"Sine Sweep Vibration Testing for Modal Response Primer”

Eric Sauther
Department of Optical Sciences, University of Arizona Opto-Mechanical Engineering; OPTI 521 Opto-mechanical Enginering Fall 2013; Meinel Optical Science building 1630 E University Blvd
Tucson, AZ 85721AZ USA

ABSTRACT

It is important to have an introductory understanding of vibration testing, and applied techniques in order to verify (and provide empirical proof) that the design will respond as specified under the customer requirements. While FEA analysis may show an assembly's modeled performance, it is necessary and required (by the customer) that test evidence be provided to verify the modeled assembly will perform as expected under real world conditions. The Sine Sweep vibration test is one portion of assembly performance verification under controlled conditions, and is used for structural dynamics characterization, durability, and fatigue testing. Basic theory as a lead in, test setup, and representative results shall be discussed.

Keywords: Sine Sweep, Vibration, Model Analysis

1 INTRODUCTION

1.1 Sine Sweep Test

In the Environmental Stress Screen (ESS) vibration domain there are different types of tests that products can be exposed to contingent on what requirement is needed to characterize product performance. Major ESS vibe categories include Random, Shock, and Sine testing with various subcategories with in each test. Vibration testing is for fulfilling customer imposed requirements under the Validation Phase of the product’s operations, or under Product Transportation conditions.

One sub-category is Sinusoidal Sweep method. This test allows for higher RMS input loads and oftentimes leads to much cleaner modal responses Sinusoidal sweep process is also used to provide symmetric excitations to emphasize symmetric modes.[1]

Instead of evaluating the dynamic properties of a structure from free vibration test data, a forced vibration test is performed using sinusoidal (harmonic) loading over a range of frequencies.
The concept is to excite the structure with harmonic loading such that at certain frequencies the structure experiences resonance. Under normal circumstances the customer will provide Sine Sweep requirements criteria relative to the environment the product will see.

1.2 Modal Analysis

Modal Analysis can be defined as analytical determination modes of vibration for a linear multiple degree-of-freedom system. These modal properties include mode shapes, resonant frequencies, modal damping, modal mass, and participation factors (a measure of the sensitivity of a mode to excitation from any particular direction). These parameters can be measured experimentally on a shake table or by field vibration tests. They can also be computed using finite element analysis software.[3]

1.3 Sinusoidal Sweep description

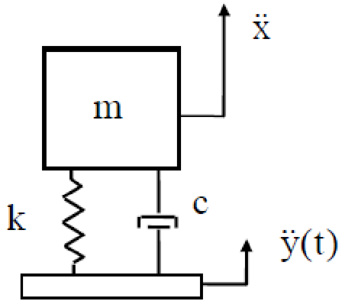
Sinusoidal Sweep testing can accomplish certain specific tasks. One of example of this is the model response of a Part or Product Assembly. Determining amplitude relationships at the natural frequencies on a structure permits modal modeling. The modal models provides valuable information regarding system integrity in mode responses. For Sinusoidal Sweep, the product under test is isolated to test one axis (normally X Axis) which has a single degree of freedom (SDOF) for its test. However, the response from the input could show in all axis.

Ideally the frequency range and time duration of a Sine Sweep input has been pre-determined to predicted the lifetime of a products usage. The parameters needed for a Sine Sweep input are, Start/Stop Frequencies (f1, and f2), Time duration of the input sweep (t), and level (or Gs) of the input which can be approximated. While stated generically in this paper, this sweep needs to be done for all three axis of the product tested.

Sine Sweep rates can be modified for all or a portion of the frequency range. This is of particular interest if a designer is concerned about the duration about a resonance frequency.

The Modal Response of a Sine Sweep input is derived from a Single Degree of Freedom (SDOF) system subjected to a Harmonic Excitation.

