NanoPWM™ Servo Drives Replace Linear Servo Drives In High Performance Positioning Applications

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1 Introduction

Many industrial applications, such as semiconductor wafer inspection systems, OLED Flat Panel Display (FPD) processing and inspection, require extreme motion performance, sub-nanometer standstill jitter and a following error while moving at a constant low speed of a few nanometers. Until now linear servo drives were utilized to address such needs. This type of drive provides good linearity and the low level of electromagnetic noise that are needed to achieve such a level of performance. However, linear drives suffer from low efficiency and reliability issues, dissipate significant amounts of heat, are bulky and large in size, are not available with high voltage and current and are expensive. New 450mm generation of semiconductors are significantly larger than the present 300mm generation and such systems require drives with much higher power, voltages and currents. The required linear servo drives are extremely large, too limited in power and thus limit the performance and through put of the systems, increase their costs and negatively affect their reliability.

NanoPWM™ is a line of switching PWM servo drives that ACS Motion Control has developed over the last 5 years to address the needs of such positioning systems. NanoPWM™ drives provide better positioning and tracking performance without the drawbacks of linear drives. They are compact, highly efficient, reliable, and can provide higher power (voltage and current) at a lower price compared with leading linear servo drives.

2 Types of Servo Drives

Two main types of servo drives are available: linear drives and switching PWM drives.

Figure 1 depicts a schematic structure of the linear drive. The drive acts like a variable resistor that adjusts its value according to the current needs and to the impedance of the load. The supply voltage is divided between the motor (load) and the drive itself. When the motor is moving at low speed and is required to provide high force (or torque) the current is high, the voltage drop on the motor is low and the voltage drop on the drive is high. The power that the drive dissipates is high.

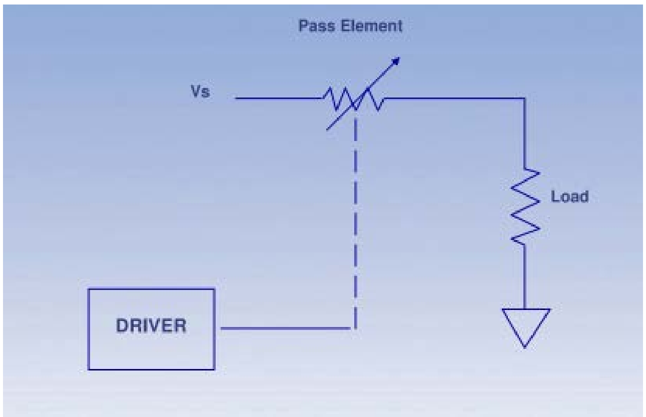

Figure 1 – Schematic description of a linear drive

Figure 2 depicts the schematic structure of a switching PWM drive. The drive acts as an on-off switch. The motor acts like an integrator averaging the voltage and current. The average current is a linear function of the switching duty cycle. At any given moment the switch is either open (no current is flowing through the switch) or is closed (low voltage drop on the switch). Thus, the power (heat) dissipated on the switch itself is very low.

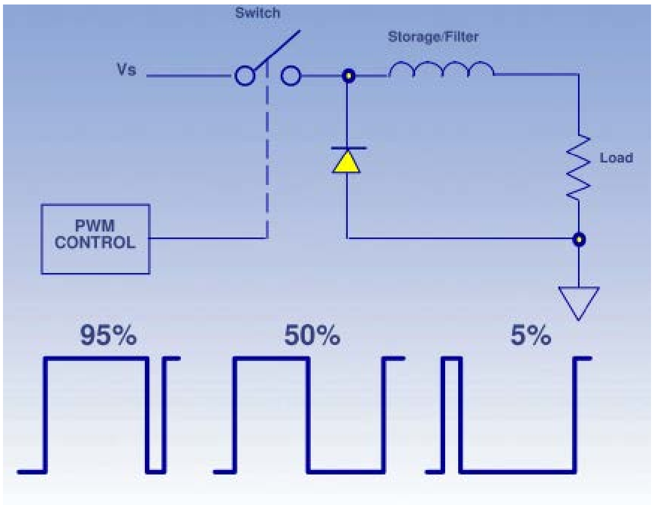

Figure 2 – Schematic description of a PWM drive

Table 1 summarizes the advantages and disadvantages of each type of drive.

