]	nonlin [%]
0.000	0.000	0.000	0.000
5.000	5.000	0.000	0.000
10.000	10.002	0.000	0.000
15.000	15.003	0.001	0.001
20.000	20.005	0.003	0.003
25.000	25.005	0.001	0.001
30.000	30.007	0.003	0.003
35.000	35.009	0.005	0.005
40.000	40.008	0.003	0.003
45.000	45.012	0.005	0.005
50.000	50.008	0.002	0.001
55.000	55.010	0.002	0.002
60.000	60.010	0.002	0.002
65.000	65.008	-0.001	-0.001
70.000	70.009	-0.001	-0.001
75.000	75.010	0.000	0.000
80.000	80.011	0.000	0.000
85.000	85.013	0.002	0.002
90.000	90.011	-0.001	-0.001
95.000	95.012	0.000	0.000
100.000	100.013	0.000	0.000

Control Function:
Expansion = 1.000134*Ctrl_In + 0.0000 µm

Displacement Curves
Displacement [µm]
Control Input [µm]

Nonlinearity
Nonlinearity [%]
Control Input [µm]

Physik Instrumente (PI) GmbH & Co. KG, Auf der Römerstraße 1, 76228 Karlsruhe - Phone (+49) 721-4846-0, Fax (+49) 721-4846-100, e-mail info@pi.ws

All PI nanopositioning systems come with extensive system performance documentation

An S-334 long-range 2-axis fast steering mirror measured with a Moeller Wedel autocollimator

An S-340 2-axis fast steering mirror platform measured with a Zygo interferometer

S-330 Piezo Tip/Tilt-Platform

High-Dynamics, Large-Angle Piezo Tip/Tilt Platforms for Fast Steering Mirrors

S-330 tip/tilt platforms with optical beam deflection angles of 4, 10 and 20 mrad

- **Resolution to 20 nrad, Excellent Position Stability**
- **Optical Beam Deflection to 20 mrad (>1°)**
- **Higher Dynamics, Stability & Linearity Through Parallel-Kinematics Design**
- **Sub-Millisecond Response**
- **For Mirrors up to 50 mm Diameter**
- **Closed-Loop Versions for Better Linearity**
- **Excellent Temperature Stability**

S-330 piezo tip/tilt platforms are fast and compact tip/tilt units, providing precise angular motion of the top platform around two orthogonal axes.

Application Examples

- Image processing / stabilization
- Interlacing, dithering
- Laser scanning / beam steering
- Optics
- Optical filters / switches
- Beam stabilization

These flexure-guided, piezoelectric platforms can provide higher accelerations than other implementations, enabling step response times in the sub-millisecond range. Closed-loop and open-loop versions with 3 different tilt ranges up to 10 mrad (20 mrad optical deflection) are available.

Parallel-kinematics design for improved stability, linearity and dynamics

PI piezo tip/tilt mirror systems are based on a parallel-kinematics design with coplanar axes and a single moving platform. Two pairs of differentially-driven piezo actuators are employed to provide the highest possible angular stability over a wide temperature range. Compared to stacked, (two-stage) piezo or galvo scanners, the single-platform design provides several advantages: smaller package size, identical dynamic performance in both axes, faster response and better linearity. It also prevents polarization rotation.

Fast Piezo Ceramic Drives

Frictionless, flexure-guided piezo ceramic drives provide higher accelerations than other actuators, such as voice-coils, and enable response in the millisecond range and below. Piezo actuators do not require energy to hold a position. The resulting low heat signature is a great advantage in infrared imaging systems like those used in astronomy.

Closed Loop Operation

For high stability and repeatability, absolute-measuring strain gauge sensors (SGS) are applied to appropriate locations on the drive train. They provide a high-bandwidth, position feedback signal to the controller. The sensors are connected in a bridge configuration to eliminate thermal drift, and assure optimal position stability. Open-loop systems are also available.

Ordering Information

S-330.2SL
High-Dynamics Piezo Tip/Tilt Platform, 2 mrad, SGS, LEMO Connector

S-330.2SD
High-Dynamics Piezo Tip/Tilt Platform, 2 mrad, SGS, Sub-D Connector

S-330.20L
High-Dynamics Piezo Tip/Tilt Platform, 2 mrad, Open-Loop, LEMO Connector

S-330.4SL
High-Dynamics Piezo Tip/Tilt Platform, 5 mrad, SGS, LEMO Connector

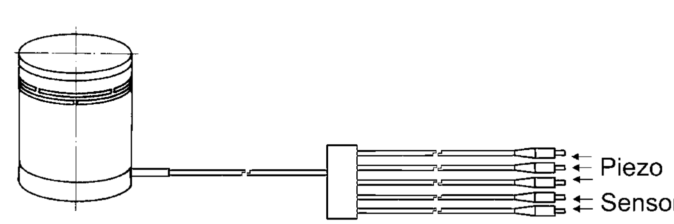
S-330.4SD
High-Dynamics Piezo Tip/Tilt Platform, 5 mrad, SGS, Sub-D Connector

S-330.40L
High-Dynamics Piezo Tip/Tilt Platform, 5 mrad, Open-Loop, LEMO Connector

S-330.8SL
High-Dynamics Piezo Tip/Tilt Platform, 10 mrad, SGS, LEMO Connector

S-330.8SD
High-Dynamics Piezo Tip/Tilt Platform, 10 mrad, SGS, Sub-D Connector

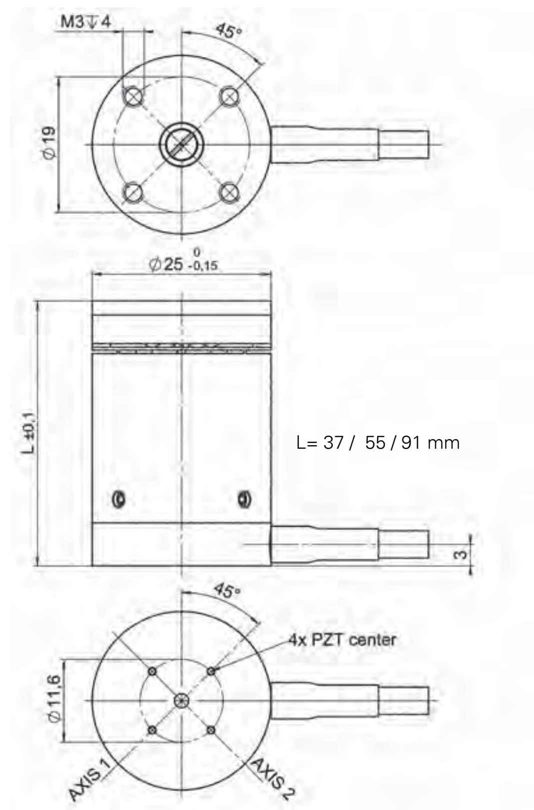
S-330.80L
High-Dynamics Piezo Tip/Tilt Platform, 10 mrad, Open-Loop, LEMO Connector



Circuit diagram and cable configuration of the S-330.xSL closed-loop versions. The S-330.xSD models feature a single Sub-D connector and can be operated by the E-616 controller.

Ceramic Insulated Piezo Actuators Provide Long Lifetime

Highest possible reliability is assured by the use of award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with ceramic-only insulation, which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.



S-330 dimensions in mm

Technical Data

Model	S-330.2SL	S-330.4SL	S-330.8SL	S-330.2SD S-330.4SD S-330.8SD	S-330.20L S-330.40L S-330.80L	Units	Tolerance
Active axes	Θ_X, Θ_Y	Θ_X, Θ_Y	Θ_X, Θ_Y	Θ_X, Θ_Y	Θ_X, Θ_Y		
Motion and positioning							
Integrated sensor	SGS	SGS	SGS	SGS	–		
Open-loop tip/tilt angle, -20 to +120 V	3.5	7	15	as SL version	as SL version	mrad	min.
Closed-loop tip/tilt angle	2	5	10	as SL version	–	mrad	
Open-loop tip/tilt angle resolution	0.02	0.1	0.2	as SL version	as SL version	µrad	typ.
Closed-loop tip/tilt resolution	0.05	0.25	0.5	as SL version	–	µrad	typ.
Linearity in Θ_X, Θ_Y	0.1	0.2	0.25	as SL version	–	%	typ.
Repeatability Θ_X, Θ_Y	0.15	0.5	1	as SL version	–	µrad	typ.
Mechanical properties							
Unloaded resonant frequency (Θ_X, Θ_Y)	3.7	3.3	3.1	as SL version	as SL version	kHz	±20 %
Resonant frequency loaded in Θ_X, Θ_Y (with 25 x 8 mm glass mirror)	2.6	1.6	1.0	as SL version	as SL version	kHz	±20 %
Distance of pivot point to platform surface	6	6	6	6	6	mm	±1 mm
Platform moment of inertia	1530	1530	1530	1530	1530	g x mm²	±20 %
Drive properties							
Ceramic type	PICMA®	PICMA®	PICMA®	PICMA®	PICMA®		
Electrical capacitance	3/axis	6/axis	12.5/axis	as SL	as SL	µF	±20 %
Dynamic operating current coefficient	0.22/axis	0.4/axis	0.8/axis	as SL	as SL	µA/(Hz • mrad)	±20 %
Miscellaneous							
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material case	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel		
Material platform	Invar	Invar	Invar	Invar	Invar		
Mass	0.2	0.38	0.7	as SL version	as SL version	kg	±5 %
Cable length	1.5	1.5	1.5	1.5	1.5	m	±10 mm
Sensor / voltage connection	LEMO	LEMO	LEMO	Sub-D connector	LEMO		
Recommended controller / amplifier							

Versions with LEMO connector: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503.00S (three channels) (p. 2-146)
or 1 x E-505.00S and 2 x E-505 (high speed applications) (p. 2-147) and E-509 controller (p. 2-152) (optional)
Open-loop: E-663 three channel amplifier (p. 2-136)
Versions with Sub-D connectors: E-616 servo controller for tip/tilt mirror systems (p. 2-132)

S-334 Miniature Piezo Tip/Tilt-Mirror

Fast Steering Mirror with up to 120 mrad Deflection

S-334 Tip/Tilt Mirror System / Scanner Provides Optical Deflection Angle up to 120 mrad

- **Miniature Design**
- **Optical Beam Deflection to 120 mrad (~ 6.8°)**
- **Coplanar Axes & Fixed Pivot Point; Eliminate Polarization Rotation**
- **Factory Installed Mirror**
- **Millisecond Response, Resolution to 0.2 µrad**
- **Closed-loop Position Servo-Control for High Accuracy**
- **For Mirrors up to 12.5 mm (0.5") Diameter**
- **Frictionless, High-Precision Flexure Guiding System**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**

S-334 piezo tip/tilt mirrors / scanners provide extremely large deflection angles in a miniaturized package. These fast steering mirror systems are based on a sophisticated parallel-kinematics design with two coplanar, orthogonal axes and a fixed pivot point.

Large Tip/Tilt Ranges with Excellent Motion Characteristics

The novel flexure/lever design with minimized inertia allows for the exceptionally large tip/tilt range of 60 mrad (50 mrad in closed-loop operation, which is equivalent to 100 mrad optical beam deflection) and very fast response in the millisecond range. These parameters make the system unique in the market of piezo driven tip/tilt mirror systems.

Sub-Microradian Resolution

In addition to the large angles and the high dynamics the S-334 provides sub-microradian resolution. The integrated high-resolution, full-bridge strain gauge sensors (SGS) provide absolute position control, excellent repeatability and high linearity, typically better than 0.05 % over the entire travel range.

Differential Drive for Improved Stability and Dynamics

The S-334 is based on a parallel-kinematics design with coplanar axes and a single moving platform. Two pairs of differentially-driven piezo actuators are employed to provide the highest dynamics and position stability over a wide temperature range.

Compared to stacked, (two-stage), piezo or galvo scanners, the single-platform design provides several advantages: smaller package size, identical dynamic performance in both axes, faster response and better linearity. It also prevents polarization rotation.

High Reliability and Long Lifetime

The compact S-334 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and provide better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free, not subject to wear and offer extraordinary reliability.

Ordering Information

S-334.1SD
High-Dynamics Piezo Tip/Tilt Platform, 25 mrad, SGS, Sub-D Connector, incl. Mirror

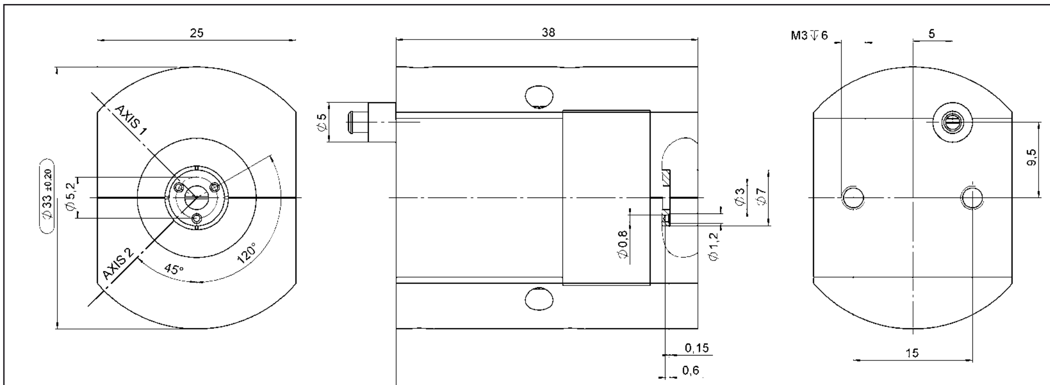
S-334.1SL
High-Dynamics Piezo Tip/Tilt Platform, 25 mrad, SGS, LEMO Connector, incl. Mirror

S-334.2SD
High-Dynamics Piezo Tip/Tilt Platform, 50 mrad, SGS, Sub-D Connector, incl. Mirror

S-334.2SL
High-Dynamics Piezo Tip/Tilt Platform, 50 mrad, SGS, LEMO Connector, incl. Mirror

Application Examples

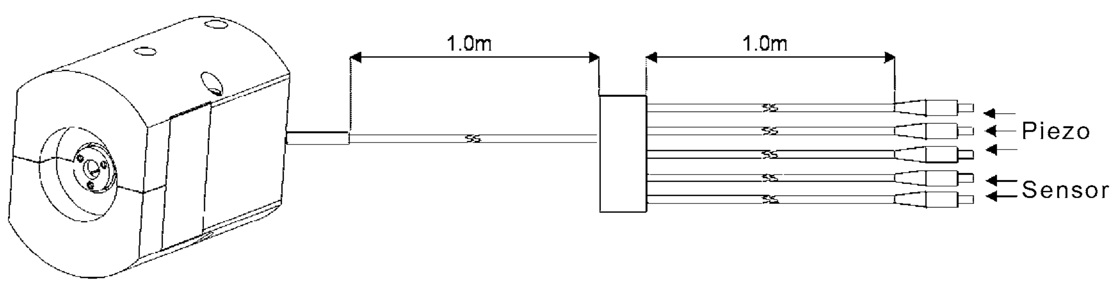
- Image processing / stablilization
- Interlacing, dithering
- Laser scanning / beam steering
- Optics
- Optical filters / switches
- Scanning microscopy
- Beam stabilization



S-334 dimensions in mm

Factory Installed Mirror

The S-334 is equipped with a factory-installed mirror 10 mm in diameter and 2 mm thick (flatness λ/5, reflectivity >98 % from 500 nm to 2 µm).



S-334.2SL cable configuration

Technical Data

Model	S-334.1SL S-334.1SD	S-334.2SL S-334.2SD	Units	Tolerance
Active Axes	θ_X, θ_Y	θ_X, θ_Y		
Motion and positioning				
Integrated sensor	SGS	SGS		
*Open-loop tilt angle at -20 to +120 V	30	60	mrad	min. (+20 %/-0 %)
*Closed-loop tilt angle	25	50	mrad	
Open-loop resolution	0.2	0.5	µrad	typ.
Closed-loop resolution	1	5	µrad	typ.
Linearity	0.05	0.05	%	typ.
Repeatability	2	5	µrad	typ.
Mechanical properties				
Resonant frequency underload (with standard mirrors)	3.0	1.0	kHz	±20 %
Load capacity	0.2	0.2	N	Max.
Distance of pivot point to platform surface	6	6	mm	±1 mm
Platform moment of inertia	1530	1530	g • mm²	±20 %
Standard mirror (mounted)	diameter: 10 mm, thickness: 2 mm; BK7, λ/5, R > 98 % (λ = 500 nm to 2 µm)	diameter: 10 mm, thickness: 2 mm; BK7, λ/5, R > 98 % (λ = 500 nm to 2 µm)		
Drive properties				
Ceramic type	PICMA® P-885	PICMA® P-885		
Electrical capacitance per axis	3	3	µF	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material casing	Titanium	Titanium		
Mass	0.065	0.065	kg	±5 %
Cable length	2	2	m	±10 mm
Sensor / voltage connection	LEMO connector / 25-pin sub-D connector	LEMO connector / 25-pin sub-D connector		

Recommended controller / amplifier
Closed-loop versions with D-sub connector: E-616 controller for tip/tilt mirror systems (p. 2-132);
Open-loop versions with LEMO connector: Modular piezo controller system E-500 (p. 2-142) with amplifier module E-503.00S (three channels) (p. 2-146) or 1 x E-505.00S and 2 x E-505 (high speed applications) (p. 2-147) and E-509 servo controller (p. 2-152 / 3-16)
Open-loop: E-663 three channel amplifier (p. 2-136)

Resolution of PI piezo tip/tilt platforms is not limited by friction or stiction. Noise equivalent motion with E-503 amplifier, (p. 2-146).

*Mechanical tilt, optical beam deflection is 120 mrad (open loop) and 100 mrad (closed-loop), respectively.

S-340 Piezo Tip / Tilt-Platform

High-Dynamics for Mirrors and Optics with a Diameter of up to 100 mm (4")

S-340 tip/tilt platform for mirrors with a diameter of up to 100 mm

- **Resolution up to 20 nrad, Excellent Position Stability**
- **Optical Beam Deflection to 4 mrad**
- **Higher Precision and Dynamics via Parallel Kinematics**
- **Only One Moving Platform with a Fixed Pivot Point Prevents the Change of the Polarization**
- **Sub-ms Response**
- **For Mirrors with a Diameter up to 100 mm**
- **Position-Controlled Versions for Better Linearity**
- **Excellent Temperature Stability**

Ordering Information

S-340.A0L
Piezo Tip / Tilt Platform, 2 mrad, Open-Loop, LEMO Connector, Aluminum Top Plate

S-340.ASL
Piezo Tip / Tilt Platform, 2 mrad, SGS, LEMO, Aluminum Top Plate

S-340.ASD
Piezo Tip / Tilt Platform, 2 mrad, SGS, Sub-D Connectors, Aluminum Top Plate

Various material for the top platforms are available on demand:

S-340.S0L / .SSL / .SSD: High-Grade Steel

S-340.T0L / .TSL / .TSD: Titanium

S-340.i0L / .iSL / .iSD: Invar

S-340 tip / tilt platforms allow high-dynamic and precise angular movements of the top platform in two orthogonal axes with a common pivot point (parallel kinematics).
The systems are designed for mirrors with a diameter of up to 100 mm and their differential drive enables an outstanding angular stability in a wide temperature range. A variety of top platforms are available to achieve an optimum thermal adaptation to different mirror materials. For operation in closed-loop, the SD versions are equipped with high-resolution strain gauge sensors in a thermally stable circuit. All versions feature a sub-μrad resolution and a tip / tilt range of 2 mrad (equivalent to 4 mrad optical beam deflection).

Application Examples

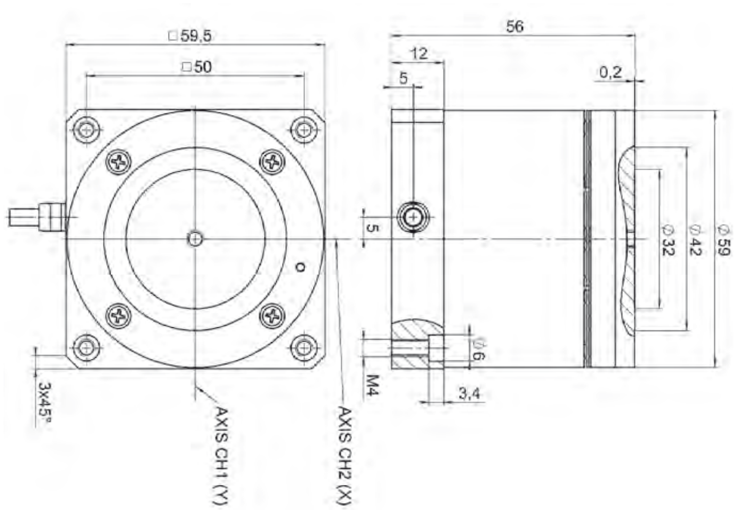
- Image processing / stablilization
- Laser scanning / beam steering
- Active and adaptive optics
- Optical filters
- Beam stabilization
- Correction of polygon mirror errors

Parallel-Kinematic Design for Improved Stability, Linearity and Dynamics

Piezo tip / tilt mirror systems of PI are based on parallel kinematics with a single movable platform for all directions of motion. The four actuators are controlled differentially in pairs depending on the tip / tilt movement of the platform. This results in an excellent stability in linear and angular positioning for a wide temperature range. Compared to systems with an independent positioner per tilt axis, parallel-kinematics offer the advantage of symmetrical dynamic properties of motion for all axes, faster response and better linearity with a compact design. For this kind of design no change of polarization of the reflected light occurs, different than for stacked single axis systems like e. g. galvo scanners.

Ceramic-Insulated Piezo Actuators Provide Superior Lifetime

The highest possible reliability is assured by employing the award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with a ceramic-only insulation which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.



S-340 dimensions in mm

Technical Data

Model	S-340.ASD/.ASL	S-340.A0L	Units	Tolerance
Active axes	θ X, θY	θX, θY		
Motion and Positioning				
Integrated sensor	SGS	–		
Open-loop tip/tilt angle, -20 to +120 V	2	2	mrad	min.
Closed-loop tip/tilt angle	2	–	mrad	
Open-loop tip/tilt angle resolution	0.02	0.02	µrad	typ.
Closed-loop tip/tilt resolution	0.2	–	µrad	typ.
Linearity in θX, θY	0.1	–	%	typ.
Repeatability in θX, θY	0.15	–	µrad	typ.
Mechanical properties				
Unloaded resonant frequency (θX, θY)	1.4	1.4	kHz	±20 %
Resonant frequency loaded in θX, θY (with glass mirror diameter 50 mm, thickness 15 mm)	0.9	0.9	kHz	±20 %
Resonant frequency loaded in θX, θY (with glass mirror diameter 75 mm, thickness 22 mm)	0.4	0.4	kHz	±20 %
Distance of pivot point to platform surface	7.5	7.5	mm	±1 mm
Platform moment of inertia	18000	18000	g · mm²	±20 %
Drive properties				
Ceramic type	PICMA®	PICMA®		
Electrical capacitance	6/axis	6/axis	µF	±20 %
Dynamic operating current coefficient	0.45/axis	0.45/axis	µA/(Hz · mrad)	±20 %
Miscellaneous				
Operating temperature range	-20 to 80	-20 to 80	°C	
Material case	Aluminum	Aluminum		
Material platform	Aluminum; or optionally Steel, Titanium or Invar	Aluminum; or optionally Steel, Titanium or Invar		
Mass	0.355	0.35	kg	±5 %
Cable length	2	2	m	±10 mm
Sensor/voltage connection	Sub-D connector / LEMO	LEMO		

Recommended controller / amplifier
Closed-loop versions with Sub-D connectors: E-616 servo controller for tip/tilt mirror systems s. p. 2-132; with LEMO connector: E-500 System s. p. 2-142.
Open-loop: E-500 System s. p. 2-142.

S-325 Piezo Z / Tip/Tilt Platform

High-Speed Tripod System for Mirrors and Optics

S-325.30L piezoelectric fast steering mirror platform / scanner

- **Optical Beam Deflection to 10 mrad, Resolution to 50 nrad**
- **Piston Movement up to 30 µm (for Path Length Adjustment)**
- **Compact Tripod Design with Coplanar Axes Eliminates Polarization Rotation**
- **Sub-Millisecond Responsiveness**
- **Closed-Loop Versions for Higher Precision**
- **For Mirrors up to 25 mm (1") Diameter**
- **Frictionless, High-Precision Flexure Guiding System**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**

The S-325 Z/tip/tilt platforms and actuators provide high speed and precise movement of the platform in two tilt axes as well as sub-nanometer linear resolution with sub-millisecond response. The design is based on a parallel-kinematics direct-drive piezo tripod (see p. 2-83), and they are especially optimized for industrial applications where 1.000.000.000 motion cycles have to be performed without failure or performance degradation. The systems are designed for mirrors and optics up to 25 mm in diameter and can be mounted in any orientation.

The tripod drive offers optimum angular stability over a wide temperature range. Compared to stacked, (two-stage), piezo or galvo scanners, the single platform design provides several advantages: smaller package size, identical size, identical dynamic performance in all axes, faster response and better linearity. It also prevents polarization rotation.

All three piezo linear actuators can be driven individually (for tip/tilt movement) or in parallel (for vertical movement) by a three-channel amplifier.

High Resolution, Stability and Dynamics

The S-325 offers piston movement of up to 30 µm (ideal for path length adjustment) and mechanical tilt up to 5 mrad (equivalent to 10 mrad optical beam deflection). The zero-friction piezo drives and flexure guidance allow sub-nanometer linear resolution and sub-microradian angular resolution.

Ordering Information

S-325.3SD
High-Dynamics Piezo Z/Tip/Tilt Platform, 5 mrad, 30 µm, SGS, Sub-D Connector

S-325.3SL
High-Dynamics Piezo Z/Tip/Tilt Platform, 5 mrad, 30 µm, SGS, LEMO Connector

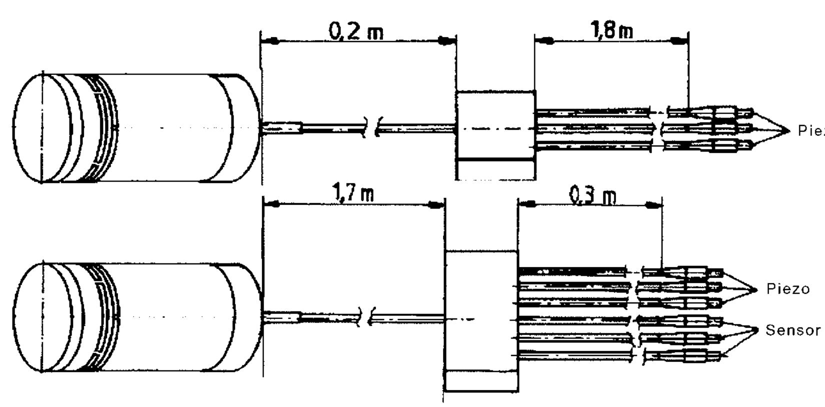
S-325.30L
High-Dynamics Piezo Z/Tip/Tilt Platform, 5 mrad, 30 µm, Open-Loop, LEMO Connector

Open-Loop and Closed-Loop Operation

In open-loop mode, the platform linear motion is roughly proportional to the applied voltage. The S-325.30L open-loop model is ideal for high-bandwidth, high-resolution applications where the absolute angular position is of secondary importance (e. g. for tracking) or where feedback is provided by an external sensor (e. g. CCD, PSD). The S-325.3SL model is equipped with high-resolution strain gauge sensors and provides absolute position control, high linearity and high repeatability. The new E-616 controller/driver module (see p. 2-132) is ideally suited for tip/tilt OEM applications.

Application Examples

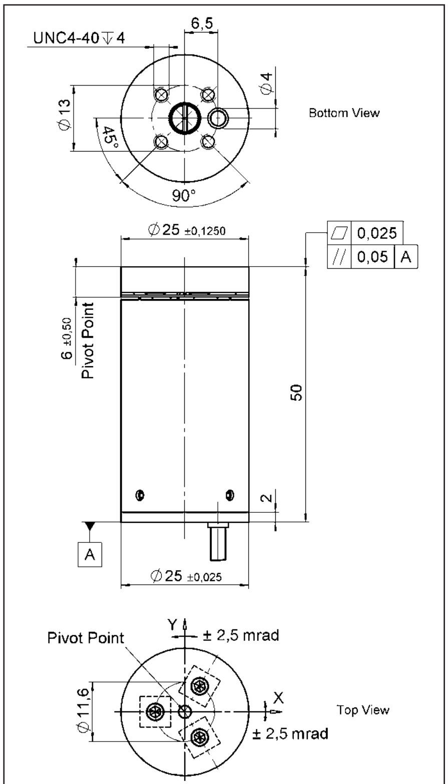
- Image processing / stablilization
- Optical trapping
- Laser scanning / beam steering
- Laser tuning
- Optical filters / switches
- Optics
- Beam stabilization



S-325 cable configuration (top: S-325.30L, bottom: S-325.3SL)

High Reliability and Long Lifetime

The compact S-325 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and provide better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free, not subject to wear and offer extraordinary reliability.



S-325 dimensions in mm

Technical Data

Model	S-325.30L	S-325.3SL	S-325.3SD	Units	Tolerance
Active axes	Z, Θ_X, Θ_Y	Z, Θ_X, Θ_Y	Z, Θ_X, Θ_Y		
Motion and positioning					
Integrated sensor	–	SGS	SGS		
Open-loop travel, 0 to +100 V	30	30	30	µm	min. (+20 %/-0 %)
Open-loop tip/tilt angle, 0 to +100 V	5	5	5	mrad	min. (+20 %/-0 %)
Closed-loop travel	–	30	30	µm	
Closed-loop tip/tilt angle	–	4	4	mrad	
Open-loop resolution	0.5	0.5	0.5	nm	typ.
Open-loop tip/tilt angle resolution	0.05	0.05	0.05	µrad	typ.
Closed-loop linear resolution	–	0,6	0,6	nm	typ.
Closed-loop tip/tilt resolution	–	0.1	0.1	µrad	typ.
Mechanical properties					
Unloaded resonant frequency	2	2	2	kHz	±20 %
Resonant frequency (with 25 x 8 mm glass mirror)	1	1	1	kHz	±20 %
Distance of pivot point to platform surface	6	6	6	mm	±0.5 mm
Platform moment of inertia	515	515	515	g • mm²	±20 %
Drive properties					
Ceramic type	PICMA® P-885	PICMA® P-885	PICMA® P-885		
Electrical capacitance	9.3	9.3	9.3	µF	±20 %
Dynamic operating current coefficient	39	39	39	µA / (Hz • mrad)	±20 %
Miscellaneous					
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	°C	
Material casing	Aluminum	Aluminum	Aluminum		
Mass	0.065	0.065	0.065	kg	±5 %
Cable length	2	2	1.5	m	±10 mm
Sensor / voltage connection	LEMO	LEMO	Sub-D		

For maximum tilt range, all three piezo actuators must be biased at 50 V. Due to the parallel-kinematics design linear travel and tilt angle are interdependent. The values quoted here refer to pure linear / pure angular motion. See equations (p. 2-84).
Recommended controller / amplifier
Versions with LEMO connector: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503.00S (three channels) (p. 2-146) or 1 x E-505.00S and 2 x E-505 (high speed applications) (p. 2-147) and E-509 controller (p. 2-152) (optional)
Single-channel (1 per axis): E-610 OEM servo controller / amplifier (p. 2-110), E-625 servo controller bench-top (p. 2-114)
Versions with Sub-D connectors: E-616 servo controller for tip/tilt mirror systems (p. 2-132)

S-310 – S-316 Piezo Z/Tip/Tilt Scanner

High-Speed System with Clear Aperture

S-310.10, S-316.10
piezo systems for scanning,
optics alignment and mirror shifter alignment

- **10 mm Clear Aperture**
- **Piezo Tripod Design**
- **Optical Beam Deflection to 2,4 mrad**
- **Piston Movement up to 12 µm (phase shifter)**
- **Sub-Millisecond Response, Sub-Microradian Resolution**
- **Closed-Loop Versions for Higher Precision**
- **For Optics, Mirrors or Other Components**
- **Frictionless, High-Precision Flexure Guiding System**
- **Parallel Kinematics for Enhanced Dynamics and Better Multi-Axis Accuracy**

S-310 to S-316 multi-axis tip/tilt platforms and Z-positioners are fast, compact units based on a piezo tripod design. They offer piston movement up to 12 µm and tilt movement up to 1.2 mrad (2.4 mrad optical beam deflection) with sub-millisecond response and settling.

Application Examples

- Image processing / stablilization
- Interferometry
- Laser scanning / beam steering
- Laser tuning
- Optical filters / switches
- Beam stabilization

The tripod design features optimum angular stability over a wide temperature range.

The systems are designed for mirrors and optics up to 25 mm in diameter and can be mounted in any orientation; the clear aperture is ideal for transmitted-light applications (e. g. for optical filters).

Open-Loop and Closed-Loop Operation

In open-loop mode, the tip/tilt angle is roughly proportional to the applied voltage. The S-310 to S-315 open-loop models are ideal for high-speed, high resolution applications where the absolute angular position is of secondary importance (e. g. for tracking) or where feedback is provided by an external sensor (e. g. CCD, PSD). The S-316.10 model is equipped with high-resolution strain gauge sensors and provides absolute position control, high linearity and high repeatability.

Available Versions

S-310.10, S-314.10

Open-loop Z-platforms; all three piezo linear actuators are electrically connected in parallel, providing vertical positioning (piston movement) of the top ring. Only one drive channel is required.

S-311.10, S-315.10

Open-loop Z/tip/tilt positioners; all three piezo linear actuators can be driven individually (or in parallel) by a three-channel amplifier. Vertical (piston movement) positioning and tip/tilt positioning are possible.

S-316.10

Closed-loop Z/tip/tilt positioner. All three piezo linear actuators are equipped with strain gauge position feedback sensors and can be driven individually (or in parallel) by a three-channel amplifier with a position servo-controller. Vertical positioning (piston movement) and tip/tilt positioning are possible. The integrated position feedback sensors provide sub-microradian resolution and high repeatability.

Ordering Information

S-310.10
Piezo Actuator, Clear Aperture, 6 µm, LEMO Connector

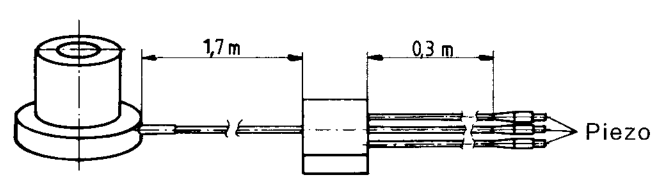
S-311.10
Piezo Z/Tip/Tilt Platform, Clear Aperture, 600 µrad, 6 µm, LEMO Connector

S-314.10
Piezo Actuator, Clear Aperture, 12 µm, LEMO Connector

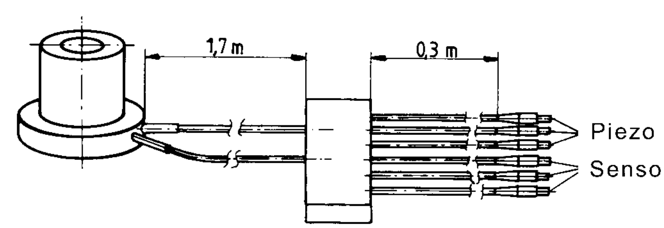
S-315.10
Piezo Z/Tip/Tilt Platform, Clear Aperture, 1.2 mrad, 12 µm, LEMO Connector

S-316.10
Piezo Z/Tip/Tilt Platform, Clear Aperture, 1.2 mrad, 12 µm, SGS, LEMO Connector

S-316.10
Piezo Z/Tip/Tilt Platform, Clear Aperture, 1.2 mrad, 12 µm, SGS, Sub-D Connector



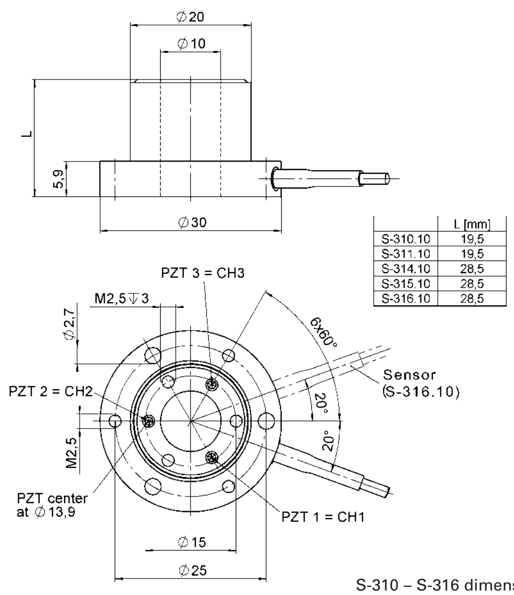
S-315 cable configuration



S-316 cable configuration

High Reliability and Long Lifetime

The compact S-310 - S-316 systems are equipped with preloaded PICMA® high-performance piezo actuators which are integrated into a sophisticated, FEA-modeled, flexure guiding system. The PICMA® actuators feature cofired ceramic encapsulation and provide better performance and reliability than conventional piezo actuators. Actuators, guidance and sensors are maintenance-free, not subject to wear and offer extraordinary reliability.



S-310 – S-316 dimensions (in mm)

Technical Data

Model	S-310.10	S-314.10	S-311.10	S-315.10	S-316.10	Units	Tolerance
Active axes	Z	Z	Z, Θ_X, Θ_Y	Z, Θ_X, Θ_Y	Z, Θ_X, Θ_Y		
Motion and positioning							
Integrated sensor	–	–	–	–	SGS		
Open-loop travel, 0 to +100 V	6 / –	12 / –	6 / –	12 / –	12 / 12	µm	min. (+20 %/-0 %)
*Open-loop tilt angle @ 0 to 100 V	–	–	600	1200	1200	µrad	min. (+20 %/-0 %)
Closed-loop travel	–	–	–	–	12	µm	
*Closed-loop tilt angle	–	–	–	–	1200	mrad	
Open-loop resolution	0.1	0.2	0.1	0.2	0.2	nm	typ.
Open-loop tip/tilt angle resolution			0.02	0.05	0.05	µrad	typ.
Closed-loop resolution	–	–	–	–	0.4	nm	typ.
Closed-loop tip/tilt resolution	–	–	–	–	0.1	µrad	typ.
Linearity	–	–	–	–	0.2	%	typ.
Mechanical properties							
Stiffness	20	10	20	10	10	N/µm	±20 %
Unloaded resonant frequency (Z)	9.5	5.5	9.5	5.5	5.5	kHz	±20 %
Resonant frequency (with 15 x 4 mm glass mirror)	6.5	4.4	6.5	4.1	4.1	kHz	±20 %
Resonant frequency (with 20 x 4 mm glass mirror)	6.1	4.2	6.1	3.4	3.4	kHz	±20 %
Distance of pivot point to platform surface	–	–	5	5	5	mm	±1 mm
Platform moment of inertia	–	–	150	150	150	g • mm²	±20 %
Drive properties							
Ceramic type	PICMA® P-882	PICMA® P-882	PICMA® P-882	PICMA® P-882	PICMA® P-882		
Electrical capacitance	0.39	0.93	0.39	0.93	0.93	µF	±20 %
Dynamic operating current coefficient	8	10	8	10	10	µA / (Hz • mrad)	±20 %
Miscellaneous							
Operating temperature range	-20 to 80	-20 to 80	-20 to 80	-20 to 80	-20 to 80	°C	
Material	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel		
Mass	0.45	0.55	0.45	0.55	0.55	kg	±5%
Cable length	2	2	2	2	2	m	±10 mm
Sensor connection	–	–	–	–	LEMO		

Resolution of PI piezo tip/tilt platforms is not limited by friction or stiction. Noise equivalent motion with E-503 amplifier (p. 2-146).

*Mechanical tilt, optical beam deflection is twice as large. For maximum tilt range, all three piezo actuators must be biased at 50 V. Due to the parallel-kinematics design linear travel and tilt angle are interdependent. The values quoted here refer to pure linear / pure angular motion (equations p. 2-84).

Recommended controller / amplifier
Single-channel (1 per axis): E-610 servo-controller / amplifier (p. 2-110), E-625 servo-controller, bench-top (p. 2-114)

Multi-channel: modular piezo controller system E-500 (p. 2-142) with amplifier module E-503 (three channels) (p. 2-146) or E-505 (1 per axis, high-power) (p. 2-147) and E-509 controller (p. 2-152) (optional), E-517 interface module (p. 2-156) (optional)

S-323 Piezo Z/Tip/Tilt Platform

High Dynamics & Stability Nanopositioning System with Direct Metrology

The S-323 Z/tip/tilt platform integrates capacitive sensors for highest resolution and stability

- Optical Beam Deflection to 6 mrad
- Sub-µrad Resolution for High Positioning Stability
- Position Servo-Control with Capacitive Sensors
- Frictionless, High-Precision Flexure Guiding System
- System Combination with Digital Controllers for Highest Linearity

Model	Active axes	Travel range	Resolution	Unloaded resonant frequency
S-323.3CD	Z, θ_X, θ_Y	30 µm, ±1.5 mrad	0.1 nm, ±0.05 µrad	1.7 kHz

S-303 Piezo Phase Shifter

Highest Dynamics and Stability with Capacitive Feedback Sensor

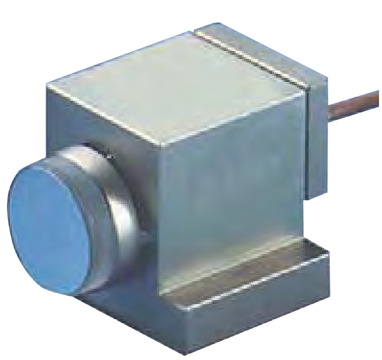
S-303 closed-loop model (left) and open-loop model (right). DIP switch for size comparison

- 25 kHz Resonant Frequency for Sub-Millisecond Dynamics
- Capacitive Sensor Option for Highest Linearity and Stability
- 3 µm Travel Range
- Compact Size: 30 mm Diameter x 10 mm
- Aperture with Open-Loop Versions
- Invar Option for Highest Thermal Stability

Model	Active axes	Closed-loop/ open-loop travel @ -20 to +120V	Closed-loop/ open-loop resolution	Unloaded resonant frequency
S-303.CD (closed-loop)/ S-302.0L (open-loop)	Z	2 / 3 µm	0.03 nm	25 kHz

S-224 -S-226 Piezo Tilt-Mirror

Fast Steering Mirror Combines Highest Dynamics and Compact Design



S-224 Piezo tip/tilt mirror for high-speed beam steering tasks and image stabilization applications

- Optical Beam Deflection to 4.4 mrad
- Sub-µrad Resolution, Sub-Millisecond Response
- Frictionless, High-Precision Flexure Guiding System
- Includes BK7 Mirror
- Optional Position Feedback Sensor
- Outstanding Lifetime Due to PICMA® Piezo Actuators

Model	Active axes	Open-loop tilt angle @ 0 to +100V	Closed-loop/ open-loop resolution	Unloaded resonant frequency
S-224.00 (open-loop)/ S-226.00 (closed-loop)	θ_X	2.0 / 2.2 mrad	0.05 / 0.1 µrad	9 kHz

Details on Specifications for Active Optics / Steering Mirrors

Motion and Positioning

Performance specifications are valid for room temperature (22° ±3 °C) and closed-loop systems are calibrated at this temperature (specifications for other operating temperatures on request). Recalibration is recommended for operation at a significantly higher or lower temperature. Custom designs for ultra-low or ultra-high temperatures on request.

Integrated feedback sensor

Absolute measuring capacitive and strain gauge (SGS) sensors are used to provide position information to the controller. For details see the tutorial "Piezoelectrics in Positioning" section (see p. 2-187).

Open-loop linear travel @ 0 to 100 V

Typical open-loop travel at 0 to 100 V operating voltage. Max. recommended operating voltage range is -20 to +120 V (extremes for short durations only).

Closed-loop linear travel

Travel provided in closed-loop operation. PI piezo amplifiers have an output voltage range of -20 to +120 V or -30 to +135 V to provide enough margin for the servo-controller to compensate for load changes, etc.

Open-Loop Tilt Angle @ 0 to 100 V

Typical open-loop tilt angle at 0 to 100 V operating voltage. For differential-drive tilt platforms, 0° is reached at 50 V drive voltage, the maximum negative angle at 0 V and the maximum positive angle at 100 V. Max. operating voltage range is -20 to +120 V (outside 0 to 100 V for short durations only).

Closed-Loop Travel

Tilt provided in closed-loop operation at room temperature. PI piezo amplifiers have an output voltage range of -20 to +120 V or -30 to 135 V to provide enough margin for the controller to compensate for load changes etc.

Open-loop / closed-loop resolution

Resolution of piezo flexure stages is basically infinitesimal because it is not limited by stiction or friction. Instead of resolution, the noise-equivalent motion is specified. Values are typical results (RMS, 1 σ), measured with E-503 amplifier module in E-500/501 chassis.

Full-range repeatability (typ.)

Typical values in closed-loop mode (RMS, 1 σ). Repeatability is a percentage of the total distance or angle traveled. For small ranges, repeatability is significantly better.

Pitch / Yaw / Roll / Rotational Runout

Typical rotational off-axis error; sometimes associated with a particular motion axis, as in "Rotational runout (Z motion)".

Straightness / Flatness / Crosstalk

Typical linear off-axis error; sometimes associated with a particular motion axis, as in "Crosstalk (Z motion)".

Mechanical Properties

Stiffness

Static large-signal stiffness of the piezo mechanics in operating direction at room temperature. Small-signal stiffness and dynamic stiffness may differ because of effects caused by the active nature of piezoelectric material, compound effects, etc. For details see the tutorial "Piezoelectrics in Positioning" section (see p. 2-189 *ff*).

Unloaded resonant frequency

Lowest tilt resonant frequency around active axis without mirror attached to platform (does not specify the maximum operating frequency). For details see the tutorial "Piezoelectrics in Positioning" Section (see p. 2-192 *ff*).

Resonant frequency with mirror

Example of how a load (mirror) attached to the platform affects the resonant frequency (calculated data). See "Dynamic Behavior" (p. 2-84) for further details.

Drive Properties

Electrical capacitance

The piezo capacitance values indicated in the technical data tables are small-signal values (measured at 1 V, 1000 Hz, 20 °C, no load). Large-signal values at room temperature are 30 to 50 % higher. The capacitance of piezo ceramics changes with amplitude, temperature, and load, up to 200 % of the unloaded, small-signal capacitance at room temperature. For detailed information on power requirements, refer to the amplifier frequency-response graphs in the "Piezo Drivers / Servo Controllers" (see p. 2-99 *ff*) section of this catalog.

Dynamic Operating Current Coefficient (DOCC)

Average electrical current (supplied by the amplifier) required to drive a piezo actuator per unit frequency and unit displacement (sine-wave operation). For example, to find out if a selected amplifier can drive a given piezo tilt platform at 50 Hz with 300 µrad amplitude, multiply the DOC coefficient by 50 and 300 and check if the result is less than or equal to the output current of the selected amplifier. For details see the tutorial "Piezoelectrics in Positioning" (see p. 2-195 *ff*) section.

Miscellaneous

Operating temperature range

Typically -20 to +80 °C, the temperature range indicates where the piezo stage may be operated without damage. Performance specifications are valid for room temperature (22 °C) and closed-loop systems are calibrated for optimum performance at this temperature (specifications for other operating temperatures on request). Recalibration is recommended for operation at a significantly higher or lower temperature. Custom designs for ultra-low or ultra-high temperatures on request.

Material

Flexure stages are usually made of anodized aluminum or stainless steel. Small amounts of other materials may be used internally (for spring preload, piezo coupling, mounting, thermal compensation, etc.).

- Al: Aluminum
- N-S: Non-magnetic stainless steel
- S: Ferromagnetic stainless steel
- I: Invar
- T: Titanium

Voltage connection

Standard operating voltage connectors are LEMO and sub-D type connectors.

LEMO connector: LEMO FFA. 00.250, male. Cable: coaxial, RG 178, Teflon coated, 1 m

Sensor connection

Standard sensor connectors are LEMO and sub-D type connectors.

Sub-D special connectors contain both piezo voltage and sensor connections.

For extension cables and adapters, see "Accessories" (p. 2-168 *ff*), in the "Piezo Drivers / Servo Controllers" Section.

Piezo Drivers / Servo Controllers

Piezo Drivers & Controllers

Simple Control of High Performance Systems

PI offers the largest selection of digital and analog piezo drivers / linear amplifiers and piezo motion controllers worldwide.

The electronics play a key role for maximum performance of piezoelectric nanopositioning stages, steering mirrors and actuators. Ultra-low-noise, high-stability servo-controllers and linear amplifiers are essential, because piezoelectric actuators respond to even microvolt changes of the drive voltage with motion.

For industrial applications, where maximum throughput is crucial, PI offers digital control algorithms for dynamic linearization and reduced settling times. For dynamic high-power applications, PI's unique energy-recovery power amplifiers provide up to 2000 W of peak power!

All standard PI nanopositioning systems are fully CE and RoHS compliant.

Analog and Digital Control for Your Choice

Analog controllers provide true real-time signal processing with very high resolution because no signal conversion is required. This can be advantageous in applications where the control signals are only available in analog form.

Additionally to classical piezo controllers, PI offers a wide range of digital servo controllers. The advantage of digital control is the possibility to use advanced control models and polynomial linearization to improve system response and accuracy significantly. Further advantages are integrated signal generators, trigger functions, system analysis, autocalibration and parameters that can be changed on-the-fly. High-resolution DA and AD converters, fast DSPs and real-time control algorithms allow fast processing for optimizing the system performance.

PI Digital Piezo Controllers—the Winning Margin in Precision

- 1 to 6 axes
- Network and synchronization capability for multi-axis applications
- Based on DSP (Digital Signal Processor) and/or embedded PC
- Optimized control and motion algorithms
- Modern interfaces: high-speed RS-232, remote operation via TCP/IP or USB
- Extensive software package
- All parameters can be changed on-the-fly
- Dynamic tuning with comfortable NanoCapture™ software
- Two notch filters per axis (standard) for higher dynamics
- Polynomial linearization provides to 0.01% linearity
- DDL: Dynamic linearization eliminates tracking errors
- Plug and Play, ID chip implemented in Sub-D connector of stage.
- Auto Zero function
- Automatic coordinate transformation for simple control of complex parallel-kinematics systems
- Freely programmable Trigger I/O
- Optional analog I/O

30-channel controller, consisting of three E-500.621 chassis, each with a capacity of up to twelve E-621 modules.

Operating Characteristics of Piezo Amplifiers

Power Requirements for Piezo (PZT) Operation

The operating limits of a piezo amplifier depend on the amplifier power, the amplifier design, and of course, the piezo's electrical capacitance. For dynamic applications, PZTs require high charge and discharge currents. Those requirements are best met by power amplifiers that can source and sink high peak currents. The average current is of secondary importance. For exact information on maximum operating frequency with a given PZT load refer to the individual operating limits graphs.
Open-loop operating limits data for all PI piezo power amplifiers in this catalog were taken after 15 minutes of continuous operation (PZT and amplifier) at room temperature. At power up, (cold conditions) maximum operating frequency is higher.

The indicated capacitance values are small-signal values for actual piezo actuators (measured at 1 V, 1000 Hz, 20 °C, no load). The capacitance of piezo ceramics changes significantly with amplitude, temperature, and load, up to approximately 200% of the unloaded small-signal capacitance at room temperature. See tutorial "Electrical Fundamentals" (p. 2-195) for more information.

Therefore the operating limits graphs actually reflect a much higher load to the amplifier than a standard capacitor of the same value would represent.

Adjusting Control Input

In order to achieve minimum distortion of the output waveform, it is important to ensure that the control input amplitude is reduced in proportion to the roll-off of the output voltage at higher frequencies.

Example: The E-503 (E-663) amplifier can drive a 23 µF load at 100 V peak-to-peak (sinewave) up to approximately 15 Hz. At higher frequencies the output voltage drops off, e. g. to 80 V at 20 Hz. Therefore it would be important to reduce the input voltage amplitude to 8 V (gain = 10) at this frequency. Otherwise the amplifier will output a clipped distorted sinewave.
See "Introduction Flexure Stages" (p. 2-10) for more information on controller selection.

Application-Specific Settings

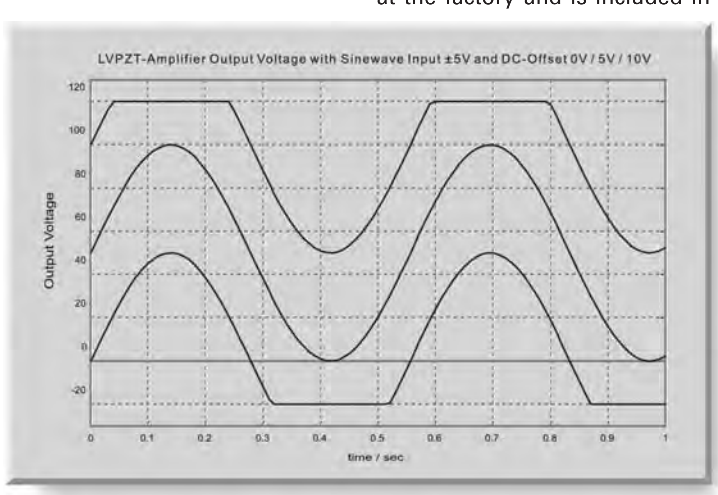
To achieve optimum performance each position servo-controller must be adjusted for displacement range, frequency response, settling time and optimum match with the position sensor. This adjustment is done at the factory and is included in the price of the controller Test & Metrology (see p. 2-187).

To optimize the system settings, additional information about the desired operating bandwidth, the mass to be moved by the piezo and the spring constant of any preload or of the material the piezo pushes against is required.

The position servo-control portion of all analog PI piezo servo-controllers is identical, employing a proportional integral (P-I) algorithm specially optimized for piezo actuators. A differential term is not recommended with piezo actuators because it only increases the noise. One or several notch filters are used to greatly improve dynamics / bandwidth.

High System Bandwidth

All PI nanopositioning controllers (analog and digital) are equipped with one or more user-tunable notch filters. A controller with notch filter can be tuned to provide higher bandwidth because side-effects of system resonances can be suppressed before they affect system stability. For the most demanding step-and-settle applications, PI's exclusive Mach™ InputShaping® implementation is available as an option.



The diagram shows how the piezo amplifier input range can be varied with the DC-offset potentiometer. This principle is also valid for HVPZT amplifiers, where the typical input range is 0 to +10 V and the output range is 0 to 1000 V. The DC-offset potentiometer allows for continuous shifting of the input range between 0 V to +10 V and -10 V to 0 V.

Interfaces

Digital or Analog Interfacing?

Analog interfacing provides high bandwidth and remains the most common way of commanding piezoelectric motion systems. It is usually the choice when the control signal in the application is provided in analog form. A key advantage of analog interfacing is its intrinsic deterministic (real-time) behavior, contrasted to the difficulty of accurately timing high-bandwidth communications on present-day multitasking PCs.

However, when analog control signals are not available, or when a significant distance between the control signal source and the nanopositioning controller would affect signal quality, digital interfacing, which must not be confused with digital control, is the preferred choice.

Digital signals can be transferred through copper wires, or for complete EMI immunity, through optical fibers.

Supported Digital Interfaces

PI's controllers are equipped with fast TCP/IP, USB and RS-232 interfaces (for details and exceptions see data sheets). Positioning commands can be formulated directly in SI units (e.g. microns and microradians), a feature which facilitates programming the system. In addition, parameters for the servo-loop, low-pass and notch filters are easily optimized and can be stored in non-volatile memory.

An optional parallel interface (PIO) bypasses the command parser and allows reading and writing up to 20,000 positions per second. Fast PCI interfaces offer transfer rates up to 1 MHz.

Interface Bandwidth vs. Timing

Piezo-driven stages can respond to a motion command on a millisecond or microsecond time scale.

That is why synchronization of motion commands and data acquisition have a high impact on the quality of many applications, like imaging or micromachining. The USB, for example, was designed to transfer huge blocks of data at high speeds, but exact timing was a much lesser concern. While insignificant in less responsive positioning systems, this kind of non-deterministic behavior may not be tolerable in high-speed tracking or scanning applications. Each motion command—comprising just a few bytes—must be transferred instantaneously and without latency. A lower-bandwidth bus with higher timing accuracy may perform better in many applications.

There are several factors that affect the response of a digital interface: the timing accuracy of the operating system on the controlling computer; the bus timing protocol; the bandwidth of the bus; and, the time it takes the digital interface (in the piezo controller) to process each command. Parallel-port interfaces do not require command parsing and offer the best combination of throughput and timing accuracy.

In addition to the interface properties, the bandwidth of the nanopositioning system (mechanics and servo) matters. A slow system (e.g. 100 Hz resonant frequency) will not benefit from a responsive interface as much as a high-speed mechanism.

Analog In- and Outputs

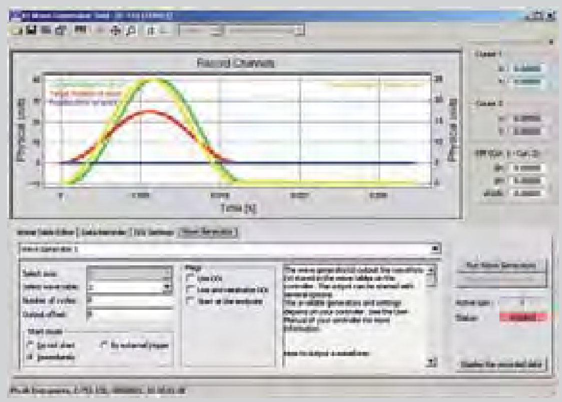
Optionally available analog inputs can be configured in a flexible way: either as a control input—the applied voltage can be connected with one of the available axes and is interpreted e.g. as a position value—or as an external sensor—e.g. used as an autofocus signal instead of an integrated sensor.

Optional analog outputs allow the control of external power amplifiers or can be used as monitor signal interfaces.

The individual data sheets for the controllers inform about number, voltage range (usually ±10 V) and availability of the analog I/Os.

PI controllers are available with a number of different interfaces for highest flexibility. In addition to the modern Ethernet (TCP/IP) and USB, many industrial customers still appreciate the robust RS-232 protocol

Support of Controller-Specific Features



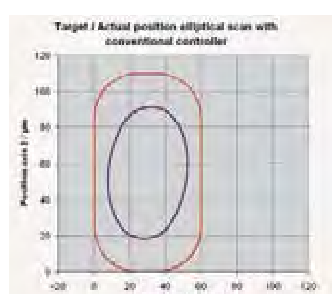
Complex trajectories can be created, stored and executed with the Wave Generator tool

Extensive Software Support

Digital controllers come with a large variety of software tools, such as the PIMikroMove™ graphic user interface or the NanoCapture™ system analysis program. Additional LabVIEW drivers and DLL's for easy setup, system optimization and integration in application-specific programs are included. Comprehensive documentation, Online Help and sample code offer added value. Even analog systems can be controlled with PI's LabVIEW driver set, optionally with HyperBit functionality.

Simple, General Command Set Saves Time

General Command Set (GCS) is PIs universal command set for uniform control of nano- and micropositioning systems. All PI piezo, piezomotor and motor controllers including hexapods and hybrid systems support the command set. With GCS the control is independent of the used hardware, so that different devices can be controlled together or new devices can be used with minimum adaption efforts. See p. A-11 *ff* for details.



Elliptical scan with a XY piezo scanner and conventional P-I-servo controller. The outer curve shows the desired position, the inner curve shows the actual motion

The same scan as before but with a DDL controller. The tracking error is reduced to a few nanometers, desired and actual position cannot be distinguished in the graph

Data Recorder: Data Acquisition and Output

The flexibly configurable data recorder enables simultaneous recording and read-out of input and output signals, such as for sensor positions or control voltages depending on time stamps or using trigger signals.

Wave and Profile Generator: Pre-Defined and Programmable Trajectory Profiles

Trajectory profiles of arbitrary, user-defined mathematical functions enable complex 2-axis motion. Depending on the controller used, either time and position data value pairs can be saved (Wave Generator) or complete trajectory profiles with velocity, acceleration and jerk (rate of change of acceleration) can be specified (Profile Generator). The functionality includes:

- Programming of complex functions
- Quick access to common functions (e. g. sine, ramps, triangle and square waves ...)
- Coordination of two axes, e. g. for applications requiring circular motion
- Saving of defined functions in the controller

All controller specific functionalities are available as DLL function calls and LabVIEW VIs, which enables their simple integration in external programs. Additional graphical user interfaces allow convenient selection and customization.

Improved Piezo Control: Dynamic Digital Linearization (DDL)

Conventional piezo controllers cannot completely avoid phase-shift and tracking errors in applications with rapid, periodic motion. This is due in part to the non-linear nature of the piezoelectric material, the finite control bandwidth and the inherent limitations of P-I (proportional-integral) servo-control, which only reacts when a position error is detected. The DDL option (ordering number E-710.SCN), available with recent digital piezo controllers such as E-753 (single-channel, see p. 2-108) or E-712 (multi-channel, see p. 2-140), solves this problem. This technology, developed by PI, reduces the error between the current and desired position to imperceptible values. The dynamic linearity and effectively usable bandwidth are thus improved by up to three orders of magnitude. DDL is of benefit to single- and multi-axis applications where motion follows a given trajectory repeatedly (see measurement curves).

Digital Control

Digital Processes Improve Performance

Objective positioner for microscopy with digital single-channel control: The optimum for resolution and settling time

Digital technology opens up new opportunities for improving performance in control engineering which did not exist with conventional analog technology.

A significant advantage of PI's digital controllers is that all motion parameters can be specifically influenced by calculating algorithms.

These advantages lie mainly in the improved precision and dynamic properties, and also the ease of operation of PI's positioning systems and drive solutions.

High-Resolution Signal Conversion

The most important requirement here is that the signal conversion from analog input signals to digital data for the subsequent processing is done quickly and with high resolution. Information which is lost at conversion is lost forever. The same applies to the generation of the analog control signal: The best algorithms are useless if the analog control signal cannot be generated in high resolution. PI therefore uses the latest generation of A/D and D/A converters with a minimum 20-bit resolution. Analog signals are thus resolved into more than one million data points.

Fast Data Processing

The incoming volume of data needs to be processed rapidly in order to compete with the conventional analog controllers in terms of "real time". This requires fast processors. PI relies on modern DSPs and powerful PC solutions, depending on the task the controller has to fulfill.

A control cycle is thus completed, for example, in 0.02 milliseconds – this corresponds to a servo rate of 50 kHz. Updated sensor data and control signals have therefore also to be provided.

Digital Processes Improve Performance

The performance of a positioning system is no longer decided by its mechanical properties alone. In the case of dynamic applications, for example, it is naturally also important that the system is as stiff as possible and the moving mass very small, the sensor bandwidth broad and the amplifier flank steep. There will nevertheless be phase shifts between the control signal – the target motion – and the actual motion. Linearization algorithms minimize the difference between the target and the actual value and allow faster settling and also the adjustment of the control signal.

Parallel kinematic Hexapod with digital controller for fast processing of the complex motion

Digital Data Processing

Classical nanopositioning technology employs the following algorithms in digital controllers to improve the system performance:

Linearization of the Electronics:

All digital PI controllers for nanopositioning behave in a similar way. This allows any piezo devices which are tuned to digital control to also be operated by different controllers without any loss of performance. The tuning data required are stored on an ID-Chip in the stage and retrieved by the controller at power up.