Below consider a SDOF system with damping. The relationship is as follows:



where

m	is the mass
c	is the viscous damping coefficient
k	is the stiffness
x	is the absolute displacement of the mass
y	is the base input displacement

A Damped harmonic isolator is described as:

$$z" = 2\varepsilon\omega_n z' + {\omega_n}^2 = -ASin(\omega t)$$

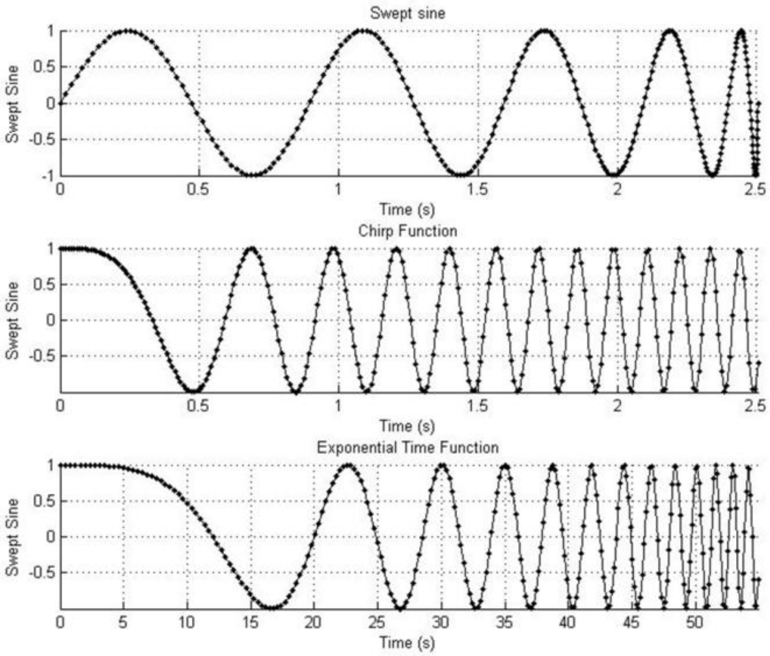
Where $y"(t) = A\sin(\omega t)$, z is a relative displacement functional relationship of change in position for the spring and damping components, and ε is the damping ratio.

From here the designer can take the Laplace transform and find the Displacement, Velocity, and Acceleration components for a Harmonic Sine input into a system.

For Sine Sweep, ramping through a range of frequencies is required in order to define resonance. The sweep rate can vary, but the simplest input is linear. So in a basic relationship above a designer may build the customers input parameters insert into the vibration system for a Sine Sweep input. This can be performed by structural analyst at critical interfaces to monitor, but are only controller inputs for the tester to input into the Vibration table software.

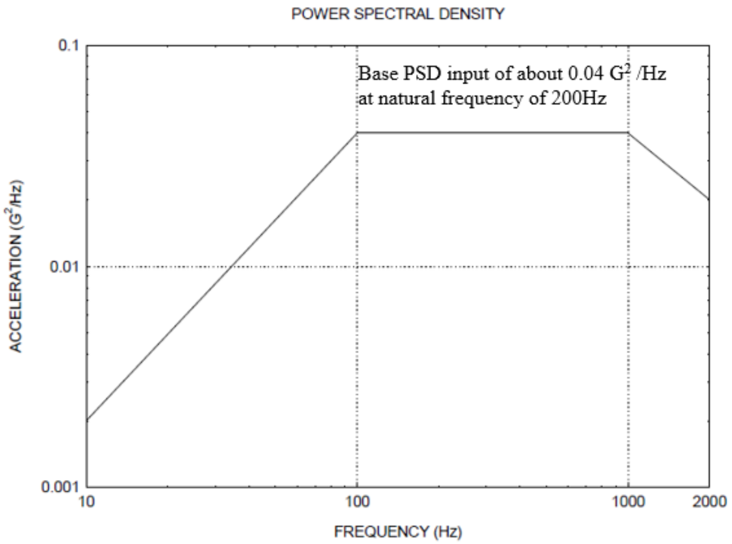
Table 1 Sine Sweep Rate Parameters

Linear Sine Sweep input	$\mathrm{Y(t)=Sin}\{2\pi\{\frac{f1(-1+2^{Rt})}{R\ln(2)}\}\}$
Sweep Rate in terms of Octaves	$R = \frac{N}{t2 - t1}$
Number of Octaves (cycles) in the Frequency Range to be swept	$N = \frac{\ln\frac{f2}{f1}}{\ln(2)}$



1-1 Three Sine Sweep general input types exist Linear Sweep (Top) is most common

The Base ASD is expressed as the squared of the Acceleration (Grms) over a Bandwidth Δf where the frequencies are the range determined by the input Sine Sweep.