	PWM Drive	Linear Drive	Comments
Motion performance	Good	Excellent	PWM drives are inferior due to current ripple and zero crossover distortion
Output power	High	Low	The linear drive is limited in current and power due to low efficiency
Electromagnetic noise	High	Low	
Efficiency	High	Low	
Protection against excessive voltage, current and power	Very good	Difficult and expensive to implement	
Dimensions and weight	Small and light	Large and heavy	
Cost	Low	High	

Table 1 - Advantages and disadvantages of each type of drive

3 The Need

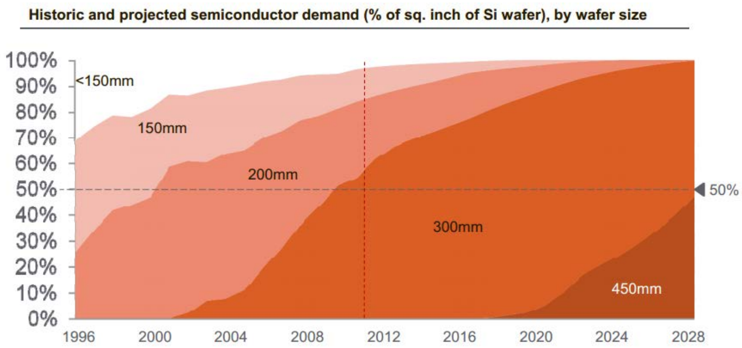

Figure 3 – Semiconductors wafer roadmap

Semiconductor wafer inspection systems require stand still jitter of sub nanometer and following tracking error of a few nanometers. Today, most systems are built to handle 300mm diameter wafers. The next generation of wafers has a diameter of 450mm. They require the same and better positioning performance and due to larger size and weight, higher power motor and drives are needed to maintain and improve the machine throughput. Such systems require drives that combine the advantages of linear and PWM drives. The NanoPWM™ is such a drive. It provides the performance, it is highly efficient, can operate at high voltages, providing high currents. It is compact and more cost effective.

The main characteristics of the NanoPWM™ drives are depicted in Figure 4 and 5.