Linearization of the Mechanics:

The linearity of regulated systems as a whole is a measure of its positional accuracy. Piezo actuators as such have a high degree of nonlinearity – up to 15% of the travel – and this must be compensated by the control in order for the system to reach the position as accurately as possible. With digital controllers, the nonlinearity of the motion is reduced using calculations with higher order polynomials to values below 0.001% – which corresponds to an accuracy of better than one nanometer for a travel range of 100 µm.

Controller and Controlling Methods:

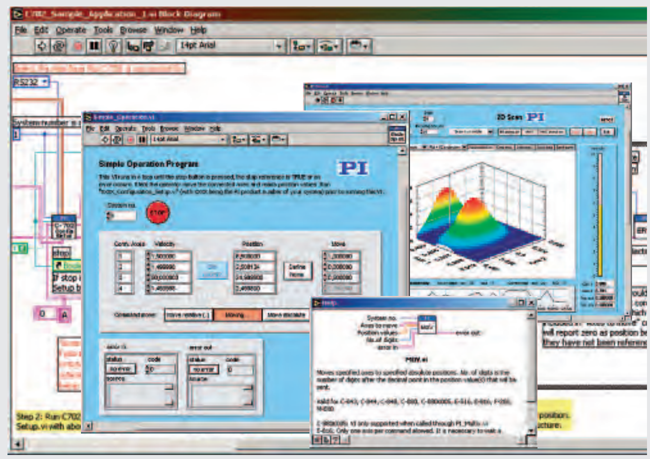
The task of the controller is to compensate differences between target and actual position. This is conventionally done with PID controllers. Depending on the application, other control concepts in combination with linearizing algorithms can bring about better results, however. PI thus offers model-based state controllers (Advanced Piezo Control) as an optional extra.

Dynamic Linearization:

Digital Dynamic Linearization (DDL) reduces the deviation of periodic trajectories during the motion even further. This is relevant for scanning applications, where the task is to identify a certain position and take it up again with precision, or for applications where the trajectory must be maintained for processing steps.

Digital Control

Simplified Operation and Advanced Functionality



Quick access to the full functionality

Operation via Software

The complete digitalization of all operational steps makes the process parameters easily accessible via software. PI software additionally provides diagnostic tools and tuning support, such as the graphic display of step responses for parameter optimization.

Operation via Digital Interfaces

Fast USB or TCP/IP interfaces, as well as RS-232, are the standard interfaces supported by modern digital controllers. Furthermore, PI also provides real-time capable interfaces such as a 32-bit parallel input / output interface (PIO). Customized serial interfaces are also possible to provide a link to the application environment.

Simplified Control of Multi-Axis Systems

PI uses parallel kinematics for precise positioning in three or more axes. The actuators and drives here act simultaneously on the platform to be moved – in the case of hexapods, for example. The motion of the platform in the six directions requires that the individual axes be coordinated. This coordinate transformation enables the user to place commands in Cartesian coordinates, while the controller controls the individual drives required for this.

Additional Functions of the Digital Controllers*

Computing power and memory size which go hand in hand with digital controllers allow useful additional functions to be implemented.

Coordinate transformation for parallel kinematics for simple control in Cartesian coordinates.

Coordination of the walk motion for PiezoWalk® Drives; linearization of the actuator travel for Walk Drives.

Software access to all motion parameters and the graphic display of the effects.

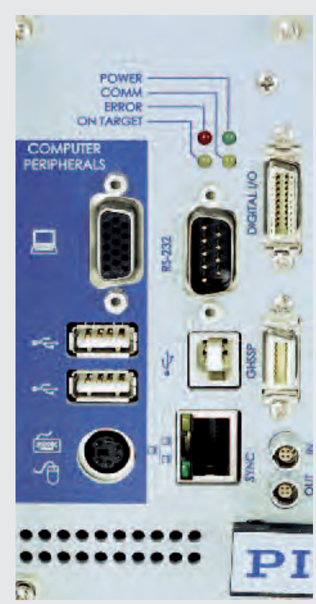
Macro memory to store and retrieve motions which can be triggered externally.

Function generator and trajectory memory for the retrieval of predefined trajectories and the generation of customized wave forms.

Data recorders record sensor and control data for subsequent processing.

The **ID Chip** permits the flexible exchange of controllers and nanopositioners without the need to retune the operational parameters.

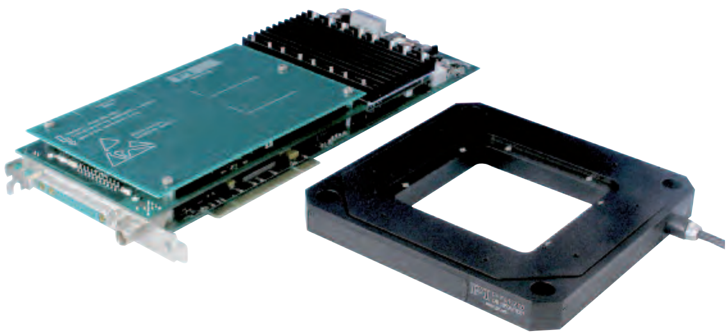
* Not all controllers have all the functions.
The individual ranges of functions are listed in the relevant datasheets.



The E-712 provides RS-232, USB and RS-232 as standard interfaces. Additionally, digital I/O lines and optional analog interfaces or a real-time PIO are available.

Digital Control

Exceeding the Pure Function…



The digital E-761 nanopositioning controller as PC Plug-in card (here with XY nanopositioning system) presents a low-cost alternative to the tabletop or rack-mounting version with casings.

Piezo, Nano, Positioning

PI offers the world's largest selection of positioning and drive systems for precise positioning in the accuracy range from one micrometer down to below one nanometer. Piezo actuators, piezo walk or ultrasonic drives as well as conventional motors and combinations of all these enable PI to provide custom-engineered positioning systems. The requirements of biotechnology, semiconductor production, optical metrology and astronomy have one thing in common here: The high degree of precision required and PI as the supplier of the solution.

As Flexible as the Drive: The Control

Fast settling or slow speed with high constancy, high positional stability, positional resolution and dynamics – different applications require a high degree of control flexibility. PI therefore offers a broad spectrum of electronics from very versatile controllers to highly specialized ones: As an OEM board for integration, a plug-and-play desktop unit or with a modular construction.

Continuous Progress

As far as PI is concerned, the certification of a quality management system is a commitment to continuously improve products and processes. Suppliers are integrated into the development process in order to transfer PI's high standards to them. PI's absolute commitment to quality leads it to train its own staff in Development and Production, provide laboratories for EMC and environmental tests, and use the latest CAD and simulation tools. A commitment which those working in the field of nanotechnology cannot do without.

Piezo Amplifier in cost-efficient and compact OEM Design

Service

The **scope of supply** of a PI system consisting of controller and stage includes everything required for its operation.

- Any necessary external power supplies
- All power, communication and system cables
- The comprehensive operating manual in printed form
- Software CD with comprehensive setup function

Firmware and software updates are available free of charge via the Internet, as are the operating manuals. You will receive access to the PI download portal when you purchase the controller. Firmware updates can easily be carried out via the standard controller interfaces.

PI offers comprehensive **software support**. PI software is included in the scope of supply and serves to start up the system, and also to analyze and optimize the system's behavior. DLLs, LabView drivers or the support of MatLab facilitate the programming.

It goes without saying that the PI software is compatible with the latest Microsoft operating systems and can also be operated under LINUX.

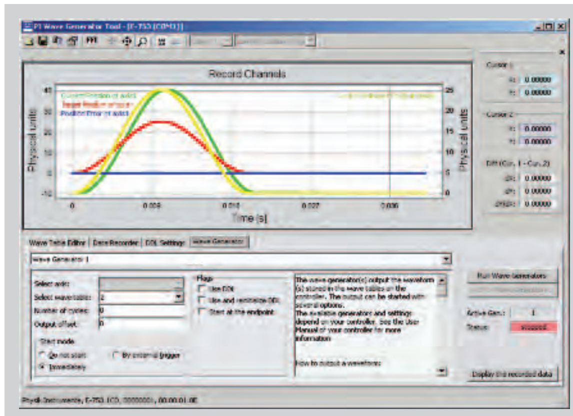
When developing the instruments, top priority is given to the use of state of the art components. This ensures a **long availability and replaceability** of the systems even beyond the product lifecycle.

Customized product development and adaptations are an important part of our technical progress. We offer you:

- The complete range of our product spectrum from electronic components and complete devices as an OEM circuit board to the modular system in a case.
- Small batch production and mass production.
- Product development according to special product standards (country or market-specific standards such as the Medical Devices Act) and the corresponding certification.
- Adaptation of the systems to special environmental conditions (vacuum, space, clean room)
- Copy-exactly agreements

Advanced Functionality – Requirements from the Applications

Trajectory Storage, Data Recorder, Macros, System Recognition, Autofocus…



Data recorder and wave generator are part of the MikroMove® software for all digital controllers.

Data Recorder:
Data Acquisition and Output

The flexibly configurable data recorder enables simultaneous recording and read-out of input and output signals, such as for sensor positions or control voltages depending on time stamps or using trigger signals.

Wave and Profile Generator:
Pre-Defined and Programmable Trajectory Profiles

Trajectory profiles of arbitrary, user-defined mathematical functions enable complex 2-axis motion. Depending on the controller used, either time and position data value pairs can be saved (Wave Generator) or complete trajectory profiles with velocity, acceleration and jerk (rate of change of acceleration) can be specified (Profile Generator). The functionality includes:

- Programming of complex functions
- Quick access to common functions (e. g. sine, ramps, triangle and square waves ...)
- Coordination of two axes, e. g. for applications requiring circular motion
- Saving of defined functions in the controller

All controller specific functionalities are available as DLL function calls and LabVIEW VIs, which enables their simple integration in external programs. Additional graphical user interfaces allow convenient selection and customization.

Autofocus

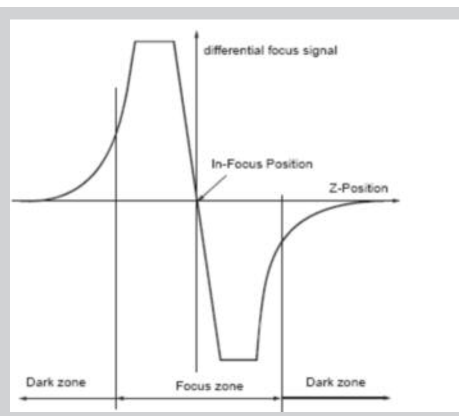
Autofocus routines stored in the firmware allow a function to be implemented which regulates according to an external sensor signal – on the signal output of a vision system, for example. The underlying zero transition method regulates towards a voltage of 0 V at the analog input of the digital controller. This must be able to perform the autofocus routine and have an analog control input.

The autofocus algorithms are possible as standard functions for the E-753 (1 channel), E-725 (3 channels) and E-712 (up to 6 channels) nanopositioning controllers.

ID-Chip Recognition for Automatic Adaptation of the Controllers to the Piezomechanics

The best results for the positional accuracy (linearity) of the piezo system are achieved by adapting various operating parameters. These depend on the individual stage. If digital electronics are tuned once, these parameters are stored in the ID-Chip of the stage. They are therefore automatically available again for the operation at a different digital controller, without the need for an adaptation. This exchangeability between stage and controller is a significant step forward for the flexible use of the systems.

ID-Chip recognition is performed in all E-753, E-725 and E-712 nanopositioning controllers.



Autofocus with the zero transition method: If the control signal is zero, the position is stably maintained. Possible drifts, which lead to a change of the input signal, can be compensated in this way.

BRO12E Digital Control 09/06.2 Subject to change without notice.

DDL: Dynamic Digital Linearization

Nanometer Trajectory during Dynamc Scans

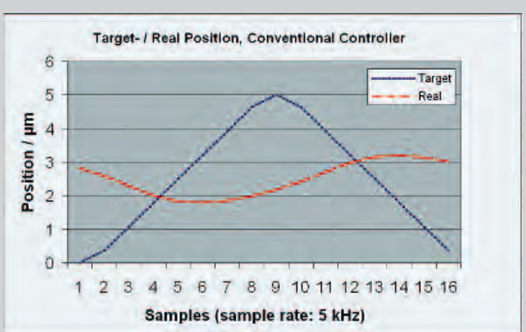
Improved Piezo Control: Dynamic Digital Linearization (DDL)

Conventional piezo controllers cannot completely avoid phase-shift and tracking errors in applications with rapid, periodic motion. This is due in part to the non-linear nature of the piezoelectric material, the finite control bandwidth and the inherent limitations of P-I (proportional-integral) servo-control, which only reacts when a position error is detected. The DDL option (ordering number E-710.SCN), available with recent digital piezo controllers such as E-753 (single-channel, see p. 2-108) or E-712 (multi-channel, see p. 2-140), solves this problem. This technology, developed by PI, reduces the error between the current and desired position to imperceptible values. The dynamic linearity and effectively usable bandwidth are thus improved by up to three orders of magnitude. DDL is of benefit to single- and multi-axis applications where motion follows a given trajectory repeatedly (see measurement curves).

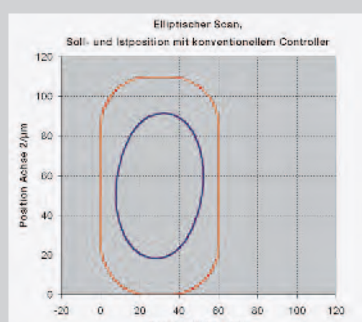
Ordering Information

E-710.SCN
Firmware Upgrade DDL
(Dynamic Digital Linearization)

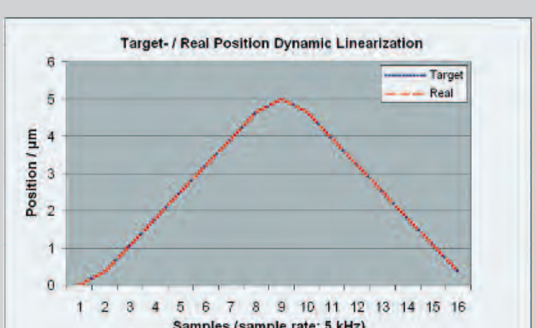
Available for controller E-712, E-725 and E-753.



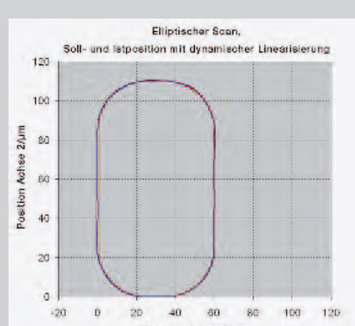
Nanopositioning systems with conventional PID controller: Single axis movement with a 312 Hz triangular signal. The difference between target and actual position can be up to 2.6 µm.



Elliptical scan with a XY piezo scanner and conventional P-I-servo controller. The outer curve shows the desired position, the inner curve shows the actual motion.



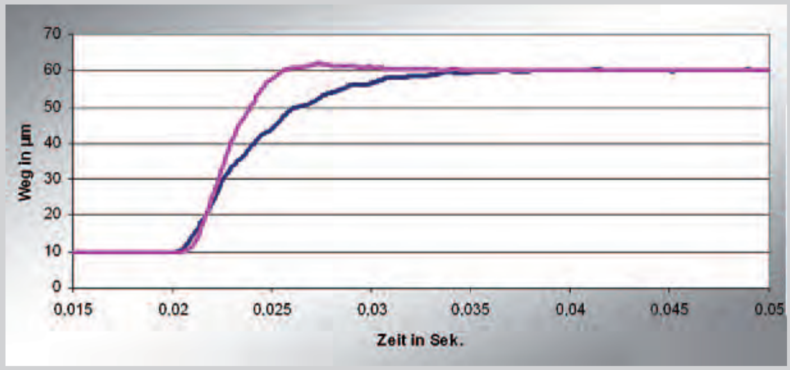
Nanopositioning system with DDL option: The same single axis movement as above, with 312 Hz triangular signal. The difference between target and actual position is practically unobservable and is about 7 nanometers.



The same scan as before but with a DDL controller. The tracking error is reduced to a few nanometers, desired and actual position cannot be distinguished in the graph.

Advanced Piezo Control

Alternative Regulation Concept for Faster Settling



Transient response of an system with optimated PID parameters (blue) and Advanced Piezo Control (pink).

An alternative control concept is provided for the modular E-712 controller for nanopositioning systems: Advanced Piezo Control. It is based on a state controller which, in turn, is based on a model of the positioning system.

Advanced Piezo Control actively damps the resonance frequency, in contrast to conventional PID controllers with notch filter where the mechanical resonance is cut out of the excitation spectrum.

Advanced Piezo Control for Faster and More Stable Control

The consequences are faster settling times and lower sensitivity with respect to interferences from the outside.

The phase trueness is significantly improved compared to the damping with one or even two notch filters. This has immediate effects on the trajectory trueness and the settling response.

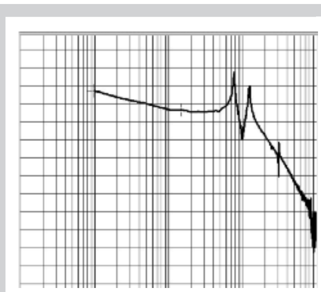
Limitations of the Advanced Piezo Control

If the mechanical system has too many resonances close together, or if the resonance frequency to be damped is about 1 kHz or more, the state controller in this form no longer has any advantage over conventional PID controllers. Please discuss your application with us.

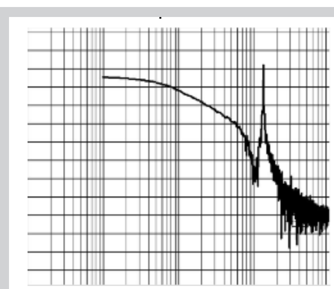
Ordering Information

E-712.U1
Firmware Upgrade Advanced Piezo Control Regleroption

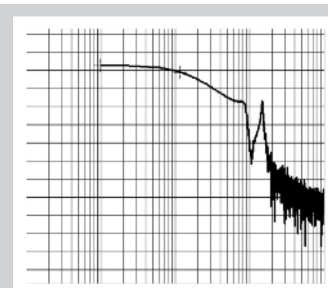
Advanced Piezo Control is also available for the Controller E-753 (1 Channel) and for the E-725 (3 Channels). Ask your PI Sales Department.



Bode diagram of an unloaded, unregulated system with two resonance frequencies.



Bode diagram of a regulated system with one notch filter at the first resonance.



Bode diagram of a system regulated with Advanced Piezo Control. The resonances are better suppressed, the phase deviation is lower compared to the suppression with a notch filter.

PI Software

Operating Positioning Systems Effectively & Conveniently

Communication between PI components is based upon a universal command set (GCS – General Command Set). It decouples hardware and software, and is used for all drive principles.

The high quality of positioning systems is made apparent in daily operation by PI software. Starting with simple commissioning, through convenient operation with a graphical interface, to quick and simple integration in customized programs with high performance, PI software covers all aspects important to an application.

Universal Command Set Simplifies Commissioning and Programming

For uniform operation of nano and micropositioning systems, the universal PI General Command Set (GCS) is used. GCS operation is independent of the controller or drive principle used, so that several positioning systems can be controlled together, or new systems can be introduced with a minimum of programming effort. With GCS the development of custom application programs is simplified and less prone to errors, because the commands for all supported devices are identical in syntax and function. Through the use of the GCS command set with its convenient functions, the orientation phase and application development process is significantly accelerated.

The GCS commands are available at the controller terminal, in macros and in the form of a universal driver set for LabVIEW (VIs), Windows dynamic link libraries (DLL) and Linux libraries for 32- and 64-bit platforms. This facilitates the development of custom macros, as well as integration with programming languages like LabVIEW, C++ or MATLAB.

All about software in the internet—a server offers download of manuals and software CD mirrors

Software Updates Online

PI supports users with free updates, detailed online help and well structured manuals which ease initiation of the inexperienced but still answer the detailed questions of the professional.

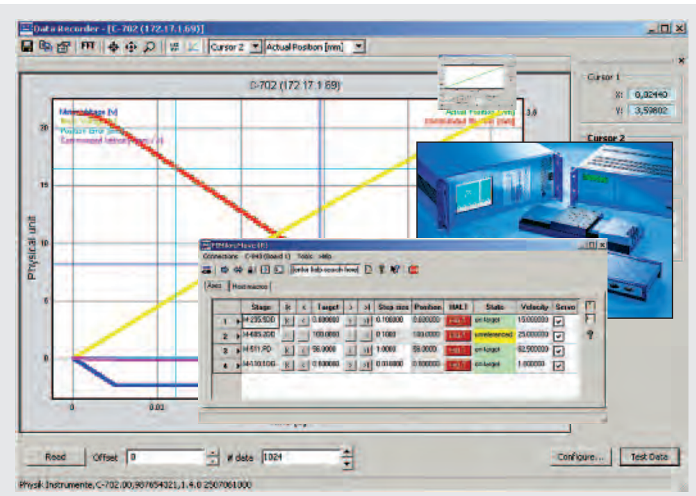
Supported Operating Systems

- Microsoft Windows Vista
- Microsoft Windows XP
- Microsoft Windows 2000
- Linux

PI

PIMikroMove™ Software

Simple Operation of Positioning Systems



A uniform interface for all axes

- **Operation of PI Motor, Piezo, Piezomotor, Hexapod & Hybrid Controllers**
- **1D/2D Scan and AutoFind**
- **Macros for Recurring Tasks and Automation**
- **Optimizing all Servo Parameters**

PI positioning systems can be controlled with PIMikroMove™ in a clear and simple manner; all connected controllers and axes are accessed via the same graphical interface.

PIMikroMove™ supports quick commissioning of controllers and positioners, comprehensive system optimization as well as the programming of macros.

All Axes in One View

With PIMikroMove™ all axes connected can be controlled from one program instance. This, independent of which PI controller is connected to which axis and which interface (TCP/IP, USB, RS-232, GPIB, PCI). For example, it is possible to have two axes in an XY application connected to two different controllers, but still command them with PIMikroMove™ from the same window.

Optimal System Behavior

PIMikroMove™ also allows the user to optimize the system behavior through convenient servo tuning. This possibility is especially helpful if the mechanical properties of a system are changed, for example by applying a different load. The system response and stability can then be optimized with the convenient parameter tuning tool. For recurring tasks, different sets of optimized parameters can be saved as stage profiles and then activated as needed in custom-programmed applications.

Macros Ease Recurring Tasks

PIMikroMove™ considerably simplifies the creation of macros for recurring tasks. Execution of a macro, consisting of a previously stored list of GCS commands, can be commanded over the interface or, if supported by the controller, run automatically on power-up, with or without a host PC connected.

Controllers without their own macro facility, like the C-843, can be commanded by host macros which PIMikroMove™ edits and stores in the host PC. Host macro execution can be triggered with digital I/O lines or software commands and support multiple axes connected to different controllers.

With the position pad, two or more independent axes can be moved by a mouse or joystick as an XY stage, also in vector moves.

1D/2DScan and AutoFind

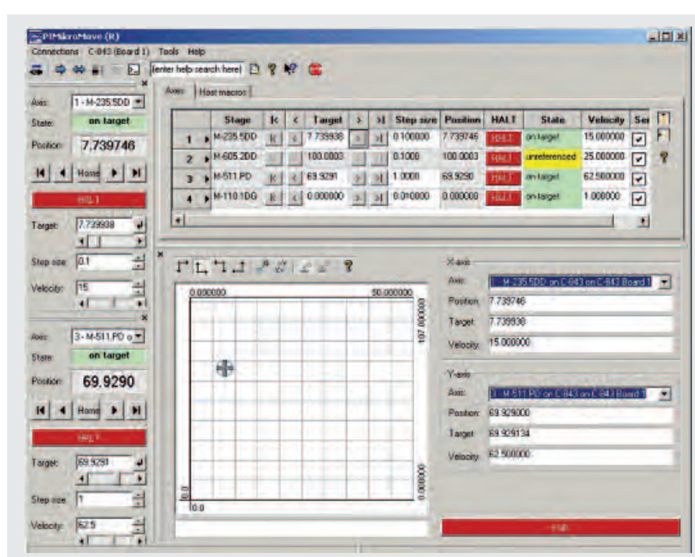
Scan 1D/2D can measure an input source while moving up to two axes. Moved axes and input source need not be assigned to the same controller. The input source to be measured can be an analog input, an axis position or a raw position sensor value. The measured data is visualized and can be saved to a file on the host PC. AutoFind tries to find the maximum of an intensity signal by modifying the position of two axes.

FFT, Profile Generator, Data Recorder

PIMikroMove™ also supports controller-specific features.

Data recorder: record various motion and system parameters, run FFT (Fast Fourier Transformation) on the data as well as export it to programs like Microsoft Excel (CSV format).

Profile Generator: synchronize motion of several axes along multi-order, mathematically defined curves or customized arbitrary functions.



All axes and the position pad can be displayed in one window

E-753 Digital Piezo Controller

High-Speed, Single-Axis Controller

E-753 Single-channel digital controller together with the PIHera® P-629.1CD nanopositioning stage with 1500 µm travel

- **Next Generation Digital Controller Provides Higher Flexibility, Accuracy and Speed**
- **100 kHz Sensor Sampling; 32-bit Floating Point DSP; 24-bit Low-Noise D/A Converters**
- **Ethernet (TCP/IP) Interface for Remote Control Capability, RS-232**
- **Auto-Loading of Calibration Data from Stage ID-Chip for Interchangeability of Controller and Mechanics**
- **Additional High-Bandwidth Analog Control Input / Sensor Input**
- **Digital I/O Lines for Task Triggering**
- **Extensive Software Support**
- **For Nanopositioning Systems with Capacitive Sensors**

The E-753 next-generation digital piezo controller is the result of PI's 30+ years of experience with piezo motion control systems. It is ideal when it comes to meeting the most demanding accuracy and dynamic-performance requirements of nanopositioning systems of the highest precision class. The E-753 replaces the E-750 controller.

Digital Linearization and Control Algorithms for Highest Accuracy

Linearization algorithms based on higher-order polynomials improve the positioning accuracy to 0.001 % of the travel range. During fast periodic motion, as typical for scanning applications, the tracking accuracy can be further improved with Dynamic Digital Linearization (DDL, E-710.SCN). This optionally available control algorithm reduces the tracking error by a factor of up to 1000 and enables the spatial and temporal tracking during a dynamic scan.

Higher Velocity and Bandwidth for Dynamic Applications

The controller is perfectly suited for high-dynamics operation thanks to its high-resolution DA-converter and high-performance voltage amplifier. The high-speed processor with a sensor sampling rate of 100 kHz assures settling times in the millisecond range and below.

Flexibility for a Variety of Applications

PI nanopositioning systems which are equipped with an ID-chip and calibrated with a digital controller have the mechanics-related calibration and servo-control parameters stored in the chip. The controller automatically adapts to the connected mechanics by the appropriate use of this data, so that recalibration is not necessary when system components are replaced.

The integrated wave generator can save and output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined profiles can be created.

Simple System Integration

All parameters can be checked and reset via software. System setup and configuration is done with the included NanoCapture™ and PIMikroMove™ user-interface software. Interfacing to custom software is facilitated with included LabVIEW drivers and DLLs. System programming is the same with all PI controllers, so controlling a system with a variety of different controllers is possible without difficulty.

Ordering Information

E-753.1CD
High-Speed Single-Channel Digital Piezo Controller for Capacitive Sensors

E-710.SCN
DDL (Dynamic Digital Linearization) Firmware Upgrade

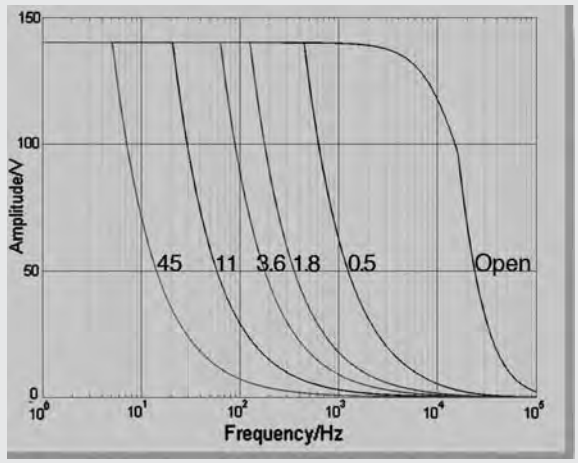
E-753.IO
Cable for Digital I/O Lines, 1.5 m, Solderable End

Ask about custom designs

P-725 PIFOC® objective Z-positioner and E-753 controller constitute an optimal system for high-speed, high-resolution positioning and scanning.

Technical Data

Model	E-753.1CD
Function	Digital controller for single-axis piezo nanopositioning systems with capacitive sensors
Axes	1
Processor	DSP 32-bit floating point, 60 MHz
Sampling rate, servo-control	25 kHz
Sampling rate, sensor	100 kHz
Sensor	
Servo characteristics	P-I, two notch filters
Sensor type	Capacitive
Sensor channels	1
Sensor bandwidth	5.6 kHz
Sensor resolution	17-bit
Ext. synchronization	Yes
Amplifier	
Output voltage	-30 V to 135 V
Amplifier channels	1
Peak output power <5 ms	15 W
Average output power >5 ms	5 W
Peak current <5 ms	110 mA
Average current >5 ms	40 mA
Current limitation	Short-circuit-proof
Resolution DAC	24-bit
Interfaces and operation	
Communication interfaces	Ethernet, RS-232
Piezo connector	Sub-D special connector
Sensor connection	Sub-D special connector
Analog input	LEMO, ±10 V, 18 bit
Digital input	2 x LEMO, TTL
Digital output	2 x LEMO, TTL
Command set	GCS
User software	NanoCapture™, PIMikroMove™
Software drivers	LabVIEW drivers, DLLs
Supported functionality	Wave generator, trigger I/O, data recorder
Display	Status LEDs
Linearization	4th order polynomials, DDL (optional)
Separate protective ground connector	Yes
Miscellaneous	
Operating temperature range	5 to 50 °C
Overtemp protection	Deactivation of the piezo voltage output at 85 °C
Mass	0.9 kg (controller)
Dimensions	Controller: 264 x 125 x 48 mm (with rubber feet) Power supply: 174 x 95 x 58 mm (with rubber feet)
Power consumption	10 W max.
Operating Voltage	24 VDC from external power supply (included)



E-753 open-loop operating limits with various PZT loads. Graphs reflect the large signal-current limitation of the amplifier circuit, not the actual bandwidth.

E-609 OEM Piezo Controller with Digital Servo

Increased Performance for Low-Cost Piezo Systems with Strain Sensors


E-609 digital servo controller with a PIFOC® objective scanner

- **Fast Digital Controller, Software Configurable Servo Parameters**
- **Linearity of SGS and Piezoresistive Sensors Improved by up to 0.02 %**
- **Analog Control Input for Target Values**

The E-609 opens up the possibilities of digital control for piezo-driven nanopositioning systems for the same price as analog controllers. It was designed for piezo actuators and nanopositioning stages which are equipped with more cost effective measuring systems such as strain gauges or piezoresistive sensors. The analog control input allows the users to seamlessly exchange existing analog controllers with the improved E-609. Thanks to the software configurable servo parameters and the digital signal processing a significantly higher accuracy and very simple operation is possible.

Digital Linearization for Strain Sensors: 10 x More Precise!

For the first time, the E-609 nanopositioning controller opens up the advantages of digital control to compact systems with strain sensors. These sensors are based on the strain of metal foils or semiconductor films (piezoresistive sensors) and are used when space limitations prevent the use of the more advanced capacitive sensors, or where the requirements in terms of resolution or temperature stability are not as critical. The limited linearity of these strain sensors can be improved by digital controllers, which use additional linearization algorithms to minimize the deviation between target and actual position. This improves the accuracy by up to one order of magnitude and achieves linearity values of up to 0.02 %.

Flexibility: Software Configurable Servo Parameters

All servo controllers require tuning and adjustment of servo parameters for optimum performance (e.g. as a result of changes to the load or the motion profile). With a digital controller, all adjustments are carried out by simple software commands and the resulting motion or transient characteristics can be viewed, analyzed and further optimized immediately with the provided software. It is also possible to switch between previously found sets of parameters when the controller is in operation. Since jumpers and potentiometers no longer have to be set manually, system integration becomes much more straightforward. For this purpose, the E-609 offers an USB service interface.

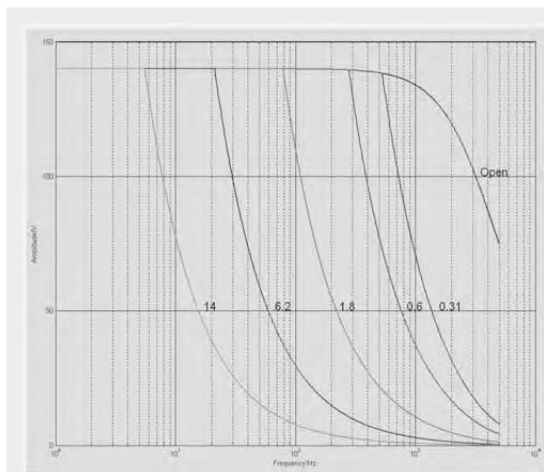
Versions With Additional Functions

The E-709 controller is available as an alternative to the E-609. This controller offers additional high-speed digital interfaces for position control. Furthermore sensor data can be read via the USB or the RS-232 interface. The unit also provides several I/O functions and comes with comprehensive software support with DLLs and LabVIEW drivers for Windows and LINUX operating systems.

Ordering Information

E-609.P0
Piezo Amplifier / Servo-Controller, 1 Channel, OEM Module, -30 to 130 V, Piezoresistive Sensor

E-609.S0
Piezo Amplifier / Servo-Controller, 1 Channel, OEM Module, -30 to 130 V, SGS-Sensor

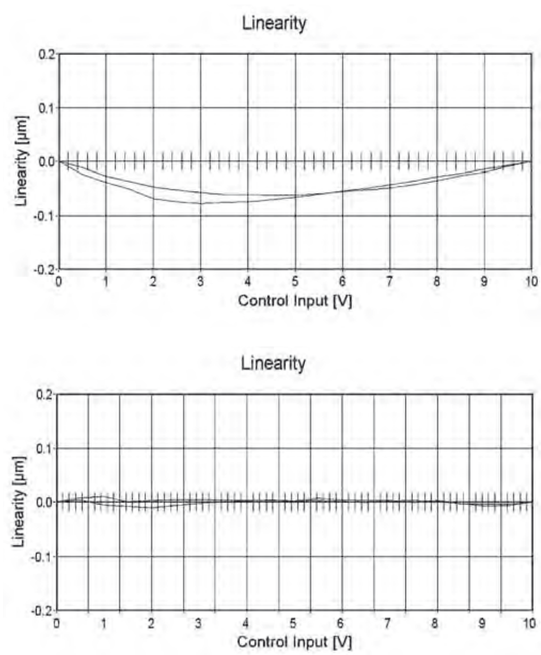


E-609: operating limits with various PZT loads (open-loop), capacitance is measured in µF

E-709 digital servo controller (preliminary case design); bench-top with digital interface

Technical Data

Modell	E-609.P0 E-609.S0
Function	Digital controller for single-axis piezo nanopositioning systems, OEM board
Channels	1
Processor	DSP 32-bit floating point, 150 MHz
Servo characteristics	P-I, two notch filters
Sampling rate, servo-control	10 kHz
Sampling rate, sensor	10 kHz
Sensor	
Sensor type	Piezoresistive sensor (.P0) Metal foil strain gauge sensors (.S0)
Linearization	5th order polynomials
Sensor bandwidth	5 kHz
Sensor resolution	16-bit
Ext. synchronization	No
Amplifier	
Output voltage	-30 V to +130 V
Peak output power	10 W (<5 ms)
Average output power	5 W (>5 ms)
Peak current	100 mA (<5 ms)
Average output current	50 mA (>5 ms)
Current limitation	Short-circuit-proof
Resolution DAC	16-bit
Interfaces and operation	
Interface / communication	Analog
Piezo / sensor connector	9-pin sub-D connector
Analog input / control in	SMB, 0 to 10 V
Sensor monitor output	SMB, 0 to 10 V
Digital input	USB interface for parameter input
User software	Configuration tool for input of parameters and display of system behavior
Display	Status LED, overflow LED
Miscellaneous	
Operating temperature range	5 to 50 °C (over 40 °C, max. av. power derated)
Dimensions	160 x 96 x 33 mm
Mass	0.2 kg
Operating voltage	24 VDC
Power consumption	24 W



Comparison of the linearity of a strain gauge sensor with analog controller (top) and the E-709 digital controller (bottom), which improves the linearity by up to one order of magnitude

E-709 Compact and Cost-Optimized Digital Piezo Controller

Increased Performance for Piezo Systems with Strain Sensors

Compact, low-cost E-709 digital controller (preliminary case design) with P-712 piezo-scanner

- **Fast Digital Controller, Software Configurable Servo Parameters**
- **Linearity of SGS and Piezoresistive Sensors Improved by up to 0.02 %**
- **2 Digital Interfaces: USB, RS-232**
- **Comprehensive I/O Functions**
- **Additional High-Bandwidth Analog Control Input / Sensor Input**
- **Low-Cost OEM Versions Available**
- **Comprehensive Software Package**

The E-709 opens up the possibilities of digital control for piezo-driven nanopositioning systems for the same price as analog controllers. It was designed for piezo actuators and nanopositioning stages which are equipped with cost effective measuring systems such as strain gauges or piezoresistive sensors. The advantage: higher precision, more control options and very simple operation. In addition, PI provides the full functionality of its comprehensive software packages free of charge! The E-709 can also be used for applications providing analog control signals. In addition to 2 digital interfaces, a standard broadband analog input is installed as well.

Digital Linearization for Strain Sensors: 10 x More Precise!

For the first time, the E-709 nanopositioning controller opens up the advantages of digital control to compact systems with strain sensors. These sensors are based on the strain of metal foils or semiconductor films (piezoresistive sensors) and are used when space limitations prevent the use of the more advanced capacitive sensors, or where the requirements in terms of resolution or temperature stability are not as critical.

The limited linearity of these strain sensors can be improved by digital controllers, which use additional linearization algorithms to minimize the deviation between target and actual position. This improves the accuracy by up to one order of magnitude and achieves linearity values of up to 0.02 %.

Flexibility: Software Configurable Servo Parameters

All servo controllers require tuning and adjustment of servo parameters for optimum performance (e.g. as a result of changes to the load or the motion profile). With a digital controller, all adjustments are carried out by simple software commands and the resulting motion or transient characteristics can be viewed, analyzed and further optimized immediately with the provided software. It is also possible to switch between previously found sets of parameters when the controller is in operation. Since jumpers and potentiometers no longer have to be set manually, system integration becomes much more straight forward.

OEM Versions at an Even Lower Price

E-709 controllers are also offered without case. A lower cost version sold as the E-609 is available for purely analog control signals, maintaining the advantages of digital signal processing and parameter setting. The target position is controlled via an analog signal, allowing system components with analog output (e.g. autofocus) to be integrated easily.

An E-709 version for capacitive position sensors is also available to control the large variety of ultra-high precison single-axis nanopositioning systems PI offers.

Ordering Information

E-709.PRG
Digital Piezo Controller, 1 Channel, -30 to 130 V, Piezoresistive Sensors, Bench-Top

E-709.SRG
Digital Piezo Controller, 1 Channel, -30 to 130 V, SGS-Sensor, Bench-Top

E-709.PR
Digital Piezo Controller, 1 Channel, OEM Module, -30 to 130 V, Piezoresistive Sensors

E-709.SR
Digital Piezo Controller, 1 Channel, OEM Module, -30 to 130 V, SGS-Sensor

Accessories

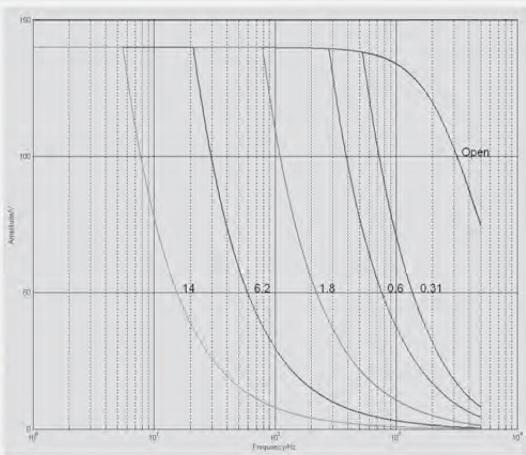
E-709.01
Adapter HD-Sub-D 26-pin to Sub-D 9-pin with I/O Lines, 0.5 m

E-709.02
Adapter Cable HD-Sub-D 26-pin to Open Leads, 1 m

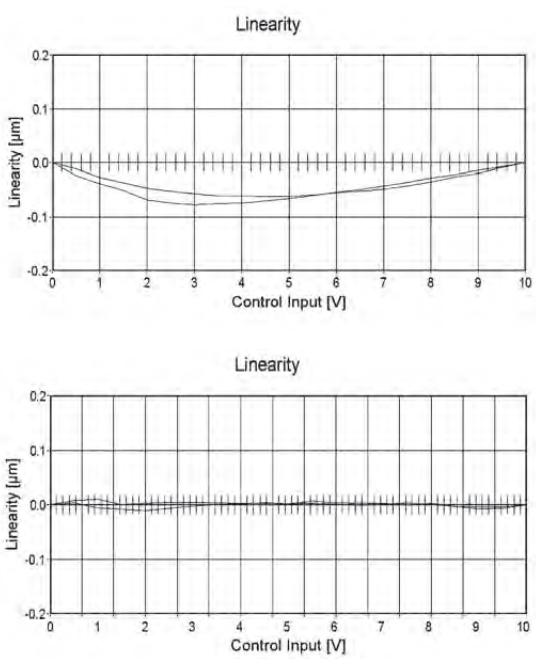
E-709.03
Adapter LEMO to Sub-D 9-pin

The E-709 is also available as a compact, low-cost controller for capacitive sensor-equipped positioning systems.

E-709 OEM Version board



E-709: operating limits with various PZT loads (open-loop), capacitance is measured in µF



Comparison of the linearity of a strain gauge sensor with analog controller (top) and the E-709 digital controller (bottom), which improves the linearity by up to one order of magnitude

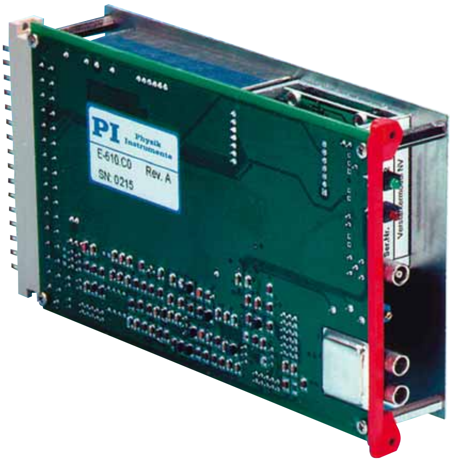
Technical Data

Modell	**E-709.SR** **E-709.SRG** **E-709.PR** **E-709.PRG**
Function	Digital controller for single-axis piezo nanopositioning systems (.SR, .PR: OEM board)
Channels	1
Processor	DSP 32-bit floating point, 150 MHz
Servo characteristics	P-I, two notch filters
Sampling rate, servo control	10 kHz
Sampling rate, sensor	10 kHz
Sensor	
Sensor type	Metal foil strain gauge sensors (.SR, .SRG), Piezoresistive sensors (.PR, .PRG)
Linearization	5th order polynomials
Sensor bandwidth	5 kHz
Sensor resolution	16 bit
Ext. synchronization	No
Amplifier	
Output voltage	-30 V to +130 V
Peak output power	10 W (<5 ms)
Average output power	5 W (>5 ms)
Peak current	100 mA (<5 ms)
Average current	50 mA (>5 ms)
Current limitation	Short-circuit-proof
Resolution DAC	16 bit
Interfaces and operation	
Communication interfaces	USB, RS-232
Piezo / sensor connector	Sub-D 9-pin
I/O connector	HD-Sub-D 26-pin, 1x analog control input 0 to 10 V, 1x sensor monitor 0 to 10 V, 1x digital input (LVTTL, programmable), 5x digital output (LVTTL, 3x predefined, 2x programmable)
Command set	PI General Command Set (GCS)
User software	PIMikroMove , NanoCapture
Software drivers	LabVIEW drivers, DLLs
Supported functionality	Wave generator, data recorder, auto zero, trigger I/O
Display	Status LED, overflow LED
Miscellaneous	
Operating temperature range	8 to 50 °C (over 40 °C, max. power av. power derated)
Dimensions	160 x 96 x 33 mm
Mass	0.5 kg
Operating voltage	24 VDC
Power consumption	24 W max.

PI

E-610 Piezo Amplifier / Controller

1-Channel OEM Piezo Driver Module with Optional Position Servo-Control



E-610 Single-channel OEM module with optional position servo control

- **Cost-Effective 1-Channel OEM Solution**
- **Closed-Loop and Open-Loop Versions**
- **Notch Filter for Higher Bandwidth**
- **Position Control with Strain Gauge or Capacitive Sensor**
- **18 W Peak Power**

The E-610 is an OEM amplifier & position servo-control board for low-voltage piezo actuators and positioning systems. It integrates a low-noise piezo amplifier which can output and sink peak currents of 180 mA in a voltage range of -20 to +120 V. Three versions are available: E-610.00 (only amplifier) and closed-loop versions E-610.S0 and E-610.C0 with additional components for position measurement and servo control.

Closed-Loop and Open-Loop Piezo Positioning

The units are designed to provide high-resolution operation of piezo actuators and positioning systems in voltage-controlled mode (open-loop) and in position-controlled mode (closed-loop).

In closed-loop position control mode, displacement of the piezo is highly linear and proportional to the analog signal. The servo modifies the amplifier output voltage based on the position sensor signal. Thus, positioning accuracy and repeatability down to the sub-nanometer range is possible, depending on the piezo mechanics and on the sensor type.

PI employs proprietary position sensors for fast response and optimum positioning resolution and stability in the nanometer range and below. For high-end applications, capacitance sensors provide direct and non-contact position feedback (direct metrology). Strain gauge sensors (SGS) are available for cost-effective applications. The integrated notch filters (adjustable for each axis) improve the stability and allow high-bandwidth operation closer to the resonant frequency of the mechanics.

In open-loop (voltage-controlled) operation the output voltage is determined by an external analog signal. Open-loop operation is ideal for applications where fast response and very high resolution with maximum bandwidth are essential. Here, commanding and reading the target position in absolute values is either not important or carried out by external position sensors (see p. 2-104).

Remote Control via Computer Interface

For digital-interface computer control, consider the E-621 (see p. 2-160) and E-625 (see p. 2-114) instead.

Alternatively control via PC using a D/A board is possible. PI offers a LabVIEW driver set which can be used with certain D/A boards from National Instruments.

Operation / Contents of Delivery

A single stabilized voltage in the range of 12 to 30 V is sufficient to operate the E-610. An integrated DC/DC converter generates the piezo operating voltage and all other voltages used internally. All inputs and outputs (except capacitive sensor lines) are available on the male 32-pin rear connector. A matching female 32-pin connector is included in the contents of delivery to interface with your circuitry.

Ordering Information

E-610.00
Piezo Amplifier, 1 Channel, OEM Module, -30 to 130 V

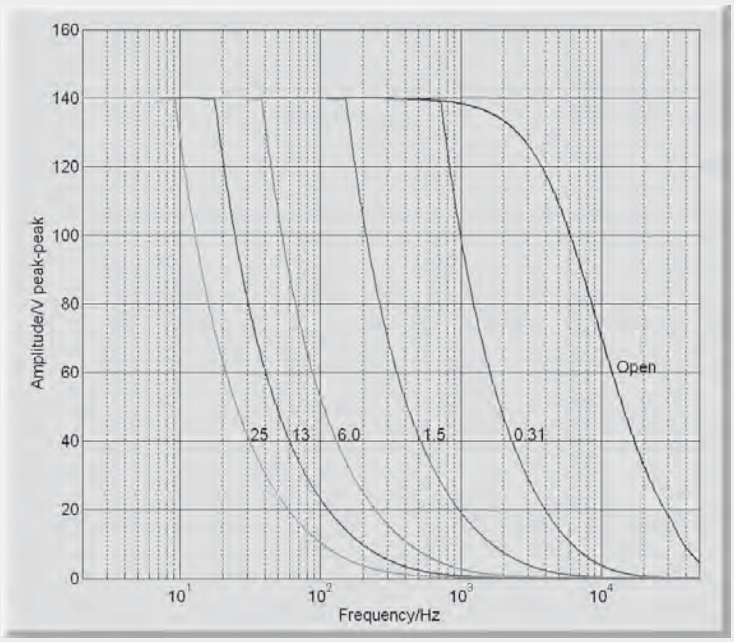
E-610.C0
Piezo Amplifier / Servo-Controller, 1 Channel, OEM Module, -20 to 120 V, Capacitive Sensor

E-610.S0
Piezo Amplifier / Servo-Controller, 1 Channel, OEM Module, -30 to 130 V, SGS-Sensor

E-500.ACD
LabVIEW Driver Set for Analog Controllers

E-500.HCD
HyperBit™ Functionality for Enhanced System Resolution (Supports Certain D/A Boards)

An OEM version with a digital controller is available – the E-609



E-610.00 and E-610.S0: Operating limits with various PZT loads (open-loop), capacitance is measured in µF

Technical Data

Model	E-610.00	E-610.C0	E-610.S0
Function	Piezo Amplifier, 1 Channel, OEM Module	Piezo Amplifier / Servo-Controller, OEM Module	Piezo Amplifier / Servo-Controller, OEM Module
Sensor			
Servo characteristics	–	P-I (analog) + notch filter	P-I (analog) + notch filter
Sensor type	–	Capazitiv	SGS
Amplifier			
Control input voltage range	-2 to +12 V	-2 to +12 V	-2 to +12 V
Output voltage	-30 to 130 V	-20 to 120 V	-30 to 130 V
Peak output power	18 W (< 15 ms)	18 W (< 50 ms)	18 W (<15 ms)
Average output power	10 W	10 W	10 W
Peak current	180 mA (< 15 ms)	180 mA (< 50 ms)	180 mA (<15 ms)
Average current	100 mA	100 mA	100 mA
Current limitation	Short-circuit proof	Short-circuit proof	Short-circuit proof
Noise, 0 to 100 kHz	1.6 mV_{rms}	0.5 mV_{rms}	1.6 mV_{rms}
Voltage gain	10 ±0.1	10 ±0.1	10 ±0.1
Input independence	100 kΩ	100 kΩ	100 kΩ
Interfaces and operation			
Input / Output	32-pin (male) on rear panel (DIN 41612 / D)	32-pin (male) on rear panel (DIN 41612 / D)	32-pin (male) on rear panel (DIN 41612 / D)
Piezo connector	LEMO	LEMO	LEMO
Sensor connection	–	LEMO	LEMO
DC Offset	External potentiometer (not included), adds 0 to 10 V to Control In	External potentiometer (not included), adds 0 to 10 V to Control In	External potentiometer (not included), adds 0 to 10 V to Control In
Miscellaneous			
Operating temperature range	+5° to +50° C	+5° to +50° C	+5° to +50° C
Dimensions	7HP/3U	7HP/3U	7HP/3U
Mass	0.3 kg	0.35 kg	0.35 kg
Operating Voltage	12 to 30 V DC, stabilized	12 to 30 V DC, stabilized	12 to 30 V DC, stabilized
Current consumption, max.	2 A	2 A	2 A

E-617 High-Power Piezo Amplifier

Top-Hat & OEM Modules with Energy Recovery for High-Dynamics 24/7 Operation

The E-617.001 high-power piezo amplifier is intended for top-hat-rail mounting in switching cabinets

- **Peak Power to 280 W**
- **High Currents to 2000 mA**
- **Energy Recovery for Low Power Consumption**
- **OEM Module and Top-Hat-Rail Versions**

The E-617 is an exceptionally efficient, high-power, piezo amplifier for low-voltage piezo actuators. Providing peak power of up to 280 W and average power of 100 W, it can output and sink a peak current of 2000 mA. This allows driving high-capacitance piezo actuators at frequencies in the kilohertz range.

Energy Recovery Operating Principle

The working principle of the E-617 series is ideally suited for high-dynamics scanning and switching applications.

The innovative, efficient circuitry reduces power consumption and heat dissipation, especially in dynamic applications. Charge is transferred to the piezo actuator using low-loss PWM techniques. When the actuator is discharged, the energy not consumed is fed through the energy recovery circuitry for reuse in the next charging cycle.

Two models are available: The E-617.001 version is equipped for top-hat rail mounting which makes it ideal for automation and industry applications. The E-617.00F version is a compact module for chassis mounting.

High Performance with High Capacitive Loads

The E-617 amplifiers provide precision control of piezo actuators and positioning systems in open-loop operation with an analog control voltage amplified by the factor 10. Such analog operation is ideal for applications where fast response and very high resolution with maximum bandwidth are essential, but where commanding and reading the target position absolutely is either not important or carried out by external position sensors.

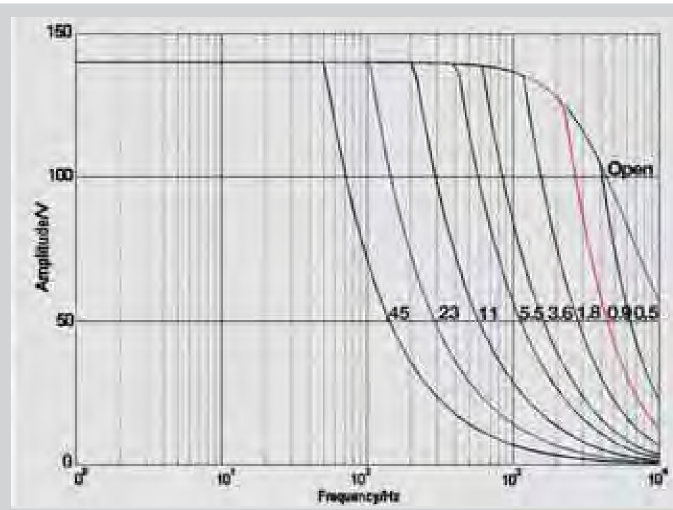
Power Supply / Contents of Delivery

Only one unipolar stabilized voltage in the range of 23 to 26 V is required to operate the E-617.

All connections of the E-617.001 top-hat rail module are conveniently provided on the front of the device. All inputs and outputs of the E-617.00F OEM module are via a 32-pin rear connector. Mating connectors are included.

Remote Control via Computer Interface

Optionally, digital control via an external D/A converter is possible. For several D/A boards from National Instruments, PI offers a corresponding LabVIEW driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented Hyperbit™ technology providing enhanced system resolution.



E-617: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Ordering Information

E-617.001
High-Power-Piezo Amplifier with Energy Recovery, 1 Channel, -30 to 130 V, 100 W, Top-Hat Rail

E-617.00F
High-Power-Piezo Amplifier with Energy Recovery, OEM-Module, 1 Channel, -30 to 130 V, 100 W

The same functionality and specifications are available in the E-504 amplifier module. see p. 2-148.

E-617.00F high-power piezo amplifier OEM module

Technical Data

Model	E-617.001	E-617.00F
Function	High-Power-Piezo Amplifier with Energy Recovery, 1 Channel, -30 to 130 V, for Top-Hat Rail mounting	High-Power-Piezo Amplifier with Energy Recovery, OEM-Module, 1 Channel, -30 to 130 V
Amplifier		
Input voltage	-2 to +12 V	-2 to +12 V
Output voltage	-30 to +130 V	-30 to +130 V
Peak output power <5 ms	280 VA	280 VA
Average output power >5 ms	Equivalent to 100 W reactive power	Equivalent to 100 W reactive power
Peak current, <5 ms	2000 mA	2000 mA
Average current, >5 ms	1000 mA	1000 mA
Current limitation	Short-circuit-proof	Short-circuit-proof
Voltage gain	10 ±0.1	10 ±0.1
Amplifier bandwidth, small signal	3.5 kHz	3.5 kHz
Ripple, noise, 0 to 100 kHz	<30 mV_{rms} <100 mV_{pp}	<30 mV_{rms} <100 mV_{pp}
Capacitive base load (internal)	2.5 µF	2.5 µF
Suggested capacitive load	>3 µF	>3 µF
Output impedance	0.5 Ω	0.5 Ω
Amplifier resolution	1 mV	1 mV
Amplifier classification	class D (switching amp), 100 kHz	class D (switching amp), 100 kHz
Input impedance	100 kΩ	100 kΩ
Interfaces and operation		
Piezo connector	Phoenix-plug connector MINI-COMBICON 3-pin MC1.5/3-ST-3.81	LEMO ERA.00.250.CTL (front); DIN 41612 32-pin (rear)
Analog input	Phoenix-plug connector MINI-COMBICON 6-pin IMC1.5/6-ST-3.81	SMB
DC-Offset	External potentiometer (not included), adds 0 to + 10 V to Control In	External potentiometer (not included), adds 0 to + 10 V to Control In
Miscellaneous		
Operating temperature range	+5 to +50 °C (10% derated over 40 °C)	+5 to +50 °C (10% derated over 40 °C)
Dimensions	205 x 105 x 60 mm	7HP/3U
Mass	1 kg	0.35 kg
Operating voltage	23 to 26 VDC, stabilized, on Phoenix plug MINI-COMBICON 3-pin IMC1.5/3-ST-3.81	23 to 26 VDC, stabilized, on 32-pin rear connector
Max. power consumption	<30 W	<30 W

E-618 High-Power Piezo Amplifier

High Currents up to 20 A, High Dynamics

The E-618 piezo amplifier offers high currents for dynamic operation which make it ideally suited for fast switching applications (here: the E-618.10G 9.5'' chassis version)

- **Peak Power 3200 W**
- **Peak Current of up to 20 A**
- **Micro Second Rise Time**
- **15 kHz Bandwidth for High Dynamics Applications**
- **Piezo Ceramics Protection with Temperature Sensor**
- **Analog an Optional Digital Interfaces**

Ordering Information

E-618.10
High-Power-Piezo Amplifier Module, 1 Channel, -30 to 130 V, 20 A

E-618.10G
High-Power-Piezo Amplifier, 1 Channel, -30 to 130 V, 20 A, Bench-Top

E-618.1G
High-Power-Piezo Controller, 1 Channel, -30 to 130 V, 20 A, Controller & Interface / Display Upgrade possible, 19"

E-618.20G
High-Power-Piezo Amplifier, 2 Channels, -30 to 130 V, 20 A, 19"

Accessories

E-618.X11
Piezo Cable, 1 m, Solderable End

E-618.X01
Extension Cable, 1 m

E-618.X03
Extension Cable, 3 m

Ask about custom designs!

The E-618 high-power amplifier/controller is specifically designed for ultra-high-dynamics operation of piezo actuators (translators). It can output and sink a peak current of 20 A and an average current of 800 mA in a voltage range of -30 to 130 V.

Besides the amplifier module, three standard configurations are available:

- E-618.10G is a bench-top amplifier in a 9.5'' chassis, for open-loop operation (1 channel)
- E-618.1G is the amplifier module in a 19'' rackmount chassis that can hold additional interface / display modules
- E-618.20G is a 2-channel version in a 19'' rackmount chassis

Fast Switching

The amplifier features a high bandwidth of more than 15 kHz combined with extremely short rise times in the microsecond range and a high output power. This makes it ideal for fast switching applications for valves, pumps, for microstructure and material testing. Furthermore, it is perfectly suited for systems for active vibration control.

Piezo Overtemperature Protection

To protect the mechanics especially in high-dynamics applications, the E-618 features a temperature sensor input and controller circuit that shuts down the amplifier if the PZT exceeds the maximum temperature threshold.

Analog and Digital Control

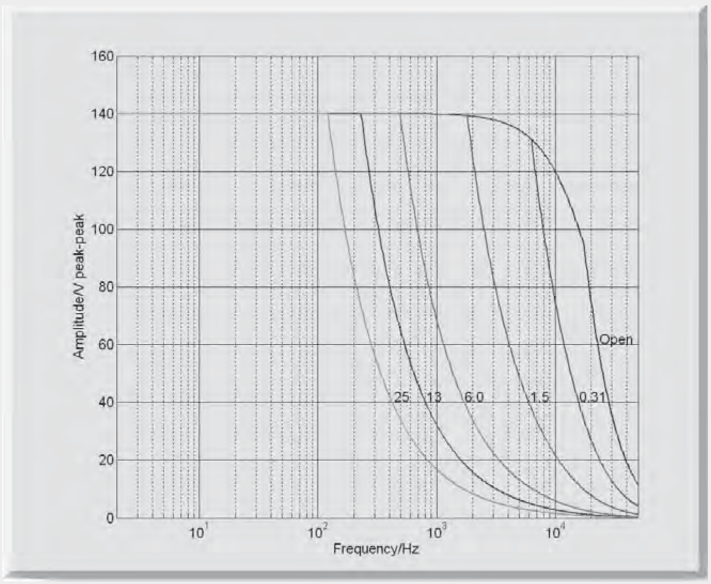
All E-618 amplifiers come with a high bandwidth analog interface. An optional 24-bit computer interface is available as E-517.

Ceramic-Insulated Piezo Actuators Provide Superior Lifetime

The highest possible reliability is assured by employing the award-winning PICMA® multilayer piezo actuators. PICMA® actuators are the only actuators on the market with a ceramic-only insulation which makes them resistant to ambient humidity and leakage-current failures. They are thus far superior to conventional actuators in reliability and lifetime.

Note: Spezial Connector Required

The high electrical currents require adequate connectors and cabling. Therefore, standard piezo systems and actuators have to be adapted.



E-618: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Technical Data

Model	E-618.10
Function	Power amplifier module for PICMA® multilayer piezo actuators
Amplifier	
Input voltage	-2 to +12 V
Output voltage*	-30 to 130 V
Peak output power	3200 W (<0.3 ms)
Average output power	100 W (>0.3 ms)
Peak current	20 A (<0.3 ms)
Average current	0.8 A (>0.3 ms)
Current limitation	Short-circuit-proof
Voltage gain	10 ±0.1
Ripple, noise, 0 to 100 kHz	200 mV_{pp} / 24 mV_{rms} (no load), 2 mV_{rms} (1 µF)
Input impedance	100 kΩ
Interfaces and operation	
Piezo connector	LEMO EGG.1B.302.CLL, with security cover
Control input	BNC
Temperature sensor (piezo actuator)	PT 1000; LEMO socket; deactivation of the piezo voltage output at 150 °C
Display	Power, PZT temp overflow LEDs
DC Offset	10-turn pot., adds +10 to 0 V to Control In
Miscellaneous	
Operating temperature range	+5 °C to +50 °C (10 % derated over 40 °C)
Dimensions	215 x 123 x 185 mm 42HP / 3U 19" rackmount chassis
Mass	2.65 kg
Operating voltage	100 – 120 or 220 – 240 VAC, selectable
Max. power consumption	15 VA (no load) 160 VA (max. load)

*Max. 85 °C, deactivation of the piezo voltage output (internal overtemp protection)

E-625 Piezo Servo-Controller & Driver

Compact Bench-Top Device with High-Speed Interface

E-625.CR compact piezo servo-controller

- Integrated 24-Bit USB Interface
- Network Capability with up to 12 Channels
- 12 W Peak Power
- Position Control with Strain Gauge or Capacitive Sensor
- Notch Filter for Higher Bandwidth
- Table for User-Defined Curves
- Additional Analog Interface

The single-channel E-625 piezo controller is equipped with a RS-232 and USB interface and precision 24-bit A/D converters for exceptional positional stability and resolution. It integrates a low-noise integrated piezo amplifier which can output and sink peak currents of 120 mA for low-voltage piezoelectric actuators. Servo-controller versions for position sensing with capacitive or SGS sensors are available.