1-2 Typical ASD input Plot for Sine Sweep

The ASD plot above can be an expressed requirement with a related input table. This is either directly an input from the customer, Industry Standard, or stated through a Military, NAVMAT Standard (USA only).

Base Motion acting as input to Product and fixture	$\frac{1}{\sqrt{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2+(2Cr\left(\frac{\omega}{\omega_n}\right))^2}}$
Transmissibility= $\frac{Isolated\ Motion}{Base\ Motion}$ $PSD_{isolated\ motion} = T^2\ PSD_{Base}$	$\sqrt{\frac{1+\left(2\ \frac{\omega}{\omega_n}\ Cr\right)^2}{\left(1-\left(\frac{\omega}{\omega_n}\right)^2\right)^2+(2Cr\left(\frac{\omega}{\omega_n}\right))^2}}$

The Peak Transmissibility is approx equal to Q for an input frequency equal to $f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

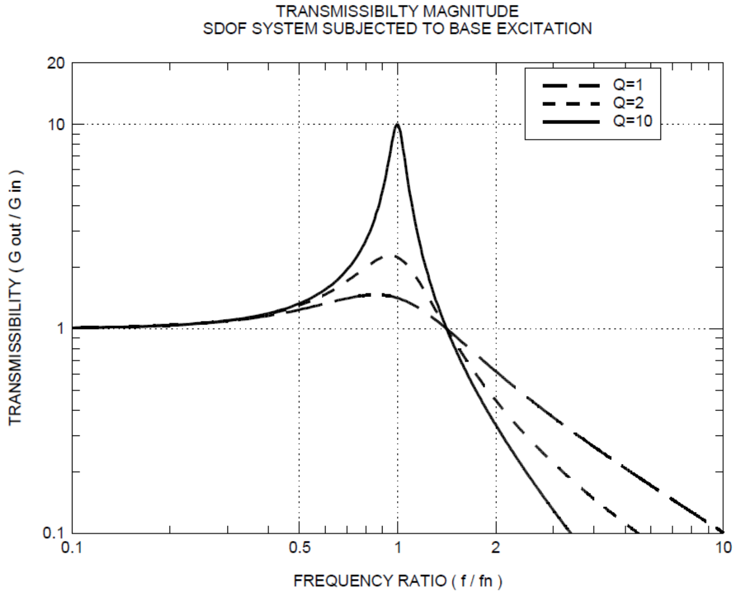
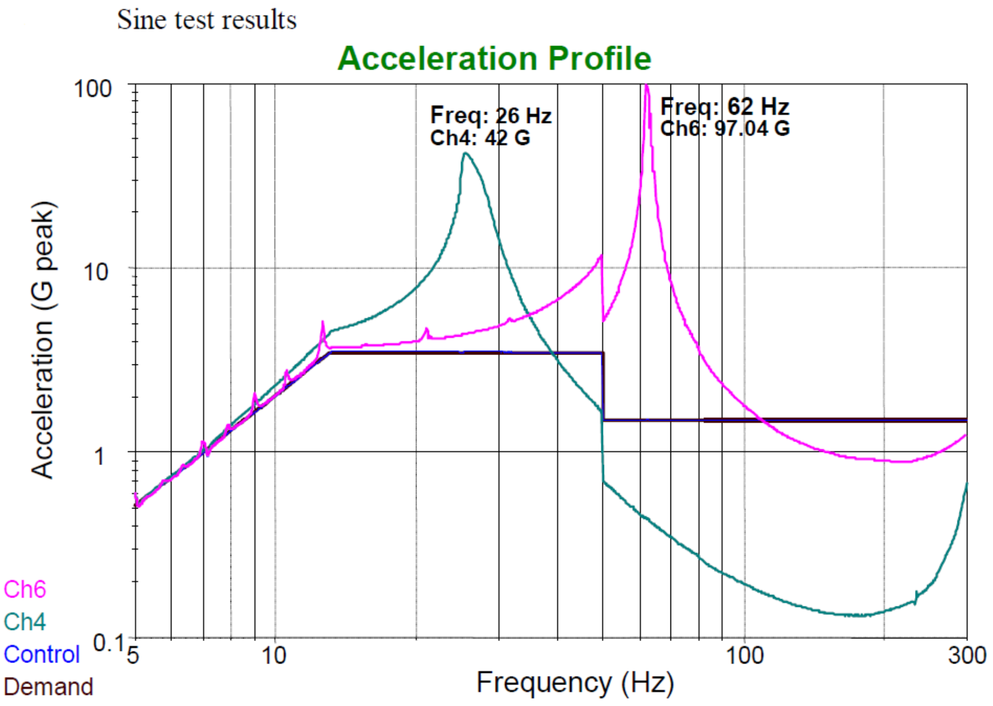