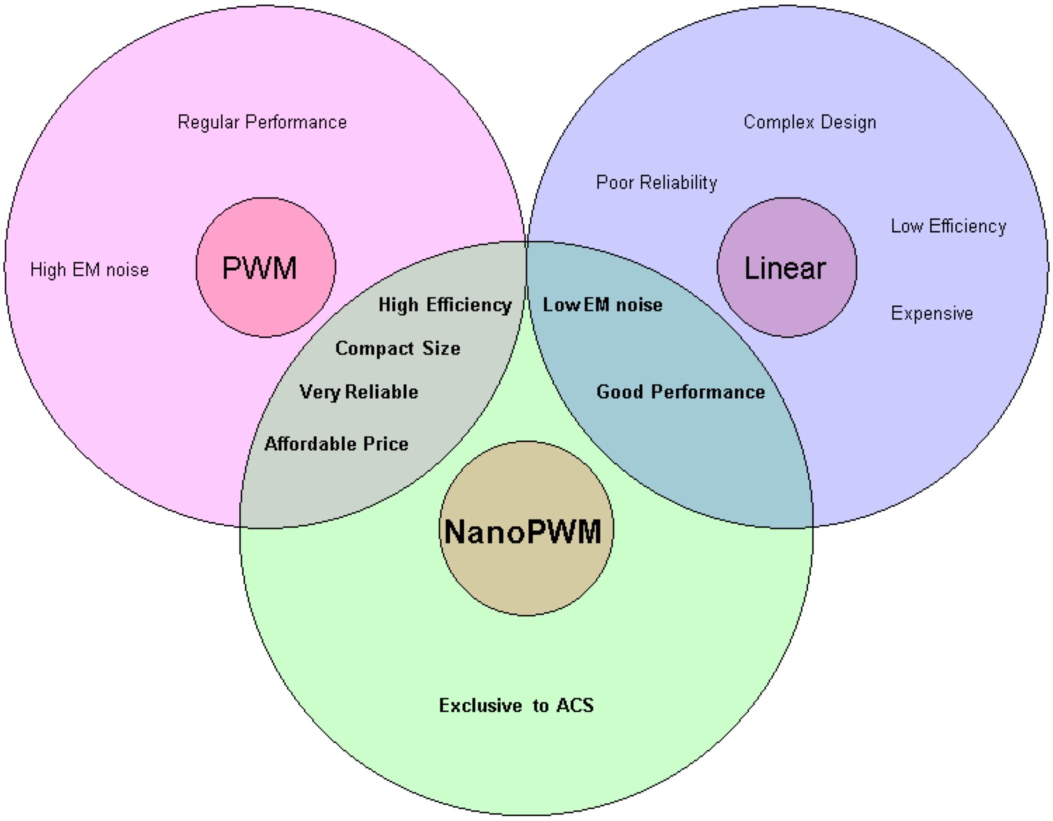

Figure 4 – NanoPWM™ drives combine the advantages of linear and PWM drives

Figure 5 – Size of Linear and PWM drives with similar power

4 Performance Comparison

Tests have been performed on two types of stages:

1. A linear stage with ironless linear motor, cross-roller mechanical bearings and a Magnascale laser analog SIN-COS encoder with a basic resolution of 0.4 mico-meter.
2. A high performance 300 mm wafer inspection positioning XY gantry stage iron core motors and a Magnascale encoder 0.25um with basic resolution of 0.25um
   On this stage the standstill jitter as well as move & settle time have been measured using NanoPWM drive only.

The motion control system consists of ACS Motion Control's MC4U control module with three types of drives:

- NanoPWMTM
- Standard PWM
- Standalone linear drive

In each test, drive and control algorithms were tuned for optimal performance and similar bandwidth.

The drives have similar characteristics as depicted in table 2:

	NanoPWMTM PWM Drives	**Linear Drive**
Voltage [Vdc]	100	+/-50
Peak current [A]	30	25
Continuous current [A]	15	8

Table 2 – Main characteristics of drives

The following performance indexes were tested and measured:

- Standstill jitter
- Following / tracking error when moving at a constant “low” velocity.

5 Standstill Error – NanoPWM™ vs Linear Drive, Linear Stage

The results are depicted in Figure 6 and summarized in Table 3.