PI employs proprietary position sensors for fast response and optimum positioning resolution and stability in the nanometer range and below. For high-end applications, capacitance sensors provide direct and non-contact position feedback (direct metrology). Strain gauge sensors (SGS) are available for cost-effective applications. The integrated notch filters (adjustable for each axis) improve the stability and allow high-bandwidth operation closer to the resonant frequency of the mechanics.

Multi-Axis Network for up to 12 Channels

Up to twelve E-625 for capacitive or SGS sensors can be networked and controlled over a single PC interface. The different units are connected in parallel (not daisy-chained) over the link providing higher data rates than possible with serial links. Between the individual E-625s, parallel networking is realized via optional E-625.CN cables.

High-Resolution Digital Interface

The digital interface includes high-precision 24-bit A/D converters for optimum position stability and resolution and supports fast communication with the host-computer.

Waveform Memory

The built-in wave table can store user-defined data points internally. These values can then be output automatically (or under the control of an external signal) and programmed for point-by-point or full-scan triggering. Thus, trajectory profiles can be repeated reliably and commanded easily.

Extensive Software Support

The controllers are delivered with Windows operating software. Comprehensive DLLs and LabVIEW drivers are available for automated control.
The extensive command set is based on the hardware-independent General Command Set (GCS), which is common to all current PI controllers for both nano- and micropositioning systems. GCS reduces the programming effort in the face of complex multi-axis positioning tasks or when upgrading a system with a different PI controller.

Ordering Information

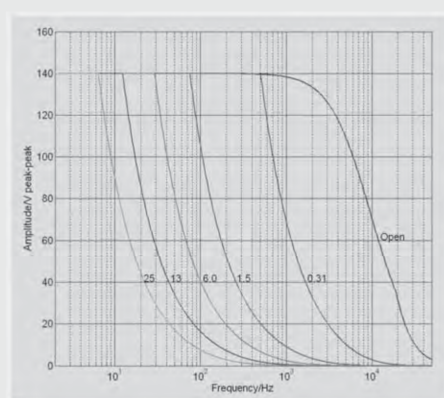
E-625.CR
Piezo Amplifier / Servo-Controller, 1 Channel, -30 to 130 V, Capacitive Sensor, USB, RS-232

E-625.SR
Piezo Amplifier / Servo-Controller, 1 Channel, -20 to 120 V, SGS-Sensor, USB, RS-232

E-625.CN
Network Cable for Networking of Two E-625

E-625.C0
PIFOC® Piezo Amplifier / Servo-Controller, 1 Channel, -20 to 120 V, Capacitive Sensor

E-625.S0
PIFOC® Piezo Amplifier / Servo-Controller, 1 Channel, -20 to 120 V, SGS-Sensor



E-625.CR: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Ideal system configuration:
E-625.CR with P-725 PIFOC® microscope objective positioner

Two single-channel piezo controllers: E-625 and the more powerful E-665 (background)

Technical Data

Model	E-625.SR / E-625.CR
Function	Piezo Amplifier / Servo-Controller
Axes	1
Sensor	
Servo characteristics	P-I (analog), notch filter
Sensor type	SGS (.SR) / capacitive (.CR)
Amplifier	
Control input voltage range	-2 to 12 V
Min. output voltage	-20 to 120 V / -30 to 130 V
Peak output power, < 5 ms	12 W
Average output power	6 W
Peak current, < 5 ms	120 mA
Average current	60 mA
Current limitation	Short-circuit-proof
Noise, 0 to 100 kHz	0.8 mVrms
Voltage gain	10 ±0.1
Input impedance	100 kΩ
Interfaces and operation	
Interface / communication	USB, RS-232 (9-pin Sub-D connector, 9.6–115.2 kBaud), 24-bit A/D and 20-bit D/A E-625.S0 and E-625.C0 without interface
Piezo connector	LEMO ERA.00.250.CTL (.SR) / Sub-D Special (.CR)
Sensor connection	LEMO EPL.0S.304.HLN (.SR) / Sub-D Special (.CR)
Control input sockets	SMB
Sensor monitor socket	SMB
Controller network	up to 12 channels, parallel
Command set	PI General Command Set (GCS)
User software	PIMikroMove™
Software drivers	LabVIEW drivers, DLL's
Supported functionality	Wave table, 256 data points, external trigger, 16 macros
Miscellaneous	
Operating temperature range	+5 to +50 °C
Overheat protection	Deactivation at 75°C
Dimensions	205 x 105 x 60 mm
Mass	1.05 kg
Operating voltage	12 to 30 V DC, stabilized (power supply included)
Current consumption	2 A

E-665 Piezo Amplifier / Servo Controller

Display, Analog & Digital Interface

Control of the E-665.SR piezo servo-controller is realized either via the digital high-speed interface or directly via the analog input

- Integrated 24-Bit USB Interface
- Network Capability with up to 12 Channels
- 36 W Peak Power
- Notch Filter for Higher Bandwidth
- Position Control with Strain Gauge or Capacitive Sensor
- Table for User-Defined Curves
- Additional Analog Interface

The E-665 is a bench-top piezo linear amplifier and position servo-controller with integrated high-speed 24-bit computer interface and a high-bandwidth analog interface. It integrates a low-noise piezo amplifier which can output and sink peak currents of 360 mA for low-voltage piezoelectric actuators (-20 to 120 V). Servo-controller versions for position sensing with capacitive or SGS sensors are available.

Closed-Loop Piezo Positioning

PI employs proprietary position sensors for fast response and optimum positioning resolution and stability in the nanometer range and below. For high-end applications, capacitance sensors provide direct and non-contact position feedback (direct metrology). Strain gauge sensors (SGS) are available for cost-effective applications.

The piezo controllers comprise additional circuitry for position sensing and servo-control. In closed-loop position control mode, displacement of the piezo is highly linear and proportional to the analog signal. The servo modifies the amplifier output voltage based on the position sensor signal. Thus, positioning accuracy and repeatability down to the sub-nanometer range is possible, depending on the piezo mechanics and on the sensor type.

High-Resolution Digital Interface

The digital interface includes high-precision 24-bit A/D converters for optimum position stability and resolution and supports fast communication with the host-computer.

Waveform Memory

The built-in wave table can store user-defined datapoints internally. These values can then be output automatically (or under the control of an external signal). Thus, trajectory profiles can be repeated reliably and commanded easily.

Multi-Axis Network for up to 12 Channels

Up to twelve E-665s for capacitive or SGS sensors can be networked and controlled over a single PC interface. The different modules are connected in parallel (not daisy-chained) over the link providing higher data rates than possible with serial links.

Extensive Software Support

The controllers are delivered with Windows operating software.

The extensive command set is based on the hardware-independent General Command Set (GCS), which is common to all current PI controllers for both nano- and micropositioning systems. GCS reduces the programming effort in the face of complex multi-axis positioning tasks or when upgrading a system with a different PI controller.

Ordering Information

E-665.CR
Piezo Amplifier / Servo-Controller, 1 Channel, -20 to 120 V, Capacitive Sensor, USB, RS-232

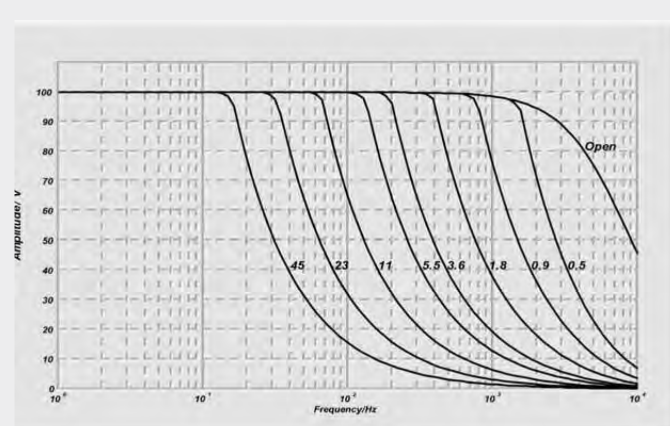
E-665.SR
Piezo Amplifier / Servo-Controller, 1 Channel, -20 to 120 V, SGS-Sensor, USB, RS-232

E-665.C0
PIFOC® Piezo Amplifier / Servo-Controller, 1 Channel, Capacitive Sensor

E-665.S0
PIFOC® Piezo Amplifier / Servo-Controller, 1 Channel, SGS Sensor

E-625.CN
Network Cable for Networking of Two E-625

The GCS commands are available at the controller terminal, in macros and in the form of a universal driver set for LabVIEW (VIs) or Windows dynamic link libraries (DLL).



E-665: operating limits with various PZT loads (open-loop), capacitance is measured in μF

PI

Technical Data

Model	**E-665.SR, E-665.CR**
Function	Piezo amplifier & position servo-controller with digital interface
Axes	1
Sensor	
Servo characteristics	P-I (analog), notch filter
Sensor type	SGS (.SR) / capacitive (CR)
Amplifier	
Control input voltage range	-2 to +12 V
Min. output voltage	-20 to 120 V
Peak output power, < 20 ms	36 W
Average output power	12 W
Peak current, < 20 ms	360 mA
Average current	120 mA
Current limitation	Short-circuit-proof
Noise, 0 to 100 kHz	0.5 (.SR) / 4.0 (.CR) mV_{rms}
Voltage gain	10 ±0.1
Input impedance	100 kΩ
Interfaces and operation	
Interface / communication	USB and RS-232 (9-pin Sub-D connector, 9.6–115.2 kBaud), 24-bit A/D, 20-bit D/A
Piezo connector	LEMO ERA.00.250.CTL (.SR) / Sub-D special (.CR)
Sensor connection	LEMO EPL.0S.304.HLN (.SR) / Sub-D special (.CR)
Analog input	BNC
Sensor monitor socket	BNC
Controller network	up to 12 channels, parallel
Command set	PI General Command Set (GCS)
User software	PIMikroMove™
Software drivers	LabVIEW drivers, DLLs
Supported functionality	Wave table, 256 data points, external trigger, 16 macros
Display	2 x 4½-digits, LED
DC Offset	10-turn pot., adds 0 to 10 V to Control In
Miscellaneous	
Operating temperature range	5 to 50 °C (10 % derated over 40 °C)
Overheat protection	Deactivation at 85 °C
Dimensions	236 x 88 x 273 mm + handles
Mass	2.5 kg
Operating voltage	100–120 / 220–240 VAC, 50–60 Hz (linear power supply)
Max. power consumption	50 W

PI

E-661 Piezo Controller with Parallel Interface

For Maximum Command-Throughput Capacity

E-661.CP high-speed bench-top controller with parallel interface

Ordering Information

E-661.CP
Piezo Controller with High-Speed Parallel Interface, -20 to 120 V, Capacitive Sensor

- **10 µs High-Speed Parallel Command Port**
- **Additional Analog Interface**
- **For Piezo Stages with Capacitive Sensors**
- **Notch Filter for Higher Bandwidth**
- **Integrated Piezo Power Amplifier**
- **OEM Modules and Multi-Channel System Available**

The compact, high-speed E-661 piezo controller is designed for nanopositioning systems with integrated capacitive position feedback sensors. It possesses a low-noise integrated piezo amplifier providing -20 to 120 V with 80 mA sink and source capability. The E-661 comes with a metal case for EMI protection and an external power supply.

High-Speed Interface

The controller features a high-speed parallel command port with optical coupled inputs and extra low-noise, linear, 16-bit D/A converters. Real-time position feedback is realized via a special trigger option. Additionally a broadband analog interface is installed (0 to 10 V).

Nanometer Resolution in Milli-Seconds

This high-performance controller is designed for nanopositioning tasks with highest precision and maximum turnover. Positioning with nanometer precisions and settling times of a few milliseconds are achieved in combination with the P-726 (see p. 2-32) objective positioners or P-753 (see p. 2-16) LISA™ actuators. More and more high-tech branches require "nanometer accuracy within milliseconds". This is the case in microscopy/pharmaceutical research or quality testing for read/write heads, where every millisecond saved raises the throughput and helps reduce costs.

Single and Multi-Channel Systems

The same performance is available in modular form as the E-612.C0 (see p. 2-162). Up to four E-612.C0 piezo amplifier modules can be installed in one E-501.10 chassis for a multi-channel system. An internal address bus allows control of all modules over a single parallel command port.

Model	**E-661.CP**
Function	High-Speed Piezo Controller
Channels	1
Capacitive sensor circuit	
Clock frequency	1.6 MHz
Bandwidth	1.5 kHz
Amplifier	
Output voltage	-20 to +120 V
Average output power	8 W
Average current	80 mA
Current limitation	Short-circuit proof (5 minutes to shutdown)
Bandwidth (no load)	>500 Hz
Digital circuit	
Data	16-bit
Input level	TTL
Timing	THmin 10 µs; TLmin 10 µs
Input current	10 mA
On-target indication	On: target position ±0.025 % to 0.2 %, jumper-selectable
Analog input / output	
Control input voltage	-2 to 12 V
Input impedance	27 kΩ, 1 nF
Sensor monitor output	
Voltage range	-12 to +12 V (jumper-selectable)
Output impedance	10 Ω (10 nF)
Bandwidth	1.5 kHz
Connectors	
Digital interface	25-pin sub-D
Piezo	LEMO ERA.00.250
Sensor	LEMO EPL.00.250
Sensor monitor output	SMB
Analog input	SMB
Power consumption	15 V, 2 A (external power supply included)
Dimensions	125 x 50 x 262 mm

E-660 Piezo Driver

OEM Module / Bench-Top

E-660.OE OEM Version

E-660.00 Bench-top piezo driver

Ordering Information

E-660.00
Piezo Amplifier, 5 to 110 V, Bench-Top

E-660.OE
Amplifier Module, 5 to 110 V, OEM Version

- **Compact Single-Channel Piezo Driver**
- **Output Voltage Range 5 to 110 V**
- **12 V Battery or External PS Operation**

The E-660.00 piezo driver is a low-cost amplifier for low-voltage piezo actuators and positioning stages. It can output and sink a peak current of 20 mA and an average current of 10 mA. The E-660 is designed for static and low-level dynamics applications. The low operating current of only 150 mA @ 12 V makes the unit suitable for battery operation.

Voltage-Controlled Piezo Operation

This precision piezo driver is designed for voltage-controlled piezo operation in both dynamic and static mode. Its output voltage is determined by the analog control signal at the BNC Control Input socket, optionally combined with the DC-offset potentiometer. Voltage-controlled operation (in contrast to position-controlled operation) is used in applications where the fastest possible response and very high resolution with maximum bandwidth are essential, and/or when commanding and reading the target position in absolute values is either not important or accomplished with external position feedback.

The precision 10-turn potentiometer can also be used alone to set the output voltage manually.

Compact OEM Version

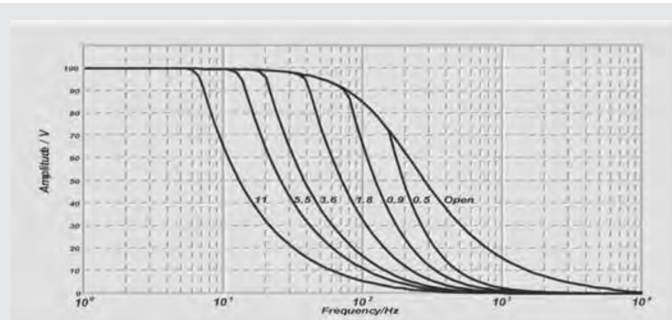
The E-462.OE version is fully enclosed in a metal case and designed for mounting on circuit boards. All inputs and outputs are via 8 header pins located on the bottom of the module. This OEM module does not provide manual controls.

Remote Control via Computer Interface

Optionally, digital control via an external D/A converter is possible. For several D/A boards from National Instruments, PI offers a corresponding LabVIEW driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented HyperBit™ technology providing enhanced system resolution.

Technical Data

Model	E-660.00	E-660.OE	Unit
Function	Power amplifier	Power amplifier	
Channels	1	1	
Amplifier			
Input voltage	0 to +11	0 to +11	V
Output voltage	5 to 110	5 to 110	V
Peak output power	2	2	W
Average output power	1	1	W
Peak current, < 5 ms	20	20	mA
Average current, >5 ms	10	10	mA
Current limitation	Short-circuit-proof	Short-circuit-proof	
Voltage gain	10 ±0.1	10 ±0.1	
Ripple, noise, 0 to 10 kHz	5	5	mVrms
Input impedance	100	10	kΩ
Interfaces and operation			
Piezo connector	LEMO ERA.00.250.CTL	Header pins	
Control Input sockets	BNC	Header pins	
DC-Offset	1-turn pot., adds 10 to 0 V to Control In	–	
Miscellaneous			
Operating temperature range	5 to +50	5 to +50	°C
Dimensions	160 x 90 x 60	67 x 41 x 20	mm
Mass	0.5	0.25	kg
Operating voltage	10 to 15 VDC, stabilized	10 to 15 VDC, stabilized	V
Max. power consumption	3	3	W

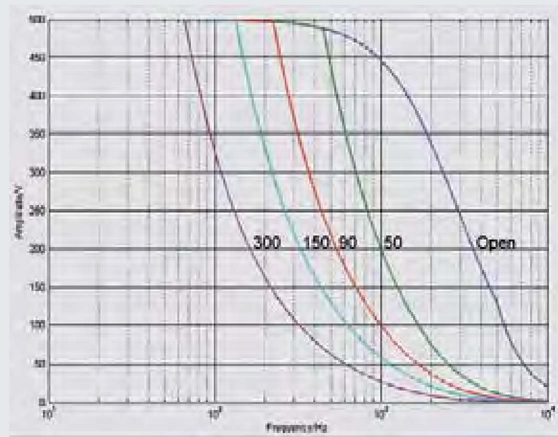


E-660: operating limits with various PZT loads (open-loop), capacitance is measured in µF

E-413 DuraAct™ & PICAShear™ Piezo Driver

Bipolar Operation for Patch Transducers and Shear Actuators

The E-413.D2 OEM amplifier module for piezoceramic DuraAct™ patch transducers (left). The piezo amplifier for piezo shear actuators is available as a bench-top version (E-413.00, front, right) or as an OEM module (E-413.OE, rear, right)



E-413: operating limits with various PZT loads (open-loop), capacitance is measured in nF

- **Peak Power to 50 W**
- **OEM Module / Bench-Top for PICAShear™ Actuators**
- **OEM Module for DuraAct™ Piezoelectric Patch Transducers**

Technical Data

Model	E-413.00	E-413.OE	E-413.D2
Function	Power amplifier for PICAShear™ piezo actuators, bench-top	Power amplifier for PICAShear™ piezo actuators, OEM module	Power amplifier for DuraAct™ piezoelectric patch transducers, OEM module
Amplifier			
Input voltage range	-5 to +5 V	-5 to +5 V	-2 to 8 V
Output voltage range	-250 to 250 V	-250 to 250 V	-100 to 400 V
Amplifier channels	1	1	1
Peak output power	50 W (<3 ms)	50 W (<3 ms)	50 W (<5 ms)
Average output power	<12 W (>3 ms)	<12 W (>3 ms)	<6 W (>5 ms)
Peak current	100 mA (<3 ms)	100 mA (<3 ms)	100 mA (<5 ms)
Average current	24 mA (>3 ms)	24 mA (>3 ms)	12 mA (>5 ms)
Current limitation	Short-circuit proof	Short-circuit proof	Short-circuit proof
Voltage gain	50 ±0.1	50 ±0.1	50 ±0.1
Ripple, noise, <10 kHz	100 mV_{P-P} @100 nF	100 mV_{P-P} @100 nF	100 mV_{P-P} @100 nF
Amplifier resolution	<10 mV	<10 mV	<10 mV
Input impedance	100 kΩ	100 kΩ	100 kΩ
Interface and operation			
Piezo connector	Conec sub-D 5W1 with HV (rear)	DIN 41612, 32-pin. (rear)	DIN 41612, 32-pin. (rear)
Control input voltage	SMB connector (rear)	DIN 41612, 32-pin. (rear)	DIN 41612, 32-pin. (rear)
Miscellaneous			
Operating temperature range	+5 to +50 °C (10 % derated over 40 °C)	+5 to +50 °C (10 % derated over 40 °C)	+5 to +50 °C (10 % derated over 40 °C)
Dimensions	220 x 105 x 54 mm	14HP / 3U	7HP / 3U
Mass	1.14 kg	0.8 kg	0.4 kg
Operating voltage	24 V / 2 A	24 V / 2 A	24 V / 1 A
Power consumption	48 W	48 W	24 W

Ordering Information

E-413.D2
Piezo Amplifier for DuraAct™ Patch Transducers, -100 to +400 V

E-413.00
Piezo Amplifier for PICAShear™ Actuators, -250 to +250 V, Bench Top

E-413.OE
Piezo Amplifier for PICAShear™ Actuators, -250 to +250 V, OEM Module

Accessories:

E-500.ACD
LabVIEW Driver Set for Analog Controllers (Supports Certain D/A Boards)

E-500.HCD
HyperBit™ Functionality for Enhanced System Resolution

E-462 PICA™ Piezo Driver

Compact, Bench-Top or OEM Module

E-462.00 Bench-top piezo amplifier

- **Single-Channel Piezo Driver**
- **Output Voltage Range 10 to 1000 V**
- **12 V Battery or External PS Operation**
- **For Static or Quasi-Static Operation**
- **DC-Offset Potentiometer for Input-Signal Bias & Manual Control**

The E-462.00 piezo driver is a low-cost amplifier / driver for PICA™ high-voltage PZTs. It can output a peak current of 0.5 mA and is specially designed for static and quasi-static applications. Because the unit requires an operating current of only 80 mA @ 12 V, battery operation is possible.

Analog Control

E-462 amplifiers are designed to provide precise control of open-loop piezo positioning systems. The amplifier output voltage is determined by the analog signal at the Control Input combined with the DC-offset potentiometer setting.

PCB-Mount Version for OEMs

The E-462.OE version is fully enclosed in a metal case and designed for mounting on circuit boards. All input connections are via 6 header pins located on the bottom. The HV output is via a coaxial cable with LEMO connector. This OEM module does not provide manual controls. If dynamic (>1 Hz) PZT operation is required, please consider the E-464 (see p. 2-139) (3-channel bench-top amplifier), E-470 (see p. 2-158) or E-508 (see p. 2-150) amplifiers (modular systems with sensor / servo option).

Computer Control

Optionally digital control via a D/A converter is possible. For several D/A boards from National Instruments PI offers a corresponding LabVIEW™ driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented Hyperbit™ technology providing enhanced system resolution.

Ordering Information

E-462.00
HVPZT Piezo Amplifier, 1000 V

E-462.OE
HVPZT Piezo Amplifier Module, 1000 V, OEM Version

E-500.ACD
LabVIEW™ Driver Set for Analog Controllers (Supports Certain D/A Boards)

E-500.HCD
HyperBit™ Functionality for Enhanced System Resolution

Extension cables, adapters & connectors: see in "Accessories" in the "Piezo Drivers / Servo Controllers" section (page 2-168 *ff*).

Ask about custom designs!

Technical Data

Model	E-462.00	E-462.OE
Function	Power amplifier for PICA™ high-voltage PZTs	Power amplifier for PICA™ high-voltage PZTs
Amplifier		
Channels	1	1
Output voltage	10 to 1000 V	10 to 1000 V
Average output power	0.3 W	0.3 W
Peak output power < 5ms	0.5 W	0.5 W
Max. average output current	0.3 mA	0.3 mA
Peak output current < 5 ms	0.5 mA	0.5 mA
Current limitation	Short-circuit-proof	Short-circuit-proof
Ripple, noise 0 to 100 kHz	50 mV_{RMS} 50 (100 nF) mV_{P-P}	
Voltage gain	100 ±1	200 ±1
Control input voltage	0 to +10 V	0 to +5 V
Input impedance	10 kΩ	10 kΩ
Frequency response	Static and quasi-static applications only	Static and quasi-static applications only
Interface and operation		
PZT voltage output socket	LEMO EGG.0B.701.CJL1173	LEMO PHG.0B.701.CJL1173 D42
Control input socket	BNC	Header pins
DC-Offset	1-turn pot., adds 0 to +10 V to Control input	–
Miscellaneous		
Dimensions	160 x 90 x 60 mm	67 x 41 x 20 mm
Mass	0.5 kg	0.25 kg
Operating voltage	10 to 15, stabilized VDC	10 to 15, stabilized VDC
Max. operating current	80 mA	80 mA
Operating temperature range	+5 to +50 °C (over 40 °C, max. av. power derated 10 %)	+5 to +50 °C (over 40 °C, max. av. power derated 10 %)
Power supply	Wall-plug unit	–

E-650 Piezo Driver for Multilayer Bender Actuators

OEM Module / Bench-Top

E-650.OE amplifier for multilayer-piezo bender actuators, OEM version

E-650.00 amplifier for multilayer-piezo bender actuators

- **Specifically Designed to Drive Multilayer Bimorph Actuators Without Position Sensor**
- **Bench-Top and OEM Versions**
- **Up to 18 W Peak Power**
- **Voltage Display**

E-650.00 is a bench-top piezo driver, especially designed for low-voltage, multilayer piezo bender actuators (bimorphs) such as the PL112 to PL140 (see p. 1-94). It is equipped with a special circuit that can provide one fixed voltage and a variable voltage in the range of 0 to 60 V for differential piezo operation. The driver can output and sink a peak current of 300 mA. A 3½-digit display shows the piezo voltage.

Voltage-Controlled Piezo Operation

This precision piezo driver is designed for voltage-controlled piezo operation in both dynamic and static mode. Its output voltage is determined by the analog control signal at the BNC Control Input socket, optionally combined with the DC-offset potentiometer. Voltage-controlled operation (in contrast to position-controlled operation) is used in applications where the fastest possible response and very high resolution with maximum bandwidth are essential, and/or when commanding and reading the target position in absolute values is either not important or accomplished with external position feedback.

The precision 10-turn potentiometer can also be used alone to set the output voltage manually.

Compact OEM Version

The E-650.OE is the OEM version of the E-650.00. It provides peak output power of 8 W. The electronics are fully enclosed in a metal case. All inputs and outputs are via 8 header pins located on the bottom of the module. The E-650.OE is not intended for manual operation.

Ordering Information

E-650.00
Piezo Driver for Bender Actuators, 0 to 60 V, Bench-Top

E-650.OE
Piezo Driver Module for Bender Actuators, 0 to 60 V, OEM Version

Remote Control via Computer Interface

Optionally, digital control via an external D/A converter is possible. For several D/A boards from National Instruments, PI offers a corresponding LabVIEW driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented HyperBit™ technology providing enhanced system resolution.

Technical Data

Model	E-650.00	E-650.OE
Function	Power amplifier	Power amplifier
Amplifier		
Input voltage	0 to +10 V	0 to +10 V
Output voltage	0 to 60 V, plus fixed reference voltage of 60 V	0 to 60 V, plus fixed reference voltage of 60 V
Peak output power	18 W	8 W
Average output power	6 W	4 W
Peak current, < 5ms	300 mA	140 mA
Average current, >5 ms	100 mA	60 mA
Current limitation	Short-circuit-proof	Short-circuit-proof
Voltage gain	6 ±0.1	6 ±0.1
Amplifier bandwidth, large signal	600 Hz @ 1000 nF load, 6 kHz @ no load	200 Hz @ 1000 nF load, 3 kHz no load
Input impedance	100 kΩ	100 kΩ
Interfaces and operation		
Piezo connector	9-pin sub-D connector	Header pins
Control input sockets	BNC	Header pins
Display	3½-digit LCD	–
Miscellaneous		
Operating temperature range	5 to 50 °C	5 to 50 °C
Dimensions	160 x 125 x 50 mm	70 x 42 x 30 mm
Mass	0.7 kg	0.15 kg
Operating voltage	90–240 VAC, 50–60 Hz, (external switching P/S, included)	±15 V, 315 mA max., stabilized

PI

E-651 – E-614 Piezo Amplifier / Servo Controller

Piezo Controller for Closed-Loop Multilayer Bender Actuators

E-651 dual- and single-channel controllers for closed-loop piezo benders

- **Controller for Closed-Loop Multilayer Bimorph Actuators**
- **Bench-Top & OEM-Board Versions**
- **1- and 2-Channel Versions**

E-651 is a bench-top piezo controller, especially designed for low-voltage, multilayer piezo bender actuators equipped with strain gauge sensors such as the P-871 (see p. 1-84). One and two channel versions are available.

The E-614.2BS OEM board provides the same functionality as the E-651.2S two-channel controller in a smaller package.

Closed-Loop and Open-Loop Piezo Positioning

In closed-loop position control mode, displacement of the piezo bender is proportional to the analog signal applied to the BNC control input socket. The controller is calibrated in such a way that ±5 V input corresponds to maximum nominal deflection.

The E-651 can also be operated as piezo driver (open-loop, or voltage-controlled mode). The output voltage is then determined directly by the analog input signal in the -5 to +5 V range. Multiplying by the gain factor of 6, an output voltage range of 0 to 60 V results.

Ordering Information

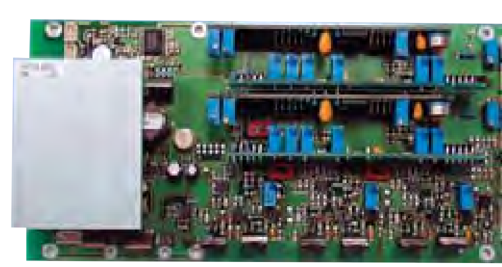
E-651.1S
Piezo Amplifier / Servo Controller for Bender Actuators, 1 Channel, 0 to 60 V, DMS-Sensor, Bench-Top

E-651.2S
Piezo Amplifier / Servo Controller for Bender Actuators, 2 Channels, 0 to 60 V, DMS-Sensor, Bench-Top

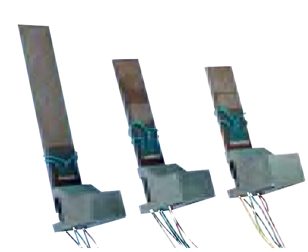
E-614.2BS
Piezo Amplifier / Servo Controller for Bender Actuators, 2 Channels, 0 to 60 V, DMS-Sensor, OEM Board

Technical Data

Models	E-651.1S	E-651.2S
Function	Piezo amplifier & servo controller for multilayer bender actuators, bench-top	Piezo amplifier & servo controller for multilayer bender actuators, bench-top
Channels	1	2
Sensor		
Servo characteristics	P-I (analog)	P-I (analog)
Sensor type	SGS	SGS
Sensor bandwidth	Low-pass filter cut-off frequency: 100 Hz / 5 kHz selectable	Low-pass filter cut-off frequency: 100 Hz / 5 kHz selectable
Amplifier		
Input voltage	-5 to +5 V	-5 to +5 V
Output voltage	0 to 60 V, plus fixed reference voltage of 60 V	0 to 60 V, plus fixed reference voltage of 60 V
Peak output power per channel, < 5 ms	1 W	1 W
Average output power per channel, >5 ms	0.5 W	0.5 W
Peak current per channel	6 mA	6 mA
Average current per channel	18 mA	18 mA
Current limitation	Short-circuit-proof	Short-circuit-proof
Voltage gain	**6**	**6**
Input impedance	100 kΩ	100 kΩ
Interfaces and operation		
Piezo / sensor connector	LEMO EPG.0B.307.HLN	LEMO EPG.0B.307.HLN
Analog input	BNC	BNC
Sensor monitor output	0 to +10 V for nominal displacement	0 to +10 V for nominal displacement
Sensor monitor socket	BNC	BNC
Miscellaneous		
Operating temperature range	5 to 50 °C	5 to 50 °C
Overtemp protection	Deactivation at 75 °C	Deactivation at 75 °C
Dimensions	125 x 90 x 265 mm	125 x 90 x 265 mm
Mass	1.36 kg	1.45 kg
Operating voltage	14 to 16 V DC (C-890.PS wide-range power supply included)	14 to 16 V DC (power supply C-890.PS included)
Power consumption	15 W	15 W



E-614.2BS two-channel OEM controller board



PICMA® P-871 closed-loop piezo bender actuators, providing displacement up to 1.6 mm with high linearity

E-481 PICA™ Piezo High-Power Amplifier/Controller

2000 W and Energy Recovery for High Efficiency

E-481.00 high-power amplifier, optionally available with E-509 servo-controller and E-517 interface and display module

- **Peak Power 2000 W**
- **Energy Recovery**
- **Output Voltage 0 to ±1000 V or Bipolar**
- **Overheat Protection for Piezo Actuators with Temperature Sensor**
- **Optional Position Servo-Control Modules**
- **Computer Interface & Display Modules**

The E-481 high-power piezo amplifier/controller is specifically designed for dynamic operation of high-capacitance PICA™ PZT actuators.

The E-481 is based on a novel design combining pulse width modulation and energy recovery. Instead of dissipating the reactive power in heat sinks, this energy is temporarily stored in inductive elements. Only the active power used by the piezo actuator has to be delivered. The energy not used by the actuator is returned to the amplifier and reused as supply voltage via a step-up transforming process. A peak sink and source current of up to 2000 mA is possible.

Selectable Output Range

The output range can be set to positive, negative or bipolar, and provides a voltage swing of 1100 V in open-loop operation.

Open-Loop and Closed-Loop Operation

E-481 amplifiers can be used to drive open- and closed-loop piezo positioning systems.

For open-loop piezo operation the amplifier output voltage is determined by the analog signal at the Control Input combined with the DC-offset potentiometer setting. Open-loop operation is ideal for applications where the fastest response and the highest bandwidth are essential. Here, commanding and reading the target position in absolute values is either not important or carried out by an external feedback loop. The Control In signal can be adjusted by various settings.

Optional Servo Controller Upgrade

The E-481.00 allows easy installation of an optional E-509 (see p. 2-152) sensor- / servo-controller module for closed-loop piezo position control. In this mode the amplifier is slaved to the E-509 servo controller. Depending on the attached piezo mechanics and feedback sensor, positioning accuracy and repeatability in the nanometer range and below are feasible.

Computer Control

The E-517 computer interface/display module can also be installed in the E-481.

Optionally digital control via a D/A converter is possible. For several D/A boards from National Instruments PI offers a corresponding LabVIEW™ driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented Hyperbit™ technology providing enhanced system resolution.

Thermal Piezo Protection Circuit

The E-481 features a temperature sensor input and control circuit to shut down the amplifier if the connected piezo ceramic exceeds a maximum temperature threshold.

Ordering Information

E-481.00
HVPZT Piezo Amplifier / Controller, Energy Recovery, 1100 V, 2000 W, 19''

Note
Requires Piezo Actuators with Option P-177.50, Temperature Sensor and Protective Air

Upgrades
Sensor / Servo-Control Modules

E-509.C1A
Sensor / Servo-Controller Module, Capacitive Sensor

E-509.S1
Sensor / Servo-Controller Module, SGS-Sensor

Interface / Display Modules

E-517.i1
Interface-/Display Module, 24 Bit D/A Ethernet, USB, RS-232, 1 Channel

E-515.01
Display Module for PZT Voltage and Position

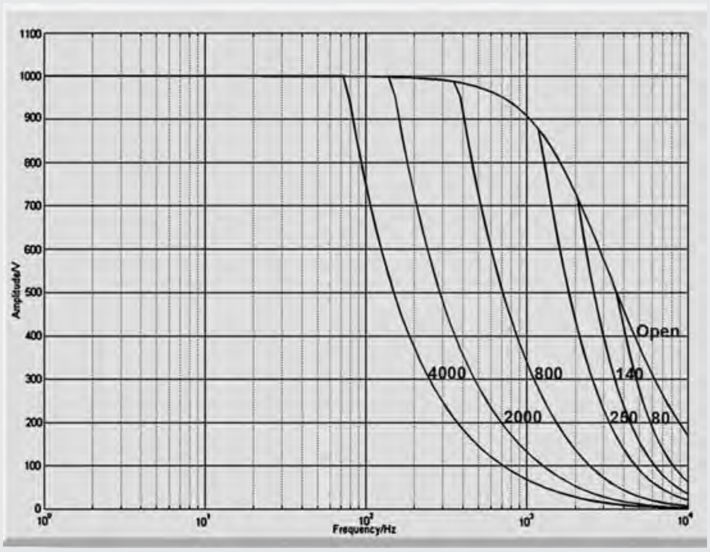
E-500.ACD
LabVIEW with Driver Set for Analog Controllers

E-500.HCD
Hyperbit™ Functionality for Enhanced System Resolution

Supports Certain D/A Boards.

Extension cables, adapters & connectors: see in "Accessories" in the "Piezo Drivers / Servo Controllers" section, (p. 2-168 *ff*).

Ask about custom designs!



E-481: operating limits with various PZT loads, capacitance is measured in nF

Technical Data

Model	E-481.00
Function	Power amplifier for PICA™ high-voltage PZTs
Amplifier	
Output voltage	0 to 1100 V (default) (Selectable -260 to +780 V -550 to +550 V +260 to -780 V 0 to -1100 V)
Amplifier channels	1
Average output power	equivalent to 630 VA reactive power
Peak output power <5 ms	2000 VA
Average current	>600 mA
Peak current <5 ms	2000 mA
Amplifier bandwidth, small signal	5 kHz (660 nF), 1 Hz (3.4 µF)
Amplifier bandwidth, large signal	1.4 kHz (660 nF), 350 Hz (3.4 µF)
Ripple, noise 0 to 100 kHz	150 mV_{RMS} 2000 mV_{P-P} (100 nF)
Current limitation	Short-circuit-proof
Voltage gain	+100
Control input voltage	Servo off: ±1/100 of selected output range Servo on: 0 to 10 V
Input impedance	100 kΩ
Interface and operation	
PZT voltage output socket	LEMO EGG.0B.701.CJL1173
Control input socket	BNC
PZT temperature sensor	Max 85 °C, high voltage output is automatically deactivated if PZT temperature out of range
DC Offset	10-turn pot., adds 0 to +10 V to Control IN
Miscellaneous	
Operating voltage	100–120 or 220–240 VAC, 50–60 Hz (fuse change required)
Operating temperature range	+5 to +50 °C (over 40 °C, max. av. power derated 10 %)
Weight	8.6 kg
Dimensions	288 x 450 x 158 mm

E-725 Digital Piezo Controller

For 3-Axis High-Speed Precision Positioning Systems

E-725 Digital 3-channel controller with P-528 Z/tip/tilt nanopositioning system

Ordering Information

E-725.3CD
Digital Multi-Channel Piezo Controller, 3-Channel, Sub-D Connector for Capacitive Sensors

E-725.3CM
Digital Multi-Channel Piezo Controller, for PicoCube™ and Capacitive Sensors

Ask about custom designs

- **For Nanopositioning Systems with Capacitive Sensors**
- **3-Channel Version**
- **Powerful Digital Controller: DSP 32-bit Floating Point, 225 MHz; 20 kHz Sampling Rate; 24-bit DAC**
- **Communication via Ethernet, USB, RS-232**
- **4th Order Polynomial Linearization for Mechanics & Electronics**
- **Dynamic Digital Linearization (DDL) Option for Improved Path Accuracy**
- **Auto-Loading of Calibration Data from Stage ID-Chip for Interchangeability of Controller and Mechanics**
- **Additional High-Bandwidth Analog Control Input / Sensor Input**
- **Optional High-Speed Parallel I/O Interface**
- **Flexible Wave Generators**
- **Digital I/O Lines for Task Triggering**
- **Extensive Software Support**

The E-725 digital piezo controller is a compact, high-performance drive electronics for nanopositioning systems with up to three axes. High-power amplifiers permit dynamic scans even for piezo systems with large range or direct drive. State-of-the-art processor technology optimizes the operating parameters for improved linearity and tracking accuracy. High-resolution D/A converters provide for nanopositioning that deserves this name.

With the E-725.3CM, PI for the first time offers a digital controller for the P-363 PicoCube™ (see p. 2-66), a fast precision scanner for atomic force microscopy.

Optional interfaces and analog in- and outputs make it possible to process external sensor or control values.

Digital Linearization and Control Algorithms for Highest Accuracy

Linearization algorithms based on higher-order polynomials improve the positioning accuracy to better than 0.01 % for capacitive sensors, typically 10 times better than achievable with conventional controllers.

More than just a Controller – Trajectory Control and Data Recording

During fast periodic motion, as typical for scanning applications, the tracking accuracy can be further improved with Dynamic Digital Linearization (DDL, E-710.SCN). This optionally available control algorithm reduces the tracking error by a factor of up to 1000.

This control algorithm enables the spatial and temporal tracking during a dynamic scan. The integrated wave generator can output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined motion profiles can be created and stored. The flexibly configurable data recorder enables simultaneous recording and read-out of the corresponding data.

Extensive Software Support

The controllers are delivered with Windows operating software. Comprehensive DLLs and LabVIEW drivers are available for automated control.

Automatic Configuration

PI digital piezo controllers and nanopositioning stages with ID-Chip can be operated in any combination, supported by the AutoCalibration function of the controller. Individual stage data and optimized servo-control parameters are stored in the ID-Chip and are read out automatically by the digital controllers.

PI

Technical Data

Model	E-725.3CD	E-725.3CM	Tolerance
Function	Digital Controller for Multi-Axis Piezo Nanopositioning Systems with Capacitive Sensors	Digital Controller for Multi-Axis Piezo Nanopositioning Systems with Capacitive Sensors	
Axes	3	3	
Processor	DSP 32-bit floating point, 225 MHz	DSP 32-bit floating point, 225 MHz	
Sampling rate, servo-control	20 kHz	20 kHz	
Sampling rate, sensor	20 kHz	20 kHz	
Sensor			
Servo characteristics	P-I, two notch filters	P-I, two notch filters	
Sensor type	Capacitive	Capacitive	
Sensor channels	3	3	
Sensor bandwidth (-3 dB)	5.6 kHz	5.6 kHz	max.
Sensor resolution	18 bit	18 bit	
Ext. synchronization	Yes	Yes	
Amplifier			
Output voltage	-30 to 135 V	-250 to 250 V	±3 V
Amplifier channels	4	4	
Peak output power per channel	25 W	47 W	max.
Average output power per channel*	10 W	10 W	max.
Peak output current per channel	190 mA	190 mA	max.
Average output current per channel*	120 mA	60 mA	max.
Current limitation	Short-circuit proof	Short-circuit proof	
Resolution DAC	24 bit	24 bit	
Interfaces and operation			
Communication interfaces	Ethernet, USB, RS-232	Ethernet, USB, RS-232	
Piezo / sensor connector	Sub-D special connector	Sub-D special connector	
Analog input	1 x Lemo, ±10 V, 18 bit	1 x Lemo, ±10 V, 18 bit	
Digital input / output	MDR20; 2 x IN, 8 x OUT	MDR20; 2 x IN, 8 x OUT	
Command set	PI General Command Set (GCS)	PI General Command Set (GCS)	
User software	NanoCapture™, PIMikroMove™	NanoCapture™, PIMikroMove™	
Software drivers	LabVIEW driver, DLLs	LabVIEW driver, DLLs	
Supported functionality	Wave-Gen, Trigger I/O	Wave-Gen, Trigger I/O	
Display	LEDs for Power, On Target, Error, Cmd	LEDs for Power, On Target, Error, Cmd	
Linearization	4th order polynomial, DDL (Dynamic Digital Linearization)	4th order polynomial, DDL (Dynamic Digital Linearization)	
Separate protective ground connector	Yes	Yes	
Miscellaneous			
Operating temperature range	5 to 50 °C	5 to 50 °C	
Overheat protection	Max. 71 °C, deactivation of the piezo voltage output	Max. 71 °C, deactivation of the piezo voltage output	
Mass	3.5 kg	3.6 kg	
Dimensions	263 x 89 x 302 mm (with handles)	263 x 89 x 302 mm (with handles)	
Power consumption	70 W	70 W	max.
Operating voltage	24 VDC from external power supply (included)	24 VDC from external power supply (included)	

* The total output power of all 4 amplifier channels should not exceed 34.5 W to avoid overcurrent (E-725 is equipped with a 3.15 AM fuse).

PI

E-710 Digital Piezo Controller

3 to 6 axes, for highest precision

E-710.6CD 6-axis Digital Piezo Controller top model of the E-710 family, shown with custom Super-Invar 6-DOF piezo flexure nanopositioning stage

- **For Nanopositioning Systems with Capacitive Feedback Sensors**
- **All Control Parameters Software-Settable**
- **3-, 4- & 6-Channel Versions**
- **Firmware Linearization: Dynamic Digital Linearization (DDL) Option Improves Scanning Linearity**
- **Coordinate Transformation for Parallel-Kinematics / Parallel-Metrology Systems**
- **Auto-Loading of Calibration Data from Stage ID-Chip for Interchangeability of Controller and Mechanics**
- **Interface Options: High-Speed Parallel I/O Interface and Analog Inputs**
- **Notchfilter for Higher Bandwidth**
- **Extensive Software Support**
- **Option: Digital Sensor-Signal Transmission over 15 m and More**

E-710 digital piezo controllers offer sophisticated functionality in a variety of configurations. Based on powerful 32-bit DSPs (digital signal processor) they include integrated, low-noise power amplifiers for piezo actuators and excitation/read-out electronics for extremely high-resolution capacitive position sensors. E-710s provide up to 8 piezo driver channels, 7 sensor channels and the processing power for coordinated control of up to 6 logical axes, e. g. for parallel kinematics systems.

Digital Linearization and Control Algorithms for Highest Accuracy

Linearization algorithms based on higher-order polynomials improve the positioning accuracy to 0.001 % of the travel range. The high-speed processor with a sensor sampling rate of 25 kHz, assures settling times in the millisecond range and below. The controller is perfectly suited for high-dynamics operation, thanks to its high-resolution DA-converters and high-performance voltage amplifiers.

More than just a Controller—Trajectory Control and Data Recording

During fast periodic motion, as typical for scanning applications, the tracking accuracy can be further improved with Dynamic Digital Linearization (DDL, E-710.SCN). This optionally available control algorithm reduces the tracking error by a factor of up to 1000.
This control algorithm enables the spatial and temporal tracking during a dynamic scan. The integrated wave generator can save and output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined profiles can be created. The flexibly configurable data recorder enables simultaneous recording and read-out of the corresponding data.

Sensor-Signal Transmission up to 15 m

A remote sensor interface box is available for applications where the distance between the mechanics and electronics is greater than 10 m. This DST option (digital sensor-signal transmission), includes a compatible E-710 controller. It is designed to reduce the interference that begins to degrade performance when the analog sensor excitation and readout signal paths exceed 10 m. The connection between the sensor box and the controller can be up to 15 m (longer distances on request), as the digital signals it carries are far more robust.

Simple System Integration

All parameters can be checked and reset via software. System setup and configuration is done with the included NanoCapture™ and PIMikroMove™ user-interface software. Interfacing to custom software is facilitated with included LabVIEW drivers and DLLs. System programming is the same with all PI controllers, so controlling a system with a variety of different controllers is possible without difficulty.

Ordering Information

See Ordering Numbers / Interface Options on next page

Options and Accessories

E-710.SCN
DDL (Dynamic Digital Linearization) Firmware Upgrade

E-710.3X3
Extension Cable for E-710.3CD, 3 Sub-D Connectors, 3 m

E-710.3X5
Extension Cable for E-710.3CD, 3 Sub-D Connectors, 5 m

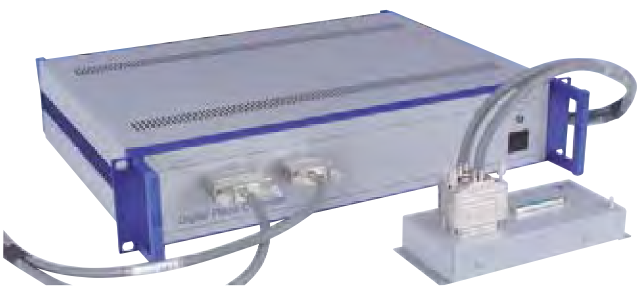
E-710.1X3
Extension Cable for E-710, 1 Sub-D Connectors, 3 m

E-710.DST4
DST Cable (Digital Signal Transmission) for E-710.6SD, 8 m

Ordering Information / Interface Options

Channels	Connector (piezomechanics)	Base Model	Parallel I/O Interface	Analog Input*	Analog Input* + Parallel I/O Interface	DST** + Analog Input*
3	1 x Special Sub-D, 3 ch.	E-710.3CD	E-710.P3D	E-710.A3D	E-710.APD	incl. Parallel I/O Interface E-710.APS
4	4 x LEMO	E-710.4CL	E-710.P4L	–	–	–
	4 x Special Sub-D, 1 ch.	E-710.4CD	E-710.P4D	–	–	–
	1 x Special Sub-D, 3 ch. + 1 x Special Sub-D, 1 ch.	E-710.C4D	E-710.4PD	–	–	–
6	2 x Special Sub-D, 3 ch.	E-710.6CD	–	Standard	–	Analog input on DST box E-710.6SD

*LEMO connector
**Digital Signal Transmission



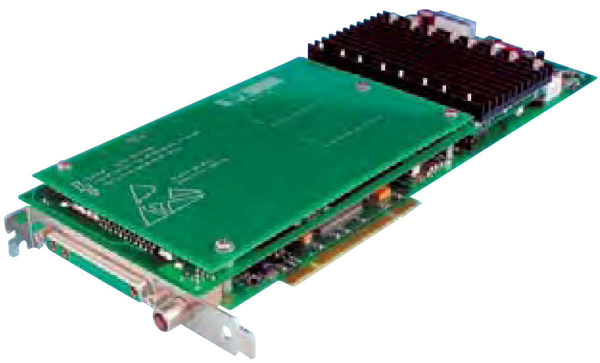
The digital sensor-signal transmission (DST) allows a distance up to 15 m between positioning unit and controller

Technical Data

Model	E-710.3CD / E-710.P3D / E-710.A3D E-710.APD / E-710.APS	E-710.4CD / E-710.4CL / E-710.C4D E-710.4PD / E-710.P4D / E-710.P4L	E-710.6CD / E-710.6SD
Function	Digital piezo controller for multi-axis nanopositioning systems with capacitive sensors	Digital piezo controller for multi-axis nanopositioning systems with capacitive sensors	Digital piezo controller for multi-axis nanopositioning systems with capacitive sensors
Axes	3	4	6
Processor	32-bit, floating-point DSP	32-bit, floating-point DSP	2 x 32-bit, floating-point DSP
Sampling rate, servo-control	200 µs / 5 kHz	200 µs / 5 kHz	200 µs / 5 kHz
Sampling rate, sensor	50 µs / 20 kHz	50 µs / 20 kHz	40 µs / 25 kHz
Sensor			
Servo characteristics	P-I, two notch filters	P-I, two notch filters	P-I, two notch filters
Sensor type	Capacitive	Capacitive	Capacitive
Sensor channels	3	4	6
Sensor resolution	16 bit	16 bit	16 bit
Ext. synchronization	Yes	Yes	Yes
Amplifier			
Output voltage	-20 to 110 V	-20 to 110 V	-20 to 110 V
Amplifier channels	4	4	8
Peak output power per channel,	25 W	25 W	25 W
Average output power per channel	6 W	6 W	6 W
Peak current per channel, <20 ms	200 mA	200 mA	200 mA
Average current per channel, >20 ms	60 mA	60 mA	60 mA
Current limitation	Short-circuit-proof	Short-circuit-proof	Short-circuit-proof
Resolution DAC	20 bit	20 bit	20 bit
Interfaces and operation see separate table			
Communication interfaces	RS-232; IEEE 488 Parallel I/O (E-710.Pxx / .xPx only)	RS-232; IEEE 488; Parallel I/O (E-710.Pxx / .xPx only)	RS-232; IEEE 488
Command set	GCS	GCS	GCS
User software	PIMikroMove™, PZTControl™, NanoCapture™	PIMikroMove™, PZTControl™, NanoCapture™	PIMikroMove™, PZTControl™, NanoCapture™
Software drivers	LabVIEW drivers, DLLs	LabVIEW drivers, DLLs	LabVIEW drivers, DLLs
Supported functionality	Wave generator, data recorder	Wave generator, data recorder	Wave generator, data recorder
Display	Power LED	Power LED	Power LED
Linearization	4th order polynomials, DDL (optional)	4th order polynomials, DDL (optional)	4th order polynomials, DDL
Miscellaneous			
Operating temperature range	5 to 50 °C	5 to 50 °C	5 to 50 °C
Dimensions	450 x 88 x 343 mm + handles	450 x 88 x 343 mm + handles	450 x 88 x 343 mm + handles
Mass	7 kg	7 kg	7 kg
Operating voltage	90–120 or 220–264 VAC, 50–60 Hz	90–120 or 220–264 VAC, 50–60 Hz	90–120 or 220–264 VAC, 50–60 Hz
Max. power consumption	60 W	60 W	120 W

E-761 Digital Piezo Controller

Cost-Efficient PCI Board for Piezo Stages with up to 3 Axes



E-761 Digital Piezo Controller in PCI-Board Format

- **For Piezo Stages with Capacitive Sensors**
- **High-Speed PCI Interface**
- **3 Logical Axes, 4 Piezo Amplifiers**
- **Additional High-Bandwidth Analog Interface**
- **32-Bit Digital Filters**
- **Notch Filter for Higher Bandwidth**
- **24-Bit Ultra-Low-Noise DAC Converters**
- **Auto-Loading of Calibration Data from Stage ID-Chip for Interchangeability of Controller and Mechanics**
- **Coordinate Transformation for Parallel-Kinematics / Parallel-Metrology Systems**
- **Extensive Software Support**

E-761 digital piezo controllers offer advanced control technology in a cost-effective PCI-board format. They were designed to run piezo stages with up to three logical axes. The E-761 incorporates four instrumentation-class, 24-bit digital-analog converters (DAC) behind ultra-low-noise power amplifiers, and is based on a specialized 32-bit digital signal processor (DSP) with proprietary firmware.

Having PCI-board format, the E-761 digital controller can be easily installed in any commercial or industrial PC, allowing for easy integration with other devices such as frame grabbers. The PCI interface with its high bandwidth makes possible a very fast communication between software and controller. This is a definite plus in time-critical applications or when controlling several axes.

Additionally, the E-761.3CT version offers three digital output lines for a variety of triggering tasks.

Improved Trajectory Accuracy Through Parallel Metrology

Digital controllers have a number of advantages over conventional analog piezo controllers. Sensor and actuator axes need not be parallel to each other, or to the orthogonal logical axes used to command the system. The flexible coordinate transformation algorithm permits operation of complex, multi-axis, parallel metrology stages (e. g. 3-axis Z-tip-tilt-stages). With parallel motion metrology, the controller compensates the undesired off-axis motion of each actuator automatically using the others (active trajectory control). High-end nanopositioning systems with active trajectory control can attain motion accuracies in the sub-nanometer range.

Digital Linearization and Control Algorithms for Highest Accuracy

Linearization algorithms based on higher-order polynomials improve the positioning accuracy to 0.001 % of the travel range.

During fast periodic motion, as typical for scanning applications, the tracking accuracy can be further improved with Dynamic Digital Linearization (DDL, E-710.SCN). This optionally available control algorithm reduces the tracking error by a factor of up to 1000.

The integrated wave generator can save and output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined profiles can be created.

Automatic Configuration

PI digital piezo controllers and nanopositioning stages with ID-chips can be operated in any combination, supported by the controller's AutoCalibration function. Individual stage data and optimized servo-control parameters are stored in the ID-Chips and are read out automatically by the digital controller.

Simple System Integration

All parameters can be set and checked by software. System setup and configuration is done with the included NanoCapture™ and PZTControl™ user-interface software. Interfacing to custom software is facilitated with included LabVIEW drivers and DLLs. All PI controllers use the same command set, a significant advantage during application software development, system upgrade or when operating a variety of different controllers from one application.

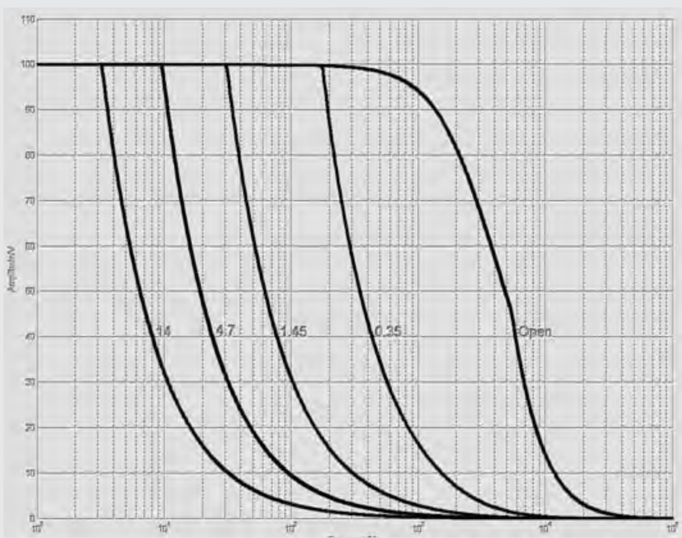
Ordering Information

E-761.3CD
Digital Piezo Nanopositioning Controller, 3 Axes, Sub-D-Special, PCI Board

E-761.00T
Trigger Output Bracket for E-761.3CD

E-761.3CT
Digital Piezo Nanopositioning Controller, 3 Axes, Sub-D-Special, PCI Board, Trigger Output

Ask about custom designs!



E-761: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Technical Data

Model	E-761.3CD	E-761.3CT
Function	Digital piezo controller and power amplifier, PCI board	Digital piezo controller and power amplifier, PCI board, trigger output
Axes	3	3
Processor	32-bit, floating-point DSP	32-bit, floating-point DSP
Sampling rate, servo-control	40 µs / 25 kHz (sensor-oversampling factor 4)	40 µs / 25 kHz (sensor-oversampling factor 4)
Sensor		
Servo characteristics	P-I, two notch filters	P-I, two notch filters
Sensor type	Capacitive	Capacitive
Sensor channels	3	3
Sensor resolution	16-bit	16-bit
Ext. synchronization	Yes	Yes
Amplifier		
Output voltage	-20 to 120 V	-20 to 120 V
Amplifier channels	4	4
Peak output power per channel,	5.3 W	5.3 W
Average output power per channel	1.7 W	1.7 W
Peak current per channel, <20 ms	50 mA	50 mA
Average current per channel, >20 ms	10 mA	10 mA
Current limitation	Short-circuit-proof	Short-circuit-proof
Resolution DAC	24-bit	24-bit
Interfaces and operation		
Interface / communication	PCI connector	PCI connector
Piezo / sensor connector	Sub-D special	Sub-D special
Control Input sockets	LEMO	LEMO
Digital output	-	3 x TTL
Command set	GCS	GCS
User software	NanoCapture™, PZTControl™	NanoCapture™, PZTControl™
Software drivers	LabVIEW drivers, Windows and Linux Libraries (DLL)	LabVIEW drivers, Windows and Linux Libraries (DLL)
Supported functionality	Wave generator	Wave generator, trigger output
Display	Status LED for piezo voltage	Status LED for piezo voltage
Linearization	4th order polynomial	4th order polynomial
Miscellaneous		
Operating temperature range	+5 to +50 °C (derated 10 % over 40 °C)	+5 to +50 °C (derated 10 % over 40 °C)
Overtemp protection	Deactivation at 60 °C	Deactivation at 60 °C
Dimensions	287 x 108 x 25 mm (2 slots)	287 x 108 x 25 mm + 122 x 45x 26 mm (3 slots)
Mass	0.56 kg	0.56 (PCI-board only)
Operating voltage	5 V	5 V
Power consumption	20 W, 4 A max.	20 W, 4 A max.

E-616 Controller for Multi-Axis Piezo Tip/Tilt Mirrors and Platforms

Flexible Multi Channel OEM Electronics with Coordinate Transformation

The E-616 OEM controller and the S-334 fast steering mirror system providing a tip/tilt range of up to 60 mrad

- Three Integrated Amplifiers Provide up to 10 W Peak Power
- Closed-Loop and Open-Loop Versions
- Internal Coordinate Transformation Simplifies Control of Parallel Kinematics Designs (Tripod & Differential Drive)
- Compact and Cost-Effective Design for OEMs

The E-616 is a special controller for piezo based tip/tilt mirrors and tip/tilt platforms. It contains two servo controllers, sensor channels and power amplifiers in a compact unit. The controller works with high-resolution SGS position sensors used in PI piezo mechanics and provides optimum position stability and fast response in the nanometer and µrad-range respectively. A high output power of 10 W per channel allows dynamic operation of the tip/tilt mirrors for applications such as (laser) beam steering and stabilization.

Tripod or Differential Piezo Drive? One for All!

PI offers two basic piezo tip/tilt mirror designs. Both are parallel-kinematics designs where the individual piezo actuators affect the same moving platform. With the tripod design (e. g. S-325, see p. 2-92) the platform is driven by three piezo actuators placed with 120° spacing. The differential drive design (S-330, see p. 2-88 or S-334, see p. 2-90) with two orthogonal axes and a fixed pivot point is based on two pairs of actuators operating in push / pull-mode. The differential evaluation of two sensors per axis provides an improved linearity and resolution.

Internal Coordinate Transformation Simplifies Control

Parallel-kinematics require the transformation of the commanded tilt angles into the corresponding linear motion of the individual actuators. In the E-616.S0, this is taken care of by an integrated circuit, eliminating the need of additional external hardware or software. Additionally with the E-616.S0 all actuators can be commanded by an offset-voltage simultaneously. As a result a vertical movement, for example for optical path tuning, is obtained.

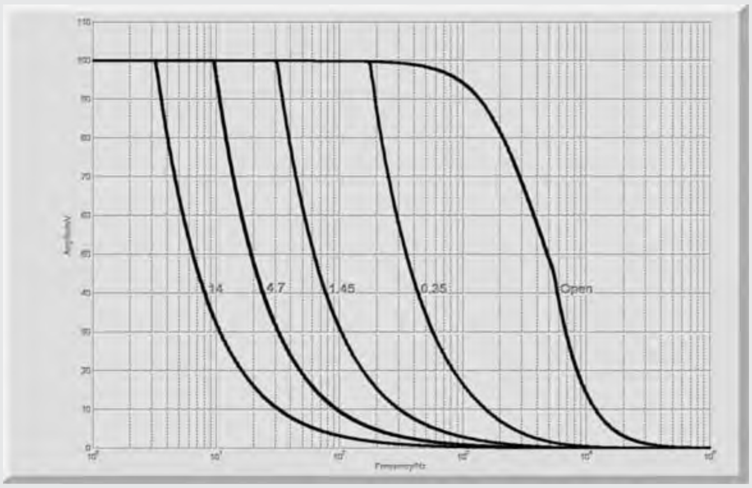
Simple Setup and Operation

To facilitate integration, setup and operation the E-616 features both front and rear panel connections: The 25 pin sub-D piezo & sensor connector is located on the front, along with offset trim pots and LEDs for Power and Overflow. A 32 pin rear connector allows commanding and reading the sensor and amplifier monitor outputs.