Figure 1-3 Excitation due to a Sine Sweep input

A Sine test definition consists of entering a set of input variables, consisting of acceleration, velocity and displacement amplitudes and their associated frequencies, plus slope segments. The software automatically calculates crossover frequencies or ASD amplitudes when slopes used.
The maximum peak values for acceleration and velocity and the maximum peak-peak displacement for the test are automatically displayed. If the tests dynamic demands exceed the shaker system's limits, the software automatically warns the operator and aborts test depending on the response amplitude.

At a reference point, the Sine input the product will see a maximum G level at resonance. As the test approaches the Resonance frequency, the tester can set the G level (normally with a margin of safety) and "dwell" around that Frequency band of interest. At resonance, vibration levels applied are amplified by the Amplification Factor (aka Quality Factor) Q. Where Q can be described in relation to the Damping Coefficient as $Q=1/2C_R$ Where $C_R=\frac{C}{C_c}$ can be defined as the critical Damping, C is the System Damping, and $C_c = 2m\omega_n$ is the System Critical Damping. This is also known from first order relationships that the natural frequency can be identified as $\omega_n = \sqrt{\frac{k}{m}}$ in Radians/sec.

Some important things to note in Figure 1-4. The response is about the input range of the sine sweep. The spectral width can be calculated to first order to help in setting up your “Dwell” area (normally done for Sine on Random) testing to investigate the response around resonance (see Ch4 in figure). The Spectral width will be approximately $\Delta f = \frac{f_n}{Q}$. Another thing to take note of is the delta in response to Sine input. It is important to understand the resonance response apriori in order to set the appropriate input level so as to not cause damage to the Product. Normal Margin of Safety for the response is 4 times. However, in a Modal investigation the margin does get adjusted anywhere from 2 to 10 balancing safety and response of Product under test.



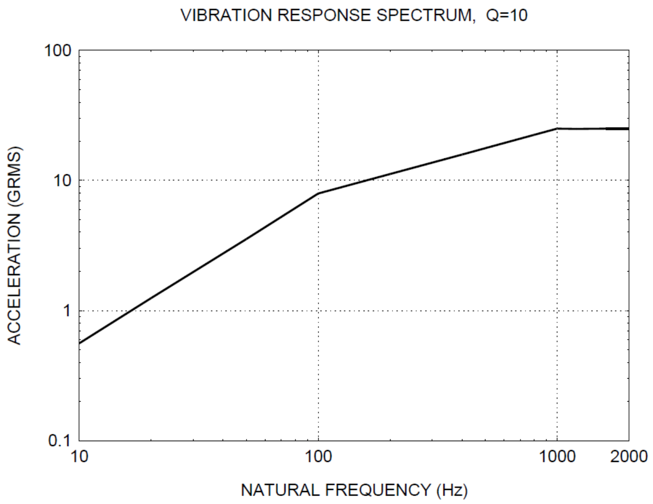
1-4 Plot Representation of a Sine Input and Response of two posts of different lengths (Responses in ch4 and ch6)

NOTE: The Control signal followed the prescribed input signal closely. This is relevant later.