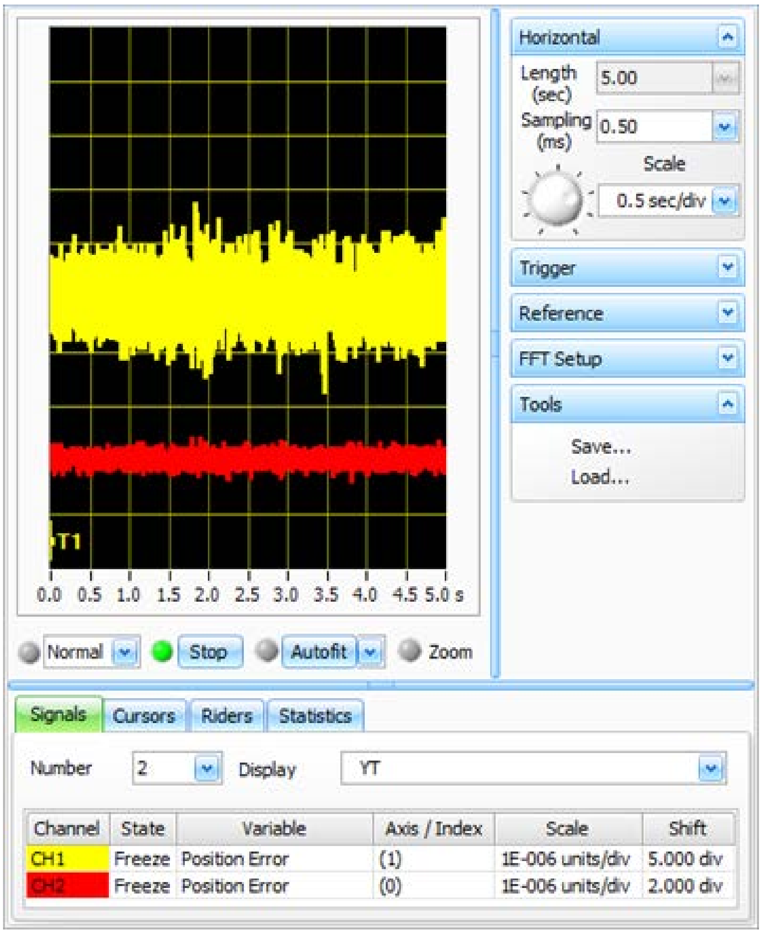

Figure 6 – NanoPWM™ (red) VS linear drive (yellow) standstill jitter

	NanoPWM	Linear Drive
Standstill jitter[nm] p-p	0.8	3.6
Standstill jitter [nm] Std.Dev.	0.13	0.6

Table 3 - NanoPWM (red) VS linear drive (yellow) standstill jitter

The standstill jitter when using NanoPWM™ drive is significantly smaller than the jitter when using a linear drive. (4.5 times smaller: 0.8nm vs. 3.6nm)

6 Tracking Error at Low Velocity – NanoPWMTM vs Linear Drive, Linear Stage

The tracking error was measured when moving at a constant velocity of 1 mm/second. The results are depicted in Figure 7 and summarized in Table 4.

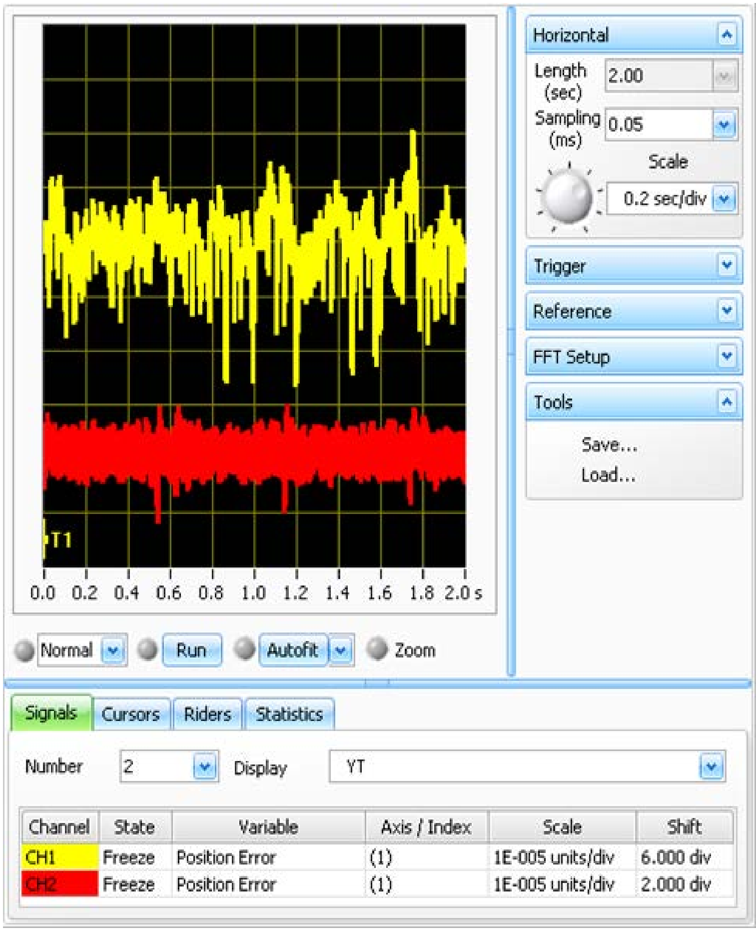

Figure 7 – NanoPWMtm (red) vs. linear drive (yellow) tracking error

	NanoPWMTM	Linear Drive
Tracking error [nm] p-p	22	48
Tracking error [nm] Std. Dev.	3.6	7.7