Ordering Information

E-616.SS0
Multi Channel Servo-Controller / Driver for Piezo Tip/Tilt Mirror Platforms with SGS and Differential Drive

E-616.S0
Multi Channel Servo-Controller / Driver for Piezo Tip/Tilt Mirror Platforms with SGS and Tripod Drive



E-616: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Technical Data

Model	E-616.S0	E-616.SS0
Function	Controller for parallel-kinematics piezo tip/tilt mirror systems with strain gauge sensors, tripod design	Controller for parallel-kinematics piezo tip/tilt mirror systems with strain gauge sensors, differential design
Tilt axes	2	2
Sensor		
Servo characteristics	P-I (analog), notch filter	P-I (analog), notch filter
Sensor type	SGS	SGS
Sensor channels	3	2
External synchronization	200 kHz TTL	200 kHz TTL
Amplifier		
Control input voltage range	-2 V to +12 V	-2 V to +12 V
Output voltage	-20 V to +120 V	-20 V to +120 V
Amplifier channels	3	3
Peak output power per channel	10 W	10 W
Average output power per channel	5 W	5 W
Peak current	100 mA	100 mA
Average current per channel	50 mA	50 mA
Current limitation	Short-circuit-proof	Short-circuit-proof
Voltage gain	10	10
Amplifier bandwidth, small signal	3 kHz	3 kHz
Amplifier bandwidth, large signal	See frequency diagram	See frequency diagram
Ripple, noise, 0 to 100 kHz	<20 mVpp	<20 mVpp
Amplifier resolution	<1 mV	<1 mV
Interfaces and operation		
Piezo / sensor connector	25-pin sub-D connector	25-pin sub-D connector
Analog input	32-pin connector	32-pin connector
Sensor monitor output	0 to +10 V for nominal displacement	0 to +10 V for nominal displacement
Sensor monitor socket	32-pin connector	32-pin connector
Display	Power-LED and sensor OFL display	Power-LED and sensor OFL display
Miscellaneous		
Operating temperature range	5 °C to 50 °C	5 °C to 50 °C
Overheat protection	Max. 75 °C, deactivation of the piezo voltage output	Max. 75 °C, deactivation of the piezo voltage output
Dimensions	160 mm x 100 mm x 10 TE	160 mm x 100 mm x 10 TE
Mass	700 g	700 g
Operating voltage	12 to 30 V DC	12 to 30 V DC
Power consumption	30 W	30 W

E-536 PicoCube™ Piezo Controller

High Dynamics, High Resolution, for up to 3 Axes

E-536.3C 3-channel PicoCube™ Controller

- **For P-363 PicoCube™ Systems**
- **Peak Power 3 x 100 W**
- **Ultra-Low Noise**
- **Output Voltage ±250 V**

The E-536 is a controller for the P-363 PicoCube™ pico-positioning system providing three ultra-low-noise amplifier channels for piezo shear actuators. The controller design meets the special requirements of the high-speed, ultra-high-performance PicoCube™ XY(Z) piezo stages (see p. 2-74) of ±250 V for both static and dynamic applications.

The high-performance E-536.3x can output and sink peak currents up to 200 mA featuring a small-signal bandwidth of 10 kHz. The E-536.3xH ultra-high-resolution models provide a position resolution below 0.03 nm at a peak power of 50 W. Both models are available with or without a servo module for closed-loop or open-loop operation.

Superior Resolution and High Dynamics

Open-loop operation is ideal for applications where fast response and very high resolution with maximum bandwidth are essential. Here, commanding and reading the traget position in absolute values is either not important or carried out by external position sensors. Together with the P-363 PicoCube™ a resolution of 0.05 nm or better is achieved.

Excellent Position Accuracy with Capacitive Sensors

The E-536.3C versions have integrated sensor electronics and servo-controllers for closed-loop position control. Position feedback is provided by capacitive sensors, like those in the PicoCube™, with resolutions down to 0.1 nm.

Computer Control

Control via PC is possible by installing the E-517, 24-bit interface/display module.

Optionally digital control via a D/A converter is possible. For several D/A boards from National Instruments PI offers a corresponding LabVIEW™ driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented Hyperbit™ technology providing enhanced system resolution.

Ordering Information

E-536.3C
PicoCube™ Piezo Controller, 3 Channels, Capacitive Sensors

E-536.30
PicoCube™ Piezo Controller, 3 Channels, Open-Loop

E-536.3CH
PicoCube™ Piezo Controller, 3 Channels, High-Resolution, Capacitive Sensors

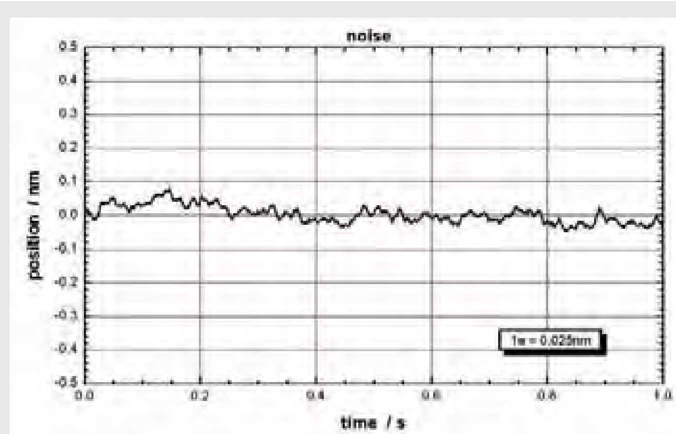
E-536.30H
PicoCube™ Piezo Controller, 3 Channels, High-Resolution, Open-Loop

E-517.i3
Interface- / Display Module, 24 Bit D/A, TCP/IP, USB, RS-232, 3 Channels

E-500.HCD
Hyperbit™ Functionality for Enhanced System Resolution

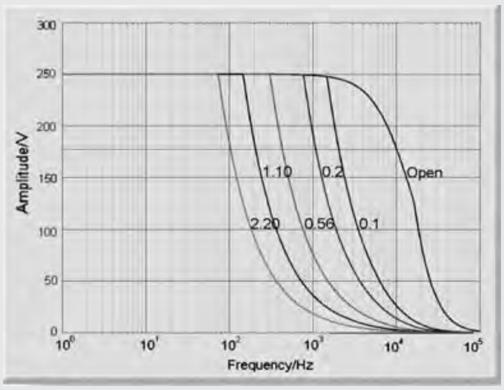
(Supports certain D/A boards.)

E-536 controller with P-363 PicoCube™ pico-positioning system

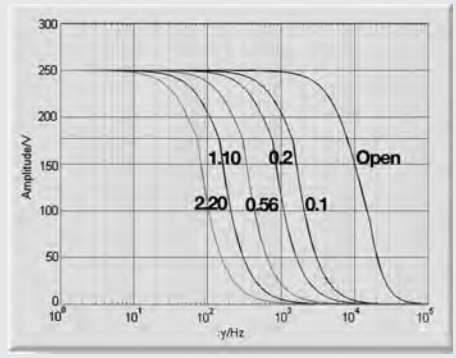


Positional noise measurement of E-536 amplifier driving a P-363 pico-positioning system in open loop shows 1-sigma resolution of 25 picometers (0.025 nm). Measured with ultra-high-resolution capacitive sensor

PI



E-536.3x: operating limits with various PZT loads, capacitance is measured in µF



E-536.3xH: operating limits with various PZT loads, capacitance is measured in µF

Technical Data

Model	E-536.3C / E-536.30	E-536.3CH / E-536.30H
Function	Power amplifier & servo-controller for P-363 PicoCube™	Power amplifier & servo-controller for P-363 PicoCube™
Amplifier		
Output voltage	-250 to +250 V	-250 to +250 V
Amplifier channels	3	3
Average output power per channel	10 W, limited by temperature sensor	6 W, limited by temperature sensor
Peak output power per channel, <3 ms	100 W	50 W
Average current	30 mA	15 mA
Peak current per channel, <3 ms	200 mA	100 mA
Amplifier bandwidth, small signal	10 kHz	2 kHz
Amplifier bandwidth, large signal, @ 100 nF	0.2 kHz	0.125 kHz
Ripple, noise, 0 to 100 kHz	0.8 mV_{RMS}, <5 mV_{P-P} (100 nF)	0.5 mV_{RMS}, <3 mV_{P-P} (100 nF)
Current limitation	Short-circuit proof	Short-circuit proof
Voltage gain	+50	+50
Input impedance	100 kΩ	100 kΩ
Sensor*		
Servo characteristics	Analog proportional-integral (P-I) algorithm with notch filter	Analog proportional-integral (P-I) algorithm with notch filter
Sensor type	capacitive sensors	capacitive sensors
Sensor channels	3 / -	3 / -
Sensor bandwidth	1.5 kHz	1.5 kHz
Sensor Monitor output	0 to +10 V	0 to +10 V
Interfaces and operation		
PZT output sockets	LEMO EGG.0B.701.CJL.1173	LEMO EGG.0B.701.CJL.1173
Sensor target and probe sockets	LEMO EPL.00.250.NTD	LEMO EPL.00.250.NTD
Control Input sockets	SMB	SMB
Sensor Monitor socket	LEMO FGG.0B.306.CLAD56	LEMO FGG.0B.306.CLAD56
Control Input voltage	Servo off: -5 to +5 V, Servo on: 0 to +10 V	Servo off: -5 to +5 V, Servo on: 0 to +10 V
DC Offset	10-turn pot., adds 0 to +10 V to Control IN	10-turn pot., adds 0 to +10 V to Control IN
Miscellaneous		
Operating voltage	115 VAC / 50-60 Hz or 230 VAC / 50-60 Hz	115 VAC / 50-60 Hz or 230 VAC / 50-60 Hz
Mass	8.1 kg / 7.8 kg (with E-516 module)	8.1 kg / 7.8 kg (with E-516 module)
Dimensions	450 x 132 x 296 mm + handles	450 x 132 x 296 mm + handles

*only E-536.3Cx with capacitive sensors
Interfaces / communication: RS-232, TCP/IP, USB (with optional E-517 computer interface and display module only)
Operating temperature range: +5 °C to +50 °C (over 40 °C, max. av. power derated 10 %), high-voltage output is automatically deactivated if temperature is too high by internal temperature sensor (75 °C max.)

E-663 Three-Channel Piezo Driver

For Open-Loop Piezo Systems and Actuators Without Position Sensors

E-663.00 bench-top device

- 3 Independent Channels
- 3 x 14 W Peak Power
- Output Voltage Range -20 to 120 V
- High-Bandwidth Analog Control Interface
- Precision 10-Turn Potentiometers for Manual Control
- 3 LED Voltage Displays

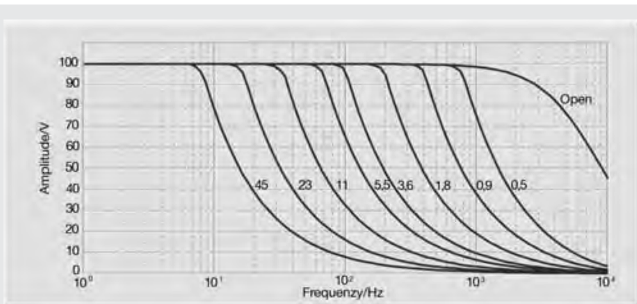
The E-663.00 is a piezo driver module for low-voltage piezo actuators and positioners. It contains three independent amplifiers that can output and sink a peak current of 140 mA in the -20 to +120 V voltage range. Three 3½-digit LED displays show the output voltage of each individual channel.

Voltage-Controlled Piezo Operation

This precision piezo driver is designed for voltage-controlled piezo operation in both dynamic and static modes. In open-loop (voltage-controlled) piezo operation the amplifier output voltage is determined by an analog signal at the Control Input optionally combined with the DC-offset potentiometer. Voltage controlled operation (in contrast to position-controlled operation) is used in applications where the fastest possible response and very high resolution with maximum bandwidth are essential, and/or when commanding and reading the target position in absolute values is either not important or accomplished with an external feedback loop. (see p. 2-104) The precision 10-turn potentiometer can also be used alone to set the output voltage manually.

Remote Control via Computer Interface

Optionally, digital control via an external D/A converter is possible. For several D/A boards from National Instruments, PI offers a corresponding LabVIEW driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented HyperBit™ technology providing enhanced system resolution.



E-663: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Ordering Information

E-663.00
Piezo Amplifier, 3 Channels, -20 to 120 V, Bench-Top

Technical Data

Model	E-663.00	Tolerance
Function	Power amplifier	
Channels	3	Max.
Amplifier		
Input voltage	-2 to +12 V	
Min. output voltage	-20 to 120 V	
Peak output power per channel	14 W	Max.
Average output power per channel	6 W	Max.
Peak current per channel	140 mA	<5 ms
Average current per channel	60 mA	>5 ms
Current limitation	Short-circuit-proof	
Noise, 0 to 100 kHz	<1 mVrms	
Voltage gain	10 ±0.1	
Input impedance	100 kΩ	
Interfaces and operation		
Piezo connector	3 x LEMO ERA.00.250.CTL	
Control Input socket	3 x BNC	
Display	3 x 3 1/2 -digit, LED	
DC-Offset	3 x 10-turn pots, adds 0 to 10 V to Control In	
Miscellaneous		
Operating temperature range	5 to +50°C	
Dimensions	236 x 88 x 273 mm + handles	
Mass	4.6 kg	
Operating voltage	90–120 / 220–240 VAC, 50–60 Hz (linear power supply)	
Power consumption	60 W	Max.

E-664 NanoCube® Piezo Controller

For XYZ-Nanopositioning System P-611.3S

E-664 Controller for NanoCube®
XYZ nanopositioning systems

- **Integrated Amplifier with 3 x 14 W Peak Power**
- **Position Servo-Control with Notch Filter for Higher Bandwidth and Stability**
- **3 Displays for Voltage / Position**
- **Cost-Effective Controller for P-611.3S NanoCube® Nanopositioning Systems**
- **Manual and External Control**

The E-664 is a bench-top amplifier & position servo-controller that is especially designed for the P-611.3S NanoCube® XYZ nanopositioning system (see p. 2-52). Three integrated low-noise amplifiers and control circuitry for strain gauge position sensors allow closed-loop position resolution down to 2 nm and dynamic operation.

The combination of the E-664 servo-controller and P-611.3S NanoCube® piezo stage makes for a very cost-effective precision 3D nanopositioning system.

Closed-Loop and Open-Loop Piezo Positioning

The E-664 servo controller can be operated both in closed-loop (position-control) and in open-loop (voltage-control) mode. In closed-loop mode, piezo displacement is proportional to the analog signal applied to the BNC control-input socket. The integrated notch filters (adjustable for each axis) improve the stability and allow high-bandwidth operation closer to the piezo-mechanics resonant frequency. In open-loop operation the output voltage is determined by the analog control signal at the BNC Control Input socket, optionally combined with the DC-offset potentiometer. Voltage controlled operation (in contrast to position-controlled operation) is used in applications where the fastest possible response and very high resolution with maximum bandwidth are essential, and/or when commanding and reading the target position in absolute values is either not important or accomplished with an external feedback loop (see p. 2-104). The precision 10-turn potentiometers can also be used alone to set the output voltages manually.

Versatile I/O Supports Automation

On-target and overflow status information is displayed separately for every channel. This information is also present on a 14-pin I/O connector on the rear panel that also carries the analog control input and sensor monitor lines.

Remote Control via Computer Interface

Optionally, digital control via an external D/A converter is possible. For several D/A boards from National Instruments, PI offers a corresponding LabVIEW driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented HyperBit™ technology providing enhanced system resolution.

Ordering Information

E-664.S3
NanoCube® Piezo Controller,
3 Channels, SGS-Sensors,
-20 to 120 V

Technical Data

Model	**E-664.S3**
Function	Power amplifier & position servo controller for P-611.3S NanoCube® nanopositioning system
Axes	3
Sensor	
Servo characteristics	P-I (analog), notch filter
Sensor type	SGS
Amplifier	
Input voltage	-2 to +12 V
Output voltage	-20 to 120 V
Peak output power per channel <5 ms	14 W
Average output power per channel >5 ms	6 W
Peak current per channel <5 ms	140 mA
Average current per channel >5 ms	60 mA
Current limitation	Short-circuit-proof
Voltage gain	10 ±0.1
Ripple, noise, 0 to 100 kHz	<1 mVrms
Interfaces and operation	
Piezo connector	25-pin sub-D connector
Sensor connector	25-pin sub-D connector
Control Input sockets	3 x BNC (rear), I/O connector
I/O ports	14-pin connector for on-target and overflow status, Control In and sensor monitor outputs
Display	3 x 3½-digits, LED
Miscellaneous	
Operating temperature range	5 to 50°C
Overtemp protection	Deactivation at 75°C
Dimensions	236 x 88 x 273 mm + handles
Mass	3 kg
Operating voltage	90–120 / 220–240 VAC, 50–60 Hz (linear power supply)
Max. power consumption	60 W

E-760 NanoCube® Piezo Controller Card

For C-880 Automation Controller and F-206 Hexapod Precision Alignment System

E-760 controller card with P-611.3SF NanoCube® XYZ nanopositioning system

- **3 x 9 W Peak Power**
- **Position Servo-Control**
- **For P-611 NanoCube® and F-206 HexAlign™ 6-DOF Alignment Systems**
- **Built-in Optical Metrology for Automated Alignment**

The E-760 is a piezo amplifier and position servo-controller card that was especially designed for the P-611 NanoCube® (see p. 2-50) XYZ nanopositioning system operated together with the F-206, M-824, M-840 or M-850 (see p. 4-6 *ff*). In addition to three low-noise amplifiers and position servo-controller circuits, it is equipped with optical metrology and I/O for automatic alignment of photonics components. All functions are accessible via the computer-bus interface. In addition, there is an analog input for position control and an FC connector for the optical metrology. Thus, positioning accuracy and repeatability down to the sub-nanometer range is possible.

Ordering Information

E-760.3SV
NanoCube® Piezo Controller, Board for C-880 and F-206 Controller Systems, Photodetector (Visual Range)

E-760.3Si
NanoCube® Piezo Controller, Board for C-880 and F-206 Controller Systems, Photodetector (Infrared Range)

Technical Data

Models	E-760.3SV	E-760.3Si	Units
Function	Piezo controller card for P-611 NanoCube® systems	Piezo controller card for P-611 NanoCube® systems	
Axes	3	3	
Sensor			
Servo characteristics	P-I (analog), notch filter	P-I (analog), notch filter	
Sensor type	SGS	SGS	
Sensor channels	3	3	
Amplifier			
Input voltage	-2 to +12 V	-2 to +12 V	
Output voltage	-20 to 120 V	-20 to 120 V	
Amplifier channels	3	3	
Peak output power per channel	9	9	W
Average output power per channel	1	1	W
Peak current per channel, <5 ms	90	90	mA
Average current per channel, >5 ms	8	8	mA
Current limitation	Short-circuit-proof	Short-circuit-proof	
Voltage gain	10 ±0.1	10 ±0.1	
Interfaces and operation			
Communication interfaces	Standard computer bus (ISA); FC-connector	Standard computer bus (ISA); FC-connector	
Piezo / sensor connector	25-pin sub-D connector	25-pin sub-D connector	
Analog input	8-pin connector (piezo); FC connector (optical metrology)	8-pin connector (piezo); FC connector (optical metrology)	
Supported functionality	Visible-range detector	Infrared-range detector	

E-464 PICA™ Piezo Driver / Amplifier

For Piezo Systems and Actuators, for up to 3 Axes

E-464.00 3-channel HVPZT amplifier

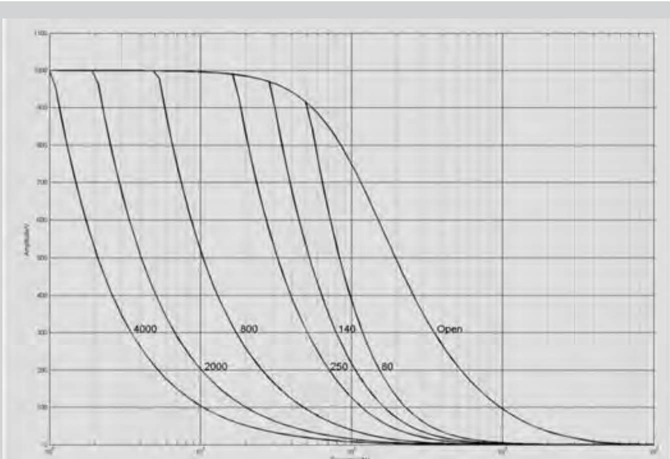
- **3 Powerful Channels**
- **Peak Power 3 x 25 W**
- **Output Voltage Range 0 to 1100 V**
- **3 LED Voltage Displays**
- **Precision DC-Offset Potentiometers for Input-Signal Bias & Manual Control**

The E-464 is a bench-top piezo driver/amplifier for PICA™ high-voltage PZTs. Its three low-noise, 4-quadrant amplifiers provide a gain of 100 and can output and sink a peak current of 25 mA and an average current of >3 mA each. If only 1 channel is operated, an average output power of 12 W can be achieved.

Three 3$^1/_2$-digit LED displays show the output voltage of each individual channel.

Analog Control

E-464 amplifiers are designed to provide precise control of open-loop piezo positioning systems. The amplifier output voltage is determined by the analog signal at the Control Input combined with the DC-offset potentiometer setting.



E-464: operating limits with various PZT loads, capacitance is measured in nanofarads

Computer Control

Optionally digital control via a D/A converter is possible. For several D/A boards from National Instruments PI offers a corresponding LabVIEW™ driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented HyperBit™ technology providing enhanced system resolution.

Ordering Information

E-464.00
HVPZT Piezo Amplifier,
3 Channels, 1100 V, Bench-Top

E-500.ACD
CD with Driver Set for Analog Controllers

E-500.HCD
HyperBit™ Functionality for Enhanced System Resolution
Supports certain D/A boards

Extension cables, adapters & connectors: see in "Accessories" (p. 2-168 *ff*)

Ask about custom designs!

Technical Data

Model	E-464.00
Function	Power amplifier for PICA™ high-voltage PZTs
Amplifier	
Output voltage	0 to +1100 V
Amplifier channels	3
Average output power per channel	>3.5 W (up to 12 W if 1 channel is operated)
Peak output power per channel, <5 ms	25 W
Average current per channel	>3.5 mA (up to 12 mA if 1 channel is operated)
Peak current per channel, <5 ms	25 mA
Amplifier bandwidth, small signal	1 kHz
Amplifier bandwidth, large signal	3.5 Hz (660 nF); 35 Hz (70 nF)
Ripple, noise 0 to 100 kHz	5 mV_{RMS} 50 mV_{P-P} (100 nF)
Current limitation	Short-circuit-proof
Voltage gain	+100 ±1
Control input voltage	0 to 11 V
Input impedance	100 kΩ
Interface and operation	
PZT voltage output socket	3 x LEMO EGG.0B.701.CJL1173
Control input socket	3 x BNC
DC Offset	3 x 10-turn pot, adds 0 to +10 V to Control IN
Display	3 x 3$^1/_2$-digit LED display for output voltages
Miscellaneous	
Operating voltage	100 to 120 or 220 to 240 VAC, selectable (fuse change required)
Operating temperature range	+5 to +50 °C (over 40 °C, max. av. power derated 10 %)
Mass	4.3 kg
Dimensions	236 x 88 x 273 mm + handles

E-712 Digital Piezo Controller

Modular System for up to 6 Axes with Highest Precision

E-712 digital controller for nanopositioning systems with up to 6 axes

- **Digital Controller of the Newest Generation: 600 MHz Tact Rate; up to 50 kHz Servo Update Rate; Highly Stable 20-bit D/A Converter**
- **Real-Time Operating System for Excellent Trajectory Control**
- **Modular Design for Greatest Flexibility in Meeting Custom Requirements**
- **Auto-Loading of Calibration Data from Stage ID-Chip for Interchangeability of Controller and Mechanics**
- **Versatile Interfaces: Ethernet, USB, RS-232**
- **Optional High-Bandwidth Analog Inputs and Outputs**
- **Extensive Software Support**

The E-712 digital piezo controller is ideal when it comes to meeting the most demanding accuracy and dynamic-performance requirements of multi-axis nanopositioning systems. The high-performance, real-time operating system makes possible coordinated servo-control of multiple axes (also in parallel-kinematics systems) and thus ensures excellent trajectory control even during complex motion. The modular design allows flexible confection of systems supporting the number of axes and channels required for the application. Flexibility in meeting customers' needs is also behind the interface design: The optional analog inputs and outputs support processing external sensor or control signals as well as driving external amplifiers.

Digital Linearization and Control Algorithms for Highest Accuracy

Linearization algorithms based on higher-order polynomials improve the positioning accuracy to 0.01 % of the travel range. The high-speed processor with a sensor sampling rate of 50 kHz, assures settling times in the millisecond range and below. The controller is perfectly suited for high-dynamic operation, thanks to its high-resolution DA-converters and high-performance voltage amplifiers.

More than just a Controller—Trajectory Control and Data Recording

During fast periodic motion, as typical for scanning applications, the tracking accuracy can be further improved with Dynamic Digital Linearization (DDL, E-710.SCN). This optionally available control algorithm reduces the tracking error by a factor of up to 1000.

This control algorithm enables the spatial and temporal tracking during a dynamic scan. The integrated wave generator can save and output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined profiles can be created. The flexibly configurable data recorder enables simultaneous recording and read-out of the corresponding data.

Flexible Analog Inputs

Four analog inputs allow different configurations. As Control In, the applied voltage is correlated to one of the motion axis e.g. to give a target value. Configured as the input line for an external sensor signal the inputs may be used for autofocusing instead of an integrated sensor.

Ordering Information

E-712.3CD
Modular Digital Multi-Channel Piezo Controller, 3 Channels, Capacitive Sensors

E-712.3CDA
Modular Digital Multi-Channel Piezo Controller, 3 Channels, Capacitive Sensors, Analog INs and OUTs

E-712.6CD
Modular Digital Multi-Channel Piezo Controller, 6 Channels, Capacitive Sensors

E-712.6CDA
Modular Digital Multi-Channel Piezo Controller, 6 Channels, Capacitive Sensors, Analog INs and OUTs

Ask about custom designs!

Options and Accessories

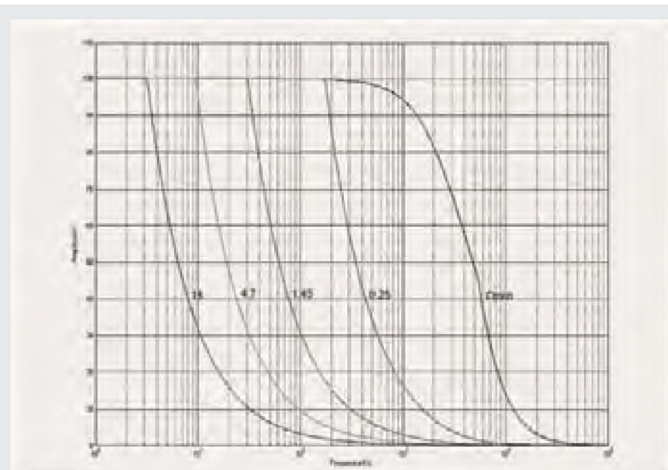
E-710.SCN
DDL (Dynamic Digital Linearization) Firmware Upgrade

E-711.i1B
Analog Cable for Analog I/O, BNC Connector, 1.5 m

E-711.i10
Analog Cable for Analog I/O, Solderable End, 1.5 m

Simple System Integration

All parameters can be checked and reset via software. System setup and configuration is done with the included NanoCapture™ and PIMikroMove™ user-interface software. Interfacing to custom software is facilitated with included LabVIEW drivers and DLLs.



E-712 operating limits with various PZT loads, capacitance is measured in µF

PI

System programming is the same with all PI controllers, so controlling a system with a variety of different controllers is possible without difficulty.

Model	E 712.3CD/E 712.3CDA	E 712.6CD/E 712.6CDA
Function	Modular digital controller for multi-axis piezo nanopositioning systems with capacitive sensors	Modular digital controller for multi-axis piezo nanopositioning systems with capacitive sensors
Axes	3	6
Processor	PC-based, 600 MHz, real-time operating system	PC-based, 600 MHz, real-time operating system
Sampling rate, servo-control	50 kHz	20 kHz
Sampling rate, sensor	50 kHz	20 kHz
Sensor		
Servo characteristics	P-I, two notch filters	P-I, two notch filters
Sensor type	Capacitive	Capacitive
Sensor channels	3	6
Sensor bandwidth (-3 dB)	5.6 kHz	5.6 kHz
Sensor resolution	16-bit	16-bit
Ext. synchronization	Yes	Yes
Amplifier		
Output voltage	-30 to +135 V	-30 to +135 V
Amplifier channels	4	8
Peak output power per channel	6 W	6 W
Average output power per channel	3.5 W	3.5 W
Peak current	140 mA	140 mA
Average current per channel	60 mA	60 mA
Current limitation	Short-circuit-proof	Short-circuit-proof
Resolution DAC	20-bit	20-bit
Interfaces and operation		
Communication interfaces	Ethernet, USB, RS-232	Ethernet, USB, RS-232
Piezo / sensor connector	Sub-D special	Sub-D special
Analog in/out	E-712.3CD: none E-712.3CDA: 4 x in, 4 x out (LEMO), ±10 V	E-712.6CD: none E-712.6CDA: 4 x in, 4 x out (LEMO), ±10 V
Digital in/out	MDR20; 2 x IN, 8 x OUT; TTL	MDR20; 2 x IN, 8 x OUT; TTL
Command set	PI General Command Set (GCS)	PI General Command Set (GCS)
User software	NanoCapture™, PIMikroMove®	NanoCapture™, PIMikroMove®
Software drivers	LabVIEW drivers, DLLs	LabVIEW drivers, DLLs
Supported functionality	Wave gen, trigger I/O	Wave gen, trigger I/O
Display	LEDs for OnTarget, Err, Power	LEDs for OnTarget, Err, Power
Linearization	4^{th} order polynomials, DDL option (Dynamic Digital Linearization)	4^{th} order polynomials, DDL option (Dynamic Digital Linearization)
Miscellaneous		
Operating temperature range	5 to 50 °C	5 to 50 °C
Overtemp protection	Max. 75 °C, deactivation of the piezo voltage output	Max. 75 °C, deactivation of the piezo voltage output
Mass	5.35 kg/5.53 kg	5.78 kg/5.96 kg
Dimensions	9,5" chassis, 236 x 132 x 296 mm + handles (47 mm length)	9,5" chassis, 236 x 132 x 296 mm + handles (47 mm length)
Power consumption	100 W max.	100 W max.
Operating voltage	90 to 240 VAC, 50-60 Hz	90 to 240 VAC, 50-60 Hz

E-500 · E-501 Modular Piezo Controller

Flexible System for Piezo Actuators and Nanopositioners

Configuration example: E-500 Chassis with optional modules: E-505 piezo amplifier (3 x), E-509.S servo-controller for SGS sensors, E-517.i3 24-bit interface / display module

Configuration example: E-501 chassis with optional modules: E-503 piezo amplifier, E-509.C2A servo-controller for capacitive position sensors, E-517.i3 24-bit interface / display module

- **Up to 3 Axes, Custom Systems up to 12 Axes and More**
- **Choice of Amplifier Modules for Low-Voltage and High-Voltage, 14 to 400 W Peak Power**
- **Choice of Position Servo Control Modules for SGS & Capacitive Sensors, 1 to 3 Channels**
- **Choice of PC Interface / Display Modules**
- **19- & 9½-Inch Chassis**

The E-500 modular piezo controller system offers a broad choice of control modules for nanopositoning systems and actuators. This includes piezo amplifier and position servo controller modules for up to three channels with different features as well as display and interface modules. Flexible configuration makes the system adaptable to a wide range of applications.

30-channel controller consisting of 3 E-500.621 chassis, each of which can accomodate up to 12 E-621 modules

E-500 systems are assembled to order, tested, and, if a servo-controller is present, calibrated with the associated piezo mechanics.

Remote Control via Computer Interface

Installing the E-517, computer interface/display module (see p. 2-156) with 24-bit resolution makes possible control from a host PC.

Optionally, digital control via an external D/A converter is possible. For several D/A boards from National Instruments, PI offers a corresponding LabVIEW driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented HyperBit™ technology providing enhanced system resolution.

Ordering Information

E-500.00
19"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

E-501.00
9½"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

E-500.ACD
LabVIEW Driver Set for Analog Controllers

E-500.HCD
HyperBit™ Functionality for Enhanced System Resolution (Supports Certain D/A Boards)

Ask about custom designs!

Two chassis are available:

The E-500.00 19'' rackmount chassis provides operating voltages for all compatible modules including amplifiers, servo-controllers, display and interface modules (see system configuration see p. 2-144).

Technical Data

Model	E-500.00	E-501.00
Function	19"-Chassis for Piezo Controller System: Amplifier Modules, Sensor- / Servo-Control Modules, Interface / Display Modules	9.5"-Chassis for Piezo Controller System: Amplifier Modules, Sensor- / Servo-Control Modules, Interface / Display Modules
Channels	1, 2, 3 (up to 3 amplifier modules)	1, 3 (1 amplifier module)
Dimensions	450 x 132 x 296 mm + handles	236 x 132 x 296 mm + handles
Operating voltage	90–264 VAC, 50–60 Hz	90–120 / 220–264 VAC, 50–60 Hz
Max. power consumption	180 W	80 W

E-500 · E-501 Modular Piezo Controller

Module Survey & Ordering Information

A more compact $9\frac{1}{2}$-inch version of the system is available as the E-501.00. It can hold one amplifier module (1- or 3-channel units available), one servo-control module (1- or 3-channel) and one display / interface module (1- or 3-channel).

A modified E-500 chassis for more channels is available on request. For systems with up to 12 channels, the E-500.621 chassis with E-621 amplifier / controller modules can be used (see p. 2-160).

The following modules can be installed in an E-500 / E-501 chassis:

Amplifier modules

E-503.00

Piezo Amplifier Module, -20 to 120 V, 3 Channels

E-504.00F

High-Power-Piezo Amplifier Module, 1 Channel, 280 W Peak Power, 100 W Average Power, -30 to 135 V

E-505.00

Piezo Amplifier Module, 200 W, -20 to 120 V, 1 Channel

E-508.00

HVPZT-Piezo Amplifier Module, +3 to +1100 V, 1 Channel

Sensor and Servo-Control Modules

E-509.C1A

Sensor / Piezo Servo-Control Module, Capacitive Sensor, 1 Channel

E-509.C2A

Sensor / Piezo Servo-Control Module, Capacitive Sensors, 2 Channels

E-509.C3A

Sensor / Piezo Servo-Control Module, Capacitive Sensors, 3 Channels

E-509.S1

Sensor / Piezo Servo-Control Module, SGS Sensor, 1 Channel

E-509.S3

Sensor / Piezo Servo-Control Module, SGS-Sensors, 3 Channels

E-509.E3 (see p. 2-152)

PISeca™ Sensor / Piezo Servo-Control Module for Single-Electrode Capacitive Sensor Probes, 3 Channels

E-509.E03 (see p. 2-152)

PISeca™ Modular Signal Conditioner Electronics for Single Electrode Capacitive Sensors, 3 Channels

Module for Servo-Control for External Piezo Amplifier

E-515.E3

In- / Output Module for Servo Control with External Piezo Amplifier, 3 Channels
Note: this module can only be used together with an E-509 servo controller module and is installed in the amplifier slot

Interface / Display Modules

E-517.i1

Interface / Display Module, 24-Bit D/A, TCP / IP, USB, RS-232, 1 Channel

E-517.i3

Interface / Display Module, 24-Bit D/A, TCP / IP, USB, RS-232, 3 Channels

E-515.01

Display Module for Piezo Voltage and Displacement, 1 Channel

E-515.03

Display Module for Piezo Voltage and Displacement, 3 Channels


E-508, p. 2-150


E-505, p. 2-147


E-503, p. 2-146


E-515, p. 2-154


E-517, p. 2-156

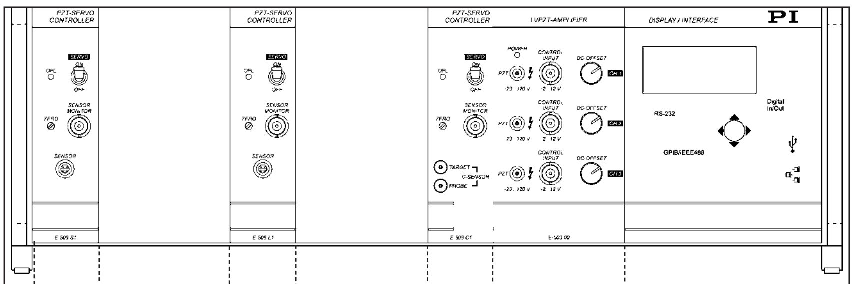

E-509, p. 2-152

E-500 · E-501 Modular Piezo Controller

System Configuration

E-500, 19” Chassis Models

E-501, 9.5” Chassis



E-500 chassis with the following optional modules: E-503 LVPZT amplifier, three E-509 piezo servo-controllers (E-509.S1: strain gauge; E-509.C1A: capacitive sensor) and DAC interface/display.

	Contr. Slot 3	Amplifier Slot 3	Contr. Slot 2	Amplifier Slot 2	Contr. Slot 1	Amplifier Slot 1	Display/ Interface Slot
Installable Amplifier Modules							
E-503.00 (-20 to 120 V, 3 ch) / E-503.00S*						◩	
E-504.00 (-30 to 135 V, 1 ch) / E-504.00S*		■		■		◩	
E-505.00 (-20 to 120 V, 1 ch) / E-505.00S*		■		■		◩	
E-508.XX (+3 to 1100 V, 1 ch)		■		■		◩	
Installable Sensor & Position Servo-Control Modules							
E-509.C1A (Capacitive, 1 ch)	■		■		◩		
E-509.S1 (SGS, 1 ch)	■		■		◩		
E-509.C2A (Capacitive, 2 ch)					◩		
E-509.C3A (Capacitive, 3 ch)					◩		
E-509.S3 (SGS, 3 ch)					◩		
Installable Display/Interface Modules							
E-515 (1 / 3 ch)							◩
E-517 (1 / 3 ch)							◩
Minimal Configuration, Piezo Amplifier Function only		■		■		◩	
Extended Configuration, Piezo Amplifier with additional Position Servo-Controller	■	■	■	■	◩	◩	
Extended Configuration, Piezo Amplifier with additional Display/Interface, no Servo-Controller		■		■		◩	◩
Extended Configuration, Piezo Amplifier with additional Servo-Controller and Display/Interface	■	■	■	■	◩	◩	◩

■ Can be installed in E-500 ◩ Can be installed in E-501 or E-500

* For differential tip/tilt systems with one fixed voltage of +100 V.

PI

Configuration Examples

- **Low-Voltage Piezo Amplifiers, 3 Channels (14 W), Medium Dynamics, No Display:**

  1 x E-501.00
  9½"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

  1 x E-503.00
  Piezo Amplifier Module, -20 to 120 V, 3 Channels

- **High-Voltage Piezo Amplifier for PICA™, 3 Channels, with PC Interface and Display:**

  1 x E-500.00
  19"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

  3 x E-508.00
  HVPZT-Piezo Amplifier Module, +3 to +1100 V, 1 Channel

  1 x E-517.i3
  Interface / Display Module, 24 Bit D/A, TCP/IP, USB, RS-232, 3 Channels

- **High-Voltage Piezo Amplifier / Servo-Controller (Strain Gauge Sensors), 3 Channels, with PC Interface and Display:**

  1 x E-500.00
  19"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

  3 x E-508.00
  HVPZT-Piezo Amplifier Module, +3 to +1100 V, 1 Channel

  1 x E-509.S3
  Sensor / Piezo Servo-Control Module, SGS-Sensors, 3 Channels

  1 x E-517.i3
  Interface / Display Module, 24 Bit D/A, TCP/IP, USB, RS-232, 3 Channels

- **Position Feedback Control of a P-734.2CL XY Nanopositioning Stage (Capacitive Position Sensors), Minimum Response Time, Analog Control:**

  1 x E-500.00
  19"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

  2 x E-505.00
  Piezo Amplifier Module, 200 W, -20 to 120 V, 1 Channel

  1 x E-509.C2A
  Sensor / Piezo Servo-Control Module, Capacitive Sensors, 2 Channels

- **Position Feedback Control of a P-733.2CL XY Nanopositioning Stage (Capacitive Position Sensors) and P-721.CLQ PIFOC® Objective Positioner (Capacitive Position Sensor), Medium Dynamics, PC Control, Compact Design:**

  1 x E-501.00
  9½"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

  1 x E-503.00
  Piezo Amplifier Module, -20 to 120 V, 3 Channels

  1 x E-509.C3A
  Sensor / Piezo Servo-Control Module, Capacitive Sensors, 3 Channels

  1 x E-517.i3
  Interface / Display Module, 24 Bit D/A, TCP/IP, USB, RS-232, 3 Channels

- **Position Feedback Control of a S-325 Tip/Tilt Platform (Strain Gauge Sensors), Minimum Response Time, Analog Control:**

  1 x E-500.00
  19"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

  2 x E-505.00
  Piezo Amplifier Module, 200 W, -20 to 120 V, 1 Channel

  1 x E-505.00S
  Offset Voltage Supply for Tip/Tilt Systems, One Fixed Voltage of +100 V

  1 x E-509.S3
  Sensor / Piezo Servo-Control Module, SGS-Sensors, 3 Channels

- **Position Feedback Control of a P-733.2CL XY Nanopositioning Stage (Capacitive Position Sensors) and a P-721.SL2 PIFOC® Objective Positioner (Strain Gauge Position Sensor), Minimum Response Time, Analog Control:**

  1 x E-500.00
  19"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

  3 x E-505.00
  Piezo Amplifier Module, 200 W, -20 to 120 V, 1 Channel

  1 x E-509.C2A
  Sensor / Piezo Servo-Control Module, Capacitive Sensors, 2 Channels

  1 x E-509 .S1
  Sensor / Piezo Servo-Control Module, SGS Sensor, 1 Channel

- **Position Feedback Control of 3 P-841.10 Piezo Translators (Strain Gauge Position Sensors), Medium Dynamics, Analog Control, with Future Upgrade Option for High-Power, High-Dynamics Amplifiers E-505 (Large Chassis):**

  1 x E-500.00
  19"-Chassis for Modular Piezo Controller System, 1 to 3 Channels

  1 x E-503.00
  Piezo Amplifier Module, -20 to 120 V, 3 Channels

  1 x E-509.S3
  Sensor / Piezo Servo-Control Module, SGS-Sensors, 3 Channels

  Option:

  1 x E-515.03
  Display Module for Piezo Voltage and Displacement, 3 Channels

E-503 Piezo Amplifier Module

3 Channels, for E-500 Piezo Controller System

E-503.00 Piezo amplifier module

- **Module for E-500 Piezo Controller Rack**
- **3 x 14 W Peak Power**
- **Output Voltage Range -20 to 120 V**
- **Prepared for Position Servo-Control Upgrade (optional)**
- **Prepared for Interfaces / Display Modules (optional)**

The E-503 is a piezo driver module for low-voltage piezo actuators and positioners. It contains three independent amplifiers that can output and sink a peak current of 140 mA in the -20 to 120 V voltage range. For frequency response with selected capacitive loads, see graph below. The piezo amplifier module is designed to work in the E-500 Controller system (see p. 2-142).

The units are designed to provide high-resolution operation of piezo actuators and positioning systems in voltage-controlled mode (open-loop) and optionally in position-controlled mode (closed-loop).

Modular Design for Flexibility: Optional Servo Controller Upgrade

The E-503 amplifier module can be installed in the E-500 / E-501 controller chassis. The modular design makes the E-500 piezo controller system very flexible. An optional E-509 piezo servocontroller module can be installed along with the E-503 amplifier module, for closed-loop piezo position control. In this configuration, the E-503 output voltage is set by the servo-control loop.

Voltage Controlled Piezo Positioning

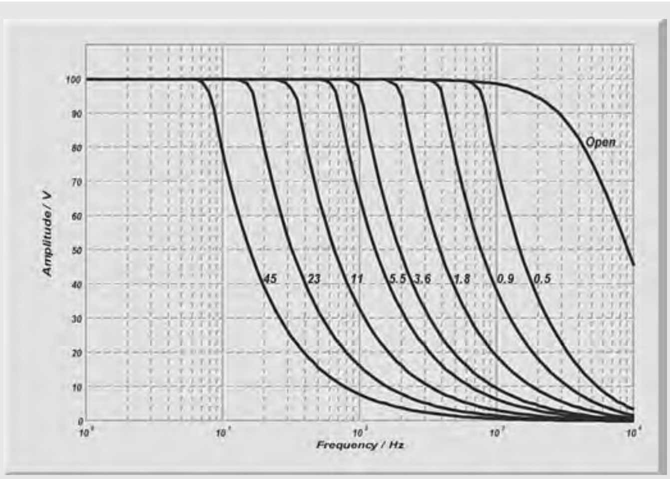
In open-loop (voltage-controlled) piezo operation the amplifier output voltage is determined by an analog signal at the Control Input optionally combined with the DC-offset potentiometer. Open-loop operation is ideal for applications where fast response and very high resolution with maximum bandwidth are essential. Here, commanding and reading the target position in absolute values is either not important or carried out by external position sensors. The precision 10-turn potentiometer can also be used alone to set the output voltage manually.

Bestellinformation

E-503.00
Piezo Amplifier Module,
-20 to 120 V, 3 Channels

E-503.00S
Piezo Amplifier Module,
-20 to 120 V, 3 Channels,
Modified E-503.00 for S-330, S-334, S-340 Tip/Tilt Systems, with
One Fixed Voltage of +100 V,
Two Variable Voltages

Ask about custom designs



E-503: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Technical Data

Model	E-503.00	E-503.00S
Function	Power amplifier	Power amplifier
Channels	3	2
Amplifier		
Control input voltage range	-2 to +12 V	-2 to +12 V
Output voltage	-20 bis 120 V	-20 bis 120 V; one additional fixed voltage of +100 V
Peak output power per channel	14 W	14 W
Average output power per channel	6 W	6 W
Peak current per channel, <5 ms	140 mA	140 mA
Average current per channel, >5 ms	60 mA	60 mA
Current limitation	Short-circuit-proof	Short-circuit-proof
Voltage gain	10 ±0.1	10 ±0.1
Input impedance	100 kΩ / 1 nF	100 kΩ / 1 nF
Interfaces and operation		
Piezo connector	LEMO ERA.00.250.CTL	LEMO ERA.00.250.CTL
Analog input	BNC	BNC
DC Offset	10-turn pot., adds 0 to 10 V to Control In	10-turn pot., adds 0 to 10 V to Control In
Miscellaneous		
Operating temperature range	5 to 50 °C	5 to 50 °C
Overheat protection	Deactivation at 85 °C	Deactivation at 85 °C
Dimensions	14HP/3U	14HP/3U
Mass	0.9 kg	0.9 kg
Operating Voltage	E-500 System	E-500 System
Max. power consumption	30 W	30 W

PI

E-505 Piezo Amplifier Module

High Power, E-500 Piezo Controller System

E-505.00 is a high-performance amplifier module for the piezo servo-controller system E-500

tors and positioning systems in voltage-controlled mode (open-loop) and optionally in position-controlled mode (closed-loop). For switching applications the E-505.10 version provides a peak output current of up to 10 A.

For frequency response with selected capacitive loads, see graph below.

Ordering Information

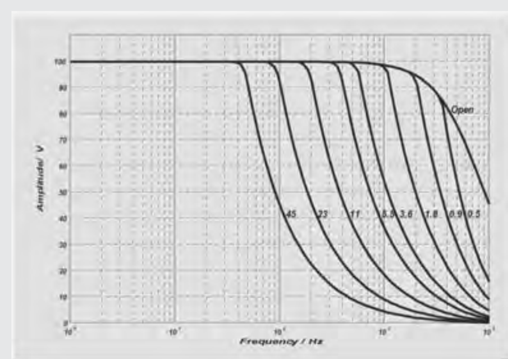
E-505.00
Piezo Amplifier Module, 200 W, -20 to 120 V, 1 Channel

E-505.10
Piezo Amplifier Module for Switching Applications, 1000 W, -20 to 120 V, 1 Channel

E-505.00S
Offset Voltage Supply for Tip/Tilt Systems, One Fixed Voltage of +100 V

- **200 W Peak Power**
- **Output Voltage Range -20 to 120 V**
- **Module for E-500 Piezo Controller Rack**
- **Prepared for Position Servo-Control Upgrade (optional)**
- **Prepared for Interfaces / Display Modules (optional)**

The E-505 piezo amplifier module is designed to work in the E-500 Controller system (see p. 2-142). It features a low-noise, high-power amplifier for low-voltage piezo actuators and positioners, that can output and sink a peak current of up to 2000 mA in the -20 to 120 V voltage range. The E-505 units are designed to provide high-resolution operation of piezo actua-



E-505: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Technical Data

Model	E-505.00	E-505.10	E-505.00S
Function	Power amplifier	Power Amplifier for Switching Applications*	Offset Voltage Supply for Tip/Tilt Systems
Channels	1	1	1
Amplifier			
Control input voltage range	-2 to +12 V	-2 to +12 V	–
Output voltage	-20 to +120 V	-20 to +120 V	100 V
Peak output power	200 W (<5 ms)	1000 W (<200 µs)	200 W (<5 ms)
Average output power	30 W	30 W	30 W
Peak current	2 A (<5 ms)	10 A (<200 µs)	2 A (<5 ms)
Average current	300 mA	300 mA	300 mA
Current limitation	Short-circuit-proof	Short-circuit-proof	Short-circuit-proof
Noise, 0 to 100 kHz	<0.7 mVrms	1.0 mVrms	<0.7 mVrms
Voltage gain	12 ±0.1	12 ±0.1	–
Input impedance	1 MΩ / 1 nF	1 MΩ / 1 nF	–
Interfaces and operation			
Piezo connector	LEMO ERA.00.250.CTL	LEMO ERA.00.250.CTL	LEMO ERA.00.250.CTL
Analog input	BNC	BNC	–
DC-Offset	10-turn pot., adds 0 to 10 V to Control In	10-turn pot., adds 0 to 10 V to Control In	–
Miscellaneous			
Operating temperature range	+5 to +50 °C	+5 to +50 °C	+5 to +50 °C
Overheat protection	Deactivation at +85 °C	Deactivation at +85 °C	Deactivation at +85 °C
Dimensions	14HP/3U	14HP/3U	14HP/3U
Mass	0.9 kg	0.9 kg	0.9 kg
Operating Voltage	E-500 System	E-500 System	E-500 System
Max. power consumption	45 W	45 W	45 W

* For piezo actuators with special high-current layout

Modular Design for Flexibility: Optional Servo Controller Upgrade

Up to three E-505 amplifier modules can be installed in one E-500 chassis. The flexible, modular design of the E-500 piezo servo-controller system allows easy installation of an optional E.509 sensor- / servo-controller module for closed-loop operation. The output voltage is then set by the servo-control loop. Closed-loop piezo mechanics from PI can provide positioning accuracy and repeatability down to the nanometer range and below.

E-504 Piezo Amplifier Module

High Power through Energy Recovery, E-500 Piezo Controller System

E-504.00F High-power amplifier module with energy recovery

- Peak Power 280 W
- High Average Output Power 100 W
- Very Energy Efficient Through Energy Recovery
- Output Voltage Range -30 to 130 V
- Module for E-500 Piezo Controller Rack
- Prepared for Position Servo-Control Upgrade (optional)
- Prepared for Interface / Display Modules (optional)

The E-504 power amplifier extends the E-500 modular piezo controller system with a high-output amplifier for low-voltage actuators and positioners.

The innovative, efficient energy recovery circuitry reduces power consumption and heat dissipation, especially in dynamic applications. This makes possible peak output currents up to 2000 mA and a peak power of 280 W, with an average output power of up to 100 W.

Working Principle

Charge is transferred to the piezo actuator using low-loss PWM techniques. When the actuator is discharged, the energy not consumed is fed through the energy recovery circuitry for reuse in the next charging cycle.

The working principle of the E-504 series is perfectly qualified for high-dynamics scanning and switching applications. For applications where static position stability in the sub-nanometer range is essential, the E-505 (see p. 2-147) amplifier module is recommended.

Modular Design for Flexibility: Optional Servo-Controller Upgrade

Up to three E-504 amplifier modules can be installed in one E-500 controller chassis. The flexible, modular design of the E-500 piezo controller system allows easy installation of an optional E-509 sensor- / servo-controller module for closed-loop operation. The output voltage of the E-504 is then set by the servo-control loop. Closed-loop piezo mechanics from PI can provide positioning accuracy and repeatability down to the nanometer range and below.

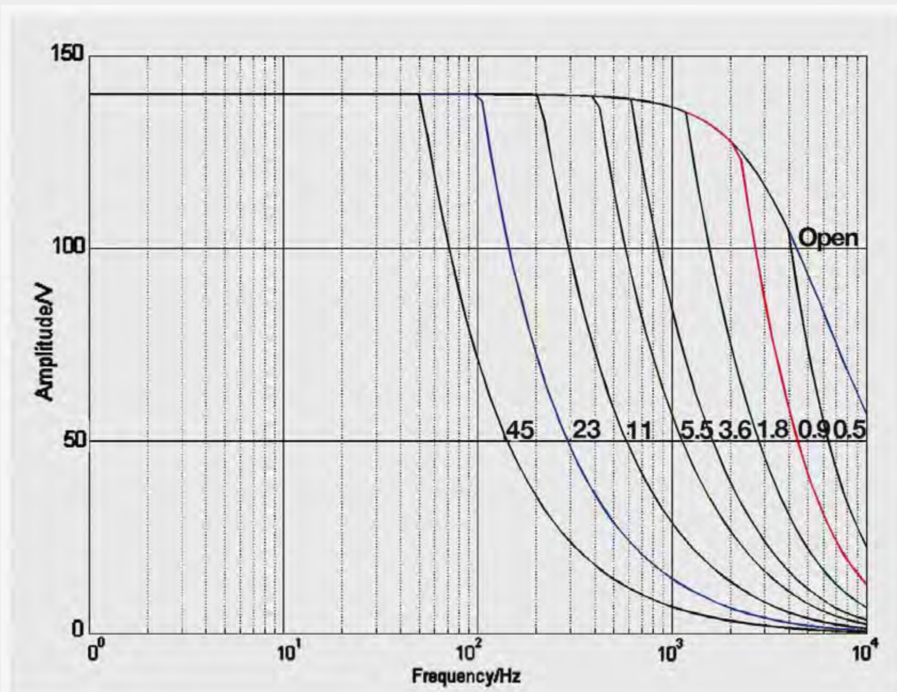
Open-Loop Operation

In open-loop (voltage-controlled) piezo operation the amplifier output voltage is determined by an analog signal at the Control Input, optionally combined with the DC-offset potentiometer. Open-loop operation is ideal for applications where fast response and very high resolution with maximum bandwidth are essential. Here, commanding and reading the target position in absolute values is either not important or carried out by external position sensors. The precision 10-turn potentiometer can also be used alone to set the output voltage manually.

The same functionality and specifications are available in the E-617 amplifier module. (see p. 2-112).

Ordering Information

E-504.00F
High-Power-Piezo Amplifier Module, 1 Channel, 280 W Peak Power, 100 W Average Power, -30 to 130 V



E-504: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Technical Data

Model	E-504.00F
Function	Power amplifier with energy recovery, 1 channel
Amplifier	
Control input voltage range	-2 to +12 V
Output voltage	-30 V to 130 V
Peak output power <5 ms	280 W
Average output power	Equivalent to 100 W reactive power
Peak output current <5 ms	2000 mA
Average current	1000 mA
Current limitation	Short-circuit-proof
Voltage gain	10 ±0.1
Ripple, noise, 0 to 100 kHz	5 mV_{RMS} 20 mV_{P-P}
Output impedance	0,5 Ω / 2,5 µF
Interfaces and operation	
Piezo connector	LEMO ERA.00.250.CTL
Analog input	SMB
DC-Offset	10-turn pot., adds 0 to +10 V to Control In
Miscellaneous	
Operating temperature range	+5 to +50°C
Dimensions	One 14T slot wide, 3H high
Mass	0.9 kg
Operating voltage	E-500 System
Max. power consumption	<30 W

E-506 Linearized Piezo Amplifier

Charge Control for High Dynamics

E-506.10 charge-controlled Piezo driver module

- **Highly Linear Amplifier Module**
- **280 W Peak Power**
- **Output Voltage Range -30 to 130 V**
- **Module for E-500 Piezo Controller Rack**
- **Prepared for Position Servo-Control Upgrade (optional)**
- **Prepared for Interfaces / Display Modules (optional)**

The E-506.10 piezo amplifier module uses a charge control principle. Here, the input signal controls the amount of electrical charge which is transferred to the piezo actuator. The result is a highly precise, linear displacement of the piezo actuator in high-dynamics operation.
The typical hysteresis which piezo actuators show when operated with a voltage-controlled piezo amplifier can such be reduced to 2 % only. An additional position feedback is not required.
The E-506.10 piezo amplifier module is designed to work in the E-500 Controller system (s. p. 2-142). It features a low-noise high-power amplifier for low-voltage piezo actuators and positioners, that can output and sink a peak current of up to 2A in the -30 to 130 V voltage range.

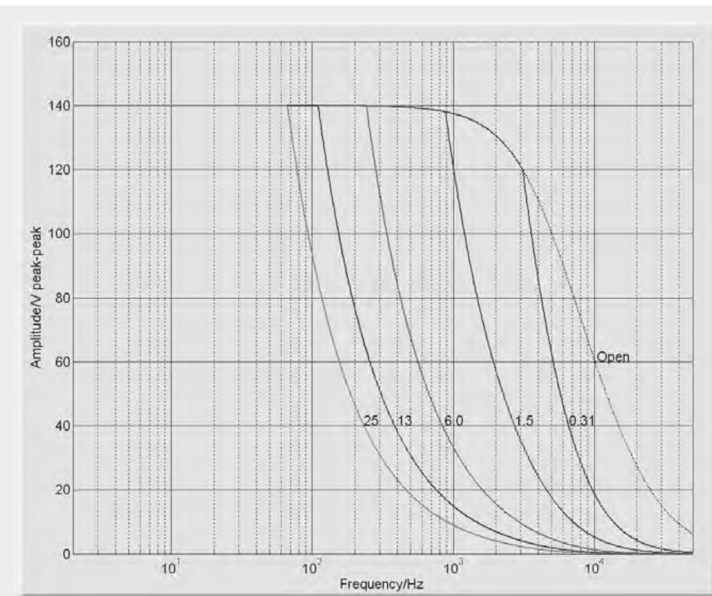
Ordering Information

E-506.10
High Linearity Piezo Amplifier Module, 30 W Average Output Power, -30 to 130 V, 1 Channel

Ask about custom designs!

Piezo Over Temperature Protection

The E-506 can evaluate a temperature sensor on the piezo actuator in order to protect the actuators, especially when used in dynamic applications. Automatic switch-off then reliably prevents the pre-set temperature threshold from being exceeded.
For frequency response with selected capacitive loads, see graph below.



E-506.10: operating limits with various PZT loads (open-loop), capacitance is measured in μF.
The minimum capacitive load is 0.3 μF

Technical Data

Model	E-506.10	
Function	Linearised amplifier module, charge-controlled	
Channels	1	
Amplifier		
Input voltage	-2 to +12 V	
Output voltage*	-30 to 130 V	
Peak output power, < 2.5 ms	280 W	max.
Average output power	30 W	max.
Peak current, < 2.5 ms	2 A	
Average current	215 mA	
Current limitation	Short-circuit-proof	
Ripple, noise	<0.6 mV_{rms}	
Reference capacitance (adjustable)	1 to 280 µF	
Input impedance	1 MΩ / 1 nF	
Interfaces and operation		
Piezo connector (voltage output)	LEMO 2-pin EGG.0B.302.CLL	
Analog input	BNC	
DC Offset	10-turn pot., adds 0 to 10 V to Control In	
Piezo temperature sensor (input)	PT 1000; LEMO socket; deactivation of the piezo voltage output at 150°C	
Miscellaneous		
Operating temperature range	+5 to +50 °C	
Dimensions	14HP / 3U	
Mass	0.9 kg	
Operating voltage	E-500 System	
Power consumption	55 W	max.

* Max. 85 °C, deactivation of the piezo voltage output (internal overtemp protection)

Minimum frequencies* for charge-controlled operation

Capacitance (piezo actuator)	ftrans
0.33 µF	250 mHz
1.06 µF	80 mHz
6.2 µF	9 mHz
14 µF	4 mHz

* Voltage-controlled operation for lower frequencies

E-508 PICA™ Piezo Amplifier Module

High-Power Module with 1100 V Output Voltage, E-500 Piezo Controller System

E-508.00 Piezo amplifier plug-in module

- **Peak Power up to 400 W**
- **Output Voltage Range 3 to ±1100 V or bipolar**
- **Plug-In Module for E-500 System**
- **E-508.OE for Switching Applications**
- **Prepared for Position Servo-Control Upgrade (optional)**
- **Prepared for Interfaces / Display Modules (optional)**

The E-508 plug-in module is a piezo driver / amplifier for the E-500 / E-501 piezo controller systems suitable for PICA™ piezo actuators (HVPZT). Its low-noise, 4-quadrant amplifiers can output and sink peak currents of 50 mA (E-508.OE: up to 400 mA) over an 1100 V range. The units are designed to provide high-resolution operation of piezo actuators and positioning systems in voltage-controlled mode (open-loop) and optionally in position-controlled mode (closed-loop).

Modular Design for Flexibility: Optional Servo Controller Upgrade

Up to three E-500 piezo amplifier modules can be installed in one E-500 chassis. The flexible, modular design of the E-500 piezo controller system allows easy installation of an optional E.509 sensor- / servo-controller module for closed-loop operation. The output voltage is then set by the servo-control loop. Closed-loop piezo mechanics from PI can provide positioning accuracy and repeatability down to the nanometer range and below.

Voltage Controlled Piezo Positioning

In open-loop (voltage-controlled) piezo operation the amplifier output voltage is determined by an analog signal at the Control Input optionally combined with the DC-offset potentiometer. Open-loop operation is ideal for applications where fast response and very high resolution with maximum bandwidth are essential. Here, commanding and reading the target position in absolute values is either not important or carried out by external position sensors (see p. 2-104). The precision 10-turn potentiometer can also be used alone to set the output voltage manually.

OEM Version for Fast Switching Applications

The E-508.OE is the high-current OEM version, especially designed for switching applications. It can output a peak current of 400 mA for 5 ms. The E-508.OE is directly controlled by an analog signal.

For extensions, adapter cables and connectors, see "Accessories" in the piezo electronics chapter (see p. 2-168 *ff*).