Assuming the table is well characterized where PSD is known for the Isolated System, this can be calculated for the Base PSD (base input level) for the Product with the first order calculation for Transmissibility. From there a designer may use the Miles Equation to calculate the maximum response acceleration at the natural frequency. The Miles Equation is as follows:

$$AccelRMS = \sqrt{\frac{\pi}{2}[BasePSD][f_n][Q]}$$

has an RMS response of 1σ value with a zero mean. Since the peak response is not precisely known, the rule of thumb is to look at 3 σ standard deviation. With this, if the maximum response was predicted to be 10 Gs then the 3 σ peak response is 30 Gs at roughly a 99% probability distribution.



2 EXPERIMENTAL VERIFICATION

While other Vibration Test Equipment exist, this paper wil confine the discussion to the use of a Sine Sweep input to a Vibration Slip Table.

2.1 Test Flow Method

The following Test Flow can be employed for a Sine Sweep test with expected Model Response:

- Characterize Vibe Table, with Product Mounting Fixture, and Product Mass Simulator if not already done.
- Mount Product Accelerometers. Control Accelerometer should already be in place from Table Characterization. Input variables, consisting of acceleration, velocity and displacement amplitudes their associated frequencies, Warning and Abort levels
- Mount Fixture and Product onto Vibe Table
- Mount Fixture and Unit
- Apply Chosen Accelerometers to prescribed Product and fixture locations
- Input Accel Spectral Density profile, for Input levels (Gs) frequencies, durations, Warning and Abort levels, for the Sine Sweep Test Run. Input the Vibe Table Characterization File.
- Observe Control Accelerometer response during test while running through the profile
- Upon Test Completion Review Test Accelerometer Data For Pass/Fail Criteria

A designer should be aware of the hardware components that drive, monitor and controller the vibration table, will most likely be using software entries to set the parameters for the product sine sweep test. A representation of a software interface will be shown later in this document.

2.2 Machine Vibration Characterization

The Vibration output of the Slip table must be characterized prior to mounting the production item. This helps to verify the machine is still working in its nominal condition. Also, there are a variety of characteristics of the Vibe table (that should be provided by the Manufacturer) that should be checked out. A variety of handling will happen, especially if the Vibe table is handled by various product groups, so it is good practice to take note of any changes when first coming into the area. Some the characteristics are, but are not limited to:

- Start up and Shutdown transients
- Force changes due to temperature changes (temperature sensors may be used to monitor this)
- Closed loop control system is functioning as expected
- All accelerometers being used are in good physical condition
- First time Physical characterization of the System can be accomplished through a test known as Tuning.

2.2.1 Tuning

Tuning is the process of separating out the machine's own operational frequency from any structural frequency so it can be isolated from the test output of the product. The floor and foundation also have a natural frequency component that could couple in through the Vibe Table. Ideally, the tuning of the table has already been performed, and a site survey has been performed (for environmental components) so tuning is not necessary for normal testing. If any the conditions have changed, it should show in the Machine Characterization that is done before testing commences.

2.3 Vibration Test Fixture

2.3.1 Test Fixture Design

2.3.1.1 Basic Concepts for testing [4]

For all products to be vibration tested, and interface fixture needs to be created to securely mount the Product to the Vibration Table. In vibration test fixture design, the following inputs of test article and test equipment are to be considered prior to designing a fixture.