Table 4 - NanoPWMTM (red) vs. linear drive (yellow) tracking error

Using NanoPWMTM the tracking error is significantly smaller resulting in a much smoother motion, which is vital for applications such as wafer inspection process.

7 Standstill Error – NanoPWM™ vs Standard PWM Drive, Linear Stage

The results are depicted in Figure 8 and summarized in Table 5.

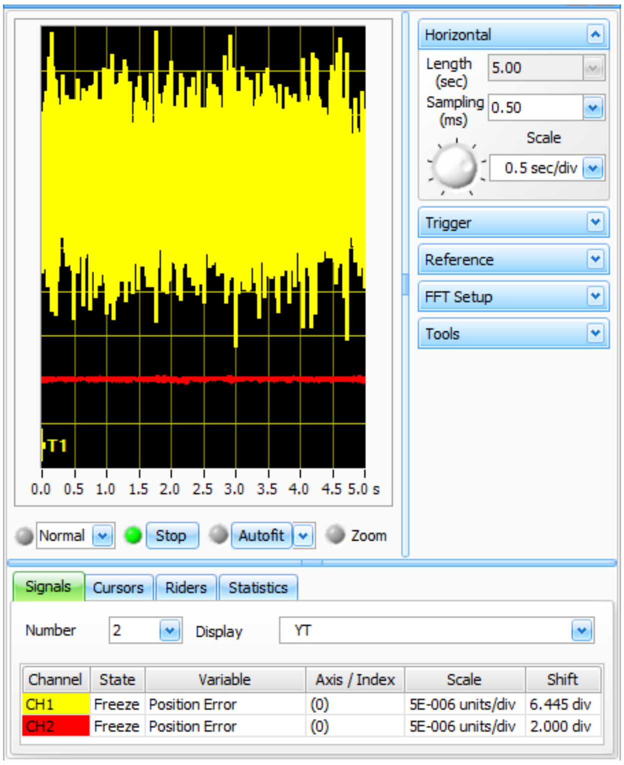

Figure 8 – NanoPWM™ (red) VS PWM (yellow) standstill jitter

	NanoPWM™	**Standard PWM**
Standstill jitter[nm] p-p	0.8	36
Standstill jitter[nm] Std. Dev.	0.13	6

Table 5 - NanoPWM™ (red) vs. PWM drive (yellow) standstill jitter

Using NanoPWM™ the standstill jitter is about 2% of the jitter achieved with standard PWM drives. Flat Panel Display handling systems are large and the voltage and current requirements of the motor and drives are beyond the capabilities of commercially available linear servo drives. OLED (Organic LED) displays require higher accuracies and tracking and standstill jitter of a few nanometers. NanoPWM™ provides the proper answer to such needs.

8 Standstill Jitter using NanoPWM Drive, Gantry Stage

Scope resolution; 1nm/div.