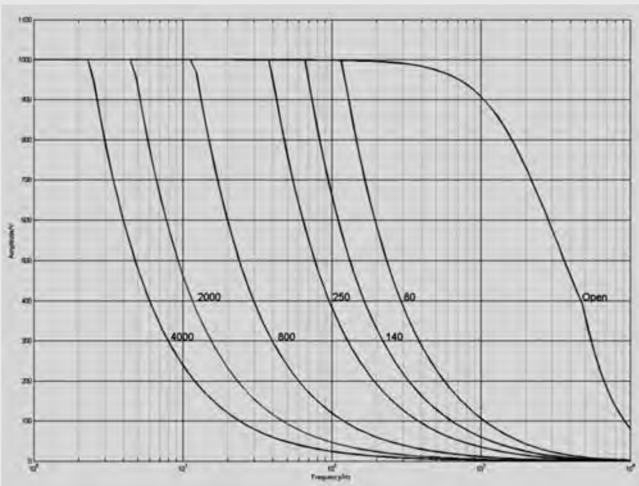
Ordering Information

E-508.00
HVPZT Piezo Amplifier Module, +3 to +1100 V, 1 Channel

E-508.OE
HVPZT Piezo Amplifier Module, OEM Version, 400 mA Peak Current

Ask about custom designs!

The E-508.00 plug-in module (right) and the E-508.OE, OEM module optimized for switching applications



E-508: operating limits with various PZT loads (open-loop), capacitance is measured in nF

Technical Data

Model	E-508.00	E-508.OE	Unit
Function	Power amplifier for PICA™ high-voltage piezos	Power amplifier for PICA™ high-voltage piezos	
Amplifier			
Output voltage	3 to +1100 (Standard) (-260 to +780 -550 to +550 +260 to -780 -3 to -1100) (jumper selectable)	3 to +1100 (Standard) (-260 to +780 -550 to +550 +260 to -780 -3 to-1100) (factory-settable)	V
Amplifier channels	1	1	
Average output power	13	13	W
Peak output power, <5 ms	50	400	W
Average current	12	12	mA
Peak current, <5 ms	50	400	mA
Amplifier bandwidth, small signal	6	10	kHz
Amplifier bandwidth, large signal	50 (200 nF)	50 (200 nF)	Hz
Ripple, noise 0 to 100 kHz	5 50 (100 nF)	20 200 (100 nF)	mV_{RMS} mV_{P-P}
Current limitation	Short-circuit-proof	Short-circuit-proof	
Voltage gain	+100 ±1, -100 ±1 (selectable)	+100 ±1, -100 ±1 (selectable)	
Control input voltage	Servo off: ±1/100 of selected output range Servo on: 0 to 10 V	Servo off: ±1/100 of selected output range Servo on: 0 to 10 V	
Input impedance	100	100	kΩ
Interfaces and operation			
Piezo voltage output	LEMO EGG.0B.701.CJL.1173	LEMO EGG.0B.701.CJL.1173	
Input	BNC	SMB	
DC-Offset	10-turn pot., adds 0 to 10 V to Control In	–	
Miscellaneous			
Operating voltage	E-500 System	E-500 System	
Operating temperature range	+5 to +50 °C (10 % derated over 40 °C)	+5 to +50 °C (10 % derated over 40 °C)	°C
Mass	0.75	0.75	kg
Dimensions	14 HP/3 U	14 HP/3 U	

PI

E-509 Signal Conditioner / Piezo Servo Module

3-Channel Servo-Controller Module for E-500 Piezo Controller System

E-509 3-channel servo-controller module for nanopositioning systems with strain gauge sensors

Ordering Information

E-509.C1A
Sensor / Piezo Servo-Control Module, Capacitive Sensor, 1 Channel

E-509.C2A
Sensor / Piezo Servo-Control Module, Capacitive Sensors, 2 Channels

E-509.C3A
Sensor / Piezo Servo-Control Module, Capacitive Sensors, 3 Channels

E-509.S1
Sensor / Piezo Servo-Control Module, SGS Sensor, 1 Channel

E-509.S3
Sensor / Piezo Servo-Control Module, SGS-Sensors, 3 Channels

Ask about custom designs!

- **Position Servo-Control for Piezo Mechanics with SGS or Capacitive Sensors**
- **1-, 2- and 3-Channel Versions**
- **Improves Linearity**
- **Eliminates Drift and Hysteresis**
- **Notch Filter for Higher Bandwidth**
- **Increases Piezo Stiffness**
- **ILS Circuitry Maximizes Capacitive Sensor Linearity**
- **Plug-In Module for E-500 System**
- **Prepared for Interfaces / Display Modules (optional)**

The E-509 module is both a signal conditioner for high-resolution capacitive and SGS displacement sensors and a servo-controller for closed-loop piezo nanopositioning mechanics. It compensates for the drift and hysteresis inherent in PZT materials and quickly adjusts the operating voltage on the PZT as soon as a change in force or load occurs. Single- and multi-channel versions for strain gauge and capacitive sensors are available.

Nanometer-Precise Piezo Positioning

The proportional-integral (P-I) algorithm used by the E-509 servo-controller is optimized for piezo operation. Both P and I parameters as well as the control bandwidth can be set internally. The integrated notch filters (adjustable for each axis) improve the stability and allow high-bandwidth operation closer to the piezomechanics' resonant frequency. Closed-loop piezo mechanics from PI can provide positioning accuracy and repeatability down to the nanometer range and below.

Two Types of Sensors

PI employs proprietary position sensors for fast response and optimum positioning resolution and stability in the nanometer range and below. For high-end applications, capacitance sensors provide direct and non-contact position feedback (direct metrology). Strain gauge sensors (SGS) are available for cost-effective applications.

For PISeca™ single-plate high-resolution capacitive sensors (see p. 3-8), the E-509.E3 or E-509.E03 versions are available (see p. 2-152).

The E-509 controller module installed in an E-501 9½-inch chassis together
with E-516 digital interface and E-503 three-channel amplifier modules

Technical Data

Model	E-509.C1A/E-509.C2A/E-509.C3A	E-509.S1/E-509.S3
Function	Signal conditioner & servo-controller for piezo mechanics	Signal conditioner & servo-controller for piezo mechanics
Channels	1/2/3	1/3
Sensor		
Servo characteristics	P-I (analog), notch filter	P-I (analog), notch filter
Sensor type	Capacitive	SGS
Sensor channels	1 / 2 /3	1 / 3
Sensor bandwidth	0.3 to 3 kHz (selectable with jumper); up to 10 kHz on request	0.3; 1; 3 kHz
Noise factor	0.115 ppm/Hz½	
Thermal drift	<0.3 mV / C°	<3 mV / C°
Linearity	<0.05 %	<0.2 %
Interfaces and operation		
Sensor connection	LEMO EPL.00.250.NTD	LEMO ERA.0S.304.CLL
Sensor monitor output	0–10 V	0–10 V
Sensor monitor socket	LEMO 6-pin FGG.0B.306.CLAD56	BNC (1-ch.) / 3-pin. LEMO (3-ch.)
Supported functionality	ILS (Integrated Linearization System)	ILS (Integrated Linearization System)
Display	Overflow LED	Overflow LED
Miscellaneous		
Operating temperature range	+5 to +50 °C	+5 to +50 °C
Dimensions	7HP/3U	7HP/3U
Mass	0.35 kg	0.35 kg
Operating Voltage	E-500 System	E-500 System
Max. power consumption	4 to 8 W	4 to 8 W

E-515 Display Module for Piezo Controllers

Voltage and Displacement Display for E-500 Piezo Controller System

Ordering Information

E-515.01
Display Module for Piezo Voltage and Displacement, 1 Channel

E-515.03
Display Module for Piezo Voltage and Displacement, 3 Channels

The E-515.03 displays piezo voltage or displacement for up to three channels

- **3½-digit Display for Voltage and Position**
- **1- & 3-Channel Versions**
- **Plug-In Module for E-500 System**

The E-515.01 and E-515.03 are one and three channel display modules for piezo voltage and displacement data. Toggle switches for each channel select voltage or displacement mode. The voltage / displacement range for each channel is internally set by jumpers and trimmers.

The display module is designed to work in the E-500 piezo controller system (see p. 2-142).

Technical Data

Model	E-515.01	E-515.03
Function	Display Module for Piezo Voltage and Position	Display Module for Piezo Voltage and Position
Channels	1	3
Display linearity	0.1 %	0.1 %
Display	1 x 3½ digits	3 x 3½ digits
Dimensions	21HP/3U	21HP/3U
Mass	0.3 kg	0.3 kg
Operating voltage	E-500 System	E-500 System

E-515.E3 Servo In-/Output Module

Servo Control with External Piezo Amplifier, E-500 Piezocontroller System

The E-515.E3 plug-in module makes analog in- and output lines available on the front panel

Ordering Information

E-515.E3
In- / Output Module for Servo Control with External Piezo Amplifier, 3 Channels

- **Servo Control Connection for up to 3 External Piezo Amplifiers**
- **For Use with E-509 Servo-Controller in E-500 or E-501 Rack**
- **Easy-To-Use BNC Connectors**
- **High-Resolution, 10-Turn, DC-Offset Potentiometers**

The E-515.E3 servo in/out module allows easy connection of up to 3 external piezo amplifiers to an E-509 position servo-controller module, when installed in the modular E-500 or E-501 piezo controller rack.

BNC connections for control input and servo output (to the amplifier) are available on the front panel.

The analog control input signals can be shifted manually by 0 to 10 V with a high-resolution 10-turn, DC-offset potentiometers.

Together with the E-509 sensor & servo controller module positioning accuracy and repeatability down to the sub-nanometer range is possible, depending on the piezo mechanics and amplifier used.

Interface for Computer Control

Installing the E-517, computer interface/display module with 24-bit resolution makes possible control from a host PC.

Optionally, digital control via a D/A converter is possible. For several D/A boards from National Instruments, PI offers a corresponding LabVIEW™ driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patented Hyperbit™ technology providing enhanced system resolution.

Technical Data

Models	E-515.E3
Function	In- / Output Module for Servo Control with External Piezo Amplifier, 3 Channels
Control input voltage range	0 to 10 V in closed-loop operation with E-509
Servo Output Voltage Range	-2 to 12 V
Bandwidth	10 kHz
Current limitation	Short-circuit-proof
Input impedance	10 kΩ/1 nF
Interfaces and operation	
Control input sockets	3 x BNC
Servo-control output socket	3 x BNC
DC offset	3 x 10-turn pot., adds 0 to +10 V to Control In
Miscellaneous	
Operating voltage	E-500 system
Operating temperature range	+5 to +50 °C
Mass	280 g
Dimensions	One 7T slot wide, 3H high

E-517 Digital Piezo Controller Operation Module

Wave Generator, Data Recorder, Display, Multiple Interfaces, for E-500 System

The E-517 piezo display and D/A converter module, provides USB and TCP/IP connectivity

- **Low-Noise 24-bit D/A Converter**
- **Sample Rate 25 kHz**
- **TCP/IP, USB, IEEE 488 and RS-232 Interfaces**
- **6-Digit Display for Voltage and Position**
- **1- & 3-Channel Versions**
- **Wave Generator with Programmable Trigger-I/O**
- **Module for E-500 Piezo Controller Rack**

The E-517 is a microprocessor controlled interface and display module for the E-500 piezo controller system (see p. 2-142). It is equipped with low-noise, 24-bit D/A converters and can be controlled through four digital interfaces: TCP/IP, USB, RS-232 and IEEE 488 (GPIB).

Alternatively, stand-alone operation is possible by uploading macro command sequences to the internal non-volatile memory. For manual control a trackball interface is provided. An LCD display indicates position or operating voltages of the individual channels / axes.

Wave Generator

The integrated wave generator can output periodic motion profiles. In addition to sine and triangle waves, arbitrary, user-defined motion profiles can be created and stored.

Extensive Software Support

The controllers are delivered with Windows operating software. Comprehensive DLLs and LabVIEW drivers are available for automated control.

Ordering Information

E-517.i1
Interface / Display Module,
24 Bit D/A, TCP/IP, USB, RS-232,
Single Channel

E-517.i3
Interface / Display Module,
24 Bit D/A, TCP/IP, USB, RS-232,
3 Channels

Ask about custom designs!

PI

Technical Data

Model	E-517.i1	E-517.i3
Function	Digital operation module	Digital operation module
Channels	1	3
Processor	DSP 60 MHz	DSP 60 MHz
Sampling rate, sensor	25 kHz, 8-times oversampling	25 kHz, 8-times oversampling
Thermal drift	Stability: 0.2 mV	Stability: 0.2 mV
Linearity @ nominal range	0.01 %	0.01 %
Resolution	DAC: 24 bit, ±12 V ADC: 18 bit, sampling	DAC: 24 bit, ±12 V ADC: 18 bit, sampling
Interfaces and operation		
Interfaces/communication	Ethernet (TCP/IP), USB, RS-232, IEEE 488	Ethernet (TCP/IP), USB, RS-232, IEEE 488
I/O ports	1 trigger input 1 trigger output 5 V MDR14 connector	3 trigger inputs 3 trigger outputs 5 V MDR14 connector
Command set	PI General Command Set (GCS)	PI General Command Set (GCS)
User software	PIMikroMove™	PIMikroMove™
Software drivers	Lab VIEW drivers, Windows and Linux Libraries (DLL)	Lab VIEW drivers, Windows and Linux Libraries (DLL)
Supported functionality	Wave generator, data recorder, macro programming	Wave generator, data recorder, macro programming
Display	LCD display for monitor signals (position and voltage), states and trackball menus	LCD display for monitor signals (position and voltage), states and trackball menus
Manual control	Operation via trackball	Operation via trackball
Miscellaneous		
Operating temperature range	+5 to +50° C	+5 to +50° C
Dimensions	21HP / 3U	21HP / 3U
Mass	0.37 kg	0.37 kg
Operating voltage	E-500 system	E-500 system

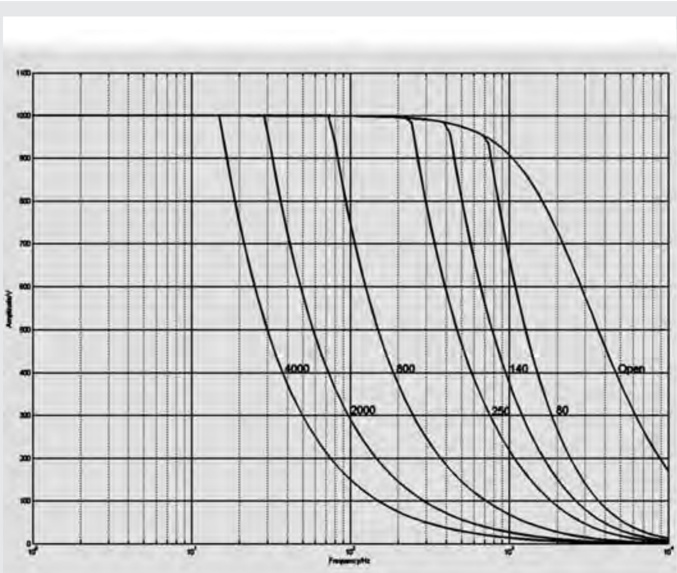
E-470 – E-472 / E-421 PICA™ Piezo Controller

Modular High-Power Amplifier/Controller

E-471 Configuration example: E-471.20 HVPZT amplifier, with optional E-509 PZT servo-controller and E-516 20-bit DAC interface/display

- **Peak Power 550 W**
- **Output Voltage 3 to 1100 V or Bipolar**
- **Optional Position Servo-Control Modules**
- **Optional 20-Bit Computer Interface Module & Display**
- **Precision DC-Offset Potentiometer for Input-Signal Bias & Manual Control**

The E-470 series high-power piezo amplifiers/controllers are specifically designed to drive high-capacitance PICA™ PZT actuators. They are based on the E-421 four-quadrant amplifier module, which can output and sink a peak current of 500 mA and an average current of 100 mA in a voltage range of 3 to 1100 V (jumper selectable bipolar range also provided). 3 standard configurations are available:



E-421, E-470, E-471, E-472: operating limits with various PZT loads, capacitance is measured in nanofarads

- E-470.20 is a bench-top amplifier in a 9.5" chassis for open-loop operation (1 channel)
- E-471.20 is the amplifier module in a 19" rackmount chassis that can hold additional servo-control, interface and display modules
- E-472.20 is a 2-channel version in a 19" rackmount chassis for dynamic open-loop operation

These amplifiers can be used to drive open and closed-loop piezo positioning systems.

Open Loop Piezo Operation

For open-loop piezo operation the amplifier output voltage is determined by the analog signal at the Control Input combined with the DC-offset potentiometer setting. Open-loop operation is ideal for applications where the fastest response and the highest bandwidth are essential. Here, commanding and reading the target position in absolute values is either not important or carried out by an external feedback loop.

Optional Servo Controller Upgrade

The E-471.20 version allows easy installation of an optional E-509 sensor- / servo-controller module for closed-loop piezo position control. In this mode the amplifier is slaved to the E-509 servo controller. Depending on the attached piezo mechanics and feedback sensor, positioning accuracy and repeatability in the nanometer range and below are feasible.

Computer Control

The E-517 computer interface/display module can also be installed in the E-471 / E-472.

Optionally digital control via a D/A converter is possible. For several D/A boards from National Instruments PI offers a corresponding LabVIEW™ driver set which is compatible with the PI General Command Set (GCS), the command set used by all PI controllers. A further option includes the patent-

Ordering Information

E-470.20
HVPZT Piezo Amplifier, 550 W, 1100 V, Bench-Top

E-471.20
HVPZT Piezo Amplifier, Controller & Interface / Display Upgrade possible, 550 W, 1100 V, Bench-Top, 19"

E-472.20
HVPZT Piezo Amplifier, 2 Channels, 550 W, 1100 V, Bench-Top, 19"

E-421.00
HVPZT Piezo Amplifier Module, 550 W, 1100 V, Integrated P / S

Upgrades for E-471.20

Sensor / Position Servo-Control Modules

E-509.C1A
Sensor / Servo-Controller Module, Capacitive Sensor

E-509.S1
Sensor / Servo-Controller Module, SGS - Sensor

Computer Interface & Display Modules

E-517.i1
Interface- / Display Module, 24 Bit D/A, TCP/IP, USB, RS-232, 1 Channel

E-515.01
Display Module for PZT Voltage and Position

E-500.ACD
CD with Driver Set for Analog Controllers

E-500.HCD
Hyperbit™ Functionality for Enhanced System Resolution

Supports certain D/A boards.

Extension cables, adapters & connectors: see in "Accessories" in the "Piezo Drivers / Servo Controllers" (page 2-168 *ff*).

Ask about custom designs!

ed HyperBit™ technology providing enhanced system resolution.

Please read details on Calibration Information (see p. 2-103).


E-421.00 HVPZT piezo amplifier module

Technical Data

Model	E-470.20, E-471.20, E-472.20, E-421.00
Function	Power amplifier for PICA™ high-voltage PZTs (servo-controller option for E-471)
Amplifier	
Output voltage	3 to +1100 V (default) (Selectable -260 to +780 V -550 to +550 V +260 to -780 V -3 to -1100 V)
Amplifier channels	1 (E-472: 2)
Average output power	110 W
Peak output power, <5 ms	550 W
Average current	100 mA
Peak current, <5 ms	500 mA
Amplifier bandwidth, small signal	DC to 3 kHz, related to load capacitance, see operating limits graph
Amplifier bandwidth, large signal	DC to 3 kHz, related to load capacitance, see operating limits graph
Ripple, noise 0 to 100 kHz	<25 mV_{RMS} 100 mV_{P-P} (200 nF)
Current limitation	Short-circuit-proof
Voltage gain	+100 ±1, -100 ±1 (selectable)
Control input voltage	Servo off: ±1/100 of selected output range Servo on: 0 to 10 V
Input impedance	100 kΩ
Interfaces and operation	
PZT voltage output	LEMO EGG.0B.701.CJL1173
Control input	BNC
DC Offset	10-turn pot., adds 0 to +10 V to Control IN
Miscellaneous	
Operating voltage	100-120 or 220-240 VAC, selectable (fuse change required)
Operating temperature range	+5 to +50 °C (over 40 °C, max. av.) power derated 10 %
Mass	5.2 kg (E-470); 7.6 kg (E-471); 10.1 kg (E-472); 2.5 kg (E-420)
Dimensions	236 x 132 x 296 mm + handles (E-470) 450 x 132 x 296 mm + handles (E-471, E-472) 215 x 123 x 185 mm (E-420)

E-621 Piezo Servo-Controller & Driver

Modules with Fast 24-Bit Interface

E-621.CR module

- **Integrated 24-Bit USB Interface**
- **Network Capability with up to 12 Channels**
- **Up to 12 W Peak Power**
- **Position Control with Strain Gauge or Capacitive Sensor**
- **Notch Filter for Higher Bandwidth**
- **Additional Analog Interface**
- **Table for User-Defined Curves**

The E-621 is equipped with an RS-232 and USB interface and precision 24-bit converters for exceptional positional stability and resolution. It integrates a low-noise piezo amplifier which can output and sink peak currents of 120 mA for low-voltage piezoelectric actuators. Servo-controller versions for position sensing with capacitive or SGS sensors are available.

Closed-Loop and Open-Loop Piezo Positioning

The E-621 controller module provides precision control of piezo actuators and positioning systems both in closed-loop and open-loop operation. The piezo controllers comprise additional circuitry for position sensing and servo-control. Displacement of the piezo is controlled by an analog signal. Positioning accuracy and repeatability down to the sub-nanometer range is possible, depending on the piezo mechanics and sensor type. High-resolution position sensors provide optimum positional stability and fast response in the nanometer range. Capacitive sensors measure position directly and without physical contact (direct metrology). Alternatively compact cost-effective strain gauge sensors (SGS) are available. The integrated notch filters (adjustable for each axis) improve stability and allow high-bandwidth operation closer to the resonant frequency of the mechanics.
In open-loop operation the output voltage is determined by an external analog signal. Open-loop operation is ideal for applications where fast response and very high resolution with maximum bandwidth are essential. Here, commanding and reading the target position in absolute values is either not important or carried out by external position sensors.

High-Resolution Digital Interface

The digital interface includes high-precision 24-bit A/D converters for optimum position stability and resolution and supports fast communication with the host-computer.

Multi-Axis Network for up to 12 Channels

Up to twelve E-621s for capacitive or SGS sensors can be networked and controlled over a single PC interface. The different modules are connected in parallel (not daisy-chained) over the link. Only an additional 10 ms internal bus communications time is required to reach any of the units behind the one actually connected to the host PC.

Waveform Memory

The built-in wave table can store user-defined data points internally. These values can then be output automatically (or under the control of an external signal) and programmed for point-by-point or full-scan triggering. Thus, trajectory profiles can be repeated reliably and commanded easily.

Software / GCS Command Set

The E-621 controller comes with Windows installation software, DLLs and LabVIEW drivers. The extensive command set is based on the hardware-independent General Command Set (GCS), which is common to all current PI controllers for both nano- and micropositioning systems. GCS reduces the programming effort in the face of complex multi-axis positioning tasks or when upgrading a system with a different PI controller.

Ordering Information

E-621.CR
Piezo Amplifier / Servo-Controller Module, 1 Channel, -30 to 130 V, Capacitive Sensor, USB, RS-232

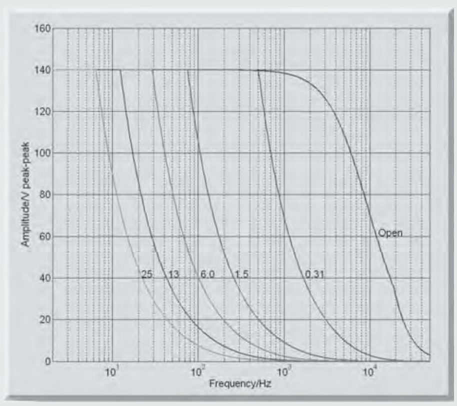
E-621.SR
Piezo Amplifier / Servo-Controller Module, 1 Channel, -20 to 120 V, SGS-Sensor, USB, RS-232

E-500.621
19“-Chassis for up to twelve E-621 Modules, Power Supply

E-501.621
9,5“-Chassis for up to four E-621 Modules, Power Supply

E-625 (top), E-665 and 12 x E-621 in an E-500 chassis (bottom)

PI



E-621.CR: operating limits with various PZT loads (open-loop), capacitance is measured in µF

Technical Data

Model	E-621.SR / E-621.CR
Function	Power amplifier & piezo controller
Sensor	
Servo characteristics	P-I (analog), notch filter
Sensor type	SGS (.SR) / capacitive (.CR)
Amplifier	
Control input voltage range	-2 to 12 V
Output voltage	-20 to 120 V / -30 to 130 V
Peak output power, <5 ms	12 W
Average output power	6 W
Peak current, <5 ms	120 mA
Average current	60 mA
Current limitation	Short-circuit-proof
Noise, 0 to 100 kHz	0.8 mV_{rms}
Voltage gain	10 ±0.1
Input impedance	100 kΩ
Interfaces and operation	
Interface / communication	USB, RS-232 (9-pin Sub-D connector, 9.6–115.2 kBaud), 24-bit A/D, 20-bit D/A
Piezo connector	LEMO ERA.00.250.CTL (.SR) / Sub-D special (.CR)
Sensor connection	LEMO EPL.0S.304.HLN (.SR) / Sub-D special (.CR)
Analog input	SMB
Sensor monitor output	SMB
Controller network	up to 12 channels, parallel
Command set	PI General Command Set (GCS)
User software	PIMikroMove™
Software drivers	LabVIEW drivers, DLLs
Supported functionality	Wave table, 256 data points, external trigger, 16 macros
DC Offset	External potentiometer (not included), adds 0 to + 10 V to Control In
Miscellaneous	
Operating temperature range	+5 °C to +50 °C (10 % derated over 40 °C)
Overheat protection	Deactivation at 75 °C
Dimensions	7HP/3U
Mass	0.6 kg
Operating Voltage	12 to 30 V DC, stabilized
Current consumption, max.	2 A

E-612 Piezo Controller Module / System

1- to 4-Channel System with High-Speed Parallel Port

E-612 module, E-661 desktop device and E-501.10 chassis (power supply included) for up to four E-612 modules

Ordering Information

E-612.C0
Piezo Controller with High-Speed Parallel Interface, OEM Module, -20 to 120 V, Capacitive Sensor

E-501.10
9,5"-Chassis for up to 4 E-612.C0 Modules, incl Power Supply

- **10 µs High-Speed Parallel Command Port**
- **Additional Analog Interface**
- **For Piezo Stages with Capacitive Sensors**
- **Notch Filter for Higher Bandwidth**
- **Integrated Piezo Power Amplifier**
- **Versatile Design: Module for Multi-Channel Chassis or Single-Channel Bench-Top Device (E-661)**

The fast E-612 piezo controller module is designed for nanopositioning systems with integrated capacitive position feedback sensors. It possesses a low-noise integrated piezo amplifier providing -20 to 120 V with 80 mA sink and source capability.

High-Speed Interface

The controller features a high-speed parallel command port with optical coupled inputs and extra low-noise, linear, 16-bit D/A converters. Real-time position feedback is realized via a special trigger option. Additionally a broadband analog interface is installed (0 to 10 V).

Nanometer Resolution in Milli-Seconds

This high-performance controller is designed for nanopositioning tasks with highest precision and maximum turnover. Positioning with nanometer precisions and settling times of a few milliseconds are achieved in combination with the P-726 objective positioners (see p. 2-32) or P-753 LISA™ actuators (see p. 2-16). More and more high-tech branches require "nanometer accuracy within milliseconds". This is the case in microscopy/pharmaceutical research or quality testing for read/write heads, where every millisecond saved raises the throughput and helps reduce costs.

Single and Multi-Channel Systems

Up to four E-612.C0 piezo controller modules can be installed in one E-501.10 chassis. An internal address bus allows control of all modules over a single parallel command port. The E-612 is also available in a compact, single-channel bench-top version (model E-661.CP). It comes with a metal case for EMI protection and an external power supply (see p. 2-116).

PI

Technical Data (Controller)

Model	E-612.C0
Function	High-Speed Piezo Controller Module
Channels	1
Capacitive sensor circuit	
Clock frequency	1.6 MHz
Bandwidth	1.5 kHz
Amplifier	
Output voltage	-20 to +120 V
Average output power	8 W
Average current	80 mA
Current limitation	short-circuit proof (5 minutes to shutdown)
Bandwidth (no load)	>500 Hz
Digital circuit	
Data	16-bit
Input level	TTL
Timing	THmin 10 µs; TLmin 10 µs
Input current	10 mA
On-target indication	On: target position ±0.025 % to 0.2 %, jumper-selectable
Analog input / output	
Control input voltage	-2 to 12 V
Input impedance	27 kΩ, 1 nF
Sensor monitor output	
Voltage range	-12 to +12 V (jumper-selectable)
Output impedance	10 Ω (10 nF)
Bandwidth	1.5 kHz
Connectors	
Digital interface	25-pin sub-D
Piezo	LEMO ERA.00.250
Sensor	LEMO EPL.00.250
Sensor monitor output	SMB
Analog input	SMB
Power consumption	+5 V, 0.12 A, ± 15 V, 0.16 A, +130 V, 80 mA max.; -27 V, 80 mA max
Dimensions	Euroboard (64-pin rear connector. Mating extender card: Mod. P-896.00)

Technical Data (Chassis & Power Supply)

Model	E-501.10
Function	Chassis for 1–4 E-612.C0 piezo controller modules
Operating voltage	90–120 VAC, 50–60 Hz; 220–264 VAC, 50–60 Hz
Power Supply	linear regulated power supply, integrated
P/S Output voltages	+130 V, 0.2 A; -27 V, 0.2 A; +24 V, 1 A; ±15 V, 0.5 A; +5 V, 1 A
Max. power consumption	50 W
Primary fuse	0,63 A slow
Dimensions	236 x 132 x 296 mm + handles

E-831 Piezo Driver

OEM Module, Power Supply for up to 3 Axes

E-831.03 amplifier module.

- **Cost Effective Piezo Driver**
- **Small Size**
- **Low Noise, High Stability**
- **Easy-to-Use**
- **Full Overcurrent, Short-Circuit and Temperature Protection**
- **Power-up/down Without Voltage Spikes**

The E-831.03 OEM piezo driver module is a very compact, cost-effective, single-channel, 4-quadrant power amplifier for low-voltage piezoelectric actuators.

It provides a peak output power of 12 W and average power of 2 W (expandable to 5 W with external heat sink). The E-831.03 is a high-precision amplifier with a fixed gain of 10.0 and outputs voltages in the range of -20 to 120 V for control input signals ranging from of -2 to 12 V. The output is fully compensated for the capacitive loads of up to 10 µF typical of PI's low-voltage PZTs such as PICMA® piezo actuators. For monitoring purposes, the output voltage is internally divided by 100 and provided at a special monitor pin.

Because piezo actuators require virtually no power in steadystate operation and the power consumption depends on the operating frequency, high-powered amplifiers are not required for many applications. With a peak output current of 100 mA (sink/source) the E-831 is well-suited for switching applications and fast transitions where the capacitive load (the piezo actuator) needs to be charged as quickly as possible. The small-signal bandwidth is about 3 kHz.

E-841.05 power supply module

Power Supplies for E-831.03

The E-841.05 (input voltage range 10 to 30V) and E-842.05 (input voltage range 30 V to 72 V) switched power supply modules provide all the operating voltages (±15 V, -26 V and +127 V DC) required by the E-831.03 amplifier module. Both models supply enough power for up to three E-831.03 amplifiers with a total output power of 5 W.

A sync. input on the power supply allows synchronization of the internal switching frequency with an external clock (185 to 220 kHz) for elimination of interference in AC-driven position sensors or DACs.

Easy Implementation

E-831 and E-841/E-842 modules are enclosed in metal cases with solderable pins for PCB mounting. They are designed to work together without additional components.

Triple Safety

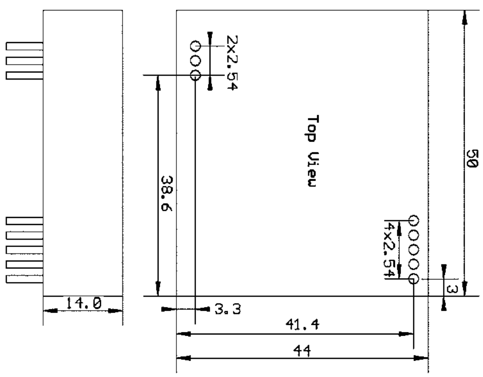
The E-831 amplifier is short-circuit proof with both a low-speed current limiter of 50 mA and a high-speed (8 msec) current limiter of 100 mA. When the case temperature rises above 70 °C (can be reached after a few minutes with maximum current) an internal temperature sensor shuts down the output stage until the temperature drops below 60 °C. This operation mode is indicated by the active-high TEMP-OFL TTL status line.

Ordering Information

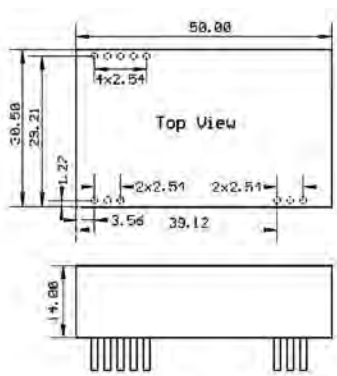
E-831.03
Single-Channel Piezo Driver Module for LVPZTs

E-841.05
Power Supply Module for E-831, Input 10 to 30 V

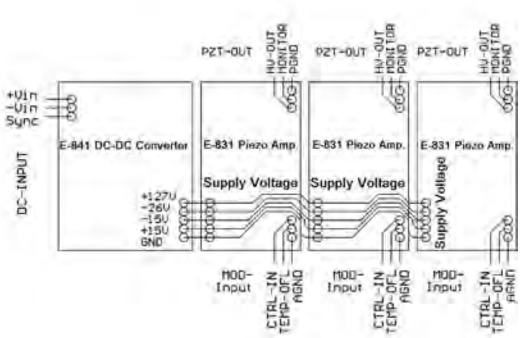
E-842.05
Power Supply Module for E-831, Input 30 to 72 V



Tiny: E-841.05/E-842.05 dimensions in mm.



Tiny: E-831.03 dimensions in mm, decimal places separated by commas in drawings.



Scheme for a three-channel amplifier consisting of an E-841 power supply and three E-831 amplifiers.

Technical Data E-831.03

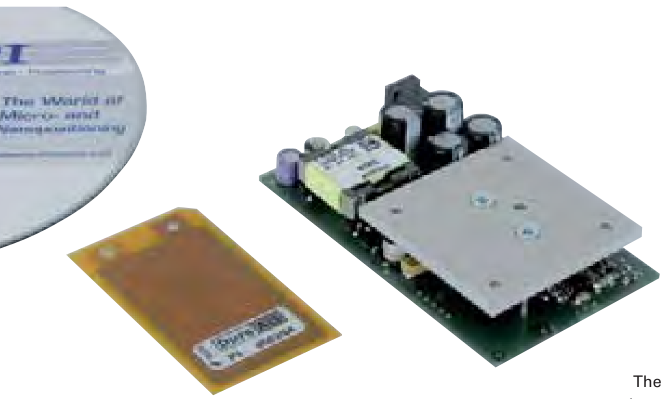
Models	E-831.03
Function:	Single-channel piezo amplifier module
Output voltage range:	from [U+ - 6 V] (121 V for U+ = 127 V) to [U- + 8 V] (-20 V for U- = 28 V)
Gain	10 ±0.1
Max. output current:	100 mA for 8 ms (sink/source)
Max. average current:	50 mA for 2 min without heatsink
Output protection:	short-circuit protected, the module is overload protected to 70 °C case temperature
Max. output power:	2 W without ext. heatsink 5 W with ext. heatsink or forced airflow
Control input range:	-2 to +12 V
Input impedance:	100 kΩ
Dynamic current requirements:	depend on load, amplitude and slew rate
Cut off frequency:	3.5 kHz, no load
Operating temperature range:	+5° to +50° Celsius
Operating voltages: (all currents without dynamic load)	+15 V / 20 mA (14 to16 V) -15 V / 7 mA (-14 th -16 V) +127 V / 1.8 mA +125 to 135 V) -26 V / 1.8 mA (-24 to -30 V)
Case	Metal shielded case, size: 50 x 30 x 14 mm
Soldering pins	1 mm diameter, 4 mm length

Technical Data E-84x.05

Models	E-841.05, E-842.05
Function:	Power Supply Module for E-831
Output voltages:	+127 V, 30 mA; -26 V, 30 mA; +15 V, 60 mA; -15 V, 20 mA
Max. output Power:	8 W
Max. average Power	8 W with forced air flow (5 W without)
Output protection:	short-circuit protected (1 min.)
Input voltage:	10 - 30 V (E-841.05); 30 - 72 V (E-842.05)
Quiescent current:	100 mA @15 V; 60 mA @30 V; 25 mA @72 V
Max. input current:	1000 mA (E-841.05 @ 10V); 200 mA (E-842.05 @ 72V)
Power-on, peak current:	1500 mA
Switching frequency	100 kHz typical
External clock frequency:	200 kHz (185 - 220 kHz possible)
Synchronization signal:	preferred TTL-level with duty cycle 50 %; operating from 1.8 V_{pp} and offsets within ±7 V
Output ripple:	<100 mV_{pp}
Operating temperature range:	5° to +50° Celsius (with power derating above 40 °C)
Case	Metal shielded case, size: 50 x 44 x 14 mm
Soldering pins	1 mm diameter, 4 mm length

E-835 DuraAct™ Piezo Driver Module

Bipolar Operation for Piezoelectric Patch Transducers



The E-835.00 piezo amplifier module for P-876 DuraAct™ patch transducers provides 30 W of power in a very compact package

- **OEM Module for DuraAct™ Piezoelectric Patch Transducers**
- **Peak Power to 30 W**
- **Output Voltage Range -100 to +250 V**
- **High Bandwidth >4 kHz**
- **Compact: 87 x 50 x 21 mm**
- **Can be Used to Drive PicaShear™ Piezo Shear Actuators**

Ordering Information

E-835.00
OEM Piezo Amplifier for DuraAct™ Patch Transducer

Ask about custom designs!

The powerful, cost-effective E-835 OEM piezo amplifier module is designed for driving the P-876 DuraAct™ piezo patch transducers. It provides a peak output power of 30 W with a peak current of 120 mA in the semi-bipolar voltage range (-100 V/+250 V). The continuous output power is rated at 3 W.

This compact piezo amplifier module supplies adequate power for a broad range of DuraAct™ patch transducer applications, e. g. active vibration damping, structure monitoring and stabilization.

Voltage-Controlled Piezo Operation

The E-835 piezo driver module provides precision control for DuraAct™ Patch Transducers both in static and dynamic operation. Its output voltage is determined by an external analog signal in the -4 to +10 V-range applied to the respective input.

Operation / Contents of Delivery

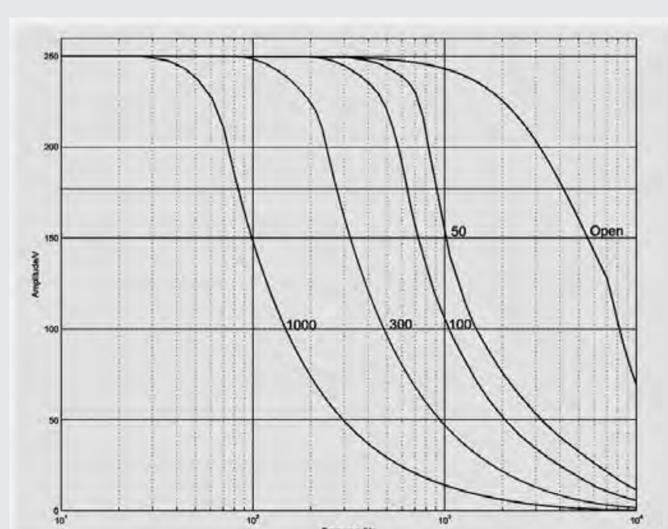
The required electrical power can be supplied by a commercial 12 V-power supply (not included). An integrated DC/DC converter provides the piezo voltage and other voltages required internally. All inputs and outputs are on solder pads.

The E-835 piezo amplifier module is also suitable for operating PICA™ Shear piezo actuators at about 60 % of the nominal maximum displacement.

Read the general considerations on piezo amplifiers.

Adaptive Structures with Piezo Patch Transducers

P-876 DuraAct™ patch trans ducers combine the actuatorand sensor functionality of piezoceramic materials. Used as a bender or contraction actuators, they provide high deflection with high force and precision. Other possible DuraAct™ operation modes are as high-dynamics sensor (e. g. for structural health monitoring) or as energy harvesters.



E-835.00: frequency response with various PZT loads (250 V, open-loop), capacitance is measured in nF

Model	E-835.00
Function	Power amplifier for DuraAct™ piezo patch transducers
Channels	1
Amplifier	
Input voltage	-4 to 10 V
Output voltage	-100 to 250 V
Peak output power	30 W (<15 ms)
Average output power	3 W
Peak current	120 mA (<15 ms)
Average current	40 mA
Current limitation	Short-circuit-proof
Voltage gain	25
Amplifier bandwidth, small signal	4.2 kHz (60 nF)
Amplifier bandwidth, large signal	4.2 kHz (unloaded); 500 Hz (60 nF)
Ripple, noise, 20 MHz	2 mV_{pp}
Output impedance	33 Ω
Amplifier resolution	<10 mV
Input impedance	100 kΩ
Interfaces and operation	
Piezo voltage	Soldering pads
Control input	Soldering pads
Piezo voltage monitor	Soldering pad, 1:100
Miscellaneous	
Operating temperature range	+5 °C to +50 °C (10 % derated over 40 °C)
Overheat protection	Deactivation at 100 °C
Dimensions	87 x 50 x 21 mm
Mass	67 g
Operating voltage	12 V / 1.7 A; 5.5 mm – barrel connector
Max. power consumption	20 W

Accessories

Cables, Connectors & Adapters for LVPZT Piezo Translators and Nanopositioning Systems

Notes

Unless stated otherwise, PI LVPZT translators and Nanopositioners are equipped with LEMO connectors and 1 m cables. The voltage connector is an FFS.00.250.CTCE24 as shown on the P-890 cable (Fig. 2). The sensor connector is an FFA.0S.304.CLAC32 as shown on the P-892 cable (p. 2-170, Fig. 9). Standard insulation materials are Teflon for the voltage cable and PUR for the sensor cable.

Fig. 1. P-891.xx LVPZT extension cable

P-891.xx LVPZT Extension Cable (Fig. 1)

Plug (left): LEMO FFS.00.250.CTCE31
Socket (right):

LEMO PCS.00.250.CTL.CTME31
Cable: RG 174 (PVC)
P-891.01 1 m
P-891.02 2 m
P-891.03 3 m
P-891.05 5 m
P-891.10 10 m

Fig. 2. P-890 LVPZT cable LEMO/ solderable end

P-890 LVPZT Cable LEMO/ Solderable End (Fig. 2)

Plug: FFS.00.250.CTCE24
(fits LVPZT amplifiers, e.g. E-505.00)
Cable: RG 178 (Teflon)
This cable can be soldered to PZTs with pigtails
P-890.10 1 m
P-890.20 5 m

Fig. 3. P-893.10 BNC adapter cable

P-893.10 LVPZT/BNC Adapter Cable (Fig. 3)

LEMO Plug / BNC female, adapter cable
Cable: RG 174 (PVC), 1 m
Plug: LEMO FFS.00.250.CTCE31 (male) and BNC.ST.250.NTAE31.
Allows LVPZT amplifier output voltage (e.g. E-505, etc.) to be connected to an oscilloscope, etc.

Fig. 4. P-210.20 BNC-cable

P-210.20 BNC Cable (Fig. 4)

BNC plug / solderable end.
Cable: RG 174 (PVC), 1 m. This cable can be soldered to PZTs with pigtails

Fig. 5. P-894.10 LVPZT adapter

P-894.10 LVPZT Adapter (Fig. 5)

LEMO plug / 2 x LEMO socket, adapter
Type: FTL.00.250.CTF with 1 x plug (right), 2 x socket (left, center). Allows two cables with LEMO FFS.00.250 male plugs to be connected to a device with LEMO 00.250 socket (e.g. E-505.00 amplifier module) or P-891 extension cable.

Fig. 6. P-894.30 BNC adapter

P-894.30 BNC/LVPZT Adapter (Fig. 6)

LEMO socket / BNC female, adapter
Type: ABA.00.250.NTL
Allows a cable with LEMO FFS.00.250 male plug to be attached to a device with BNC socket (e.g. direct operation of an LVPZT from a signal generator).

Accessories

Cables, Connectors & Adapters for PICA™ HVPZT Piezo Translators and Nanopositioning Systems

Notes

Unless stated otherwise, PI's preloaded PICA™ HVPZT piezo translators and nanopositioners are equipped with LEMO connectors and 1 m PVC cables. The voltage connector is an FGG.0B.701.CJL.1173. With integrated P-177.10 strain gauge, an additional sensor cable is installed. The length of the sensor cable is 1 m, the material PUR and the connector a LEMO FFA.0S.304.CLAC32 as shown on the P-892 cable (see page 2-170, Fig. 9).

Fig. 7. P-202 PICA™ HVPZT cable

P-202.xx PICA™ HVPZT Cable
LEMO plug / solderable end

Plug: FGG.0B.701.CJL.1173 (fits PICA™ HVPZT amplifiers, e.g. E-508.00)

Cable with PUR insulation, 2-conductor, shielded

This cable can be soldered to PZTs with pigtails

P-202.06	0.6 m
P-202.10	1 m
P-202.12	2 m
P-202.13	3 m
P-202.15	5 m

Fig. 8. P-203 extension cable for PICA™ HVPZTs

P-203.xx PICA™ HVPZT
Extension Cable

Plug: FGG.0B.701.CJL.1173
Socket: PHG.0B.701.CJL.1173
Cable: PUR-insulation, 2-conductor, shielded

P-203.01	1 m
P-203.02	2 m
P-203.03	3 m
P-203.05	5 m
P-203.10	10 m
P-203.15	15 m

Accessories

Sensor Extension Cables

Fig. 09. P-892.xx Sensor extension cables for LVDTs and strain gauges

P-892.xx Sensor Extension Cable (Fig. 9)

For strain gauge sensors or LVDTs.
Plug (right):
FFA.0S.304.CLAC32
Socket (left):
PCA.0S.304.CLLC32
Cable: 4 wires; ≈ Ø 0.20 mm;
#32 AWG (American)
≈ #35 SWG (British)
PVC-Isolation

P-892.01	1 m
P-892.02	2 m
P-892.03	3 m
P-892.05	5 m
P-892.10	10 m

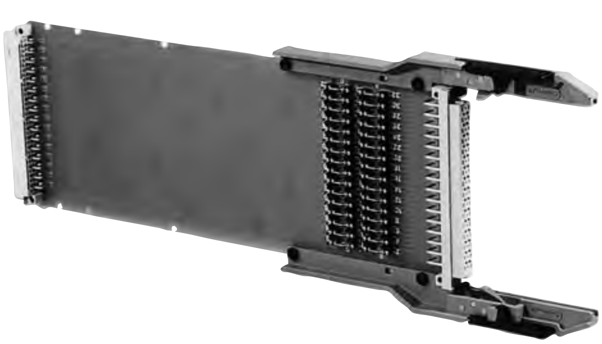
Fig. 10. D-892.xx capacitve sensor extension cables

D-892 Sensor Extension Cable Set (Fig. 10)

For capacitive sensors.
Set of two.
Plug (e.g., far left)
FFA.00.250.CTLC20

Socket (e.g., far right)
PCA.00.250.CTAC22
Cable: LSM 75 (Teflon)

D-892.01	1 m
D-892.02	2 m
D-892.03	3 m

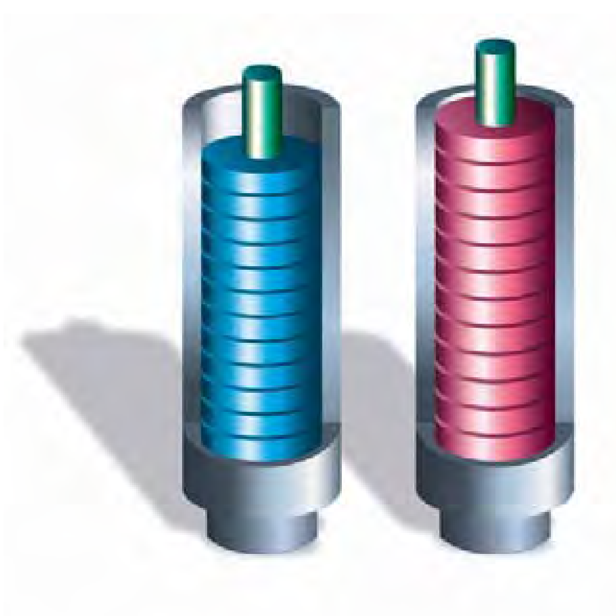


P-895.00 extension board for servicing

P-895.00 Extension Board

The board is used for the extension of the 32-pin connector of all PI E-500 and E-501 electronics (except E-515 and E-516). It is required for calibration and maintenance work. To allow the measurements of electrical current, all traces on the board are jumpered.

Tutorial Piezo Mechanisms



Contents

Piezoelectrics in Positioning

Properties / Applications

Features of Piezoelectric Positioning Systems

Unlimited Resolution

Piezoelectric actuators convert electrical energy directly to mechanical energy. They make motion in the sub-nanometer range possible. There are no moving parts in contact with each other to limit resolution.

Fast Expansion

Piezo actuators react in a matter of microseconds. Acceleration rates of more than 10,000 g can be obtained.

High Force Generation

High-load piezo actuators capable of moving loads of several tons are available today. They can cover travel ranges of several 100 µm with resolutions in the sub-nanometer range (see examples like the P-056, in the “Piezo Actuators & Components” section).

No Magnetic Fields

The piezoelectric effect is related to electric fields. Piezo actuators do not produce magnetic fields nor are they affected by them. Piezo devices are especially well suited for applications where magnetic fields cannot be tolerated.

Low Power Consumption

Static operation, even holding heavy loads for long periods, consumes virtually no power. A piezo actuator behaves very much like an electrical capacitor. When at rest, no heat is generated.

No Wear and Tear

A piezo actuator has no moving parts like gears or bearings. Its displacement is based on solid state dynamics and shows no wear and tear. PI has conducted endurance tests on piezo actuators in which no measurable change in performance was observed after several billion cycles.

Vacuum and Clean Room Compatible

Piezoelectric actuators neither cause wear nor require lubricants. The new PICMA® actuators with ceramic insulation have no polymer coating and are thus ideal for UHV (ultra-high vacuum) applications.

Operation at Cryogenic Temperatures

The piezoelectric effect continues to operate even at temperatures close to 0 kelvin. PI offers specially prepared actuators for use at cryogenic temperatures.

Piezoelectric nanopositioning systems large (e.g. for precision machining), medium (e.g. for interferometry), small (e.g. for data storage medium testing)

Applications for Piezo Positioning Technology

Data Storage

- MR head testing
- Spin stands
- Disk testing
- Active vibration cancellation
- Pole-tip recession test

Semiconductors, Microelectronics

- Nano & Microlithography
- Nanometrologie
- Wafer and mask positioning
- Critical-dimension-test
- Inspection systems
- Active vibration cancellation

Precision Mechanics

- Fast tool servos
- Non-circular grinding, drilling, turning
- Active vibration cancellation
- Structural deformation
- Tool adjustment
- Wear compensation
- Needle-valve actuation
- Micropumps
- Linear drives
- Knife edge control in extrusion tools
- Micro engraving systems
- Shock wave generation

Life Science, Medical Technology

- Scanning microscopy
- Patch clamp
- Nanoliter pumps
- Gene manipulation
- Micromanipulation
- Cell penetration
- Microdispensers

Optics, Photonics, Nanometrologie

- Scanning mirrors
- Image stabilization, pixel multiplication
- Scanning microscopy
- Auto focus systems
- Interferometry
- Fiber optic alignment
- Fiber optics switching
- Adaptive and active optics
- Laser tuning
- Stimulation of vibrations

Selection of piezo nanopositioning stages

Glossary

See also the Micropositioning Fundamentals Glossary (p. 4-128).

Actuator:

A device that can produce force or motion (displacement).

Blocked Force:

The maximum force an actuator can generate if blocked by an infinitely rigid restraint.

Ceramic:

A polycrystalline, inorganic material.

Closed-Loop Operation:

The displacement of the actuator is corrected by a servo-controller compensating for nonlinearity, hysteresis and creep. See also "Open-Loop Operation".

Compliance:

Displacement produced per unit force. The reciprocal of stiffness.

Creep:

An unwanted change in the displacement over time.

Curie Temperature:

The temperature at which the crystalline structure changes from a piezoelectric (non-symmetrical) to a non-piezoelectric (symmetrical) form. At this temperature PZT ceramics looses the piezoelectric properties.

Drift:

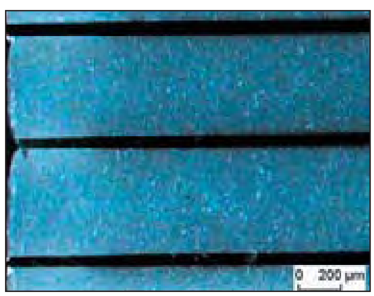
See "creep"

Domain:

A region of electric dipoles with similar orientation.

HVPZT:

Acronym for High-Voltage PZT (actuator).



Piezoceramic layers in a "classical" stack actuator (HVPZT).

Hysteresis:

Hysteresis in piezo actuators is based on crystalline polarization and molecular effects and occurs when reversing driving direction. Hysteresis is not to be confused with backlash.

LVPZT:

Acronym for low-voltage PZT (actuator).

Piezoceramic layers in a monolithic actuator (LVPZT).

Monolithic Multilayer Actuator:

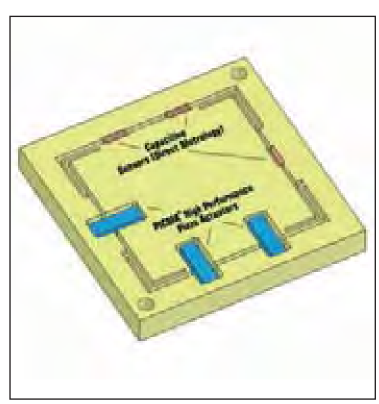
An actuator manufactured in a fashion similar to multilayer ceramic capacitors. Ceramic and electrode material are cofired in one step. Layer thickness is typically on the order of 20 to 100 µm.

Open-Loop Operation:

The actuator is used without a position sensor. Displacement roughly corresponds to the drive voltage. Creep, nonlinearity and hysteresis remain uncompensated.

Parallel Kinematics:

Unlike in serial kinematics designs, all actuators act upon the same moving platform. Advantages: Minimized inertia, no moving cables, lower center of gravity, no cumulative guiding errors and more-compact construction.



Nanopositioning system featuring parallel kinematics and parallel metrology.

Equipment for fully automated screen printing of electrodes on piezoelectric and dielectric ceramics.

Glossary (cont.)

Parallel Metrology:

Unlike in serial metrology designs, each sensor measures the position of the same moving platform in the respective degree of freedom. This keeps the off-axis runout of all actuators inside the servo-control loop and allows it to be corrected automatically (active guidance).

Piezoelectric Materials:

Materials that change their dimensions when a voltage is applied and produce a charge when pressure is applied.

Poling / Polarization:

The procedure by which the bulk material is made to take on piezoelectric properties, i.e. the electrical alignment of the unit cells in a piezoelectric material.

PZT:

Acronym for plumbum (lead) zirconate titanate. Polycrystalline ceramic material with piezoelectric properties. Often also used to refer to a piezo actuator or translator.

Serial Kinematics:

Unlike in parallel kinematics designs, each actuator acts upon a separate platform of its own. There is a clear relationship between actuators and axes.

Advantages: Simpler to assemble; simpler control algorithm.

Disadvantages: Poorer dynamic characteristics, integrated "Parallel Metrology" is not possible, cumulative guiding errors, lower accuracy.

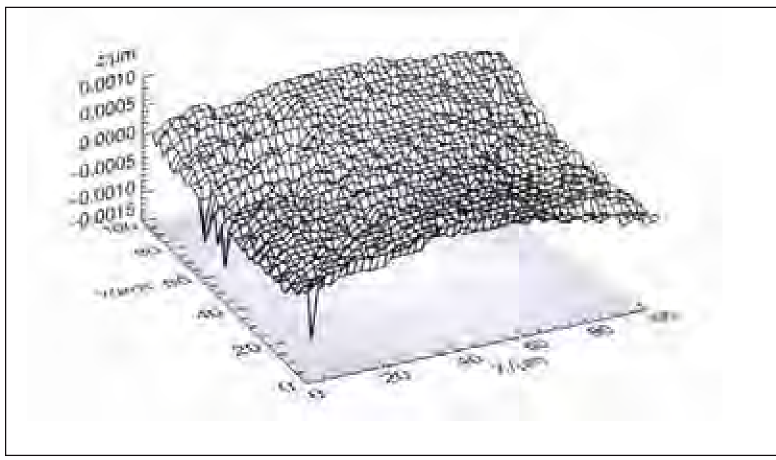
Design principle of a stacked XY piezo stage (serial kinematics).

Serial Metrology:

One sensor is assigned to each degree of freedom to be servo-controlled. Undesired off-axis motion (guiding error) from other axes in the direction of a given sensor, go unrecognized and uncorrected (see also "Parallel Metrology").

Stiffness:

Spring constant (for piezoelectric materials, not linear).



Flatness of a nanopositioning stage with active trajectory control is better than 1 nanometer over a 100 x 100 µm scanning range.

Trajectory-Control:

Provisions to prevent deviation from the specified trajectory. Can be passive (e.g. flexure guidance) or active (e.g. using additional active axes).

Translator:
A linear actuator.

Introduction

Nanopositioning with Piezoelectric Technology

Basics

The piezoelectric effect is often encountered in daily life, for example in lighters, loudspeakers and buzzers. In a gas lighter, pressure on a piezoceramic generates an electric potential high enough to create a spark. Most electronic alarm clocks do not use electromagnetic buzzers anymore, because piezoelectric ceramics are more compact and more efficient. In addition to such simple applications, piezo technology has recently established itself in the automotive branch. Piezo-driven injection valves in diesel engines require much lower transition times than conventional electromagnetic valves, providing quieter operation and lower emissions.

The term "piezo" is derived from the Greek word for pressure. In 1880 Jacques and Pierre Curie discovered that an electric potential could be generated by applying pressure to quarz crystals; they named this phenomenon the "piezo effect". Later they ascertained that when exposed to an electric potential, piezoelectric materials change shape. This they named the "inverse piezo effect". The first commercial applications of the inverse piezo effect were for sonar systems that were used in World War I. A breakthrough was made in the 1940's when scientists discovered that barium titanate could be bestowed with piezoelectric properties by exposing it to an electric field.

Features of Piezoelectric Actuators

- Piezo actuators can perform sub-nanometer moves at high frequencies because they derive their motion from solid-state crystaline effects. They have no rotating or sliding parts to cause friction
- Piezo actuators can move high loads, up to several tons
- Piezo actuators present capacitive loads and dissipate virtually no power in static operation
- Piezo actuators require no maintenance and are not subject to wear because they have no moving parts in the classical sense of the term

Piezoelectric materials are used to convert electrical energy to mechanical energy and vice-versa. The precise motion that results when an electric potential is applied to a piezoelectric material is of primordial importance for nanopositioning. Actuators using the piezo effect have been commercially available for 35 years and in that time have transformed the world of precision positioning and motion control.

Quick Facts

Actuator Designs

Note

This section gives a brief summary of the properties of piezoelectric drives and their applications. For detailed information, see "Fundamentals of Piezoelectricity" beginning on p. 2-181.

Stack actuators are the most common and can generate the highest forces. Units with travel ranges up to 500 µm are available. To protect the piezoceramic against destructive external conditions, they are often provided with a metal casing and an integrated preload spring to absorb tensile forces.

Piezo tube actuators exploit the radial contraction direction, and are often used in scanning microscopes and micropumps.

Bender and bimorph actuators achieve travel ranges in the millimeter range (despite their compact size) but with relatively low force generation (a few newtons).

Shear elements use the inverse-piezo-effect shear component and achieve long travel and high force.

For more information, see p. 2-207 *ff.*

Guided piezo actuators (1 to 6 axes) are complex nanopositioners with integrated piezo drives and solid-state, friction-free linkages (flexures). They are used when requirements like the following need be met:

- Extremely straight and flat motion, or multi-axis motion with accuracy requirements in the sub-nanometer or sub-microradian range
- Isolation of the actuator from external forces and torques, protection from humidity and foreign particles

Such systems often also include lever amplification of up to 20 times the displacement of the piezo element, resulting in a travel range of several hundred µm.

Piezomotors are used where even longer travel ranges are required. Piezomotors can be divided into two main categories:

- Ultrasonic Motors (Fig. 2a)
- Piezo-Walk® Motors (Fig. 2b)

The motion of ultrasonic piezomotors is based on the friction between parts oscillating with microscopic amplitudes. Linear ultrasonic motors are very compact and can attain high speeds combined with resolutions of 0.1 µm or better. Rotary motors feature high torques even at low rpm.

Piezo-Walk® linear drives (see p. 1-3 *ff*) offer high positioning and holding forces (up to hundreds of newtons) with moderate speeds and resolutions in the subnanometer range.

All implementations are self-locking when powered down.

Fig. 1a. Selection of classical piezo stack actuators, with adhesive used to join the layers

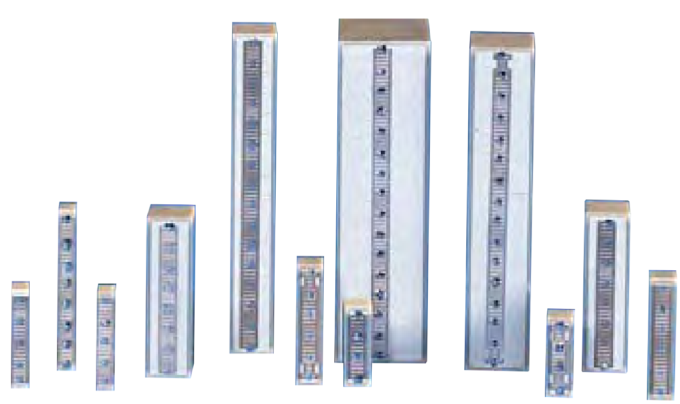


Fig. 1b. Selection of monolithic PICMA ® technology actuators

Operating Characteristics of Piezoelectric Actuators

Operating Voltage

Two types of piezo actuators have become established. Monolithic-sintered, low-voltage actuators (LVPZT) operate with potential differences up to about 100 V and are made from ceramic layers from 20 to 100 µm in thickness. Classical high-voltage actuators (HVPZT), on the other hand, are made from ceramic layers of 0.5 to 1 mm thickness and operate with potential differences of up to 1000 V. High-voltage actuators can be made with larger cross-sections, making them suitable for larger loads than the more-compact, monolithic actuators.

Stiffness, Load Capacity, Force Generation

To a first approximation, a piezo actuator is a spring-and-mass system. The stiffness of the actuator depends on the Young's modulus of the ceramic (approx. 25 % that of steel), the cross-section and length of the active material and a number of other non-linear parameters (see p. 2-189). Typical actuators have stiffnesses between 1 and 2,000 N/µm and compressive limits between 10 and 100,000 N. If the unit will be exposed to pulling (tensile) forces, a casing with integrated preload or an external preload spring is required. Adequate measures must be taken to protect the piezoceramic from shear and bending forces and from torque.