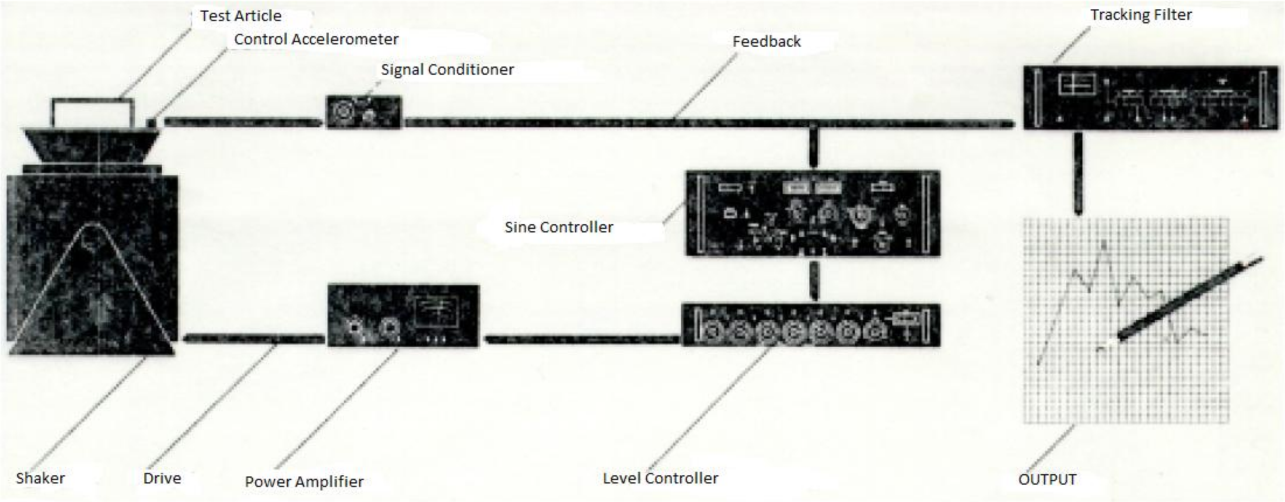
- Details of the shaker table such as pattern of the attachment
- Holes, bolt size and thread sizes are to be known to which the fixture attaches.
- Size and configuration of the test article
- Weight and center of gravity of test article
- Details of the test specimen such as the mounting interface
- Its dynamic characteristics
- Details of the dynamic test specifications
- Test axis for which fixture is designed
- Mass that can be attached to the shaker table without possibly causing damage.
- Available shaker rating.
- Necessary pre load between the table and fixture.
- Awareness of the possibilities of the shaker resonances
- Anticipated/repeated usage of the fixture
- Usually, the natural frequency of the fixture design lies within the test specification range. Thus, the most important factor in fixture design is a high natural frequency above the frequency of interest…cost permitting.

  Note that with $\omega_n = \sqrt{\frac{k}{m}}$ the weight and material of the fixture will also impact the response to a Sine Input.

2.4 Vibration Table Testing Orientation

This paper focuses on a Slip Table (Electro-dynamic Shaker type) for vibration testing, there are two major configurations for Vibration testing with benefits and limitations.

Orientation	Benefits	Limitations
Vertical	• Easier to control • Center of Gravity aligned to thrust axis of shaker • 3-axis capability • Smaller foot print • Lower cost	• Limited Size • Can handle products up to 2,500lbs
Horizontal	• Support Large Weight • 3-axis test capability	• More difficult to control • Exposed Oil Film • Higher off axis bearing load • Higher cost