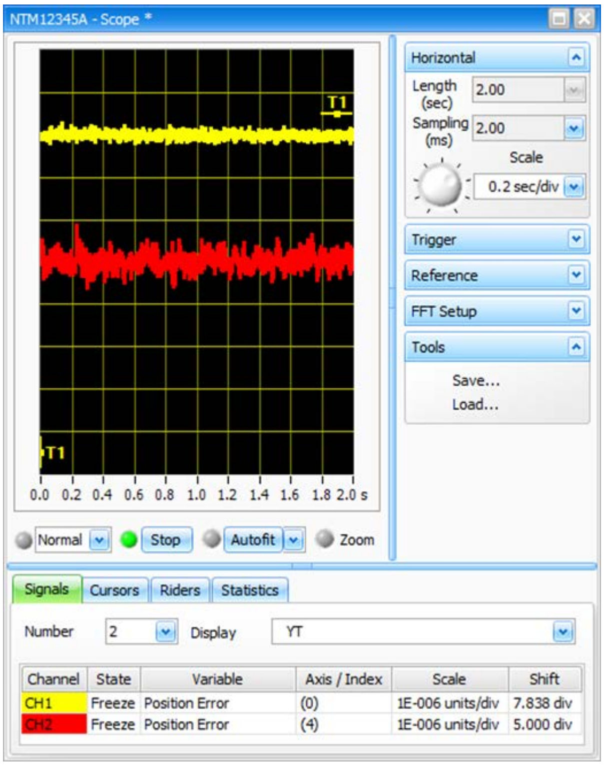

Figure 9 –Standstill jitter, Gantry axis (yellow) & Cross axis (red)

	Gantry Axis (X0, X1)	**Cross Axis (Y)**
Standstill jitter[nm] p-p	0.6	1.4
Standstill jitter[nm] Std. Dev.	0.08	0.18

Table 6 – Standstill jitter, Gantry stage

9 Move & Settle Measurements using NanoPWM Drive, Gantry Stage

In this test we measured the move & settle time making an aggressive 20mm move using 2g acceleration. The theoretical move time is 80msec. It is required to move and settle into a 100nm window within 100msec and to a 2nm window within 160msec.

This is quite a challenge. It requires a very high acceleration to minimize the (theoretical) move time and exactly such acceleration excites vibrations in the system that increases setting time. Using a NanoPWM drive with an advanced control algorithm, named ServoBoost, the specifications are met with good margin.

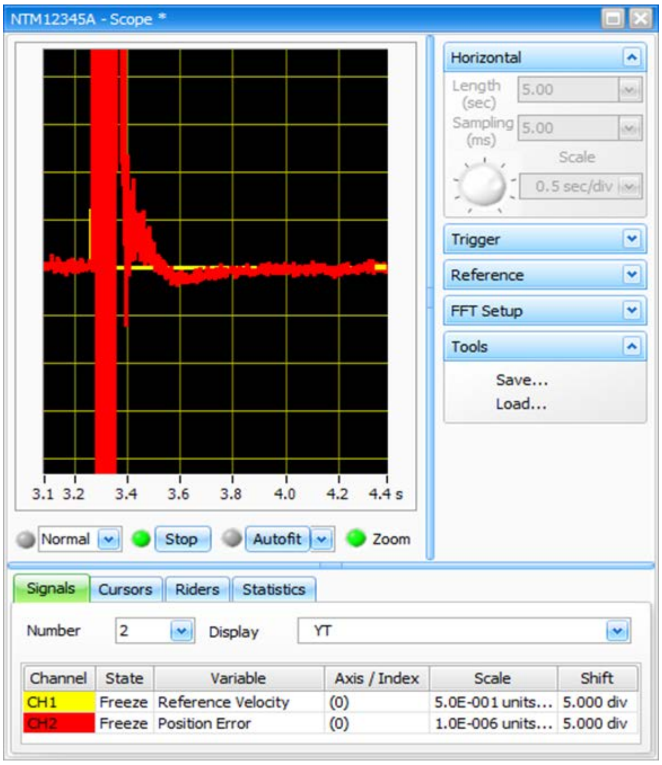

Figure 10 – Gantry axis, Move & Settle, Following error (red)

Setting window size [nm]	M&S time [ms]
100	90
2	137
1	197
0.5	240

Table 7 – M&S time, Gantry axis, 20mm move

10 Summary

In this article we present a new line of switching PWM servo drives – NanoPWM™, that combines the advantages of linear and standard PWM servo drives. The motion performance achieved with NanoPWM™ drive exceeds the performance achieved using commercially available linear servo drives. It is smaller, more reliable and lower in cost.

It is well suited to address the highly demanding motion performance needs, such as semiconductors wafers and Flat Panel Display handling systems.