Travel Range

Travel ranges of Piezo Actuators are typically between a few tens and a few hundreds of µm (linear actuators). Bender actuators and lever amplified systems can achieve a few mm. Ultrasonic piezomotors and Piezo-Walk® drives can be used for longer travel ranges.

Resolution

Piezoceramics are not subject to the "stick slip" effect and therefore offer theoretically unlimited resolution. In practice, the resolution actually attainable is limited by electronic and mechanical factors:

a) Sensor and servo-control electronics (amplifier): amplifier noise and sensitivity to electromagnetic interference (EMI) affect the position stability.

b) Mechanical parameters: design and mounting precision issues concerning the sensor, actuator and preload can induce micro-friction which limits resolution and accuracy.

PI offers piezo actuators and positioning systems that provide sub-nanometer resolution and stability. For more information, see p. 2-183 *ff*.

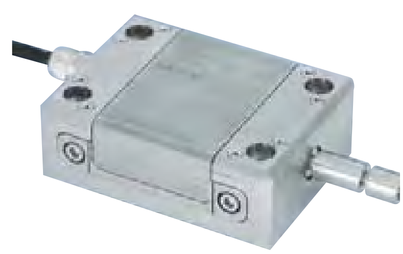


Fig. 2b. Custom linear drive with integrated NEXLINE® Piezo-Walk® piezomotor

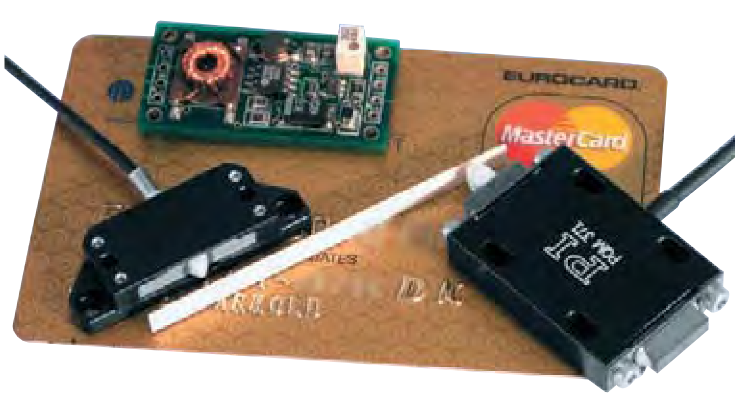


Fig. 2a. Ultrasonic piezo linear motors

Fig. 3. Example of a compact piezo nanopositioning and scanning system with integrated flexure guidance, sensor and motion amplifier

Quick Facts (cont.)

Open- and Closed-Loop Operation

In contrast to many other types of drive systems, piezo actuators can be operated without servo-control. The displacement is approximately equal to the drive voltage. Hysteresis, nonlinearity and creep effects limit the absolute accuracy. For positioning tasks which require high linearity, long-term stability, repeatability and absolute accuracy, closed-loop (servo-controlled) piezo actuators and systems are used (see p. 2-199). With suitable controllers, closed-loop operation enables reproducibilities in the sub-nanometer range.

High-Resolution Sensors for Closed-Loop Operation

LVDT (linear variable differential transformer), strain gauge and capacitive sensors are the most common sensor types used for closed-loop operation. Capacitive sensors offer the greatest accuracy. For more information, see p. 2-187 *ff.*

Dynamic Behavior

A piezo actuator can reach its nominal displacement in approximately one third of the period of its resonant frequency. Rise times on the order of microseconds and accelerations of more than 10,000 g are possible. This feature makes piezo actuators suitable for rapid switching applications such as controlling injector nozzle valves, hydraulic valves, electrical relays, optical switches and adaptive optics. For more information, see p. 2-192 *ff.*

Power Requirements

Piezo actuators behave as almost pure capacitive loads. Static operation, even holding heavy loads, consumes virtually no power. In dynamic applications the energy requirement increases linearly with frequency and actuator capacitance. At 1000 Hz with 10 µm amplitude, a compact piezo translator with a load capacity of approx. 100 N requires less than 10 W, while a high-load actuator (> 10 kN capacity) would use several hundred watts under the same conditions. For more information, see p. 2-195 *ff.*

Protection from Mechanical Damage

PZT ceramics are brittle and cannot withstand high pulling or shear forces. The mechanical actuator design must thus isolate these undesirable forces from the ceramic. This can be accomplished by measures such as spring preloads, use of ball tips, flexible couplings, etc. (for more mounting guidelines, see p. 2-216). In addition, the ceramics must be protected from moisture and the intrusion of foreign particles. Close contact between the piezo mechanics manufacturer and the user facilitates finding an optimal match between the piezo system and the application environment.

Fig. 4. Piezo actuator with water-proof case and connection for flushing/cooling air

Fundamentals of Piezoelectricity

Material Properties

Notes

The following pages give a detailed look at piezo actuator theory and their operation. For basic knowledge read "Quick Facts", p. 2-178. For definition of units, dimensions and terms, see "Symbols and Units", p. 2-217 and "Glossary", p. 2-175.

Since the piezo effect exhibited by natural materials such as quartz, tourmaline, Rochelle salt, etc. is very small, polycrystalline ferroelectric ceramic materials such as barium titanate and lead (plumbum) zirconate titanate (PZT) with improved properties have been developed.

PZT ceramics (piezoceramics) are available in many variations and are still the most widely used materials for actuator applications today.
Before polarization, PZT crystallites have symmetric cubic unit cells. At temperatures below the Curie temperature, the lattice structure becomes deformed and asymmetric. The unit cells exhibit spontaneous polarization (see Fig. 5), i.e. the individual PZT crystallites are piezoelectric.

Groups of unit cells with the same orientation are called Weiss domains. Because of the random distribution of the domain orientations in the ceramic material no macroscopic piezoelectric behavior is observable. Due to the ferroelectric nature of the material, it is possible to force permanent alignment of the different domains using a strong electric field. This process is called poling (see Fig. 6). Some PZT ceramics must be poled at an elevated temperature. The material now has a remnant polarization (which can be degraded by exceeding the mechanical, thermal and electrical limits of the material). The ceramic now exhibits piezoelectric properties and will change dimensions when an electric potential is applied.

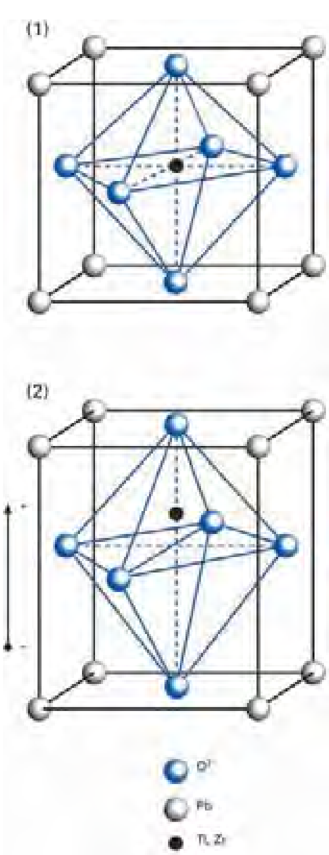


Fig. 5. PZT unit cell:
1) Perovskite-type lead zirconate titanate (PZT) unit cell in the symmetric cubic state above the Curie temperature
2) Tetragonally distorted unit cell below the Curie temperature

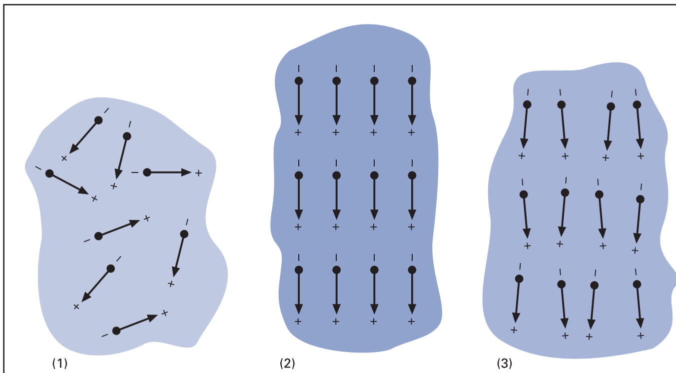


Fig. 6. Electric dipoles in domains; (1) unpoled ferroelectric ceramic, (2) during and (3) after poling (piezoelectric ceramic)

Fundamentals of Piezoelectricity (cont.)

PZT Ceramics Manufacturing Process

PI develops and manufactures its own piezo ceramic materials at the PI Ceramic factory. The manufacturing process for high-voltage piezoceramic starts with mixing and ball milling of the raw materials. Next, to accelerate reaction of the components, the mixture is heated to 75 % of the sintering temperature, and then milled again. Granulation with the binder is next, to improve processing properties. After shaping and pressing, the green ceramic is heated to about 750 °C to burn out the binder. The next phase is sintering, at temperatures between 1250 °C and 1350 °C. Then the ceramic block is cut, ground, polished, lapped, etc., to the desired shape and tolerance. Electrodes are applied by sputtering or screen printing processes. The last step is the poling process which takes place in a heated oil bath at electrical fields up to several kV/mm. Only here does the ceramic take on macroscopic piezoelectric properties.

Multilayer piezo actuators require a different manufacturing process. After milling, a slurry is prepared for use in a foil casting process which allows layer thickness down to 20 µm. Next, electrodes are screen printed and the sheets laminated. A compacting process increases the density of the green ceramics and removes air trapped between the layers. The final steps are the binder burnout, sintering (co-firing) at temperatures below 1100 °C , wire lead termination and poling.

All processes, especially the heating and sintering cycles, must be controlled to very tight tolerances. The smallest deviation will affect the quality and properties of the PZT material. One hundred percent final testing of the piezo material and components at PI Ceramic guarantees the highest possible product quality.

Sputtering facility at PI Ceramic

Definition of Piezoelectric Coefficients and Directions

Because of the anisotropic nature of PZT ceramics, piezoelectric effects are dependent on direction. To identify directions, the axes 1, 2, and 3 will be introduced (corresponding to X, Y, Z of the classical right-hand orthogonal axis set). The axes 4, 5 and 6 identify rotations (shear), θ_X, θ_Y, θ_Z (also known as U, V, W.)

The direction of polarization (axis 3) is established during the poling process by a strong electrical field applied between two electrodes. For linear actuator (translator) applications, the piezo properties along the poling axis are the most important (largest deflection).
Piezoelectric materials are characterized by several coefficients.

Examples are:

- d_{ij}: Strain coefficients [m/V] or charge output coefficients [C/N]: Strain developed [m/m] per unit of electric field strength applied [V/m] or (due to the sensor / actuator properties of PZT material) charge density developed [C/m^2] per given stress [N/m^2].

- g_{ij}: Voltage coefficients or field output coefficients [Vm/N]: Open-circuit electric field developed [V/m] per applied mechanical stress [N/m^2] or (due to the sensor / actuator properties of PZT material) strain developed [m/m] per applied charge density [C/m^2].

- k_{ij}: Coupling coefficients [dimensionless]. The coefficients are energy ratios describing the conversion from mechanical to electrical energy or vice versa. k^2 is the ratio of energy stored (mechanical or electrical) to energy (mechanical or electrical) applied.

Other important parameters are the Young's modulus Y (describing the elastic properties of the material) and ε_r the relative dielectric coefficients (permittivity).
Double subscripts, as in d_{ij}, are used to describe the relationships between mechanical and electrical parameters. The first index indicates the direction of the stimulus, the second the direction of the reaction of the system.

Example: d_{33} applies when the electric field is along the polarization axis (direction 3) and the strain (deflection) is along the same axis. d_{31} applies if the electric field is in the same direction as before, but the deflection of interest is that along axis 1 (orthogonal to the polarization axis).

In addition the superscripts S, T, E, D can be used to describe an electrical or mechanical boundary condition.

Definition:
S for strain = constant (mechanically clamped)
T for stress = constant (not clamped)
E for field = 0 (short circuit)
D for charge displacement (current) = 0 (open circuit)

The individual piezoelectric coefficients are related to each other by systems of equations that will not be explained here.

PI

Notes

The piezoelectric coefficients described here are often presented as constants. It should be clearly understood that their values are not invariable. The coefficients describe material properties under small-signal conditions only. They vary with temperature, pressure, electric field, form factor, mechanical and electrical boundary conditions, etc. Compound components, such as piezo stack actuators, let alone preloaded actuators or lever-amplified systems, cannot be described sufficiently by these material parameters alone. This is why each component or system manufactured by PI is accompanied by specific data such as stiffness, load capacity, displacement, resonant frequency, etc., determined by individual measurements. The parameters describing these systems are to be found in the technical data table for the product.

Important: There are no international standards for defining these specifications. This means that claims of different manufacturers can not necessarily be compared directly with one another.

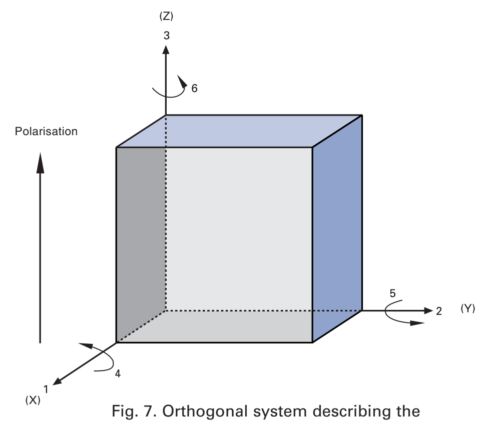


Fig. 7. Orthogonal system describing the properties of a poled piezoelectric ceramic. Axis 3 is the poling direction.

Resolution

Since the displacement of a piezo actuator is based on ionic shift and orientation of the PZT unit cells, the resolution depends on the electrical field applied. Resolution is theoretically unlimited. Because there are no threshold voltages, the stability of the voltage source is critical; noise even in the µV range causes position changes. When driven with a low-noise amplifier, piezo actuators can be used in tunneling and atomic force microscopes providing smooth, continuous motion with sub-atomic resolution (see Fig. 8).

Amplifier Noise

One factor determining the position stability (resolution) of a piezo actuator is noise in the drive voltage. Specifying the noise value of the piezo driver electronics in millivolts, however, is of little practical use without spectral information. If the noise occurs in a frequency band far beyond the resonant frequency of the mechanical system, its influence on mechanical resolution and stability can be neglected. If it coincides with the resonant frequency, it will have a far more significant influence on the system stability.

Therefore, meaningful information about the stability and resolution of a piezo positioning system can only be acquired if the resolution of the complete system—piezo actuator and drive electronics—is measured in terms of nanometers rather than millivolts. For further information see p. 2-10 and p. 2-199 *ff.*

Notes

The smooth motion in the subnanometer range shown in Fig. 8 can only be attained by frictionless and stictionless solid state actuators and guidance such as piezo actuators and flexures. "Traditional" technologies used in motion positioners (stepper or DC servo-motor drives in combination with dovetail slides, ball bearings, and roller bearings) all have excessive amounts of friction and stiction. This fundamental property limits resolution, causes wobble, hysteresis, backlash, and an uncertainty in position repeatability. Their practical usefulness is thus limited to a precision of several orders of magnitude below that obtainable with PI piezo nanopositioners.

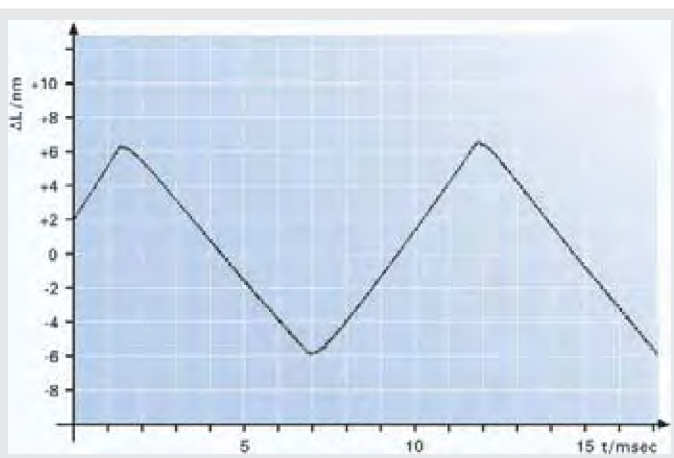


Fig. 8. Smooth response of a P-170 HVPZT translator to a 1 V, 200 Hz triangular drive signal. Note that one division is only 2 nanometers

Fundamentals of Piezomechanics

Displacement of Piezo Actuators (Stack & Contraction Type)

Commonly used stack actuators achieve a relative displacement of up to 0.2 %. Displacement of piezoceramic actuators is primarily a function of the applied electric field strength E, the length L of the actuator, the forces applied to it and the properties of the piezoelectric material used. The material properties can be described by the piezoelectric strain coefficients d_{ij}. These coefficients describe the relationship between the applied electric field and the mechanical strain produced.

The change in length, ΔL, of an unloaded single-layer piezo actuator can be estimated by the following equation:

(Equation 1)

$$\Delta L = S \cdot L_o \approx \pm E \cdot d_{ij} \cdot L_o$$

Where:

S = *strain (relative length change ΔL/L, dimensionless)*
L_0 = *ceramic length [m]*
E = *electric field strength [V/m]*
d_{ij} = *piezoelectric coefficient of the material [m/V]*

d_{33} describes the strain parallel to the polarization vector of the ceramics (thickness) and is used when calculating the displacement of stack actuators; d_{31} is the strain orthogonal to the polarization vector (width) and is used for calculating tube and strip actuators (see Fig. 9). d_{33} and d_{31} are sometimes referred to as "piezo gain".

Notes

For the materials used in standard PI piezo actuators, d_{33} is on the order of 250 to 550 pm/V, d_{31} is on the order of -180 to -210 pm/V. The highest values are attainable with shear actuators in d_{15} mode. These figures only apply to the raw material at room temperature under small-signal conditions.

The maximum allowable field strength in piezo actuators is between 1 and 2 kV/mm in the polarization direction. In the reverse direction (semi-bipolar operation), at most 300 V/mm is allowable (see Fig. 10). The maximum voltage depends on the ceramic and insulation materials.

Exceeding the maximum voltage may cause dielectric breakdown and irreversible damage to the piezo actuator.

With the reverse field, negative expansion (contraction) occurs, giving an additional 20 % of the nominal displacement. If both the regular and reverse fields are used, a relative expansion (strain) up to 0.2 % is achievable with piezo stack actuators. This technique can reduce the average applied voltage without loss of displacement and thereby increase piezo lifetime.

Stacks can be built with aspect ratios up to 12:1 (length:diameter). This means that the maximum travel range of an actuator with 15 mm piezo diameter is limited to about 200 µm. Longer travel ranges can be achieved by mechanical amplification techniques (see "Lever Motion Amplifiers" p. 2-210).

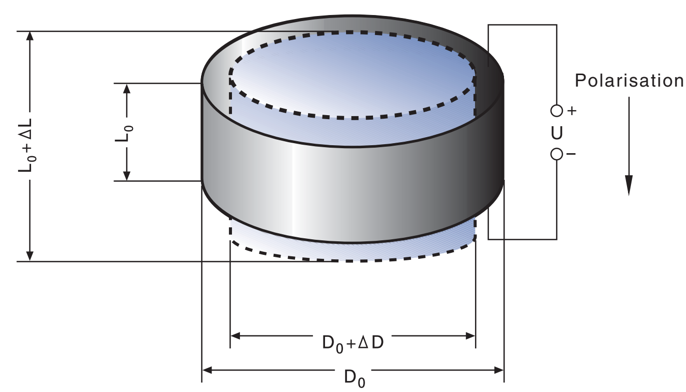


Fig. 9. Expansion and contraction of a piezoelectric disk in response to an applied voltage. Note that d_{31}, which describes the lateral motion, ΔD, is negative

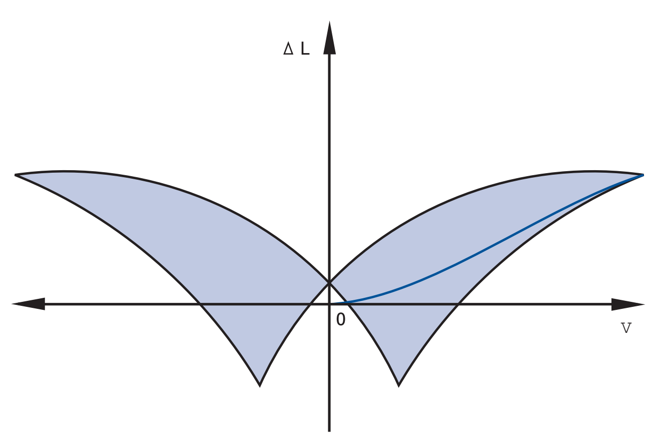


Fig. 10. Typical response of a "soft PZT" actuator to a bipolar drive voltage. When a certain threshold voltage negative to the polarization direction is exceeded, reversal of polarization can occur

Note:

PI piezo actuators and stages are designed for high reliability in industrial applications. The travel, voltage and load ranges in the technical data tables can actually be used in practice. They have been collected over many years of experience in piezo actuator production and in numerous industrial applications.

In contrast to many other piezo suppliers, PI has its own piezo ceramic development and production facilities together with the necessary equipment and knowhow. The goal is always reliability and practical usefulness. Maximizing isolated parameters, such as expansion or stiffness, at the cost of piezo lifetime might be interesting to an experimenter, but has no place in practical application.

When selecting a suitable piezo actuator or stage, consider carefully the fact that "maximum travel" may not be the only critical design parameter.

Hysteresis (Open-Loop Piezo Operation)

Hysteresis is observable in open-loop operation; it can be reduced by charge control and virtually eliminated by closed-loop operation (see p. 2-199 *ff*).

Open-loop piezo actuators exhibit hysteresis in their dielectric and electromagnetic large-signal behavior. Hysteresis is based on crystalline polarization effects and molecular effects within the piezoelectric material.
The amount of hysteresis increases with increasing voltage (field strength) applied to the actuator. The "gap" in the voltage/displacement curve (see Fig. 11) typically begins around 2 % (small-signal) and widens to a maximum of 10 % to 15 % under large-signal conditions. The highest values are attainable with shear actuators in d_{15} mode.

For example, if the drive voltage of a 50 µm piezo actuator is changed by 10 %, (equivalent to about 5 µm displacement) the position repeatability is still on the order of 1 % of full travel or better than 1 µm.

The smaller the move, the smaller the uncertainty. Hysteresis must not be confused with the backlash of conventional mechanics. Backlash is virtually independent of travel, so its relative importance increases for smaller moves.

For tasks where it is not the absolute position that counts, hysteresis is of secondary importance and open-loop actuators can be used, even if high resolution is required.

In closed-loop piezo actuator systems hysteresis is fully compensated. PI offers these systems for applications requiring absolute position information, as well as motion with high linearity, repeatability and accuracy in the nanometer and sub-nanometer range (see p. 2-199 *ff*).

Example: Piezoelectrically driven fiber aligners and tracking systems derive the control signal from an optical power meter in the system. There, the goal is to maximize the optical signal level as quickly as possible, not to attain a predetermined position value. An open-loop piezo system is sufficient for such applications. Advantages like unlimited resolution, fast response, zero backlash and zero stick/slip effect are most welcome, even without position control.

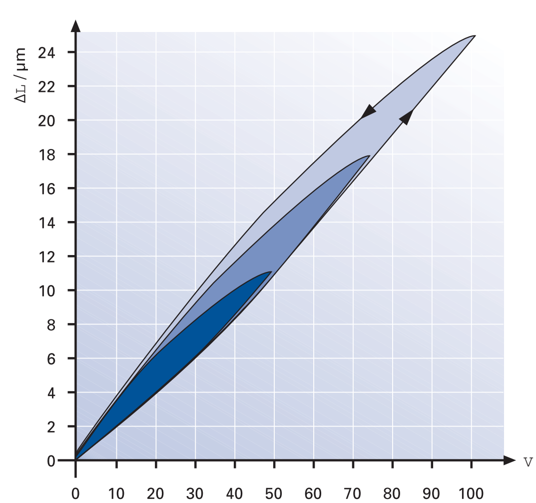


Fig. 11. Hysteresis curves of an open-loop piezo actuator for various peak voltages. The hysteresis is related to the distance moved, not to the nominal travel range

Fundamentals of Piezomechanics (cont.)

Creep / Drift (Open-Loop Piezo Operation)

The same material properties responsible for hysteresis also cause creep or drift. Creep is a change in displacement with time without any accompanying change in the control voltage. If the operating voltage of a piezo actuator is changed, the remnant polarization (piezo gain) continues to change, manifesting itself in a slow change of position. The rate of creep decreases logarithmically with time (see Fig. 12). The following equation describes this effect:

(Equation 2)

$$\Delta L(t) \approx \Delta L_{t=0.1} \left[1+\gamma \cdot \lg\left(\frac{t}{0.1}\right)\right]$$

Creep of PZT motion as a function of time.

Where:

t	=	*time [s]*
ΔL(t)	=	*change in position as a function of time*
$\Delta L_{t=0.1}$	=	*displacement 0.1 seconds after the voltage change is complete [m].*
γ	=	*creep factor, which is dependent on the properties of the actuator (on the order of 0.01 to 0.02, which is 1 % to 2 % per time decade).*

In practice, maximum creep (after a few hours) can add up to a few percent of the commanded motion.

Aging

Aging refers to reduction in remnant polarization; it can be an issue for sensor or charge-generation applications (direct piezo effect). With actuator applications it is negligible, because repoling occurs every time a higher electric field is applied to the actuator material in the poling direction.

Note

For periodic motion, creep and hysteresis have only a minimal effect on repeatability.

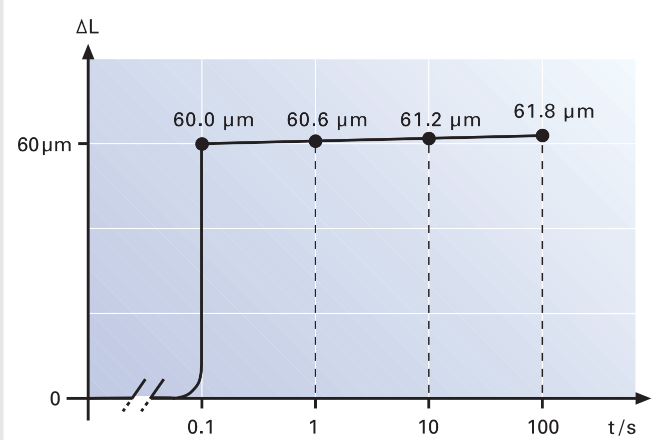


Fig. 12. Creep of open-loop PZT motion after a 60 µm change in length as a function of time. Creep is on the order of 1 % of the last commanded motion per time decade

Actuators and Sensors

Metrology for Nanopositioning Systems

There are two basic techniques for determining the position of piezoelectric motion systems: Direct metrology and indirect metrology.

Indirect (Inferred) Metrology

Indirect metrology involves inferring the position of the platform by measuring position or deformation at the actuator or other component in the drive train. Motion inaccuracies which arise between the drive and the platform can not be accounted for.

Direct Metrology

With direct metrology, however, motion is measured at the point of interest; this can be done, for example, with an interferometer or capacitive sensor.
Direct metrology is more accurate and thus better suited to applications which need absolute position measurements. Direct metrology also eliminates phase shifts between the measuring point and the point of interest. This difference is apparent in higher-load, multi-axis dynamic applications.

Parallel and Serial Metrology

In multi-axis positioning systems parallel and serial metrology must also be distinguished.

With parallel metrology, all sensors measure the position of the same moving platform against the same stationary reference. This means that all motion is inside the servo-loop, no matter which actuator caused it (see Active Trajectory Control). Parallel metrology and parallel kinematics can be easily integrated.

With serial metrology the reference plane of one or more sensors is moved by one or more actuators. Because the off-axis motion of any moving reference plane is never measured, it can not be compensated.
See also p. 2-8 *ff.*

High-Resolution Sensors

Strain Gauge Sensors

SGS sensors are an implementation of inferred metrology and are typically chosen for cost-sensitive applications. An SGS sensor consists of a resistive film bonded to the piezo stack or a guidance element; the film resistance changes when strain occurs. Up to four strain gauges (the actual configuration varies with the actuator construction) form a Wheatstone bridge driven by a DC voltage (5 to 10 V). When the bridge resistance changes, the sensor electronics converts the resulting voltage change into a signal proportional to the displacement.

A special type of SGS is known as a piezoresistive sensor. It has good sensitivity, but mediocre linearity and temperature stability. See also p. 2-8 *ff.*

Resolution: better than 1 nm (for short travel ranges, up to about 15 µm)

Bandwidth: to 5 kHz

Advantages

- High Bandwidth
- Vacuum Compatible
- Highly Compact

Other characteristics:

- Low heat generation (0.01 to 0.05 W sensor excitation power)
- Long-term position stability depends on adhesive quality
- Indirect metrology

Examples

Most PI LVPZT and HVPZT actuators are available with strain gauge sensors for closed-loop control (see the “Piezo Actuators & Components” section p. 1-61 *ff*).

Note

The sensor bandwidth for the sensors described here should not be confused with the bandwidth of the piezo mechanics servo-control loop, which is further limited by the electronic and mechanical properties of the system.

Fig. 13. Strain gauge sensors. Paper clip for size comparison

Actuators and Sensors (cont.)

Fig. 14. LVDT sensor, coil and core. Paper clip for size comparison

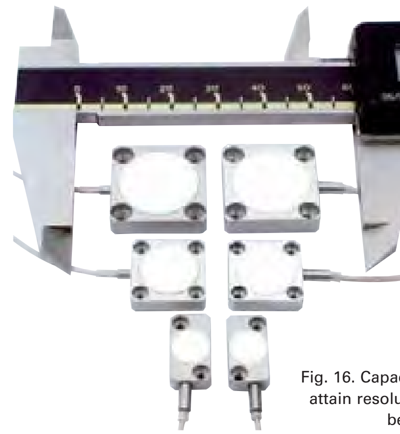


Fig. 16. Capacitive sensors can attain resolution 10,000 times better than calipers

Linear Variable Differential Transformers (LVDTs)

LVDTs are well suited for direct metrology. A magnetic core, attached to the moving part, determines the amount of magnetic energy induced from the primary windings into the two differential secondary windings (Fig. 15). The carrier frequency is typically 10 kHz.

Resolution: to 5 nm

Bandwidth: to 1 kHz

Repeatability: to 5 nm

Advantages:

- Good temperature stability
- Very good long-term stability
- Non-contacting
- Controls the position of the moving part rather than the position of the piezo stack
- Cost-effective

Other characteristics:

- Outgassing of insulation materials may limit applications in very high vacuum
- Generates magnetic field

Capacitive Position Sensors

Capacitive sensors are the metrology system of choice for the most demanding applications.

Two-plate capacitive sensors consist of two RF-excited plates that are part of a capacitive bridge (Fig. 17). One plate is fixed, the other plate is connected to the object to be positioned (e.g. the platform of a stage). The distance between the plates is inversely proportional to the capacitance, from which the displacement is calculated. Short-range, two-plate sensors can achieve resolution on the order of picometers. See the "Nanometrology" section (p. 3-1 *ff*). for details.

Resolution: Better than 0.1 nm possible

Repeatability: Better than 0.1 nm possible

Bandwidth: Up to 10 kHz

Advantages:

- Highest resolution of all commercially available sensors
- Ideally suited for parallel metrology
- Non-contacting
- Excellent long-term stability
- Excellent frequency response
- No magnetic field
- Excellent linearity

Other characteristics:

- Ideally suited for integration in flexure guidance systems, which maintain the necessary parallelism of the plates. Residual tip/tilt errors are greatly reduced by the ILS linearization system (see p. 3-18) developed by PI.

Examples

P-733 parallel kinematic nanopositioning system with parallel metrology (see p. 2-62).
P-753 LISA NanoAutomation® actuators (see p. 2-16); additional examples in the "Piezo Flexure Stages / High-Speed Scanning Systems" section.

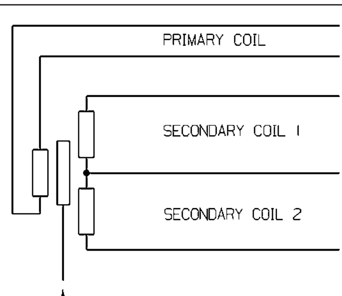


Fig. 15. Working principle of an LVDT sensor

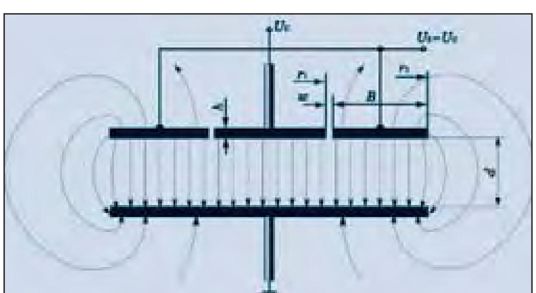


Fig. 17. Working principle of two-plate capacitive position sensors

Fundamentals of Piezoelectric Actuators

Forces and Stiffness

Maximum Applicable Forces (Compressive Load Limit, Tensile Load Limit)

The mechanical strength values of PZT ceramic material (given in the literature) are often confused with the practical long-term load capacity of a piezo actuator. PZT ceramic material can withstand pressures up to 250 MPa (250×10^6 N/m^2) without breaking. This value must never be approached in practical applications, however, because depolarization occurs at pressures on the order of 20 % to 30 % of the mechanical limit. For stacked actuators and stages (which are a combination of several materials) additional limitations apply. Parameters such aspect ratio, buckling, interaction at the interfaces, etc. must be considered.

The load capacity data listed for PI actuators are conservative values which allow long lifetime.

Tensile loads of non-preloaded piezo actuators are limited to 5% to 10% of the compressive load limit. PI offers a variety of piezo actuators with internal spring preload for increased tensile load capacity. Preloaded elements are highly recommended for dynamic applications.

The PZT ceramic is especially sensitive to shear forces; they must be intercepted by external measures (flexure guides, etc.).

Stiffness

Actuator stiffness is an important parameter for calculating force generation, resonant frequency, full-system behavior, etc. The stiffness of a solid body depends on Young's modulus of the material. Stiffness is normally expressed in terms of the spring constant k_T, which describes the deformation of the body in response to an external force.

This narrow definition is of limited application for piezoceramics because the cases of static, dynamic, large-signal and small-signal operation with open and shorted electrodes must all be distinguished. The poling process of piezoceramics leaves a remnant strain in the material which depends on the magnitude of polarization. The polarization is affected by both the applied voltage and external forces. When an external force is applied to poled piezoceramics, the dimensional change depends on the stiffness of the ceramic material and the change of the remnant strain (caused by the polarization change). The equation $\Delta L_N = F/k_T$ is only valid for small forces and small-signal conditions. For larger forces, an additional term, describing the influence of the polarization changes, must be superimposed on the stiffness (k_T). Since piezo ceramics are active materials, they produce an electrical response (charge) when mechanically stressed (e.g. in dynamic operation). If the electric charge cannot be drained from the PZT ceramics, it generates a counterforce opposing the mechanical stress. This is why a piezo element with open electrodes appears stiffer than one with shorted electrodes. Common voltage amplifiers with their low output impedances look like a short circuit to a piezo actuator.

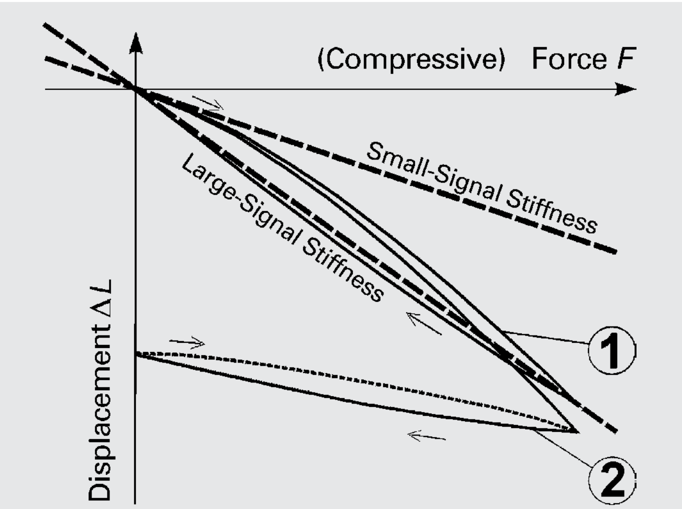


Fig. 18. Quasi-static characteristic mechanical stress/strain curves for piezo ceramic actuators and the derived stiffness values. Curve 1 is with the nominal operating voltage on the electrodes, Curve 2 is with the electrodes shorted (showing ceramics after depolarization)

Mechanical stressing of piezo actuators with open electrodes, e.g. open wire leads, should be avoided, because the resulting induced voltage might damage the stack electrically.

Note

There is no international standard for measuring piezo actuator stiffness. Therefore stiffness data from different manufacturers cannot be compared without additional information.

Fundamentals of Piezoelectric Actuators (cont.)

Force Generation

In most applications, piezo actuators are used to produce displacement. If used in a restraint, they can be used to generate forces, e.g. for stamping. Force generation is always coupled with a reduction in displacement. The maximum force (blocked force) a piezo actuator can generate depends on its stiffness and maximum displacement (see also p. 2-191). At maximum force generation, displacement drops to zero.

(Equation 3)

$$F_{max} \approx k_T \cdot \Delta L_0$$

Maximum force that can be generated in an infinitely rigid restraint (infinite spring constant).

Where:

ΔL_0 = *max. nominal displacement without external force or restraint [m]*
k_T = *piezo actuator stiffness [N/m]*

In actual applications the spring constant of the load can be larger or smaller than the piezo spring constant. The force generated by the piezo actuator is:

(Equation 4)

$$F_{max\ eff} \approx k_T \cdot \Delta L_0 \left(1- \frac{k_T}{k_T+k_S}\right)$$

Effective force a piezo actuator can generate in a yielding restraint

Where:

ΔL_0 = *max. nominal displacement without external force or restraint [m]*
k_T = *piezo actuator stiffness [N/m]*
k_S = *stiffness of external spring [N/m]*

Example

What is the force generation of a piezo actuator with nominal displacement of 30 µm and stiffness of 200 N/µm? The piezo actuator can produce a maximum force of 30 µm x 200 N/µm = 6000 N When force generation is maximum, displacement is zero and vice versa (see Fig. 19 for details).

Example

A piezo actuator is to be used in a nano imprint application. At rest (zero position) the distance between the piezo actuator tip and the material is 30 microns (given by mechanical system tolerances). A force of 500 N is required to emboss the material.

Q: Can a 60 µm actuator with a stiffness of 100 N/µm be used?

A: Under ideal conditions this actuator can generate a force of 30 x 100 N = 3000 N (30 microns are lost motion due to the distance between the sheet and the piezo actuator tip). In practice the force generation depends on the stiffness of the metal and the support. If the support were a soft material, with a stiffness of 10 N/µm, the piezo actuator could only generate a force of 300 N onto the metal when operated at maximum drive voltage. If the support were stiff but the material to be embossed itself were very soft it would yield and the piezo actuator still could not generate the required force. If both the support and the metal were stiff enough, but the piezo actuator mount was too soft, the force generated by the piezo would push the actuator away from the material to be embossed.

The situation is similar to lifting a car with a jack. If the ground (or the car's body) is too soft, the jack will run out of travel before it generates enough force to lift the wheels off the ground.

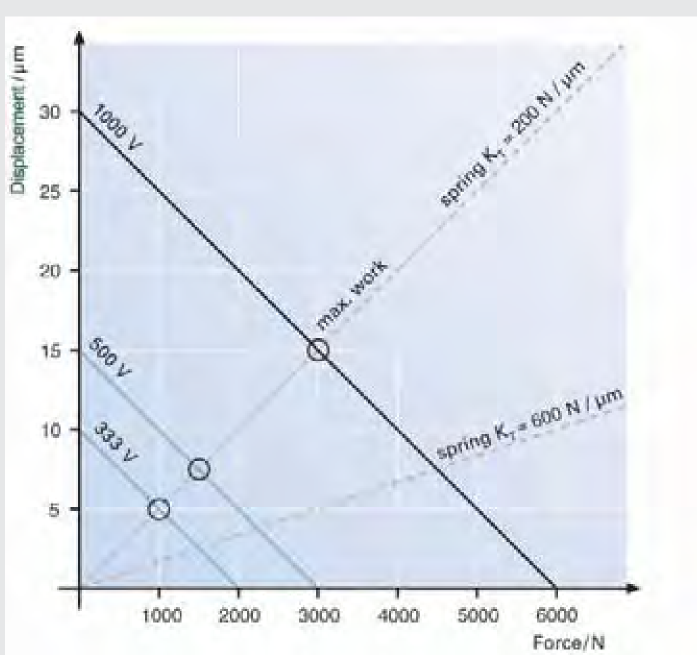


Fig. 19. Force generation vs. displacement of a piezo actuator (displacement 30 µm, stiffness 200 N/µm). Stiffness at various operating voltages. The points where the dashed lines (external spring curves) intersect the piezo actuator force/displacement curves determine the force and displacement for a given setup with an external spring. The stiffer the external spring (flatter dashed line), the less the displacement and the greater the force generated by the actuator. Maximum work can be done when the stiffness of the piezo actuator and external spring are identical

Displacement and External Forces

Like any other actuator, a piezo actuator is compressed when a force is applied. Two cases must be considered when operating a piezo actuator with a load:

a) The load remains constant during the motion process.

b) The load changes during the motion process.

Note

To keep down the loss of travel, the stiffness of the preload spring should be under 1/10 that of the piezo actuator stiffness. If the preload stiffness were equal to the piezo actuator stiffness, the travel would be reduced by 50 %. For primarily dynamic applications, the resonant frequency of the preload must be above that of the piezo actuator.

a Constant Force

Zero-point is offset

A mass is installed on the piezo actuator which applies a force F = M · g (M is the mass, g the acceleration due to gravity).
The zero-point will be shifted by $\Delta L_N \approx F/k_T$, where k_T is the stiffness of the actuator.
If this force is below the specified load limit (see product technical data), full displacement can be obtained at full operating voltage (see Fig. 20).

(Equation 5)

$$\Delta L_N \approx \frac{F}{k_T}$$

Zero-point offset with constant force

Where:

ΔL_N = *zero-point offset [m]*
F = *force (mass x acceleration due to gravity) [N]*
k_T = *piezo actuator stiffness [N/m]*

Example

How large is the zero-point offset of a 30 µm piezo actuator with a stiffness of 100 N/µm if a load of 20 kg is applied, and what is the maximum displacement with this load?

The load of 20 kg generates a force of 20 kg x 9.81 m/s² = 196 N. With a stiffness of 100 N/µm, the piezo actuator is compressed slightly less than 2 µm. The maximum displacement of 30 µm is not reduced by this constant force.

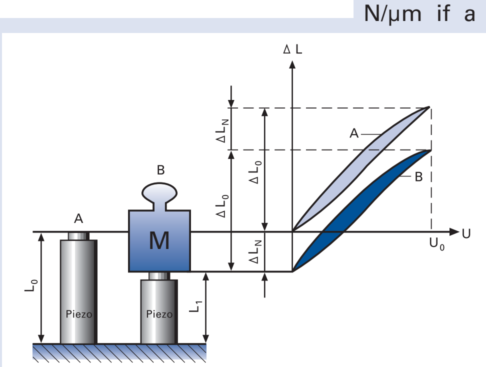


Fig. 20. Case a: Zero-point offset with constant force

b Changing Force

Displacement is reduced

For piezo actuator operation against an elastic load different rules apply. Part of the displacement generated by the piezo effect is lost due to the elasticity of the piezo element (Fig. 21). The total available displacement can be related to the spring stiffness by the following equations:

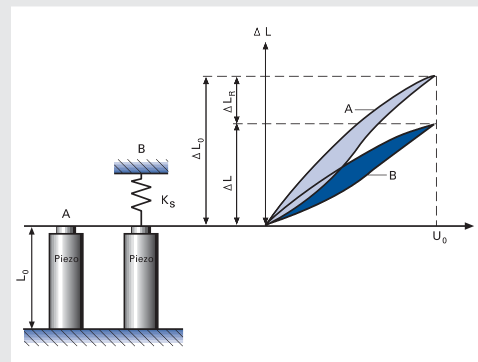


Fig. 21. Case b: Effective displacement of a piezo actuator acting against a spring load

(Equation 6)

$$\Delta L \approx \Delta L_0 \left(\frac{k_T}{k_T + k_S}\right)$$

Maximum displacement of a piezo actuator acting against a spring load.

(Equation 7)

$$\Delta L_R \approx \Delta L_0 \left(1 - \frac{k_T}{k_T + k_S}\right)$$

Maximum loss of displacement due to external spring force. In the case where the restraint is infinitely rigid ($k_s = \infty$), the piezo actuator can produce no displacement but acts only as a force generator.

Where:

ΔL = *displacement with external spring load [m]*
ΔL_0 = *nominal displacement without external force or restraint [m]*
ΔL_R = *lost displacement caused by the external spring [m]*
k_s = *spring stiffness [N/m]*
k_T = *piezo actuator stiffness [N/m]*

Example

Q: What is the maximum displacement of a 15 µm piezo translator with a stiffness of 50 N/µm, mounted in an elastic restraint with a spring constant k_S (stiffness) of 100 N/µm?

A: Equation 6 shows that the displacement is reduced in an elastic restraint. The spring constant of the external restraint is twice the value of the piezo translator. The achievable displacement is therefore limited to 5 µm (1/3 of the nominal travel).

Dynamic Operation Fundamentals

Dynamic Forces

Every time the piezo drive voltage changes, the piezo element changes its dimensions. Due to the inertia of the piezo actuator mass (plus any additional load), a rapid move will generate a force acting on (pushing or pulling) the piezo. The maximum force that can be generated is equal to the blocked force, described by:

(Equation 8)

$$F_{max} \approx \pm k_T \cdot \Delta L_0$$

Maximum force available to accelerate the piezo mass plus any additional load. Tensile forces must be compensated, for example, by a spring preload.

Where:

F_{max} = max. force [N]

ΔL_0 = max. nominal displacement without external force or restraint [m]

k_T = piezo actuator stiffness [N/m]

The preload force should be around 20% of the compressive load limit. The preload should be soft compared to the piezo actuator, at most 10% the actuator stiffness.
In sinusoidal operation peak forces can be expressed as:

(Equation 9)

$$F_{dyn} = \pm 4\pi^2 \cdot m_{eff} \left(\frac{\Delta L}{2}\right) f^2$$

Dynamic forces on a piezo actuator in sinusoidal operation at frequency f.

Where:

F_{dyn} = dynamic force [N]
m_{eff} = effective mass [kg], see p. 4-25
ΔL = peak-to-peak displacement [m]
f = frequency [Hz]

The maximum permissible forces must be considered when choosing an operating frequency.

Example:
Dynamic forces at 1000 Hz, 2 m peak-to-peak and 1 kg load reach approximately ±40 N.

Note

A guiding system (e.g. diaphragm type) is essential when loads which are heavy or large (relative to the piezo actuator diameter) are moved dynamically. Without a guiding system, there is a potential for tilt oscillations that may damage the piezoceramics.

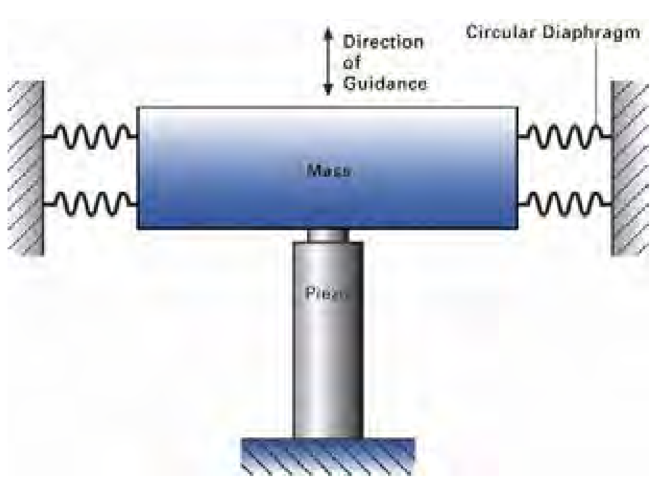


Fig. 22. Recommended guiding for large masses

Resonant Frequency

In general, the resonant frequency of any spring/mass system is a function of its stiffness and effective mass (see Fig. 23). Unless otherwise stated, the resonant frequency given in the technical data tables for actuators always refer to the unloaded actuator with one end rigidly attached. For piezo positioning systems, the data refers to the unloaded system firmly attached to a significantly larger mass.

(Equation 10)

$$f_0 = \left(\frac{1}{2\pi}\right)\sqrt{\frac{k_T}{m_{eff}}}$$

Resonant frequency of an ideal spring/mass system.

Where:

f_0 = *resonant frequency of unloaded actuator [Hz]*

k_T = *piezo actuator stiffness [N/m]*

m_{eff} = *effective mass (about 1/3 of the mass of the ceramic stack plus any installed end pieces) [kg]*

Note:
In positioning applications, piezo actuators are operated well below their resonant frequencies. Due to the non-ideal spring behavior of piezoceramics, the theoretical result from the above equation does not necessarily match the real-world behavior of the piezo actuator system under large signal conditions. When adding a mass M to the actuator, the resonant frequency drops according to the following equation:

(Equation 11)

$$f_0' = f_0 \sqrt{\frac{m_{eff}}{m'_{eff}}}$$

Resonant frequency with added mass.

m'_{eff} = *additional mass* $M + m_{eff}$.

The above equations show that to double the resonant frequency of a spring-mass system, it is necessary to either increase the stiffness by a factor of 4 or decrease the effective mass to 25 % of its original value. As long as the resonant frequency of a preload spring is well above that of the actuator, forces it introduces do not significantly affect the actuator's resonant frequency.

The phase response of a piezo actuator system can be approximated by a second order system and is described by the following equation:

(Equation 12)

$$\varphi \approx 2 \cdot \arctan\left(\frac{f}{f_0}\right)$$

Where:

φ = *phase angle [deg]*

F_{max} = *resonant frequency [Hz]*

f = *operating frequency [Hz]*

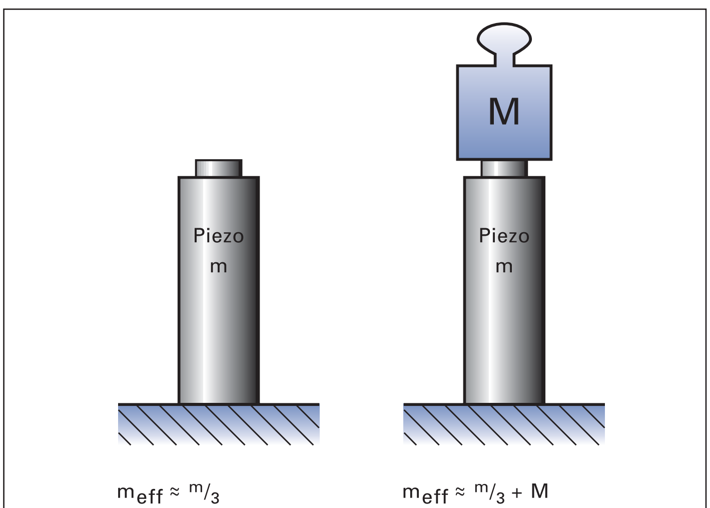


Fig. 23. Effective mass of an actuator fixed at one end

Dynamic Operation Fundamentals (cont.)

How Fast Can a Piezo Actuator Expand?

Fast response is one of the characteristic features of piezo actuators. A rapid drive voltage change results in a rapid position change. This property is especially welcome in dynamic applications such as scanning microscopy, image stabilization, switching of valves/shutters, shock-wave generation, vibration cancellation systems, etc.

A piezo actuator can reach its nominal displacement in approximately 1/3 of the period of the resonant frequency, provided the controller can deliver the necessary current. If not compensated by appropriate measures (e.g. notch filter, InputShaping®, see p. 2-201) in the servo-loop, such rapid expansion will be accompanied by significant overshoot.

(Equation 13)

$$T_{min} \approx \frac{1}{3f_0}$$

Minimum rise time of a piezo actuator (requires an amplifier with sufficient output current and slew rate).

Where:

T_{min} = *time [s]*

f_0 = *resonant frequency [Hz]]*

Example: A piezo translator with a 10 kHz resonant frequency can reach its nominal displacement within 30 µs.

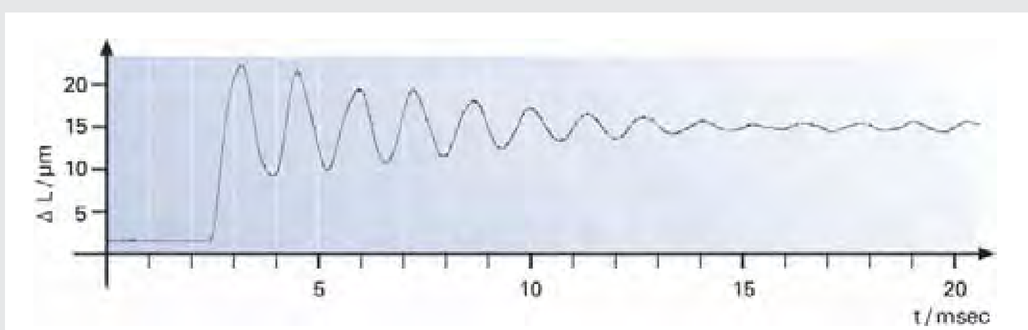


Fig. 24. Response of an undamped, lever-amplified piezo actuator (low resonant frequency) to a rapid drive-voltage change. This behavior can be prevented by intelligent control techniques or position servo-control

Piezo Actuator Electrical Fundamentals

Electrical Requirements for Piezo Operation

General

When operated well below the resonant frequency, a piezo actuator behaves as a capacitor: The actuator displacement is proportional to stored charge (first order estimate). The capacitance of the actuator depends on the area and thickness of the ceramic, as well as on its material properties. For piezo stack actuators, which are assembled with thin, laminar wafers of electroactive ceramic material electrically connected in parallel, the capacitance also depends on the number of layers.

The small-signal capacitance of a stack actuator can be estimated by:

(Equation 14)

$$C \approx n \cdot \varepsilon_{33^T} \cdot A/d_s$$

Where:

C = *capacitance [F (As/V)]*

n = *number of layers* = $\frac{l_0}{d_s}$

ε_{33^T} = *dielectric constant [As/Vm]*

A = *electrode surface area of a single layer [m²]*

d_S = *distance between the individual electrodes (layer-thickness) [m]*

l_0 = *actuator length*

The equation shows that for a given actuator length, the capacitance increases with the square of the number of layers. Therefore, the capacitance of a piezo actuator constructed of 100 µm thick layers is 100 times the capacitance of an actuator with 1 mm layers, if the two actuators have the same dimensions. Although the actuator with thinner layers draws 100 times as much current, the power requirements of the two actuators in this example are about the same. The PI high-voltage and low-voltage amplifiers in this catalog are designed to meet the requirements of the respective actuator types.

Static Operation

When electrically charged, the amount of energy stored in the piezo actuator is $E = (1/2)\ CU^2$ Every change in the charge (and therefore in displacement) of the PZT ceramics requires a current i:

(Equation 15)

$$i = \frac{dQ}{dt} = C \cdot \frac{dU}{dt}$$

Relationship of current and voltage for the piezo actuator

Where:

i = *current [A]*

Q = *charge [coulomb (As)]*

C = *capacitance [F]*

U = *voltage [V]*

t = *time [s]*

For static operation, only the leakage current need be supplied. The high internal resistance reduces leakage currents to the micro-amp range or less. Even when suddenly disconnected from the electrical source, the charged actuator will not make a sudden move, but return to its uncharged dimensions very slowly.

For slow position changes, only very low current is required.

Example: An amplifier with an output current of 20 µA can fully expand a 20 nF actuator in one second. Suitable amplifiers can be found using the "Piezo Drivers / Servo Controllers" Selection Guide on p. 2-100 *ff*.

Note

The actuator capacitance values indicated in the technical data tables are small-signal values (measured at 1 V, 1000 Hz, 20 °C, unloaded) The capacitance of piezoceramics changes with amplitude, temperature, and load, to up to 200 % of the unloaded, small-signal, room-temperature value. For detailed information on power requirements, refer to the amplifier frequency response curves in the "Piezo Drivers / Servo Controllers" (see p. 2-99 *ff*) section.

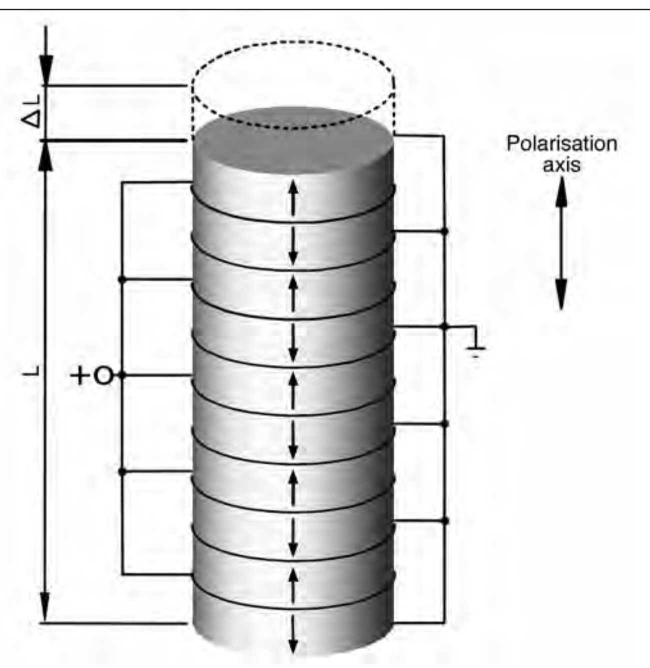


Fig. 25. Design of a piezo stack actuator

Piezo Actuator Electrical Fundamentals (cont.)

Dynamic Operation (Linear)

Piezo actuators can provide accelerations of thousands of g's and are ideally suited for dynamic applications.

Several parameters influence the dynamics of a piezo positioning system:

- The slew rate [V/s] and the maximum current capacity of the amplifier limit the operating frequency of the piezo system.
- If sufficient electrical power is available from the amplifier, the maximum drive frequency may be limited by dynamic forces (see "Dynamic Operation", p. 2-192).
- In closed-loop operation, the maximum operating frequency is also limited by the phase and amplitude response of the system. Rule of thumb: The higher the system resonant frequency, the better the phase and amplitude response, and the higher the maximum usable frequency. The sensor bandwidth and performance of the servo-controller (digital and analog filters, control algorithm, servo-bandwidth) determine the maximum operating frequency of a piezoelectric system.
- In continuous operation, heat generation can also limit the operating frequency.

The following equations describe the relationship between amplifier output current, voltage and operating frequency. They help determine the minimum specifications of a piezo amplifier for dynamic operation.

(Equation 16)

$$i_a \approx f \cdot C \cdot U_{p\text{-}p}$$

Long-term average current required for sinusoidal operation

(Equation 17)

$$i_{max} \approx f \cdot \pi \cdot C \cdot U_{p\text{-}p}$$

Peak current required for sinusoidal operation

(Equation 18)

$$f_{max} \approx \frac{i_{max}}{2 \cdot CU_{p\text{-}p}}$$

Maximum operating frequency with triangular waveform, as a function of the amplifier output current limit

Where:

i_a* = *average amplifier source/sink current [A]*

i_{max}* = *peak amplifier source/sink current [A]*

f_{max} = *maximum operating frequency [Hz]*

*C*** = *piezo actuator capacitance [Farad (As/V)]*

$U_{p\text{-}p}$ = *peak-to-peak drive voltage [V]*

f = *operating frequency [Hz]*

The average and maximum current capacity for each PI piezo amplifier can be found in the product technical data tables.

Example

Q: What peak current is required to obtain a sinewave displacement of 20 µm at 1000 Hz from a 40 nF HVPZT actuator with a nominal displacement of 40 µm at 1000 V?

A: The 20 µm displacement requires a drive voltage of about 500 V peak-to-peak. With Equation 17 the required peak current is calculated at ≈ 63 mA. For appropriate amplifiers, see the "Piezo Drivers / Servo Controllers" section (p. 2-99 *ff*).

The following equations describe the relationship between (reactive) drive power, actuator capacitance, operating frequency and drive voltage.

The average power a piezo driver has to be able to provide for sinusoidal operation is given by:

(Equation 19)

$$P_a \approx C \cdot U_{max} \cdot U_{p\text{-}p} \cdot f$$

Peak power for sinusoidal operation is:

(Equation 20)

$$P_{max} \approx \pi \cdot C \cdot U_{max} \cdot U_{p\text{-}p} \cdot f$$

P_a = *average power [W]*

P_{max} = *peak power [W]*

*C*** = *piezo actuator capacitance [F]*

f = *operating frequency [Hz]*

$U_{p\text{-}p}$ = *peak-to-peak drive voltage [V]*

U_{max} = *nominal voltage of the amplifier [V]*

It is also essential that the power supply be able to supply sufficient current.

** The power supply must be able to provide enough current.*

*** For large-signal conditions a margin of 70% of the small-signal value should be added.*

Dynamic Operating Current Coefficient (DOCC)

Instead of calculating the required drive power for a given application, it is easier to calculate the drive current, because it increases linearly with both frequency and voltage (displacement). For this purpose, the Dynamic Operating Current Coefficient (DOCC) has been introduced. The DOCC is the current that must be supplied by the amplifier to drive the piezo actuator per unit frequency (Hz) and unit displacement. DOCC values are valid for sinewave operation in open-loop mode. In closed-loop operation the current requirement can be up to 50% higher.

The peak and long-term average current capacities of the different piezo amplifiers can be found in the technical data tables for the electronics, the DOCC values in the tables for the piezo actuators.

Example: To determine whether a selected amplifier can drive a given piezo actuator at 50 Hz with 30 µm peak-to-peak displacement, multiply the actuator's DOCC by 50 x 30 and compare the result with the average output current of the selected amplifier. If the current required is less than or equal to the amplifier output, then the amplifier has sufficient capacity for the application.

Dynamic Operation (Switched)

For applications such as shock wave generation or valve control, switched operation (on/off) may be sufficient. Piezo actuators can provide motion with rapid rise and fall times with accelerations in the thousands of g's. For information on estimating the forces involved, see "Dynamic Forces," p. 2-192).

The simplest form of binary drive electronics for piezo applications would consist of a large capacitor that is slowly charged and rapidly discharged across the PZT ceramics.

The following equation relates applied voltage (which corresponds to displacement) to time.

(Equation 21)

$$U(t) = U_o + U_{p\text{-}p} \cdot (1 - e^{-t/RC})$$

Voltage on the piezo after switching event.

Where:

U_0 = *start voltage [V]*

$U_{p\text{-}p}$ = *source output voltage (peak-to-peak) [V]*

R = *source output resistance [ohm]*

C = *piezo actuator capacitance [F]*

t = *time [s]*

The voltage rises or falls exponentially with the RC time constant. Under quasi-static conditions, the expansion of the PZT ceramics is proportional to the voltage. In reality, dynamic piezo processes cannot be described by a simple equation. If the drive voltage rises too quickly, resonance occurs, causing ringing and overshoot. Furthermore, whenever the piezo actuator expands or contracts, dynamic forces act on the ceramic material. These forces generate a (positive or negative) voltage in the piezo element which is superimposed on the drive voltage. A piezo actuator can reach its nominal displacement in approximately 30 % of the period of the resonant frequency, provided the controller can deliver the necessary current. (see p. 2-194).

The following equation applies for constant-current charging (as with a linear amplifier):

(Equation 22)

$$t \approx C \cdot (U_{p\text{-}p} / i_{max})$$

Time to charge a piezoceramic with constant current. With lower-capacity electronics, amplifier slew rate can be a limiting factor.

Where:

t = *time to charge piezo to $U_{p\text{-}p}$ [s]*

C = *piezo actuator capacitance [F]*

$U_{p\text{-}p}$ = *voltage change (peak-to-peak) [V]*

i_{max} = *peak amplifier source/sink current [A]*

For fastest settling, switched operation is not the best solution because of the resulting overshoot. Modern techniques like InputShaping® (see p. 2-201) solve the problem of resonances in and around the actuator with complex signal processing algorithms.

Note

Piezo drives are becoming more and more popular because they can deliver extremely high accelerations. This property is very important in applications such as beam steering and optics stabilization. Often, however, the actuators can accelerate faster than the mechanics they drive can

Piezo Actuator Electrical Fundamentals (cont.)

follow. Rapid actuation of nanomechanisms can cause recoil-generated ringing of the actuator and any adjacent components. The time required for this ringing to damp out can be many times longer than the move itself. In time-critical industrial nanopositioning applications, this problem obviously grows more serious as motion throughputs increase and resolution requirements tighten.

Classical servo-control techniques cannot solve this problem, especially when resonances occur outside the servo-loop such as when ringing is excited in a sample on a fast piezo scanning stage as it reverses direction. A solution is often sought in reducing the scanning rate, thereby sacrificing part of the advantage of a piezo drive.

A patented real-time feedforward technology called InputShaping® nullifies resonances both inside and outside the servo-loop and thus eliminates the settling phase. For more information see p. 2-201 or visit www.Convolve.com.

Heat Generation in a Piezo Actuator in Dynamic Operation

PZT ceramics are (reactive) capacitive loads and therefore require charge and discharge currents that increase with operating frequency. The thermal active power, P (apparent power x power factor, cos φ), generated in the actuator during harmonic excitation can be estimated with the following equation:

(Equation 23)

$$P \approx \frac{\pi}{4} \cdot \tan\delta \cdot f \cdot C \cdot U_{p\text{-}p}^2$$

Heat generation in a piezo actuator.

Where:

P = power converted to heat [W]

tan δ = dielectric factor (≈ power factor, cos φ, for small angles δ and φ)

f = operating frequency [Hz]

C = actuator capacitance [F]

$U_{p\text{-}p}$ = voltage (peak-to-peak)

For the description of the loss power, we use the loss factor tan δ instead of the power factor cos φ, because it is the more common parameter for characterizing dielectric materials. For standard actuator piezoceramics under small-signal conditions the loss factor is on the order of 0.01 to 0.02. This means that up to 2 % of the electrical "power" flowing through the actuator is converted into heat. In large-signal conditions however, 8 to 12 % of the electrical power pumped into the actuator is converted to heat (varies with frequency, temperature, amplitude etc.). Therefore, maximum operating temperature can limit the piezo actuator dynamics. For large amplitudes and high frequencies, cooling measures may be necessary. A temperature sensor mounted on the ceramics is suggested for monitoring purposes.

For higher frequency operation of high-load actuators with high capacitance (such as PICA™-Power actuators, see p. 1-88), a special amplifiers employing energy recovery technology has been developed. Instead of dissipating the reactive power at the heat sinks, only the active power used by the piezo actuator has to be delivered.

The energy not used in the actuator is returned to the amplifier and reused, as shown in the block diagram in Fig. 26. The combination of low-loss, high-energy piezoceramics and amplifiers with energy recovery are the key to new high-level dynamic piezo actuator applications.

For dynamic applications with low to medium loads, the newly developed PICMA® actuators are also quite well suited. With their high Curie temperature of 320 °C, they can be operated with internal temperatures of up to 150 °C.

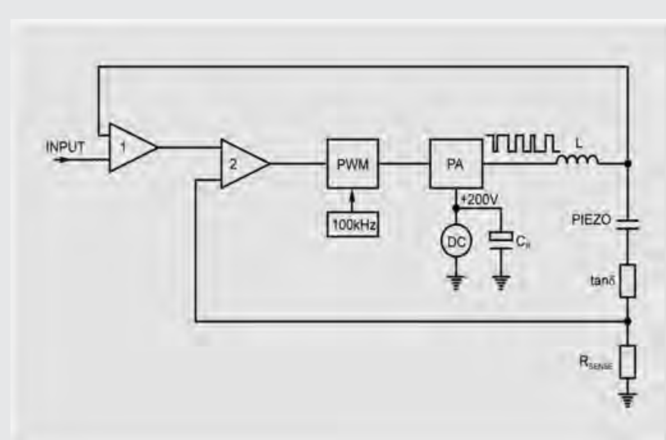


Fig. 26. Block diagram of an amplifier with energy recovery for higher frequency applications

Control of Piezo Actuators and Stages

Position Servo-Control

Fig. 27. Variety of digital piezo controllers

Position servo-control eliminates nonlinear behavior of piezoceramics such as hysteresis and creep and is the key to highly repeatable nanometric motion.

PI offers the largest selection of closed-loop piezo mechanisms and control electronics worldwide. The advantages of position servo-control are:

- High linearity, stability, repeatability and accuracy
- Automatic compensation for varying loads or forces
- Virtually infinite stiffness (within load limits)
- Elimination of hysteresis and creep effects

PI closed-loop piezo actuators and systems are equipped with position measuring systems providing sub-nanometer resolution, linearity to 0.01 %, and bandwidths up to 10 kHz. A servo-controller (digital or analog) determines the output voltage to the PZT ceramics by comparing a reference signal (commanded position) to the actual sensor position signal (see Fig. 28).

For maximum accuracy, it is best if the sensor measures the motion of the part whose position is of interest (direct metrology). PI offers a large variety of piezo actuators with integrated direct-metrology sensors. Capacitive sensors provide the best accuracy (see "Nanometrology" p. 3-1 *ff*). Simpler, less accurate systems measure things like strain in drive elements.

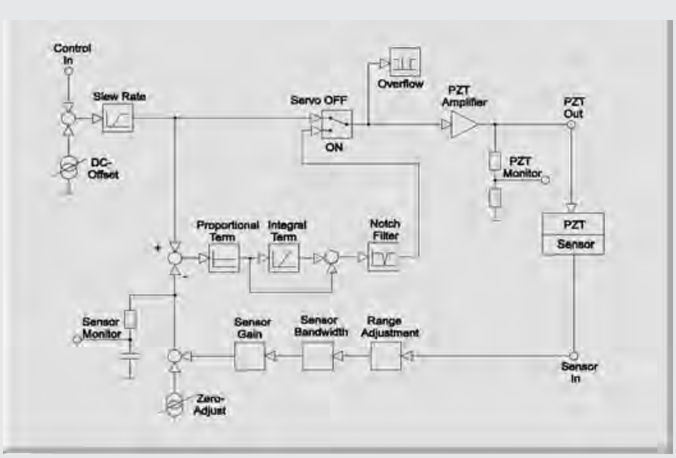


Fig. 28. Block diagram of a typical PI closed-loop piezo positioning system

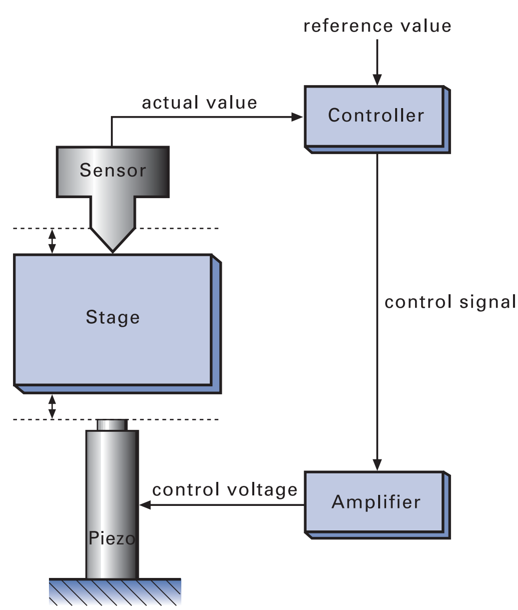


Fig. 29. Closed-loop position servo-control. For optimum performance, the sensor is mounted directly on the object to be positioned (direct metrology)

PI

Control of Piezo Actuators and Stages (cont.)

Open- and Closed-Loop Resolution

Position servo-controlled piezo drives offer linearity and repeatability many times better than that of open-loop systems. The resolution (minimum incremental motion) of piezo actuators is actually better for open-loop than for closed-loop systems. This is because piezo resolution is not limited by friction but rather by electronic noise. In open-loop, there is no sensor or servo-electronics to put additional noise on the control signal. In a servo-controlled piezo system, the sensor and control electronics are thus of considerable importance. With appropriate, high-quality systems, subnanometer resolution is also possible in closed-loop mode, as can be seen in Fig. 30 and 31. Capacitive sensors attain the highest resolution, linearity and stability.

Piezo Metrology Protocol

Each PI piezo position servo-controller is matched to the specific closed-loop piezo positioning system to achieve optimum displacement range, frequency response and settling time. The adjustment is performed at the factory and a report with plotted and tabulated positioning accuracy data is supplied with the system (see p. 2-87). To optimize the settings, information about the specific application is needed. For details see p. 2-11.

Digital controllers can automatically read important device specific values from an ID-chip integrated in the piezo mechanics. This feature facilitates using a controller with various stages/actuators and vice versa.

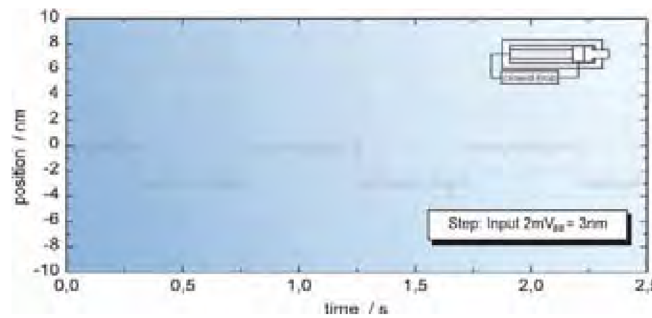


Fig. 30. Response of a closed-loop PI piezo actuator (P-841.10, 15 µm, strain gauge sensor) to a 3 nm peak-to-peak square-wave control input signal, measured with servo-control bandwidth set to 240 Hz and 2 msec settling time. Note the crisp, backlash-free behavior in the nanometer range

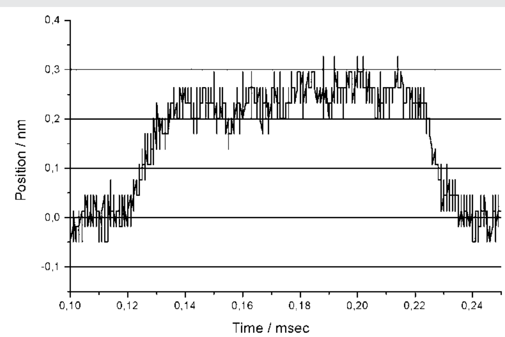


Fig. 31. PI piezo actuators with capacitive position sensors can achieve extremely high resolutions, as seen in the above result of a 250 picometer step by a S-303 phase corrector (Controller: E-509.C1A servo-controller and E-503 amplifier). The measurements were made with an ultra-sensitive capacitive sensor having a resolution of ±0.02 nm

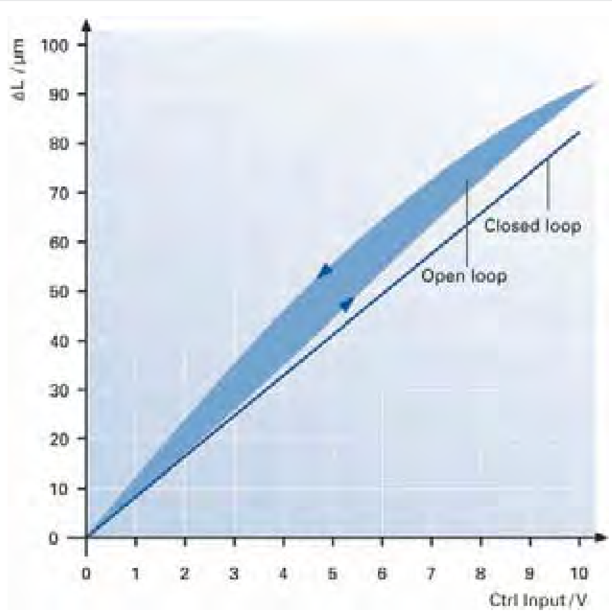


Fig. 32. Open-loop vs. closed-loop performance graph of a typical PI piezo actuator

Methods to Improve Piezo Dynamics

The dynamic behavior of a piezo positioning system depends on factors including the system's resonant frequency, the position sensor and the controller used. Simple controller designs limit the usable closed-loop tracking bandwidth of a piezoelectric system to 1/10 of the system's resonant frequency. PI offers controllers that significantly increase piezo actuator system dynamics (see table). Two of the methods are described below; additional information is available on request.

InputShaping® Stops Structural Ringing Caused by High-Throughput Motion

A patented, real-time, feedforward technology called InputShaping® nullifies resonances both inside and outside the servo-loop and virtually eliminates the settling phase. The procedure requires determination of all critical resonant frequencies in the system. A non-contact instrument like a Polytec Laser Doppler Vibrometer is especially well-suited for such measurements. The values, most importantly the resonant frequency of the sample on the platform, are then fed into the InputShaping® Signal processor. There the sophisticated signal processing algorithms assure that none of the undesired resonances in the system or its auxillary components is excited. Because the processor is outside the servo-loop, it works in open-loop operation as well.
The result: the fastest possible motion, with settling within a time equal one period of the lowest resonant frequency. InputShaping® was developed based on research at the Massachusetts Institute of Technology and commercialized by Convolve, Inc. (www.convolve.com). It is an option in several PI digital piezo controllers.

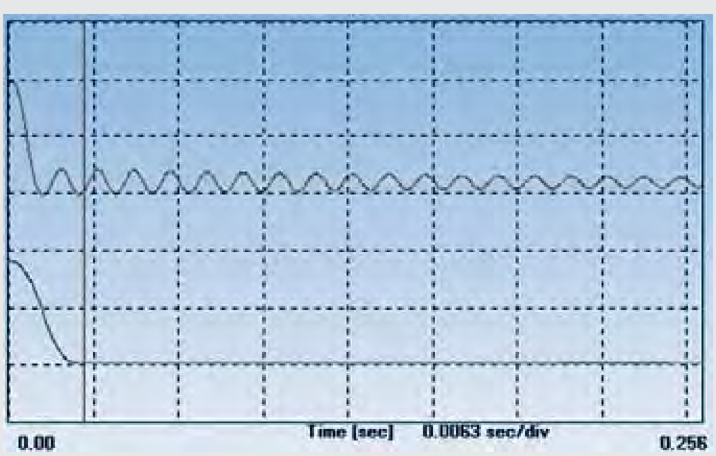


Fig. 33. InputShaping® eliminates the recoil-driven resonant reaction of loads and neighboring components due to rapid nanopositioner actuation.
Top: Polytec Laser Vibrometer reveals the resonant behavior of an undamped fixture when the nanomechanism is stepped.
Bottom: Same setup, same step, but with InputShaping®. Structural ringing is eliminated. With no excitation of vibration in the moved components, the target position is attained in a time smaller than one period of the resonant frequency

Various Methods to Improve Piezo Dynamics

Method	Goals
Feedforward	Reduce phase difference between output and input (tracking error)
Signal preshaping (software)	Increase operating frequency of the system, correct amplitude and phase response. Two learning phases required; only for periodic signals.
Adaptive preshaping (hardware)	Increase operating frequency of the system, correct amplitude and phase response. No learning phase, but settling phase required; only for periodic signals.
Linearization (digital, in DSP)	Compensate for piezo hysteresis and creep effects
InputShaping®	Cancel recoil-generated ringing, whether inside or outside the servo-loop. Reduce the settling time. Closed- and open-loop.
Dynamic Digital Linearization (DDL)	Increase operating frequency of the system, correct amplitude and phase response. Integrated in digital controller. No external metrology necessary, for periodic signals only.

Methods to Improve Piezo Dynamics (cont.)

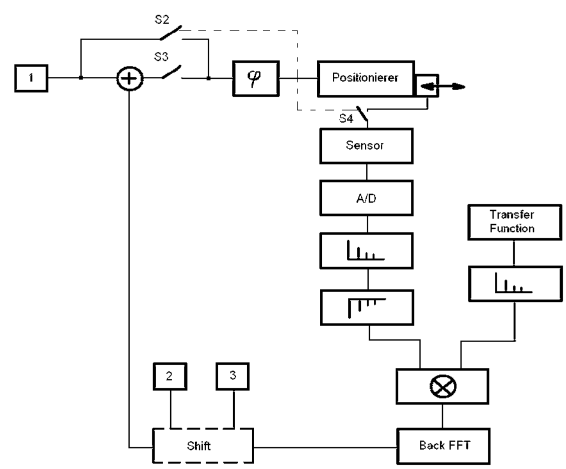


Fig. 34 a. Signal preshaping, phase 1

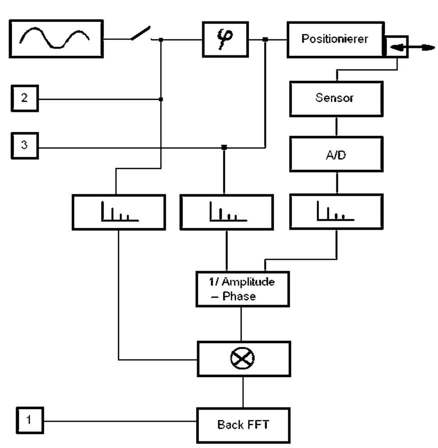


Fig. 34 b. Signal preshaping, phase 2

Signal Preshaping / Dynamic Digital Linearization (DDL)

Signal Preshaping, a patented technique, can reduce rolloff, phase error and hysteresis in applications with repetitive (periodic) inputs. The result is to improve the effective bandwidth, especially for tracking applications such as out-of-round turning of precision mechanical or optical parts. Signal Preshaping is implemented in object code, based on an analytical approach in which the complex transfer function of the system is calculated, then mathematically transformed and applied in a feedforward manner to reduce the tracking error.

Signal Preshaping is more effective than simple phase-shifting approaches and can improve the effective bandwidth by a factor of 10 and in multi-frequency applications.

Frequency response and harmonics (caused by nonlinearity of the piezo-effect) are determined in two steps using Fast Fourier Transformation (FFT), and the results are used to calculate the new control profile for the trajectory. The new control signal compensates for the system non-linearities.

For example, it is possible to increase the command rate from 20 Hz to 200 Hz for a piezo system with a resonant frequency of 400 Hz without compromising stability. At the same time, the tracking error is reduced by a factor of about 50.

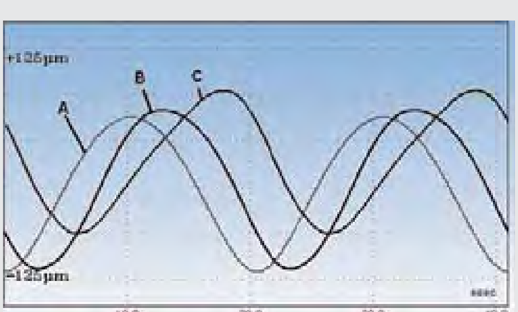


Fig. 35. No preshaping
A: Control input signal (expected motion)
B: Actual motion of system
C: Tracking error

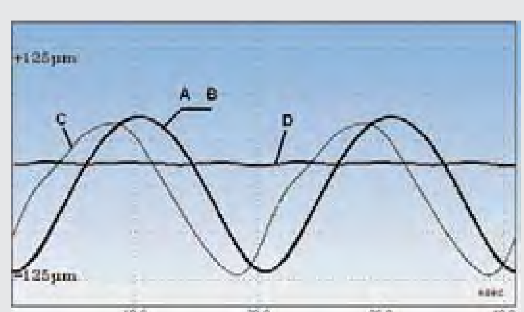


Fig. 36. Signal after preshaping phase 2
A: Expected Motion (old control signal)
B: Actual motion of system
C: New control input (producted by preshaping)
D: Tracking error

Dynamic Digital Linearization (DDL)

DDL is similar in performance to Input Preshaping, but is simpler to use. In addition, it can optimize multi-axis motion such as a raster scan or tracing an ellipse. This method requires no external metrology or signal processing (see p. 2-108). DDL uses the position information from capacitive sensors integrated in the piezo mechanics (requires direct metrology) to calculate the optimum control signal. As with preshaping, the result is an improvement in linearity and tracking accuracy of up to 3 orders of magnitude.

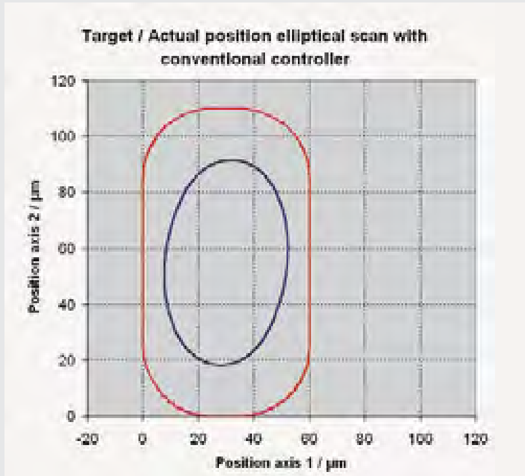


Fig. 37 a. Elliptical scan in a laser micro-drilling application with XY piezo scanning stage, conventional PID controller. The outer ellipse describes the target position, the inner ellipse shows the actual motion at the stage

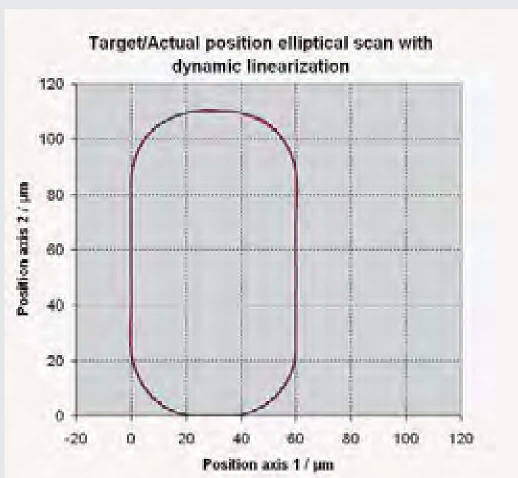


Fig. 37 b. Same scan as before, with a DDL controller. Target and actual data can hardly be discerned. The tracking error has been reduced to a few nanometers

Environmental Conditions and Influences

Temperature Effects

Two effects must be considered:

- Linear Thermal Expansion
- Temperature Dependency of the Piezo Effect

Linear Thermal Expansion

Thermal stability of piezoceramics is better than that of most other materials. Fig. 38a shows the behavior of several types of piezoceramics used by PI. The curves only describe the behavior of the piezoceramics. Actuators and positioning systems consist of a combination of piezoceramics and other materials and their overall behavior differs accordingly.

Temperature Dependency of the Piezo Effect

Piezo translators work in a wide temperature range. The piezo effect in PZT ceramics is known to function down to almost zero kelvin, but the magnitude of the piezo coefficients is temperature dependent.

At liquid helium temperature piezo gain drops to approximately 10–20 % of its room-temperature value.

Piezoceramics must be poled to exhibit the piezo effect. A poled PZT ceramic may depole when heated above the maximum allowable operating temperature. The “rate” of depoling is related to the Curie temperature of the material. PI HVPZT actuators have a Curie temperature of 350 °C and can be operated at up to 150 °C. LVPZT actuators have a Curie temperature of 150 °C and can be operated at up to 80 °C. The new monolithic PICMA® ceramics with their high Curie temperature of 320 °C allow operating at temperatures of up to 150 °C.

Note

Closed-loop piezo positioning systems are less sensitive to temperature changes than open-loop systems. Optimum accuracy is achieved if the operating temperature is identical to the calibration temperature. If not otherwise specified, PI piezomechanics are calibrated at 22 °C.

Piezo Operation in High Humidity

The polymer insulation materials used in piezoceramic actuators are sensitive to humidity. Water molecules diffuse through the polymer layer and can cause short circuiting of the piezoelectric layers. The insulation materials used in piezo actuators are sensitive to humidity. For higher humidity environments, PI offers special systems with waterproofed enclosed stacks, or integrated dry-air flushing mechanisms.
A better solution are PICMA® actuators (see Fig. 39a), which have ceramic-only insulation without any polymer covering and are thus less sensitive to water diffusion (see Fig. 39c).

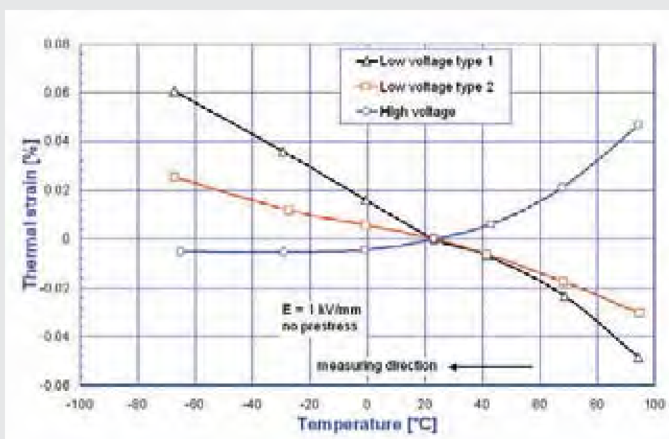


Fig. 38 a. Linear thermal expansion of different PZT ceramics

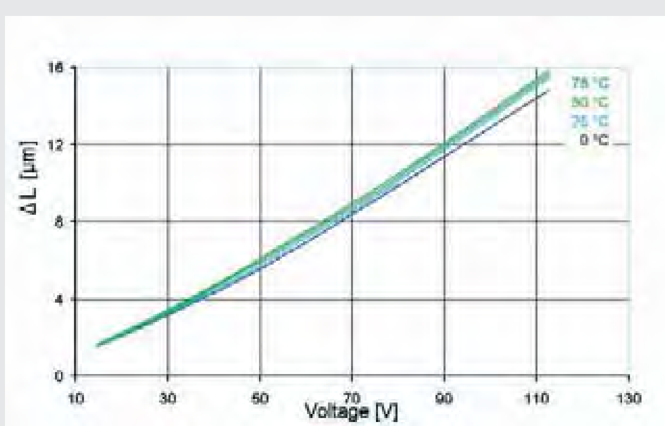


Fig. 38 b. The expansion of PICMA® piezoceramics is only slightly temperature dependent. This, and their low heat generation, makes them ideal for dynamic applications

Piezo Operation in Inert Gas Atmospheres

Ceramic-insulated PICMA® actuators are also recommended for use in inert gases, such as helium. To reduce the danger of flashover with high-voltage piezos, the maximum operating voltage must be reduced. Semi-bipolar operation is recommended, because the average operating voltage can be kept very low.

Vacuum Operation of Piezo Actuators

All PI piezo actuators can be operated at pressures below 100 Pa (~1 torr). When piezo actuators are used in a vacuum, two factors must be considered:

I. Dielectric stability

II. Outgassing

I. The dielectric breakdown voltage of a sample in a specific gas is a function of the pressure *p* times the electrode distance *s*. Air displays a high insulation capacity at atmospheric pressure and at very low pressures. The minimum breakdown voltage of ~300 V can be found at a *ps*-product of 1000 mm Pa (~10 mm torr). That is why PICMA® actuators with a maximum operating voltage of 120 V can be used in any vacuum condition. However, the operation of HVPZT actuators with dielectric layer thicknesses of 0.2 – 1.0 mm and nominal voltages to 1000 V is not recommended in the pressure range of 100 – 50000 Pa (~1 – 500 torr).

II. Outgassing behavior varies from model to model depending on design. Ultra-high-vacuum options for minimum outgassing are available for many standard low-voltage and high-voltage piezo actuators. Best suited are PICMA® ceramics (see Fig. 39a), because they have no polymers and can withstand bakeout to 150 °C (see also "Options" in the "Piezo Actuators & Components" sections, p. 2-104 *ff*).

All materials used in UHV-compatible piezo nanopositioners, including cables and connectors, are optimized for minimal outgassing rates (see Fig. 39b). Materials lists are available on request.

Fig. 39 a. PICMA® actuators are made with ceramic-only insulation and can dispense with any polymer coating. Result No measurable outgasing, insensitive to atmospheric humidity and a wider operating temperature range

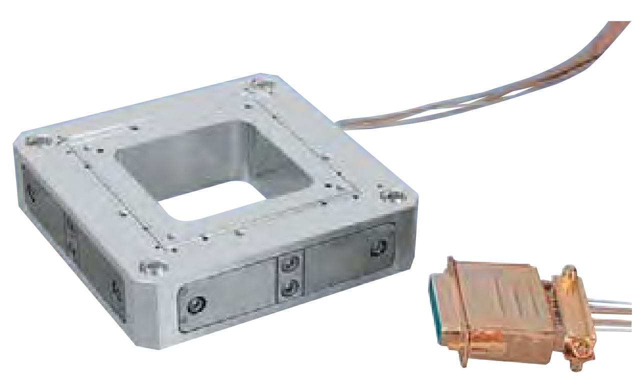


Fig. 39 b. P-733.UUD UHV-compatible XY stage for scanning microscopy applications. PICMA® ceramics are used here too. All materials used are optimized for minimal outgassing. Materials lists are available on request

Environmental Conditions and Influences (cont.)

Lifetime of Piezo Actuators

The lifetime of a piezo actuator is not limited by wear and tear. Tests have shown that PI piezo actuators can perform billions (10^9) of cycles without any measurable wear.

As with capacitors, however, the field strength does have an influence on lifetime. The average voltage should be kept as low as possible. Most PI piezo actuators and electronics are designed for semi-bipolar operation.

There is no generic formula to determine the lifetime of a piezo actuator because of the many parameters, such as temperature, humidity, voltage, acceleration, load, preload, operating frequency, insulation materials, etc., which have (nonlinear) influences. PI piezo actuators are not only optimized for maximum travel, but also designed for maximum lifetime under actual operating conditions.

The operating voltage range values in the technical data tables are based on decades of experience with nanomechanisms and piezo applications in industry. Longer travel can only be obtained with higher voltages at the cost of reduced reliability.

Example:

An P-842.60 LVPZT actuator (see p. 1-76 in the “Piezo Actuators & Components” section) is to operate a switch with a stroke of 100 µm. Of its operating time, it is to be open for 70 % and closed for 30 %.

Optimum solution: The actuator should be linked to the switch in such a way that the open position is achieved with the lowest possible operating voltage. To reach a displacement of 100 µm, a voltage amplitude of approximately 110 volts is required (nominal displacement at 100 V is only 90 µm).

Since the P-842.60 can be operated down to -20 volts, the closed position should be achieved with 90 V, and the open position with -20 volts. When the switch is not in use at all, the voltage on the piezo actuator should be 0 volts.

Statistics show that most failures with piezo actuators occur because of excessive mechanical stress. Particularly destructive are tensile and shear forces, torque and mechanical shock. To protect the ceramic from such forces PI offers a variety of actuators with preloads, ball tips, flexible tips as well as custom designs.

Failures can also occur when humidity or conductive materials such as metal dust degrade the PZT ceramic insulation, leading to irreparable dielectric breakdown. In environments presenting these hazards, PICMA® actuators with their ceramic-only insulation are strongly recommended. PI also offers hermetically sealed actuators and stages.

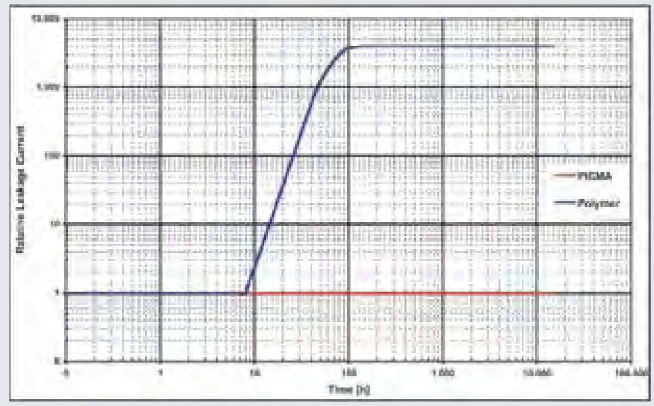


Fig. 39 c. PICMA® piezo actuators (lower curve) compared with conventional multilayer piezo actuators with polymer insulation. PICMA® actuators are insensitve to high humidity in this test. In conventional actuators, the leakage current begins to rise after only a few hours—an indication of degradation of the insulation and reduced lifetime.
Test conditions: U = 100 VDC, T = 25 °C, RH = 70%

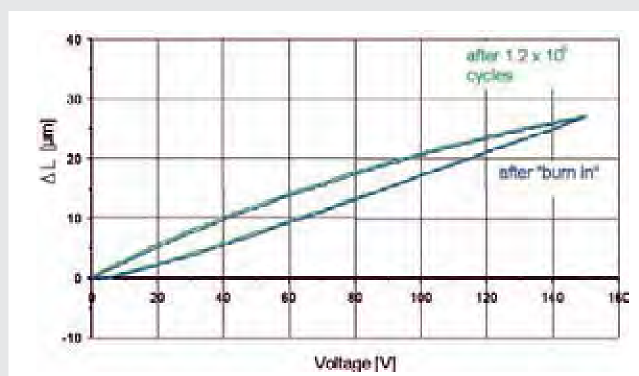


Fig. 39 d. P-885.50 PICMA® actuators with 15 MPa preload in dynamic motion test at 116 Hz. No observable wear after 1.2 billion (10^9) cycles

Basic Designs of Piezoelectric Positioning Drives/Systems

Stack Design (Translators)

The active part of the positioning element consists of a stack of ceramic disks separated by thin metallic electrodes. The maximum operating voltage is proportional to the thickness of the disks. Most high-voltage actuators consist of ceramic layers measuring 0.4 to 1 mm in thickness. In low-voltage stack actuators, the layers are from 25 to 100 µm in thickness and are cofired with the electrodes to form a monolithic unit.

Stack elements can withstand high pressures and exhibit the highest stiffness of all piezo actuator designs. Standard designs which can withstand pressures of up to 100 kN are available, and preloaded actuators can also be operated in push-pull mode. For further information see “Maximum Applicable Forces”, p. 2-189.

Displacement of a piezo stack actuator can be estimated by the following equation:

(Equation 24)

$$\Delta L \approx d_{33} \cdot n \cdot U$$

where:

ΔL = displacement [m]

d_{33} = strain coefficient (field and displacement in polarization direction) [m/V]

n = number of ceramic layers

U = operating voltage [V]

Example:

P-845, p. 1-76, etc. (see the “Piezo Actuators & Components” section)

Laminar Design (Contraction-Type Actuators)

The active material in the laminar actuators consists of thin, laminated ceramic strips. The displacement exploited in these devices is that perpendicular to the direction of polarization and electric field application. When the voltage is increased, the strip contracts. The piezo strain coefficient d_{31} (negative!) describes the relative change in length. Its absolute value is on the order of 50 % of d_{33}.

The maximum travel is a function of the length of the strips, while the number of strips arranged in parallel determines the stiffness and force generation of the element.

Displacement of a piezo contraction actuator can be estimated by the following equation:

(Equation 25)

$$\Delta L \approx d_{31} \cdot L \cdot \frac{U}{d}$$

where:

ΔL = displacement [m]

d_{31} = strain coefficient (displacement normal to polarization direction) [m/V]

L = length of the piezoceramics in the electric field direction [m]

U = operating voltage [V]

d = thickness of one ceramic layer [m]

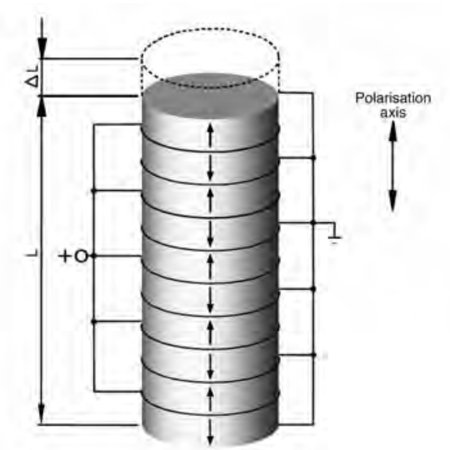


Fig. 40. Electrical design of a stack translator

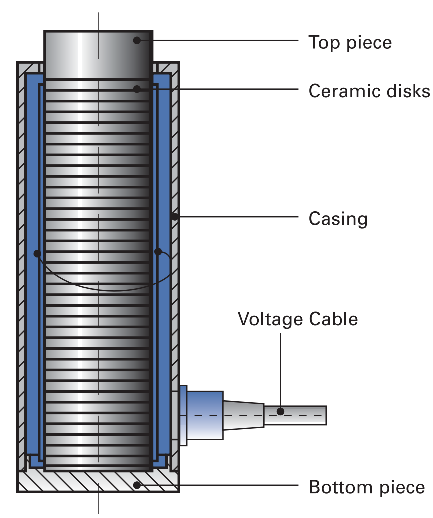


Fig. 41. Mechanical design of a stack translator

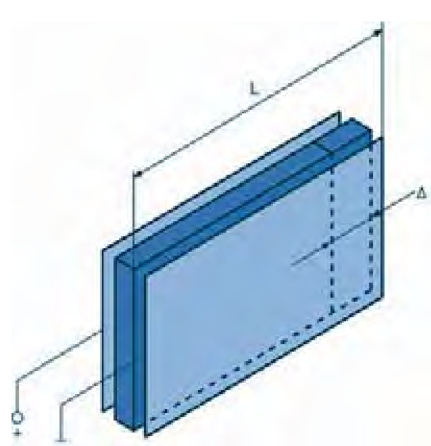


Fig. 42. Laminar actuator design

Basic Designs of Piezoelectric Positioning Drives/Systems (cont.)

Tube Design

Monolithic ceramic tubes are yet another form of piezo actuator. Tubes are silvered inside and out and operate on the transversal piezo effect. When an electric voltage is applied between the outer and inner diameter of a thin-walled tube, the tube contracts axially and radially. Axial contraction can be estimated by the following equation:

(Equation 26 a)

$$\Delta L \approx d_{31} \cdot L \cdot \frac{U}{d}$$

where:

d_{31} = *strain coefficient (displacement normal to polarization direction) [m/V]*

L = *length of the piezo ceramic tube [m]*

U = *operating voltage [V]*

d = *wall thickness [m]*

The radial displacement is the result of the superposition of increase in wall thickness (Equation 26 b) and the tangential contraction:

(Equation 26 b)

$$\frac{\Delta r}{r} \approx d_{31} \frac{U}{d}$$

r = tube radius

(Equation 26 c)

$$\Delta d \approx d_{33} \cdot U$$

where:

Δd = *change in wall thickness [m]*

d_{33} = *strain coefficient (field and displacement in polarization direction) [m/V]*

U = *operating voltage [V]*

When the outside electrode of a tube is separated into four 90° segments, placing differential drive voltages ±U on opposing electrodes will lead to bending of one end. Such scanner tubes that flex in X and Y are widely used in scanning-probe microscopes, such as scanning tunneling microscopes.

The scanning range can be estimated as follows:

(Equation 27)

$$\Delta x \approx \frac{2\sqrt{2} \cdot d_{31} \cdot L^2 \cdot U}{\pi \cdot ID \cdot d}$$

where:

Δx = *scan range in X and Y (for symmetrical electrodes) [m]*

d_{31} = *strain coefficient (displacement normal to polarization direction) [m/V]*

U = *differential operating voltage [V]*

L = *length [m]*

ID = *inside diameter [m]*

d = *wall thickness [m]*

Tube actuators cannot generate or withstand large forces. Application examples: Microdosing, nanoliter pumping, scanning microscopy, ink jet printers.

Examples:

PT120, PT130, PT140 (p. 1-100).

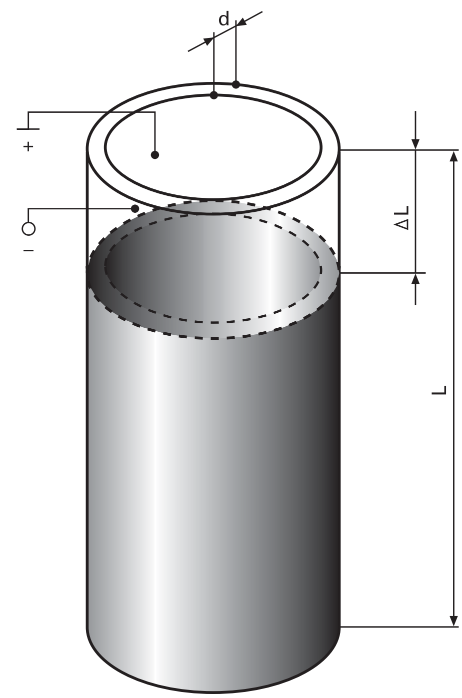


Fig. 43. Tube actuator design

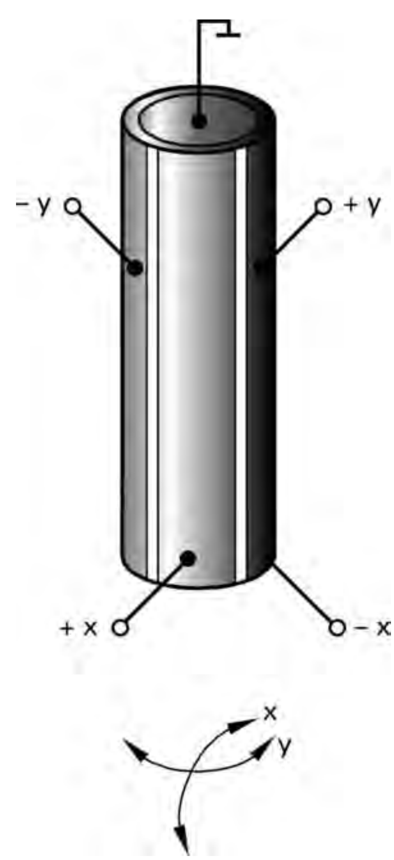


Fig. 44. Piezo scanner tube working principle

Bender Type Actuators (Bimorph and Multimorph Design)

A simple bender actuator (bimorph design) consists of a passive metal substrate glued to a piezoceramic strip (see Fig. 45a). A piezo bimorph reacts to voltage changes the way the bimetallic strip in a thermostat reacts to temperature changes. When the ceramic is energized it contracts or expands proportional to the applied voltage. Since the metal substrate does not change its length, a deflection proportional to the applied voltage occurs. The bimorph design amplifies the dimension change of the piezo, providing motion up to several millimeters in an extremely small package. In addition to the classical strip form, bimorph disk actuators where the center arches when a voltage is applied, are also available.

PZT/PZT combinations, where individual PZT layers are operated in opposite modes (contraction/expansion), are also available.

Two basic versions exist: the two-electrode bimorph (serial bimorph) and the three-electrode bimorph (parallel bimorph), as shown in Fig. 45b. In the serial type, one of the two ceramic plates is always operated opposite to the direction of polarization. To avoid depolarization, the maximum electric field is limited to a few hundred volts per millimeter. Serial bimorph benders are widely used as force and acceleration sensors.

In addition to the two-layer benders, monolithic multilayer piezo benders are also available. As with multilayer stack actuators, they run on a lower operating voltage (60 to 100 V). Bender type actuators provide large motion in a small package at the cost of low stiffness, force and resonant frequency.

Examples:

PL122 multilayer bender actuators (p. 1-94).

Shear Actuators

Shear actuators can generate high forces and large displacements. A further advantage is their suitability for bipolar operation, whereby the mid-position corresponds to a drive voltage of 0 V. In shear mode, unlike in the other modes, the electric field is applied perpendicular to the polarization direction. (see Fig. 46). The corresponding strain coefficient, d_{15}, has large-signal values as high as 1100 pm/V, providing double the displacement of linear actuators of comparable size based on d_{33}.

Shear actuators are suitable for applications like piezo linear motors, and are available as both single-axis and two-axis positioning elements.

Examples:

P-363 (p. 2-66),
N-214 NEXLINE® Piezo-Walk® motor (p. 1-10).

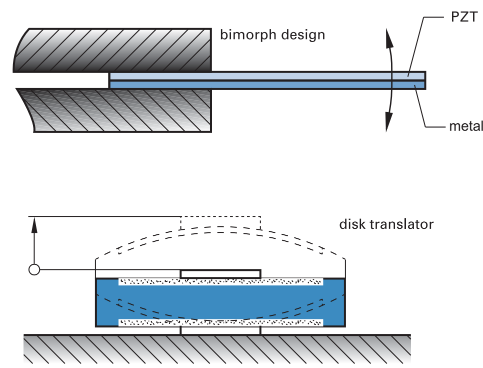


Fig. 45a. Bimorph design (strip and disk translator)

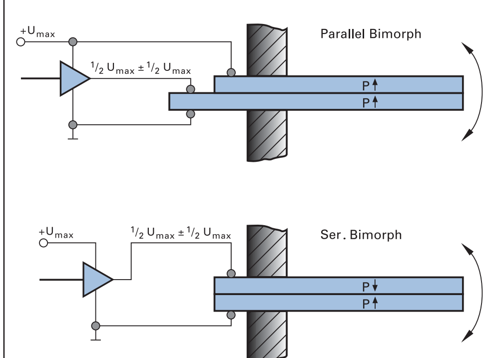


Fig. 45b. Bender Actuators: Serial and parallel bimorphs

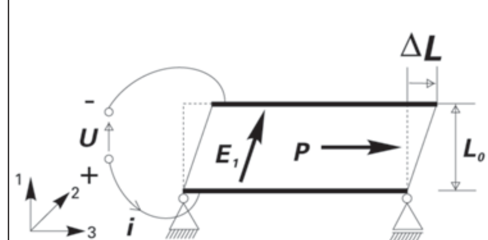


Fig. 46. Material deformation in a shear actuator

Basic Designs of Piezoelectric Positioning Drives/Systems (cont.)

Piezo Actuators with Integrated Lever Motion Amplifiers

Piezo actuators or positioning stages can be designed in such a way that a lever motion amplifier is integrated into the system. To maintain sub-nanometer resolution with the increased travel range, the lever system must be extremely stiff, backlash- and friction-free, which means ball or roller bearings cannot be used. Flexures are ideally suited as linkage elements. Using flexures, it is also possible to design multi-axis positioning systems with excellent guidance characteristics (see p. 2-211).

PI employs finite element analysis (FEA) computer simulation to optimize flexure nanopositioners for the best possible straightness and flatness (see Fig. 49 and Fig. 51).

Piezo positioners with integrated motion amplifiers have both advantages and disadvantages compared to standard piezo actuators:

Advantages:

- Longer travel
- Compact size compared to stack actuators with equal displacement
- Reduced capacitance (= reduced drive current)

Disadvantages:

- Reduced stiffness
- Lower resonant frequency

The following relations apply to (ideal) levers used to amplify motion of any primary drive system:

$$k_{sys} = \frac{k_0}{r^2}$$

$$\Delta L_{sys} = \Delta L_0 \cdot r$$

$$f_{res\text{-}sys} = \frac{f_{res\text{-}0}}{r}$$

where:

r = lever transmission ratio

ΔL_0 = travel of the primary drive [m]

ΔL_{Sys} = travel of the lever-amplified system [m]

k_{sys} = stiffness of the lever-amplified system [N/m]

k_0 = stiffness of the primary drive system (piezo stack and joints) [N/m]

$f_{res\text{-}sys}$ = resonant frequency of the amplified system [Hz]

$f_{res\text{-}0}$ = resonant frequency of the primary drive system (piezo stack and joints) [Hz]

Note:

The above equations are based on an ideal lever design with infinite stiffness and zero mass. They also imply that no stiffness is lost at the coupling interface between the piezo stack and the lever. In real applications, the design of a good lever requires long experience in micromechanics and nanomechanisms. A balance between mass, stiffness and cost must be found, while maintaining zero-friction and zero-backlash conditions.

Coupling the piezo stack to the lever system is crucial. The coupling must be very stiff in the pushing direction but should be soft in all other degrees of freedom to avoid damage to the ceramics. Even if the stiffness of each of the two interfaces is as high as that of the piezo stack alone, a 67 % loss of overall stiffness still results. In many piezo-driven systems, the piezo stiffness is thus not the limiting factor in determining the stiffness of the mechanism as a whole.

PI piezomechanics are optimized in this regard as a result of more than 30 years experience with micromechanics, nanopositioning and flexures.

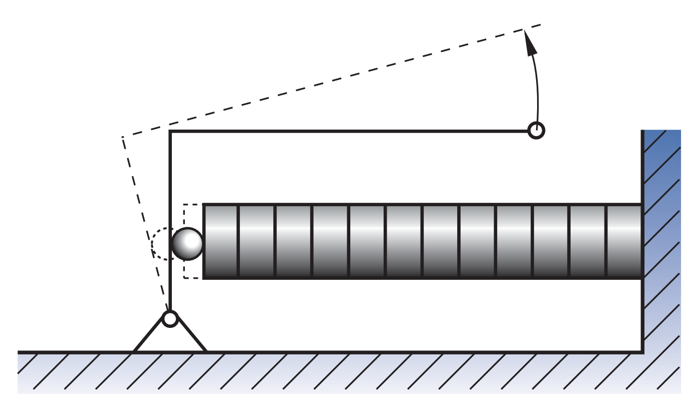


Fig. 47. Simple lever motion amplifier

Piezo Flexure Nanopositioners

For applications where extremely straight motion in one or more axes is needed and only nanometer or microrad deviation from the ideal trajectory can be tolerated, flexures provide an excellent solution.

A flexure is a frictionless, stictionless device based on the elastic deformation (flexing) of a solid material (e.g. steel). Sliding and rolling are entirely eliminated. In addition, flexure devices can be designed with high stiffness, high load capacity and do not wear. They are also less sensitive to shock and vibration than other guiding systems. They are also maintenance-free, can be fabricated from non-magnetic materials, require no lubricants or consumables and hence, unlike air cushion bearings, are suitable for vacuum operation.

Parallelogram flexures exhibit excellent guidance characteristics. Depending on complexity and tolerances, they have straightness/flatness values in the nanometer range or better. Basic parallelogram flexures cause arcuate motion (travel in an arc) which introduces an out-of-plane error of about 0.1% of the travel range (see Fig. 48). The error can be estimated by the following equation:

(Equation 28)

$$\Delta H \approx \left(\pm \frac{\Delta L}{2}\right)^2 \frac{1}{2H}$$

where:

ΔH = out-of-plane error [m]

ΔL = distance traveled [m]

H = length of flexures [m]

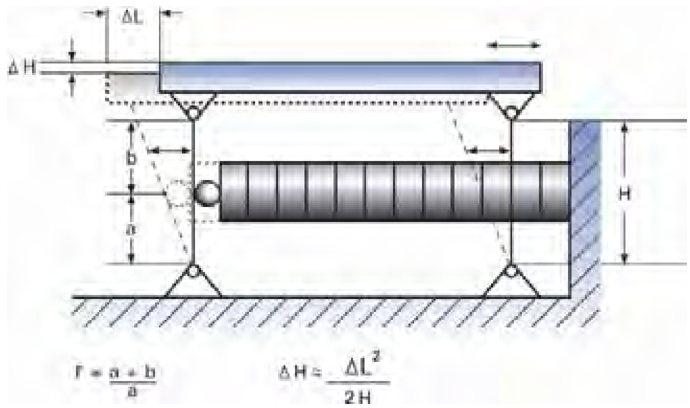


Fig. 48. Basic parallelogram flexure guiding system with motion amplification. The amplification r (transmission ratio) is given by (a+b)/a

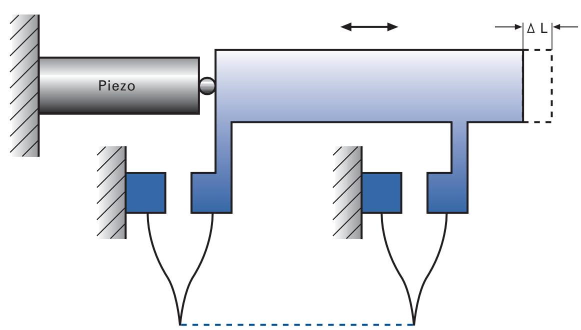


Fig. 49. Zero-arcuate-error multi-flexure guiding system

For applications where this error is intolerable, PI has designed a zero-arcuate-error multi-flexure guiding system. This special design, employed in most PI flexure stages, makes possible straightness/flatness in the nanometer or microradian range (see Fig. 49).

Note:

Flexure positioners are far superior to traditional positioners (ball bearings, crossed roller bearings, etc.) in terms of resolution, straightness and flatness. Inherent friction and stiction in these traditional designs limit applications to those with repeatability requirements on the order of 0.5 to 0.1 µm. Piezo flexure nanopositioning systems have resolutions and repeatabilities which are superior by several orders of magnitude.

Parallel and Serial Kinematics / Metrology

Direct and Indirect Metrology

Non-contact sensors are used to obtain the most accurate position values possible for position servo-control systems. Two-plate capacitive sensors installed directly on the moving platform and measuring on the axis of motion offer the best performance. Resolution and repeatability can attain 0.1 nanometer in such systems. Indirect metrology—measuring strain at some point in the drive train—cannot be used in systems with the highest accuracy requirements.

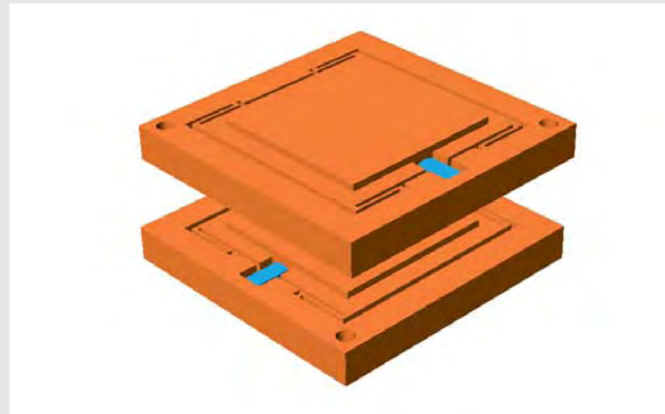


Fig. 50 a. Working principle of a stacked XY piezo stage (serial kinematics). Advantages: Modular, simple design. Disadvantages compared with parallel kinematics: More inertia, higher center of gravity, moving cables (can cause friction and hysteresis). Integrated parallel metrology and active trajectory control (automatic off-axis error correction) are not possible

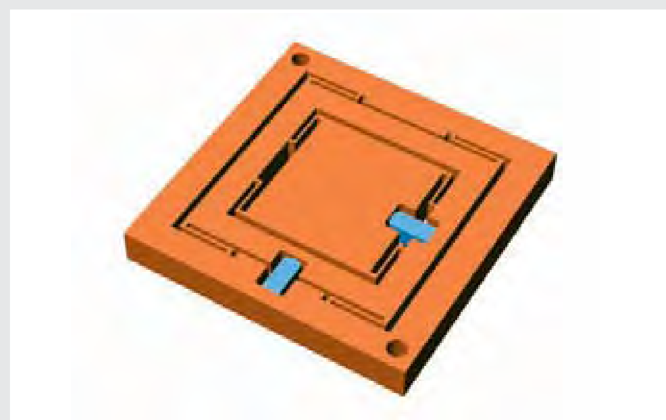


Fig. 50 b. Working principle of a nested XY piezo stage (serial kinematics). Lower center of gravity and somewhat better dynamics compared with stacked system, but retains all the other disadvantages of a stacked system, including asymmetric dynamic behavior of X and Y axes

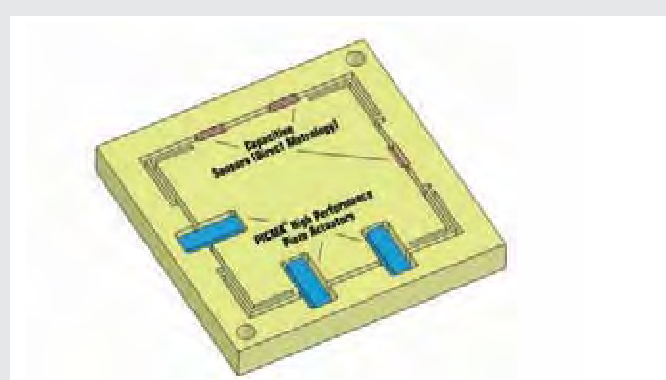


Fig. 50 c. Working principle of a monolithic XYΘ_Z parallel kinematics piezo stage. All actuators act directly on the central platform. Integrated parallel metrology keeps all motion in all controlled degrees of freedom inside the servo-loop. The position of the central, moving platform is measured directly with capacitive sensors, permitting all deviations from the prescribed trajectory to be corrected in real-time. This feature, called active trajectory control, is not possible with serial metrology

Parallel and Serial Kinematics

There are two basic ways to design multi-axis positioning systems: Serial kinematics and parallel kinematics. Serial kinematics are easier to design and build and can be operated with simpler controllers. They do, however, have a number of disadvantages compared to higher-performance and more elegant parallel kinematics systems. In a multi-axis serial kinematics system, each actuator is assigned to exactly one degree of freedom. If there are integrated position sensors, they are also each assigned to one drive and measure only the motion caused by that drive and in its direction of motion. All undesired motion (guiding error) in the other five degrees of freedom are not seen and hence cannot be corrected in the servo-loop, which leads to cumulative error.

In a parallel kinematics multi-axis system, all actuators act directly on the same moving platform. Only in this way can the same resonant frequency and dynamic behavior be obtained for the X and Y axes. It is also easy to implement parallel metrology in parallel kinematics systems. A parallel metrology sensor sees all motion in its measurement direction, not just that of one actuator, so runout from all actuators can be compensated in real-time (active trajectory control). The results are significantly less deviation from the ideal trajectory, better repeatability and flatness, as shown in Fig. 51.

Examples:

P-734, P-561 (p. 2-64, p. 2-72) . in the “Piezo Flexure Stages / High-Speed Scanning Systems” section.

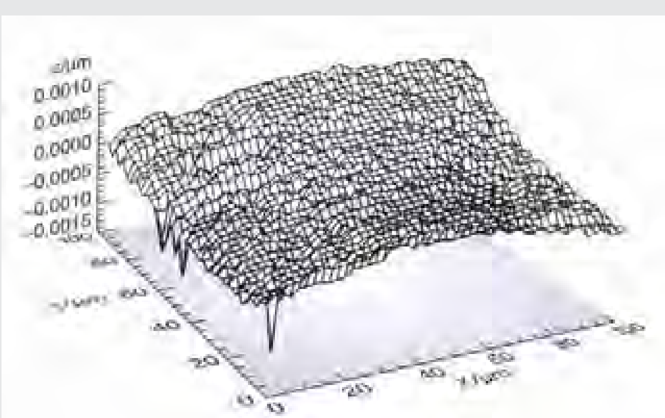


Fig. 51. Flatness (Z-axis) of a 6-axis nanopositioning system with active trajectory control over a 100 x 100 µm scanning range. The moving portion of this parallel metrology positioner is equipped with ultra-precise parallel metrology capacitive sensors in all six degrees of freedom. The sensors are continually measuring the actual position against the stationary external reference.

A digital controller compares the six coordinates of the actual position with the respective target positions. In addition to controlling the scanning motion in the X and Y directions, the controller also ensures that any deviations that occur in the other four degrees of freedom are corrected in real-time

PMN Compared to PZT

Electrostrictive Actuators (PMN)

Electrostrictive actuators operate on a principle similar to that of PZT actuators. The electrostrictive effect can be observed in all dielectric materials, even in liquids.

Electrostrictive actuators are made of an unpolarized lead magnesium niobate (PMN) ceramic material. PMN is a ceramic exhibiting displacement proportional to the square of the applied voltage under small-signal conditions. Under these conditions PMN unit cells are centro-symmetric at zero volts. An electrical field separates the positively and negatively charged ions, changing the dimensions of the cell and resulting in an expansion. Electrostrictive actuators must be operated above the Curie temperature, which is typically very low when compared to PZT materials.

The quadratic relationship between drive voltage and displacement means that PMN actuator are intrinsically nonlinear, in contrast to PZT actuators. PMN actuators have an electrical capacitance several times as high as piezo actuators and hence require higher drive currents for dynamic applications. However, in a limited temperature range, electrostrictive actuators exhibit less hysteresis (on the order of 3 %) than piezo actuators. An additional advantage is their greater ability to withstand pulling forces.

PZT materials have greater temperature stability than electrostrictive materials, especially with temperature variations of over 10 °C.
As temperature increases, available travel is reduced; at low temperatures where travel is greatest hysteresis increases (see Fig. 53 b). PMN actuators are thus best for applications with little or no temperature variations of the ceramic, be they caused by dynamic operation or by environmental factors.

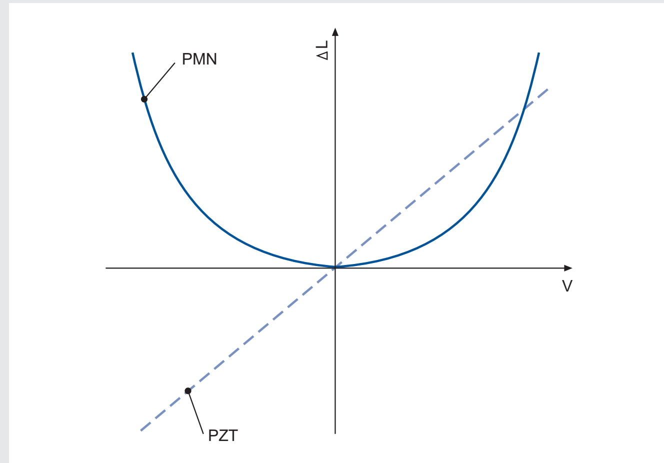


Fig. 52. Comparison of PMN and PZT material: displacement as a function of field strength (generalized)

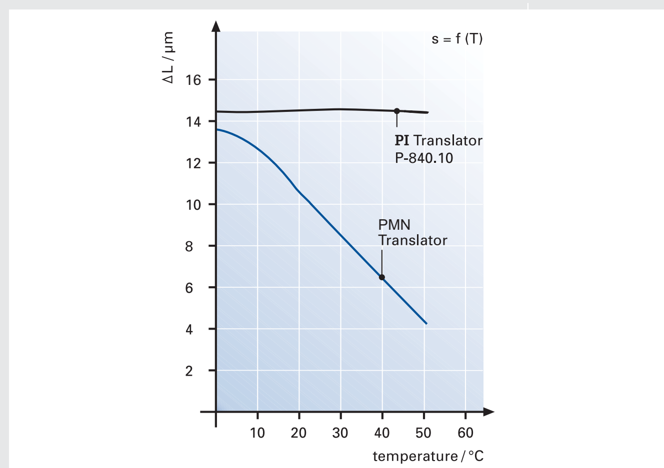


Fig. 53 a. Comparison of PMN and PZT material: displacement as a function of temperature

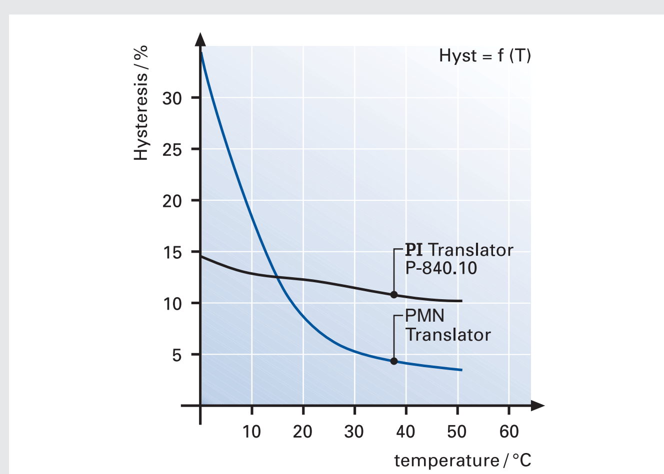


Fig. 53 b. Comparison of PMN and PZT material: hysteresis as a function of temperature

Summary

Piezoelectric actuators offer a solution to many positioning tasks that depend on highest accuracy, speed and resolution.

Examples given in this tutorial indicate a selection of the many applications common today. The relentless push for more accuracy and speed—whether in the further miniaturization of microelectronics, production of optics and higher-performance data storage devices, precise positioning of optical fiber components for telecommunications, or in the fabrication of micromechanisms—drives both the application and the further development of piezo technology.
To use the advantages of piezo positioners to their full extent, it is important to carefully analyze the system in which a piezo actuator is used as a whole. Close contact between user and manufacturer is the best recipe for success.

Piezoelectric actuators will in the future partially replace, partially complement, conventional drive technologies. They will widen the realm of the possible, and will usher in developments in areas like nanotechnology which would be unthinkable with conventional drive technologies.

Mounting and Handling Guidelines

Adherence to the following guidelines will help you obtain maximum performance and lifetime from your piezo actuators: Do not use metal tools for actuator handling. Do not scratch the coating on the side surfaces. The following precautions are recommended during handling of piezoelectric actuators:

I. Piezoelectric stack actuators without axial preload are sensitive to pulling forces. A preload of up to 50% of the blocking force is generally recommended.

II. Piezoelectric stack actuators may be stressed in the axial direction only. The applied force must be centered very well. Tilting and shearing forces, which can also be induced by parallelism errors of the endplates, have to be avoided because they will damage the actuator. This can be ensured by the use of ball tips, flexible tips, adequate guiding mechanisms etc. An exception to this requirement is made for the PICA™ Shear actuators, because they operate in the shear direction.

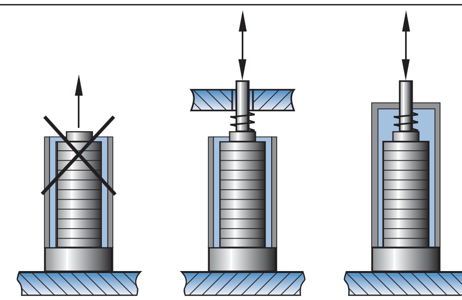
III. Piezoelectric stack actuators can be mounted by gluing them between even metal or ceramic surfaces by a cold or hot curing epoxy, respectively. Ground surfaces are preferred. Please, do not exceed the specified working temperature range of the actuator during curing.

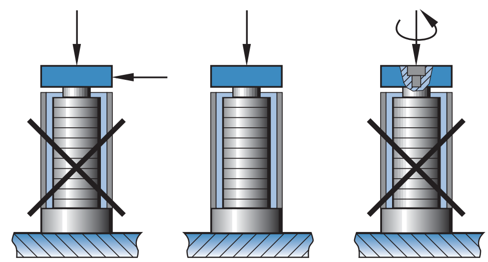
IV. The environment of all actuators should be as dry as possible. PICMA® actuators are guarded against humidity by their ceramic coating. Other actuators must be protected by other measures (hermetic sealing, dry air flow, etc).

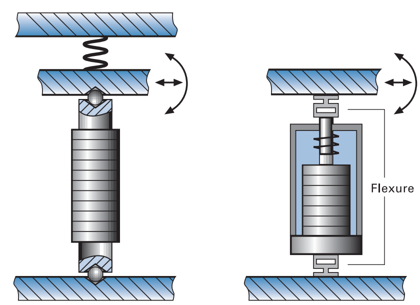
The combination of long-term high electric DC fields and high relative humidity values should be avoided with all piezoelectric actuators.

V. It is important to shortcircuit the piezoelectric stack actuators during any handling operation. Temperature changes and load changes will induce charges on the stack electrodes which might result in high electric fields if the leads are not shorted: Should the stack become charged, rapid discharging—especially without a preload—might damage the stack. Use a resistor for discharging.

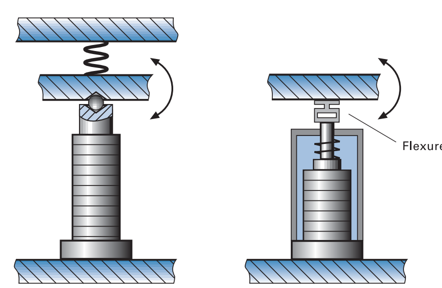
VI. Prevent any contamination of the piezo ceramic surfaces with conductive or corrosive substances. Isopropanol is recommended for cleaning. Avoid acetone and excessive ultrasonic cleaning at higher temperatures.


No pulling force without preload

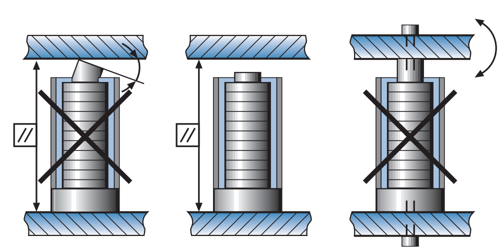

No lateral force or torque



Ball tips or flexures to decouple lateral forces or bending forces



Ball tips or flexures to decouple bending forces

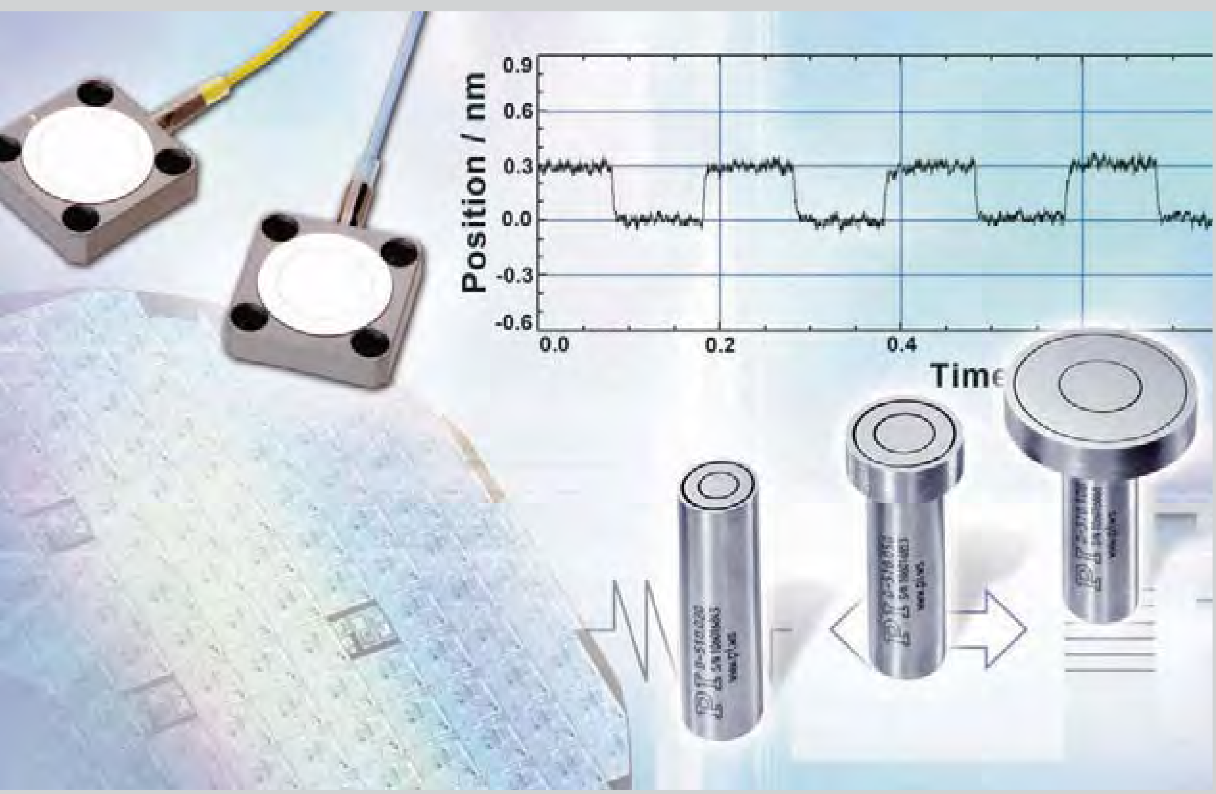

Bolting between plates is not recommended

Symbols and Units

A	Surface area [m^2] (meter^2)
α	Coefficient of Thermal Expansion (CTE) [K^{-1}] (1 / kelvin)
C	Capacitance (F) [A·s/V]
d_{ij}	Piezo modulus (tensor components) [m/V] (meter/volt)
d_s	Distance, thickness [m] (meter)
ϵ	Dielectric constant [A·s/V·m] (ampere · second / volt · meter)
E	Electric field strength [V/m] (volt/meter)
f	Operating frequency [Hz] (hertz = 1/second)
F	Force [N] (newton)
f_0	Unloaded resonant frequency [Hz] (hertz = 1/second)
g	Acceleration due to gravity: 9.81 m/s^2 (meter/second^2)
i	Current [A] (ampere)
k_S	Stiffness of restraint (load) [N/m] (newton/meter)
k_T	Stiffness of piezo actuators [N/m] (newton/meter)
L_0	Length of non-energized actuator [m] (meter)
ΔL	Change in length (displacement) [m] (meter)
ΔL_0	Nominal displacement with zero applied force, [m] (meter)
$\Delta L_{t=0.1}$	Displacement at time t = 0.1 sec after voltage change, [m] (meter)
m	Mass [kg] (kilogram)
P	Power [W] (watt)
Q	Charge [C] (coulomb = ampere x second)
S	Strain [ΔL/L] (dimensionless)
t	Time [s] (second)
T_C	Curie temperature [° C]
U	Voltage [V] (volt)
U_{p-p}	Peak-to-peak voltage [V] (volt)

PI

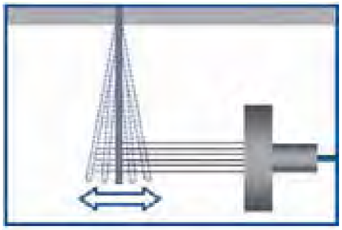
Nanometrology, Sensors for Piezo Systems



PI

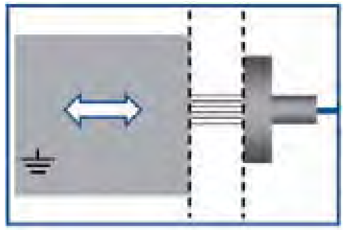
Capacitive Sensors / Signal Conditioners

Applications for Capacitive Position Sensors



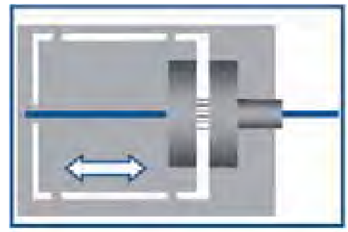
Vibration, Flatness, Thickness

The high dynamics of the PISeca™ capacitive gauge system even allows measurements of vibrations and oscillations with excellent resolution. Flatness of a rotating workpiece or differences in thickness in the nanometer range can be detected. One field of application is in the production of disk drives or in active compensation of vibration.



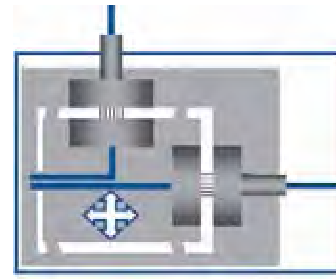
Measuring Displacement with Nanometer Precision

Capacitive displacement sensors measure the shortest of distances with highest reliability. The quantity measured is the change of capacitance between sensor plate and the target surface using a homogenous electric field. Accuracies in the sub-nanometer range are regularly achieved. Absolute measurement is possible with a well-adjusted, calibrated system.



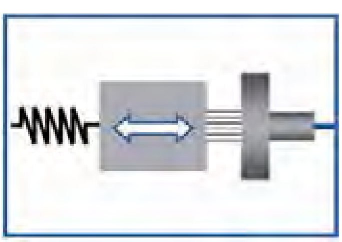
Nanopositioning / Closed-Loop Systems

One application of high-resolution displacement measurement is for nanopositioning. Two-plate capacitive sensors can measure distance, and hence position, of a moving object with excellent precision. The high sensor bandwidth allows closed-loop control in high-dynamics applications.



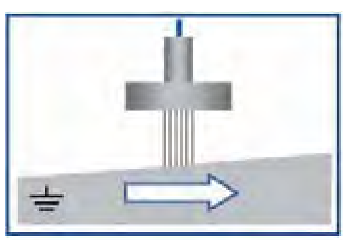
Parallel Metrology / High-Precision Multi-Axis Measurements

Closed-loop, multi-axis nanopositioning tasks are realized with high-performance positioners that make use of direct metrology and parallel kinematics. This allows measuring all degrees of freedom at the same time, which compensates guiding errors (Active Trajectory Control concept). Here, capacitance gauges are the most precise measuring systems available, and give the best position resolution results.



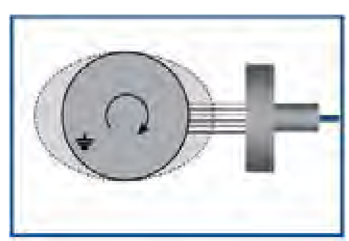
Force Sensors with Micronewton Sensitivity

Single-electrode capacitive sensors, which measure sub-nanometer displacement from a distance with no contact, are frequently used as high-resolution force sensors. In a system having suitably well-defined stiffness, the measured displacements translate to forces with resolutions in the micro-newton range, all without influencing the process being measured.



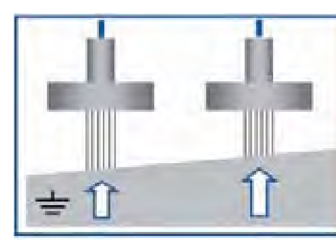
Measuring Straightness and Flatness / Active Cross-Talk Compensation

Excellent resolution in straightness and flatness measurements over long travel ranges is achieved with capacitive single electrode sensors. One application is measuring cross-talk in nanopositioning. Crosstalk, off-axis motion from one actuator in the motion direction of another, is detected immediately and actively compensated out by the servo-loops. The high sensor bandwidth provides excellent dynamic performance.



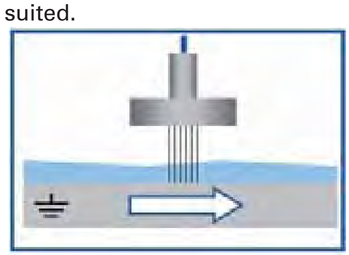
Out-of-Plane Measurement / Constant-Height Scans / Out-of-Round Measurement

Compensation of undulating and oscillating motion, e.g. in constant height scans or in white-light interferometry, are applications for which capacitive sensors are especially well suited.



Tip / Tilt Measurement and Compensation

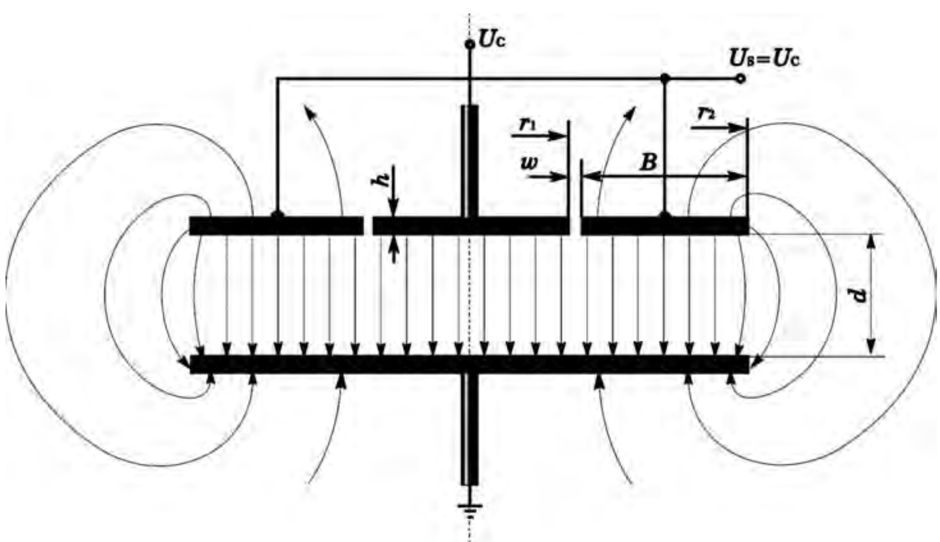
Integrating capacitive sensors in a system is a good way to measure tip/tilt motion precisely. The moved object's tip angle is measured differentially, and, if required, compensated out.



Layer Thickness with Sub-Micron Accuracy

Measuring the thickness of a film or layer of non-conducting material on a moving, conductive, surface (e.g. a rotating drum) is an ideal job for capacitive sensors due to their non-contact operation and their high dynamic performance.

Nanometrology Fundamentals



Resolution / Bandwidth

Resolution in nanopositioning relates to the smallest change in displacement that can still be detected by the measuring devices.

For capacitive sensors, resolution is in principle unlimited, and is in practice limited by electronic noise. PI signal conditioner electronics are optimized for high linearity, bandwidth and minimum noise, enabling sensor resolution down to the picometer range.

Electronic noise and sensor signal bandwidth are interdependent. Limiting the bandwidth reduces noise and thereby improves resolution. The working distance also influences the resolution: the smaller the working distance of the system, the lower the absolute value of the electronic noise.

Figure 1 shows measurements of nanometer-range actuator cycles taken with a D-015, 15 µm capacitive position sensor and a laser interferometer. The graphs clearly show the superior performance of the capacitive position sensing technique.

Figure 2 illustrates the influence of bandwidth upon resolution: the PISeca™ single-electrode sensors show excellent resolution down to the sub-nanometer range, even at high bandwidths.

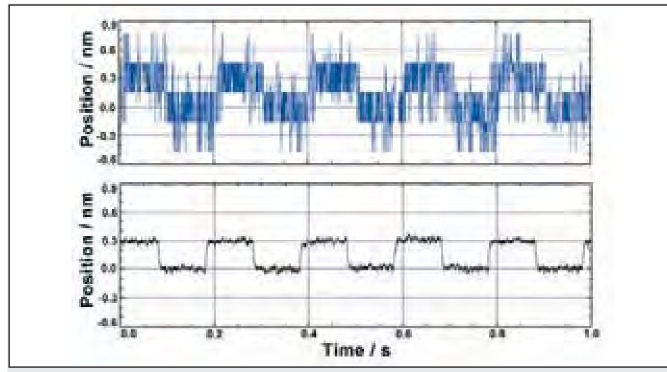


Fig. 1: Piezo nanopositioning system making 0.3 nm steps, measured with PI capacitive sensor (lower curve) and with a highly precise laser interferometer. The capacitive sensor provides significantly higher resolution than the interferometer

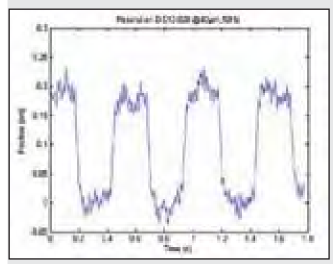


Fig. 2: Resolution significantly below 1 nm is achieved with a 20 µm PISeca™ single-electrode sensor (D-510.020) and the E-852 signal conditioner electronics. Left: 0.2 nm-steps under quasi-static conditions (bandwidth 10 Hz), right: 1 nm-steps with maximum bandwidth (6.6 kHz)

Linearity and Stability of PI sensors

The linearity of a measurement denotes the degree of constancy in the proportional relation between change in probe-target distance and the output signal. Usually linearity is given as linearity error in percent of the full measurement range. A linearity error of 0.1 % with range of 100 µm gives a maximum error of 0.1 µm. Linearity error has no influence whatsoever upon resolution and repeatability of a measurement.

Linearity is influenced to a high degree by homogeneity of the electric field and thus by any non-parallelism of the probe and target in the application. PI capacitive position sensor electronics incorporate a proprietary design providing superior linearity, low sensitivity to cable capacitance, low background noise and low drift. The Integrated Linearization System (ILS) compensates for non-parallelism influences.

A comparison between a conventional capacitive position sensor system and a PI ILS system is shown in Figure 3. When used with PI digital controllers (which add polynomial linearization) a positioning linearity of up to 0.003 % is achievable.

Figure 4 shows the linearity of a P-752.11C piezo flexure nanopositioning stage with integrated capacitive position sensor operated in closed-loop

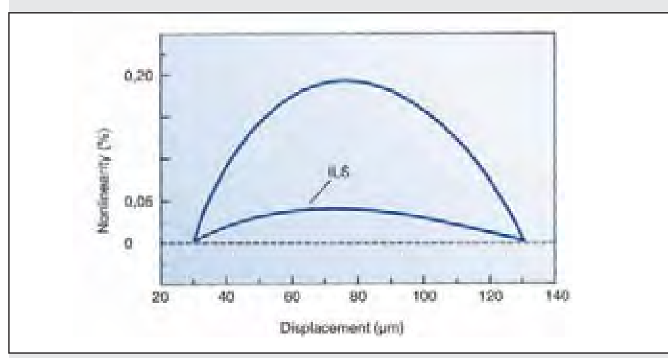


Fig. 3: Linearity of conventional capacitive position sensor system vs. PI ILS (integrated linearization system), shown before digital linearization

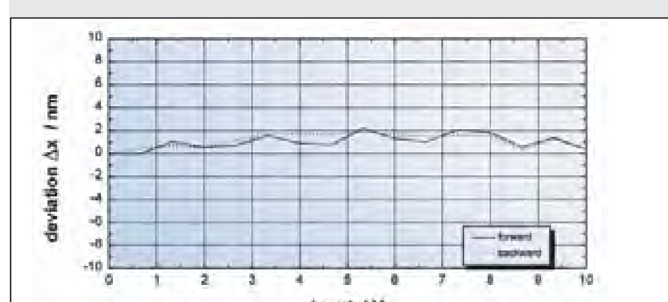


Fig. 4: Linearity of a P-752.11C, 15 µm piezo nanopositioning stage operated with E-500/E-509.C1A control electronics. The travel range is 15 µm, the gain 1.5 µm/V. Linearity is better than 0.02 %; even higher linearity is achievable with PI digital controllers

mode with an analog controller. All errors contributed by the mechanics, PZT drive, sensors and electronics are included in the resulting linearity of better than 0.02 %. Even higher linearity is achievable with PI digital controllers like the E-710.

Stability of the measurement is limited mainly by thermal and electronic drift. For accuracy and repeatability reasons, it is thus necessary to maintain constant environmental conditions. The exceptional long-term stability of the PI capacitive position sensor and electronics design is shown in Figure 5.

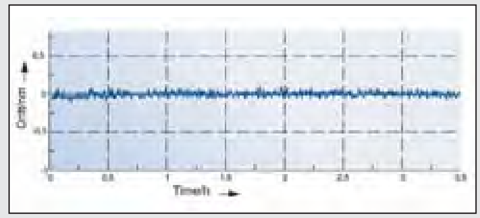


Fig. 5: Measurement stability of an E-509.C1A capacitive position sensor control module with 10 pF reference capacitor over 3.5 hours (after controller warm-up)

Principle of the Measurement

Signal/Displacement Proportionality

When a voltage is applied to the two plates of an ideal capacitor, it creates a homogenous electric field. Apart from constant factors, the electrical capacitance of the setup is determined by sensor area and plate distance. Thus, a change in displacement leads directly to a change in capacitance. This value is matched to a reference capacitance in a bridge circuit.

The Design of the signal conditioner electronics is such that the output signal is proportional to the gap change. The planes of the sensor surface ("probe") and the target form the two capacitor plates. The target should not be below a certain size because of boundary effects. This is important for applications with, say, a rotating drum as target. For metallic materials, the thickness of the target has no influence on the measurement.

Guard Ring Geometry/Design

The proportionality referred to is based on the homogeneity of the electric field. To eliminate boundary effects, the superior PI design uses a guard-ring electrode that surrounds the active sensor area and is actively kept at the same potential (see Fig. 7). This design shields the active sensor area and provides for excellent containment of the measurement zone. Thus optimum measuring linearity over the full range is achieved within the specified accuracy.

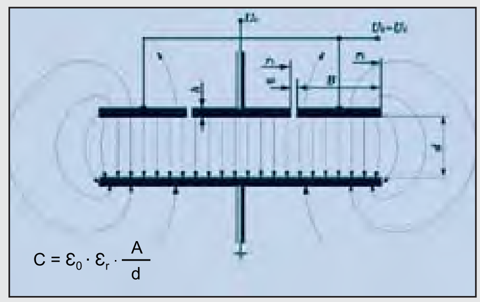


Fig. 6: Capacitive sensor working principle. The capacitance C is proportional to the active sensor area A, ϵ_0 is constant, ϵ_r is the dielectric constant of the material between the plates, generally air


Fig. 7: Capacitive sensors with guard ring design provide superior linearity

Calibration for Best Accuracy

PI's nanometrology calibration laboratories offer optimum conditions for factory calibration. As references, ultra-high-accuracy incremental sensors like laser interferometers are used.

PISeca™ systems are calibrated at PI with a NEXLINE® positioning system having a closed-loop resolution better than 0.01 nm in a test stand with friction-free flexure guidance and an incremental reference sensor featuring a resolution better than 0.1 nm (Fig. 8 and 9).

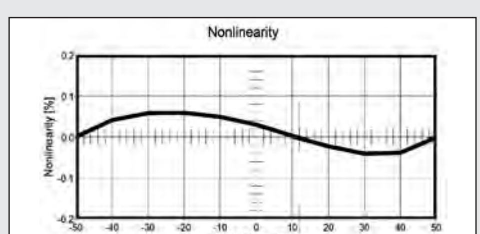


Fig. 8: Output linearity error of a PISeca™ single-electrode system is typically less than 0.1% over the full measurement range

PI

Direct Metrology, Parallel Metrology

Direct Metrology / Parallel Metrology with Two-Plate Capacitive Sensors

Capacitive sensors are the ideal choice for nanometrology applications in positioning, scanning and metrology requiring the highest possible accuracy. Two-plate capacitive sensors achieve the highest linearity and long-term stability. The measurement probe can be attached directly to the moved surface (direct metrology) and provide absolute, non-contact displacement values against a reference surface, with no influence whatsoever on the motion performed. These sensors are particularly well-suited for parallel-kinematics nanopositioning systems. There, in a multi-axis system, motion in all degrees of freedom is measured against a common reference, and the runout of the various actuators can be compensated out in real time (active trajectory control). In this way, motion accuracies in the subnanometer and submicroradian ranges can be achieved.

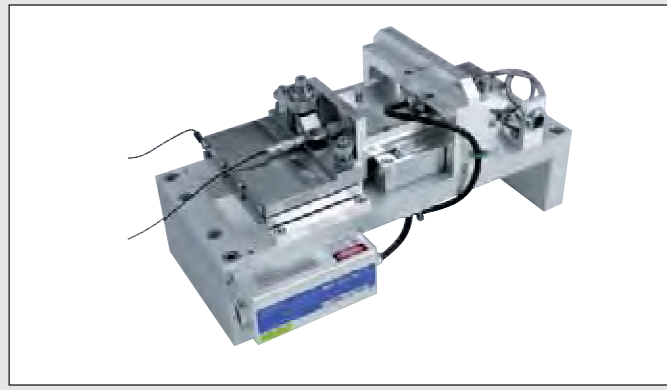


Fig. 9: Ultra-high-precision NEXLINE® positioning system with incremental sensor in a calibration and test stand for PISeca™ sensors. The resolution is significantly better than that of a laser interferometer

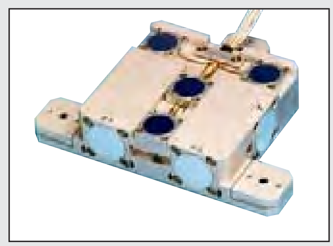


Fig. 10: Capacitive position sensors in an ultra-high-accuracy, six-axis nanopositioning system designed by PI for the German National Metrology Institute (PTB). Application: scanning microscopy

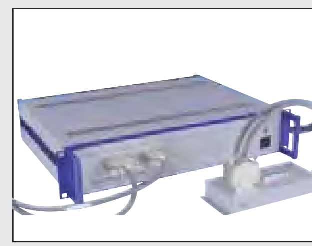


Fig. 11: Digital sensor-signal transmission (DST) allows a distance up to 15 m between positioning unit and controller, here an E-710 multi-axis digital piezo controller

Special Design Eliminates Cable Influences

When measuring distance by detection of capacitance changes, fluctuations in the cable capacitance can have an adverse effect on accuracy. This is why most capacitive measurement systems only provide satisfactory results with short, well-defined cable lengths.

PI systems use a special design which eliminates cable influences, permitting use of cable lengths of up to 3 m without difficulty. For optimum results, we recommend calibration of the sensor-actuator system in the PI metrology lab.

Longer distances between sensor and electronics can be spanned with special, loss-free, digital transmission protocols.

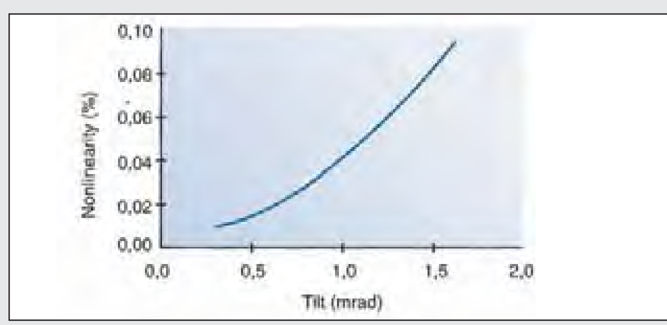


Fig. 12: Nonlinearity vs. tilt. Resolution and repeatability are not affected by tilt

Electrode Geometry, Sensor Surface Flatness and Finish

During sensor production, great care is taken to maintain critical mechanical tolerances. Measuring surfaces are diamond machined using sophisticated process control techniques. The result is the smooth, ultra-flat, mirrored surfaces required to obtain the highest resolution commercially available.

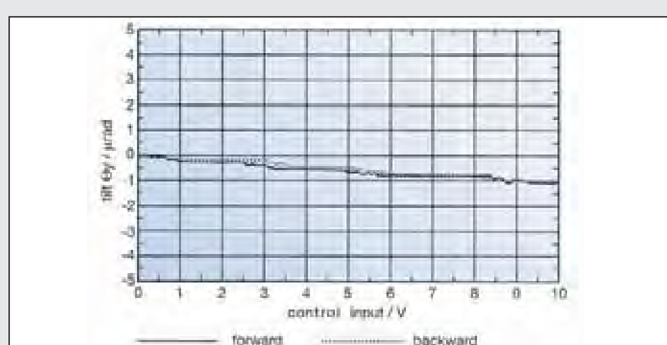


Fig. 13. Flexure-guided nanopositioning systems like the P-752 offer submicroradian guiding accuracy and are optimally suited for capacitive sensors

Parallelism of Measuring Surfaces

For optimum results, target and probe plates must remain parallel to each other during measurement. For small measurement distances and small active areas, any divergence has a strong influence on the measurement results. Tilt adversely affects linearity and gain, although not resolution or repeatability (see fig. 12).

Positioning systems with multi-link flexure guidance reduce tip and tilt to negligable levels (see Fig. 13) and achieve outstanding accuracy.

Glossary

Measurement Range

The measurement range depends on the size of the active sensor area as well as on the electronics used.
Due to PI's proprietary signal conditioner electronics design, the mid-range distance is always identical to the selected measurement range. The probe-to-target gap may vary from 50 % to 150 % of the measurement range (see Fig. 14).
The sensor capacitance is the same as that of the reference capacitance in the electronics. Different reference capacitances can be used to extend the nominal (standard) measurement range (see Fig. 15).

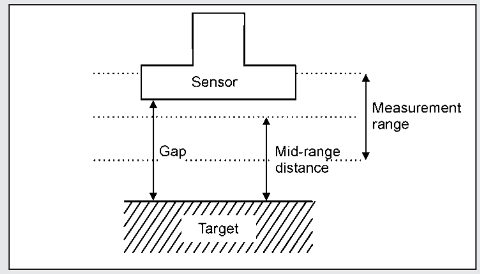


Fig. 14: Definitions: measurement range and mid-range distance have identical values

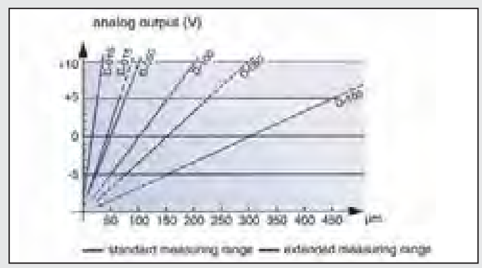


Fig. 15: Measuring ranges of different PI capacitive position sensors (standard ranges in blue, extended ranges in black)

Target

Two-electrode capacitive sensors consist of two electrodes, named probe and target.
Single-electrode sensors measure against a surface that is called the target. The target surface is, in principle, a conductive material electrically connected to ground. Measurement against semi-conductors is possible as well.

While two-plate capacitive sensors consist of two well-defined high-quality planes, with single-plate sensors, target surface characteristics can influence the results. A curved or rough surface will deteriorate the resolution because the results refer to an average gap (see Fig. 16 and 17). Surface shape also influences the homogeneity of the electric field and thereby the measurement linearity. For factory calibration, a target plane that is considerably larger than the sensor area is used.

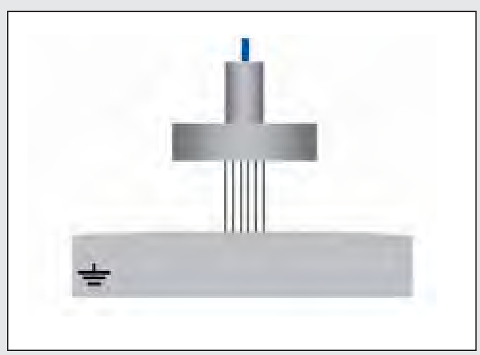


Fig. 16: Roughness of the target surface downgrades resolution and linearity

Environment

Precision measurement with nanometer accuracy requires minimizing environmental influences. Constancy of temperature and humidity during the measurement are as essential as cleanliness.
Electronics from PI are basically very temperature stable. Temperature drift is under 0.2% of full measurement range with a change of temperature of 10 C°.
Temperature changes also cause all material in the system to expand or contract, thus changing the actual measured gap.
The influence of a change in relative humidity of 30 percentage points is less than 0.5% of the measurement range. Condensation must always be avoided.
Dusty or damaged sensor surfaces will also worsen the measurement quality.
Environmental conditions at the time of calibration are noted on the calibration sheet PI provides with each individual system.

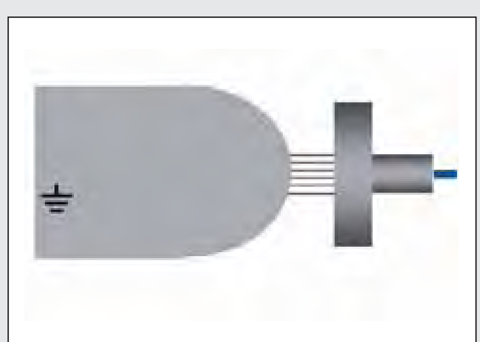


Fig. 17: Curved surfaces lead to an averaged distance measurement

D-510 PISeca™ Capacitive Sensors

Single-Plate Sensors with Excellent Position Resolution

PISeca™ high-precision capacitive sensor probes with E-852 signal conditioner electronics. Sensor probes (from left): D-510.100 with 100 µm, D-510.050 with 50 µm, D-510.020 with 20 µm nominal measurement range

- **Non-Contact Measurement for Distance / Motion / Vibration**
- **Absolute Position Sensing**
- **Sub-Nanometer Resolution**
- **Measurement Ranges to 500 µm**
- **Easy Integration**
- **High Bandwidth**

The new PISeca™ single-electrode capacitive sensors from PI perform non-contact measurements of distance, position or motion against any kind of electrically conductive target. They feature the highest resolution and linearity available.

The PISeca™ single-electrode capacitive gauges are fundamentally very temperature stable, have excellent dynamics and are easy to work with.

Application Examples

- Semiconductor technology / test & measurement
- Data storage
- Automotive industry
- Metrology
- Precision machining

Capacitive Position Sensors for Highest Accuracy and Lifetime

Single-electrode capacitive (capacitance) sensors are direct metrology devices. They use an electric field to measure change of capacitance between the probe and a conductive target surface, without physical contact. This makes them free of friction and hysteresis and provides high phase fidelity and bandwidth.

In combination with suitable sensor electronics (E-852.10) resolutions down to the sub-nanometer range and bandwidths to 10 kHz can be achieved. For high-dynamics measurements, a bandwidth up to 10 kHz is possible, with a resolution still down to the 1-nm range. With sufficient mounting accuracy, excellent linearity can be attained (up to 0.1%).

Guard-Ring Capacitor Provides Higher Linearity

Sensor design has a strong influence on linearity because the operating principle is based on that of an ideal parallel-plate capacitor. The superior PI design uses a guard-ring electrode that shields the sensor electrode from boundary effects. This ensures a homogeneous electric field in the measurement zone and results in higher measuring linearity.

Easy Handling and Integration

All PISeca™ sensor probes feature an integrated LEMO connector for easy mounting and replacement in the field. The standardized shaft diameter allows compatibility and flexibility.

Factory Calibration for Improved Linearity

Highest possible linearity and accuracy are achieved with factory calibration of the sensor probe together with the signal conditioner electronics. Two measurement ranges can be calibrated at the same time for one particular sensor probe. Factory calibration also optimizes parameters like ILS (linearization), gain and offset and eliminates cable capacitance influences. The E-852.10 provides two calibrated, optionally extended measurement ranges are available.

High-Precision Machining

The measuring surfaces of the PISeca™ sensors are machined with diamond tools using sophisticated process control techniques. The result is the smooth, ultra-flat, mirrored surface required to obtain highest resolution. The standard material is stainless steel.

Ordering Information

D-510.020
PISeca™ Single-Electrode Capacitive Sensor Probe, 8 mm Diameter, 20 µm Nominal Range

D-510.050
PISeca™ Single-Electrode Capacitive Sensor Probe, 12 mm Diameter, 50 µm Nominal Range

D-510.100
PISeca™ Single-Electrode Capacitive Sensor Probe, 20 mm Diameter, 100 µm Nominal Range

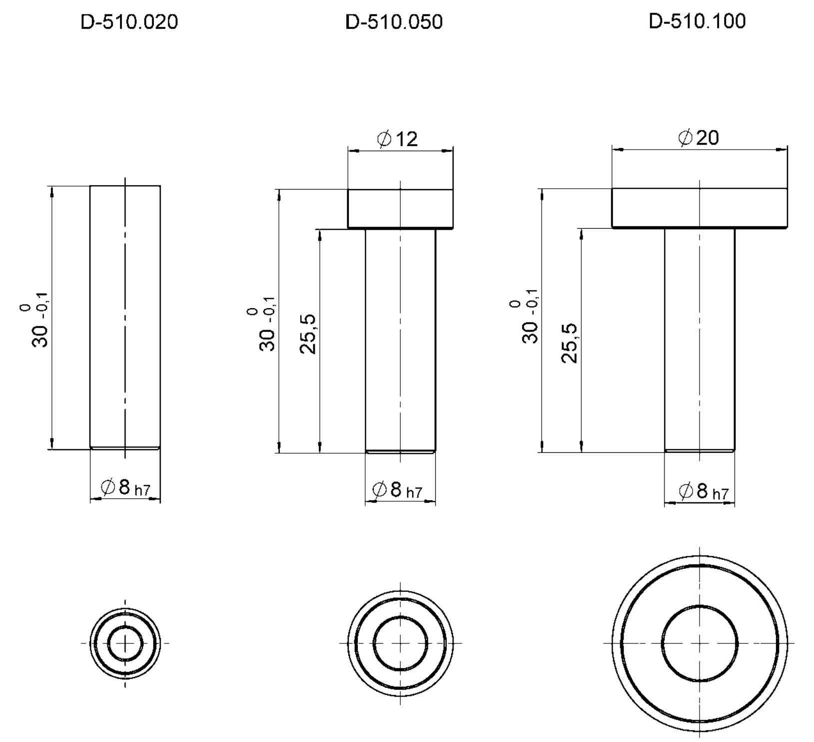
Ask about custom designs!

Custom Sensors / Two-Plate Sensors

In addition to the standard sensors listed here, PI can offer a variety of custom versions for different measuring ranges, geometries, materials match, etc. Systems with custom electronics are also available.

If ultimate performance is required, the D-100 series two-plate capacitive sensors are recommended (see p. 3-14 *ff*).

D-510.050 with LEMO-connector for easy handling



D-510.020, D-510.050 and D-510.100 capacitive sensor probes, dimensions in mm.
Sensor connection LEMO FFC00.650.CLA.543, triaxial, cable length 1 m

Technical Data

Model	D-510.020	D-510.050	D-510.100	Units	Tolerance
Sensor type	Single-electrode, capacitive	Single-electrode, capacitive	Single-electrode, capacitive		
Measurement accuracy					
Nominal measurement range*	20	50	100	µm	
Min. gap	10	25	50	µm	
Max. gap	150	375	750	µm	
Static resolution**	<0.001	<0.001	<0.001	% of measurement range	typical
Dynamic resolution**	<0.002	<0.002	<0.002	% of measurement range	typical
Linearity***	<0.2	<0.1	<0.1	%	
Mechanical properties					
Sensor active diameter	3.8	6	8.4	mm	
Sensor active area	11.2	27.9	56.1	mm^2	
Sensor diameter	8	12	20	mm	
Sensor area	50.3	113.1	314.0	mm^2	
Mounting shaft diameter	8	8	8	mm	
Miscellaneous					
Operating temperature range	-20 to +100	-20 to +100	-20 to +100	°C	
Material	Stainless steel	Stainless steel	Stainless steel		
Mass	8	10	16	g	±5 %
Recommended signal conditioner electronics	E-852.10 E-509.E	E-852.10 E-509.E	E-852.10 (p. 3-10) E-509.E (p. 3-12)		

*Extended measurement ranges available for calibration with E-852 signal conditioner electronics
**Static resolution: bandwidth 10 Hz, dynamic: bandwidth 10 kHz, with E-852.10 signal conditioner electronics
***Linearity over nominal measurement range

E-852 PISeca™ Signal Conditioner

For Capacitive Single-Plate Sensors

E-852 signal conditioner electronics with PISeca™ capacitive sensor probes D-510.100, D-510.050, D-510.020 (from left)

- **Cost-Effective System Solution for PISeca™ Capacitive Position Sensors**
- **Integrated Linearization System (ILS) for Maximum Linearity**
- **Selectable Bandwidth from 10 Hz up to 10 kHz**
- **Selectable Measurement Range**
- **LED-Bar Measuring-Range Display for Easy Integration**
- **External Synchronization for Multi-Channel Applications**

The E-852 analog sensor electronics is specially designed for the PISeca™ single-electrode capacitive position sensor. It features minimum noise and exceptional long-term stability. The combination of PISeca™ electronics and D-510 series sensors (s. p. 3-8) provides a system for capacitive displacement measurement with flexible high-end solutions for best linearity and highest resolution. Two versions are available: The E-852.10 offers a standard sensor cable length of 1 m. E-852.10A1 features an external signal amplifier to allow longer distances between sensor and signal conditioner up to 10 m. Delivery includes all required cables and accessories.

Application Examples

- Semiconductor technology / test & measurement
- Data storage
- Automotive industry
- Metrology
- Precision machining

Easy Sensor Installation

The integration of the sensor is facilitated by adjustment aids: the position can be monitored by means of the LED-bar of the E-852.10 or by the extra test point on the signal amplifier of the E-852.10A1.

Capacitive Position Sensors for Highest Accuracy

Single-electrode capacitive (capacitance) sensors are direct metrology devices. They use an electric field to measure change of capacitance between the probe and a conductive target surface, without physical contact. This makes them free of friction and hysteresis and provides high phase fidelity and bandwidth.

Selectable Bandwidth and Measurement Range

The selectable bandwidth setting allows the user to adapt the system to different applications. For the highest accuracy and sub-nanometer resolution, the bandwidth can be limited to 10 Hz.
For high-dynamics applications, the bandwidth can be increased up to 10 kHz while the resolution still remains in the 1 nm range.
The operator can choose a measurement range from 20 to 500 µm, depending on the nominal measurement range of the selected sensor.

Factory Calibration for Improved Linearity

Highest possible linearity and accuracy are achieved with factory calibration of the sensor probe together with the signal conditioner electronics. Two measurement ranges can be calibrated at the same time for one particular sensor probe. Factory calibration also optimizes parameters like ILS (linearization), gain and offset and eliminates cable capacitance influences.

Ordering Information

E-852.10
PISeca™ Signal Conditioner Electronics for Single Electrode Capacitive Sensors, 1 Channel, Low-Noise Power Supply Included

E-852.10A1
PISeca™ Signal Conditioner Electronics for Single Electrode Capacitive Sensors, 1 Channel, Low-Noise Power Supply & External Preamp for 10 m Cables Included

Ask about custom designs!

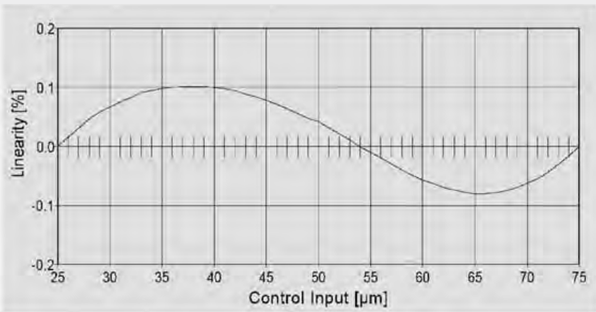
Integrated Linearization System (ILS) for Highest Accuracy

A proprietary linearization circuit compensates the influences of parallelism errors between sensor and target and guarantees an excellent measuring linearity (to 0.1 %).

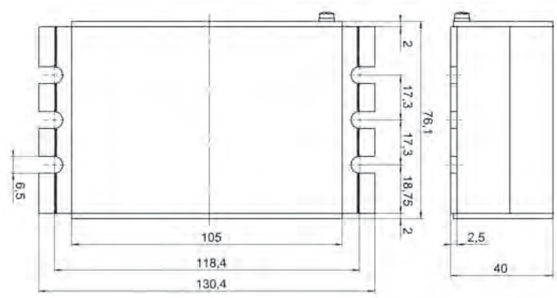
External Synchronization for Multi-Axis Applications

PISeca™ sensor electronics are equipped with I/O lines for the synchronization of multiple sensor systems.

E-852.10A1 allows longer distances up to 10 m between sensor signal amplifier and signal conditioner. Other cable lengths on request



Excellent output linearity of the E-852 signal conditioner / D-510.050 sensor combination (nominal measurement range)



E-852.10 dimensions in mm

Model	E-852	E-852.10A1	Units
Function	Signal conditioner for PISeca™ capacitive sensor probes	Signal conditioner for PISeca™ capacitive sensor probes, remote operation	
Channels	1	1	
Sensor			
Sensor type	Single-electrode, capacitive	Single-electrode, capacitive	
Sensor bandwidth	10 / 3 / 0.3, 1.1 / 0.1 / 0.01 (option)	10 / 3 / 1 / 0.3 / 0.01	kHz
Measurement range extension factors*	1 & 2.5 (calibrated); 2 & 5 (optional)	1 (calibrated) / 2 / 2.5 / 5 (on request)	
Ext. synchronization	Auto master-slave	Auto master-slave	
Temperature stability	0.71 ±0.25	0.2	mV / K
Electrical properties			
Output voltage	-10 to +10 / -5 to +5 / 0 to +10 V (selectable)	-10 to +10 / -5 to +5 / 0 to +10 (selectable)	V
Output signal	1 kΩ / 1 nF	1 kΩ / 1 nF	
Supply voltage	±15 V (125 mA), +5 V (20 mA)	±15 V (220 mA), +5 V (20 mA)	V
Static resolution**	<0.001% of measurement range (RMS)	<0.001% of measurement range (RMS)	
Dynamic resolution**	<0.002% of measurement range (RMS)	<0.002% of measurement range (RMS)	
Noise factor***	0.14	0.14	ppm/√Hz
Linearity @ nominal range	<0.1 (<0.2% for D-510.020)	<0.1 (<0.2% for D-510.020)	%
Interfaces and operation			
Sensor connection	LEMO ECP.00.650.NLL.543 socket, triaxial	LEMO ECP.00.650.NLL.543 socket, triaxial (on signal amplifier) Sub-D 9-pin, 10 m cable from signal amplifier to signal conditioner, differential signals	
Signal output	BNC	BNC	
Signal monitor	–	Test point on signal amplifier	
Display	LED bar	LED Power On	
Linearization	ILS (Integrated Linearization System)	ILS (Integrated Linearization System)	
Miscellaneous			
Operating temperature range	+5 to +40	+5 to +40	°C
Mass	Signal conditioner: 0.355 Power supply E-852.PS2: 0.55	Signal conditioner: 0.355 Power supply E-852.PS2: 0.55 Signal amplifier: 0.076	kg
Dimensions	Signal conditioner: 80x130x40 Power supply E-852.PS2: 146x76x43 (incl. mounting flanges)	Signal conditioner: 80x130x40 Power supply E-852.PS2: 146x76x43 Signal amplifier: 55x70x20 (incl. mounting flanges)	mm
Target ground connector	Banana jack, 4 mm	Banana jack, 4 mm, on signal amplifier	

*Extension factors to multiply by the nominal measurement range of D-510 sensor probes
**Static: bandwidth 10 Hz, dynamic: bandwidth 10 kHz, cable length 1 m
***Specifications in ppm (parts per million), refer to nominal measurement range

D-015 · D-050 · D-100 Capacitive Sensors

Sub-Nanometer-Resolution Position Sensors

Fig. 1. D-015, D-050, D-100 ultra-high-resolution capacitive position sensors provide up to 10,000 times higher resolution than calipers

- **For Applications Requiring Highest Precision**
- **Measuring Range to 1000 microns**
- **Resolution to 0.01 nm**
- **Linearization to 0.01 % with Digital Controller**
- **Bandwidth up to 10 kHz**
- **Servo Controller E-509.CxA, Compatible with E-500 Controller System**
- **Custom Designs**

Measurement Method

Capacitive position sensors are analog non-contact devices. A two-electrode capacitive position sensor consists of two RF-driven plates that are part of a capacitive bridge. The high-frequency AC excitation provides better long term stability than DC excited sensors (see p. 3-19, Fig. 5). One plate (probe) is fixed, the other plate (target) is connected to the object to be positioned. Since the plate size and the dielectric medium (air) remains unchanged, capacitance is directly related to the distance between the plates. Ultra-precise electronics convert the capacitance information into a signal proportional to distance.

Direct Metrology, Parallel Metrology

The sensors offered by PI are the most accurate measuring systems for nanopositioning applications currently on the market. In contrast to high-resolution sensors measuring deformation in the drive train (see p. 2-8 *ff*), like strain gauge or piezoresistive sensors, capacitive sensors are non-contact, direct-metrology devices–a fact which gives them many advantages:

- Better Phase Fidelity
- Higher Bandwidth
- No Periodic Error
- Non-Contacting
- Ideal for Parallel Metrology
- Higher Linearity
- Better Reproducibility
- Higher Long-Term Stability

Capacitive sensors are especially well-suited for parallel metrology configurations. In multi-axis nanopositioning systems, parallel metrology means that the controller monitors all controlled degrees of freedom relative to “ground” (the fixed frame) and uses each actuator to compensate the undesired off-axis motion of the others automatically (active trajectory control). As a result, it is possible to keep deviations in the sub-nanometer and sub-microradian range (see p. 2-212 *ff* in the “Tutorial” section).

Resolution

Resolution on the order of picometers is achievable with short-range, two-electrode capacitive position sensors (single-electrode capacitive position sensors provide less resolution, linearity and accuracy than two-electrode sensors). Theoretical measurement resolution is limited only by quantum noise. In practical applications, stray radiation, electronics-induced noise and geometric effects are the limiting factors. For example, with the 100 µm range, a D-100.00 sensor and E-509.C1A electronics, the effective noise factor is 0.02 nm/$\sqrt{\text{Hz}}$. This translates to 0.2 nm at 100 Hz bandwidth. The maximum standard bandwidth (jumper selectable) is 3 kHz.

Figure 2 shows a D-015, 15 µm capacitive position sensor and an interferometer, both measuring nanometer-range actuator cycles. The graphs clearly show the superior resolution of the capacitive position sensing technique.

Ordering Information

D-015.00
Capacitive Position Sensor, 15 µm, Aluminum

D-050.00
Capacitive Position Sensor, 50 µm, Aluminum

D-100.00
Capacitive Position Sensor, 100 µm, Aluminum

Ask about custom designs!

Notes

In addition to the standard sensors listed here, PI offers a variety of custom versions along with custom electronics for different measuring ranges, material match etc. If you don’t find what you are looking for, please call your local PI Sales Engineer.

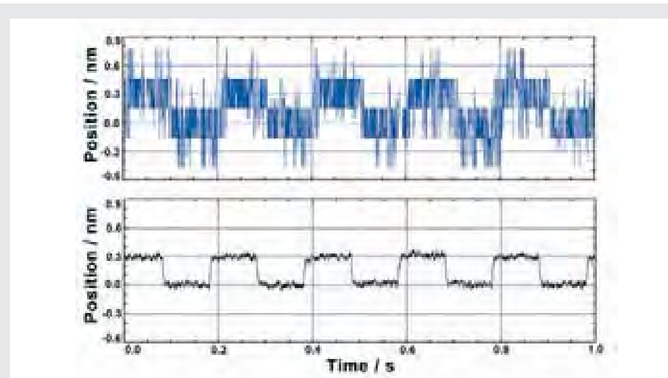
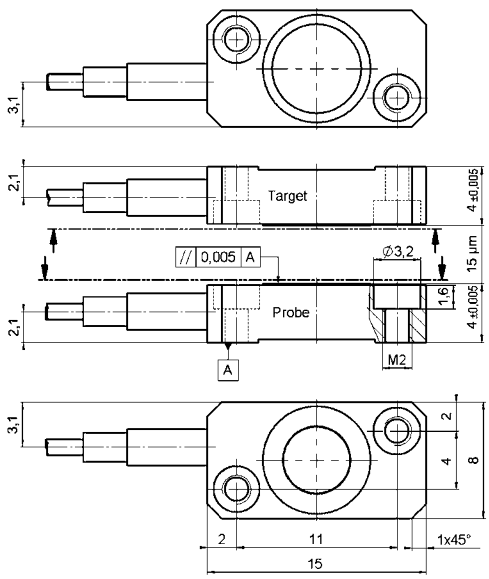
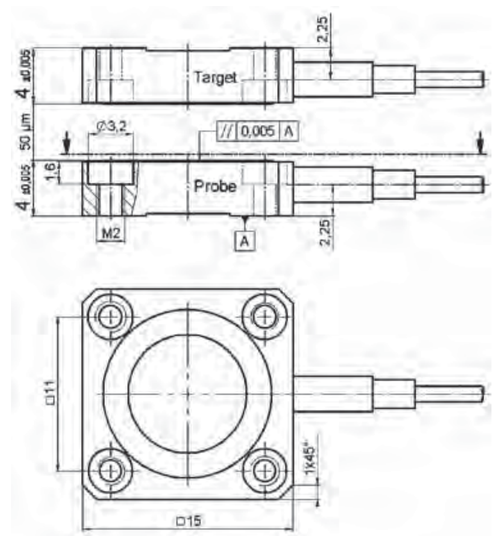


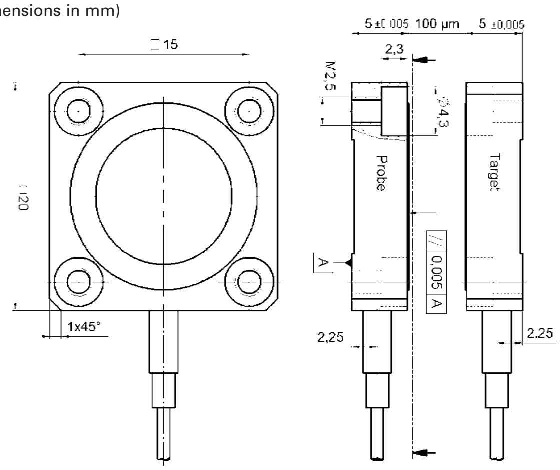
Fig. 2. Piezo nanopositioning system making 0.3 nm steps, measured with PI capacitive sensor (lower curve) and with a highly precise laser interferometer. The capacitive sensor provides significantly higher resolution than the interferometer.



D-015.00 (dimensions in mm)



D-050.00 (dimensions in mm)



D-100.00 (dimensions in mm)

Technical Data

Model	D-015.00	D-050.00	D-100.00	Units
Sensor				
Sensor typ	Capacitive	Capacitive	Capacitive	
Nominal measurement range	15	50	100	µm
Extended measurement range	45	150	300	µm
Resolution*	0.0005	0.0005	0.0005	% of measurement range
Linearity**	0.01	0.01	0.01	%
Sensor active area	16.6	67.7	113.1	mm^2
Thermal drift***	50	50	50	ppm/K
Miscellaneous				
Operating temperature range	-20 bis 80	-20 bis 80	-20 bis 80	°C
Material	Aluminum	Aluminum	Aluminum	
Recommended sensor electronics	E-509.CxA	E-509.CxA	E-509.CxA (p. 3-16)	

Ask for custom materials
*3 kHz, with E-509.C3A servo controller
**With digital controller. Up to 0,05 % typ. with E-509 analog controller
***Change of active surface size in ppm (parts per million), refers to measurement range

E-509 Signal Conditioner / Piezo Servo Module

3-Channel Servo-Controller Module for E-500 Piezo Controller System

E-509 3-channel servo-controller module for nanopositioning systems with strain gauge sensors

Ordering Information

E-509.C1A
Sensor / Piezo Servo-Control Module, Capacitive Sensor, 1 Channel

E-509.C2A
Sensor / Piezo Servo-Control Module, Capacitive Sensors, 2 Channels

E-509.C3A
Sensor / Piezo Servo-Control Module, Capacitive Sensors, 3 Channels

Ask about custom designs!

- **1-, 2- and 3-Channel Versions**
- **Improves Linearity**
- **Eliminates Drift and Hysteresis**
- **Notch Filter for Higher Bandwidth**
- **Increases Piezo Stiffness**
- **ILS Circuitry Maximizes Capacitive Sensor Linearity**
- **Plug-In Module for E-500 System**
- **Prepared for Interfaces / Display Modules (optional)**

The E-509 module is both a signal conditioner for high-resolution capacitive and SGS displacement sensors and a servo-controller for closed-loop piezo nanopositioning mechanics. For more information (see page 2-152).

Technical Data

Model	E-509.C1A/E-509.C2A/E-509.C3A	E-509.S1/E-509.S3
Function	Signal conditioner & servo-controller for piezo mechanics	Signal conditioner & servo-controller for piezo mechanics
Channels	1/2/3	1/3
Sensor		
Servo characteristics	P-I (analog), notch filter	P-I (analog), notch filter
Sensor type	Capacitive	SGS
Sensor channels	1 / 2 /3	1 / 3
Sensor bandwidth	0.3 to 3 kHz (selectable with jumper); up to 10 kHz on request	0.3; 1; 3 kHz
Noise factor	0.115 ppm/Hz½	
Thermal drift	<0.3 mV / °C	<3 mV / °C
Linearity	<0.05 %	<0.2 %
Interfaces and operation		
Sensor connection	LEMO EPL.00.250.NTD	LEMO ERA.0S.304.CLL
Sensor monitor output	0–10 V	0–10 V
Sensor monitor socket	LEMO 6-pin FGG.0B.306.CLAD56	BNC (1-ch.) / 3-pin. LEMO (3-ch.)
Supported functionality	ILS (Integrated Linearization System)	ILS (Integrated Linearization System)
Display	Overflow LED	Overflow LED
Miscellaneous		
Operating temperature range	+5 to +50 °C	+5 to +50 °C
Dimensions	7HP/3U	7HP/3U
Mass	0.35 kg	0.35 kg
Operating Voltage	E-500 System	E-500 System
Max. power consumption	4 to 8 W	4 to 8 W

Headquarters

GERMANY

Physik Instrumente (PI) GmbH & Co. KG
Auf der Römerstraße 1
76228 Karlsruhe
Tel: +49 (721) 4846-0
Fax: +49 (721) 4846-100
info@pi.ws · www.pi.ws

PI Ceramic GmbH
Lindenstraße
07589 Lederhose
Tel: +49 (36604) 882-0
Fax: +49 (36604) 882-25
info@piceramic.de
www.piceramic.de

Subsidiaries

USA (East) & CANADA

PI (Physik Instrumente) L.P.
16 Albert St.
Auburn, MA 01501
Tel: +1 (508) 832 3456
Fax: +1 (508) 832 0506
info@pi-usa.us
www.pi-usa.us

USA (West) & MEXICO

PI (Physik Instrumente) L.P.
5420 Trabuco Rd., Suite 100
Irvine, CA 92620
Tel: +1 (949) 679 9191
Fax: +1 (949) 679 9292
info@pi-usa.us
www.pi-usa.us

JAPAN

PI Japan Co., Ltd.
2-38-5 Akebono-cho
Tachikawa-shi
Tokyo 190-0012
Tel: +81 (42) 526 7300
Fax: +81 (42) 526 7301
info@pi-japan.jp
www.pi-japan.jp

PI Japan Co., Ltd.
Hanahara Dai-ni-Building #703
4-11-27 Nishinakajima,
Yodogawa-ku, Osaka-shi
Osaka 532-0011
Tel: +81 (6) 6304 5605
Fax: +81 (6) 6304 5606
info@pi-japan.jp
www.pi-japan.jp

CHINA

Physik Instrumente (PI Shanghai) Co., Ltd.
Building No. 7-301
Longdong Avenue 3000
201203 Shanghai, China
Tel: +86 (21) 687 900 08
Fax: +86 (21) 687 900 98
info@pi-china.cn
www.pi-china.cn

UK & IRELAND

PI (Physik Instrumente) Ltd.
Trent House
University Way,
Cranfield Technology Park,
Cranfield,
Bedford MK43 0AN
Tel: +44 (1234) 756 360
Fax: +44 (1234) 756 369
uk@pi.ws
www.physikinstrumente.co.uk

FRANCE

PI France S.A.S.
244 bis, avenue
Max Dormoy
92120 Montrouge
Tel: +33 (1) 55 22 60 00
Fax: +33 (1) 41 48 56 62
info.france@pi.ws
www.pifrance.fr

ITALY

Physik Instrumente (PI) S.r.l.
Via G. Marconi, 28
20091 Bresso (MI)
Tel: +39 (02) 665 011 01
Fax: +39 (02) 610 396 56
info@pionline.it
www.pionline.it

Request or download the complete PI Nanopositioning & Piezo Actuator Catalog

Call or go to: http://www.pi.ws