2-1 Representative Vibration Test Station

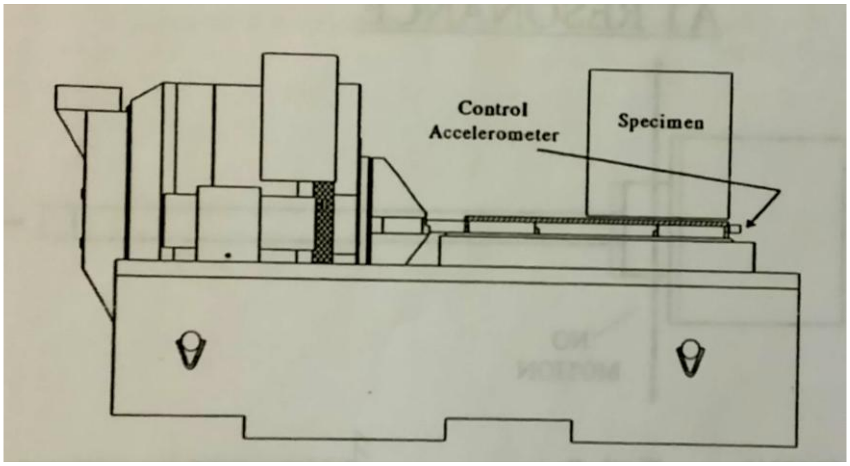
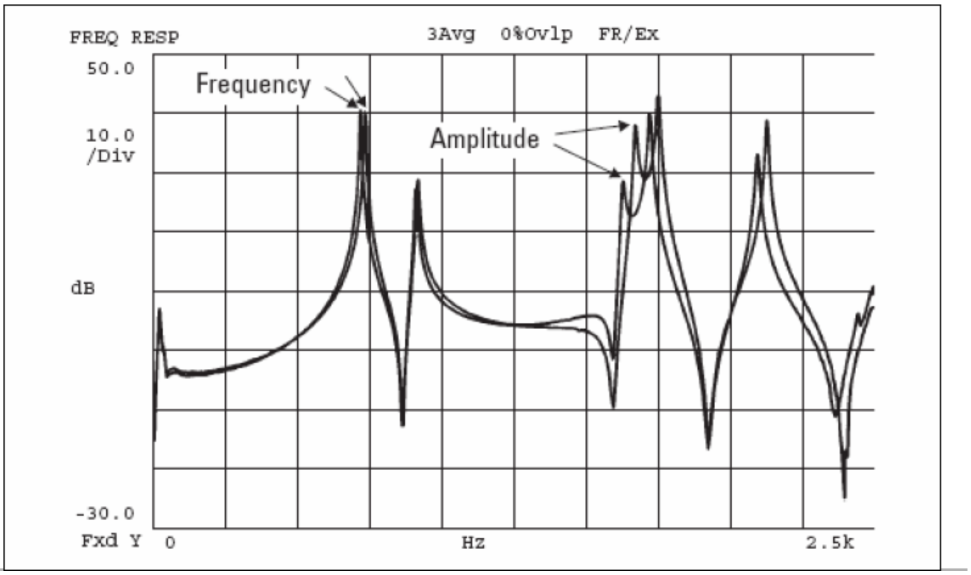


Figure 2-2 Horizontal Slip Table (AKA Shaker) with Product/Fixture on Table

2.5 Control and Measurement Accelerometers for vibration testing-Parameters

As mentioned in the Introduction, it is important to be able to accurately as possible measure the modal response of a system due to a sine wave swept input. For this reason calibrated Piezoelectric Accelerometers are used to translate vibration input into a voltage response. However, in order to get the best characteristic response from the Accelerometers, proper mounting becomes a critical part of the setup. Also, there should be a proper number of accelerometers for all of the needed measurement points. The tester cannot have a roving Accelerometer for all areas of inspection. Roving Accelerometers lead to variable test loading. This adds static accelerometers mass to the overall system and will change the response.

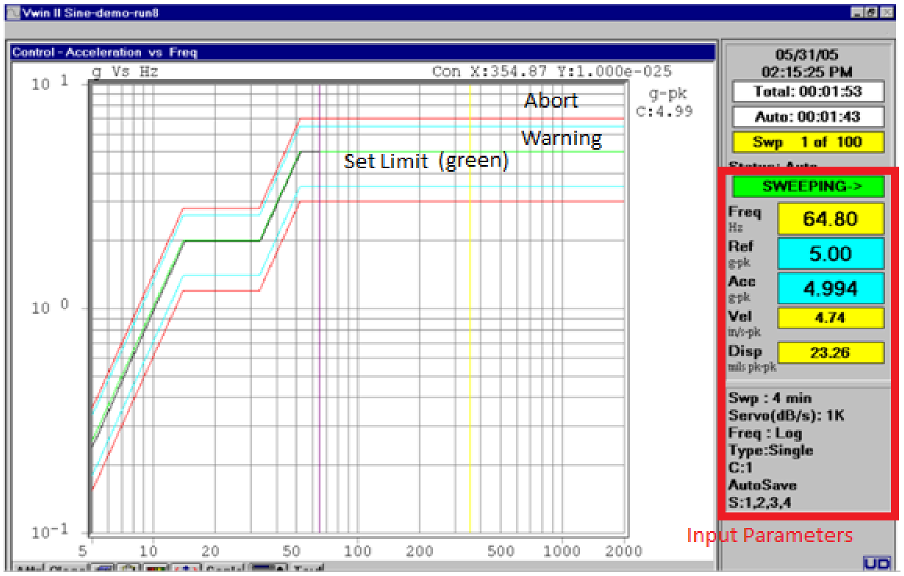


2-3 Test data variation from Roaming Accelerometer

Both software recalculated limits, and the Control Accelerometer will monitor the shaker vibration output (input into the Product/fixture). If Dynamic demands exceed the shaker system's limits, the software automatically warns the operator, or if the Control Accelerometer (part of the closed loop control system) senses an out of limit condition for the test, the System will automatically shut down. For a Sine Sweep the Control Accelerometer will closely follow the Sine Sweep parameter inputs with the Set software limits put in place. Typical Sine Sweep Limits are stated below:

Warning Limits	Abort Limits
+/- 30% of Expected Response	+/- 40% of Expected Response

2-4 Default Controller Accelerometer Limits



05/31/05
02:15:25 PM
Total: 00:01:53
Auto: 00:01:43
Swp 1 of 100
SWEEPING->
Freq Hz 64.80
Ref gpk 5.00
Acc gpk 4.994
Vel in/s-pk 4.74
Disp mils pk-pk 23.26
Swp : 4 min
Servo(dB/s): 1K
Freq : Log
Type:Single
C:1
AutoSave
S:1,2,3,4

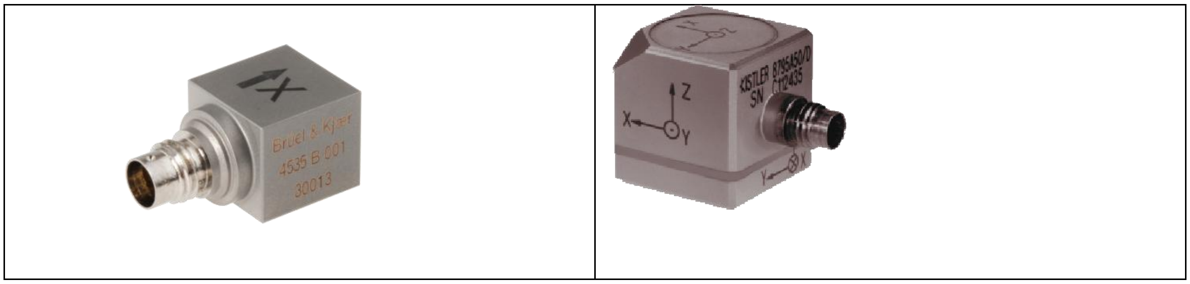
2-5 Control Accel Plot

If there is a specific area of concern about the product, the test can also be set for specific Accelerometers used.

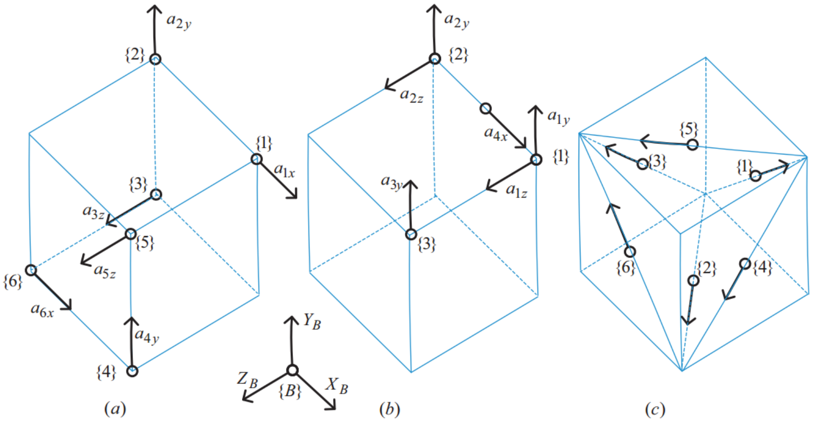
2.6 Control Accelerometer Placement and Parameters

2.7 Measurement Accelerometer Placement and Parameters

For Fixtures and units under test, acceleration levels will vary at different points on the fixture. With a fixed input level many points will not have the same vibration response. It is beneficial to have several attachment points to ensure good Transmissibility of vibration from the shaker through the fixture and to the unit under test.



2-6 Accelerometers with Axis Labels



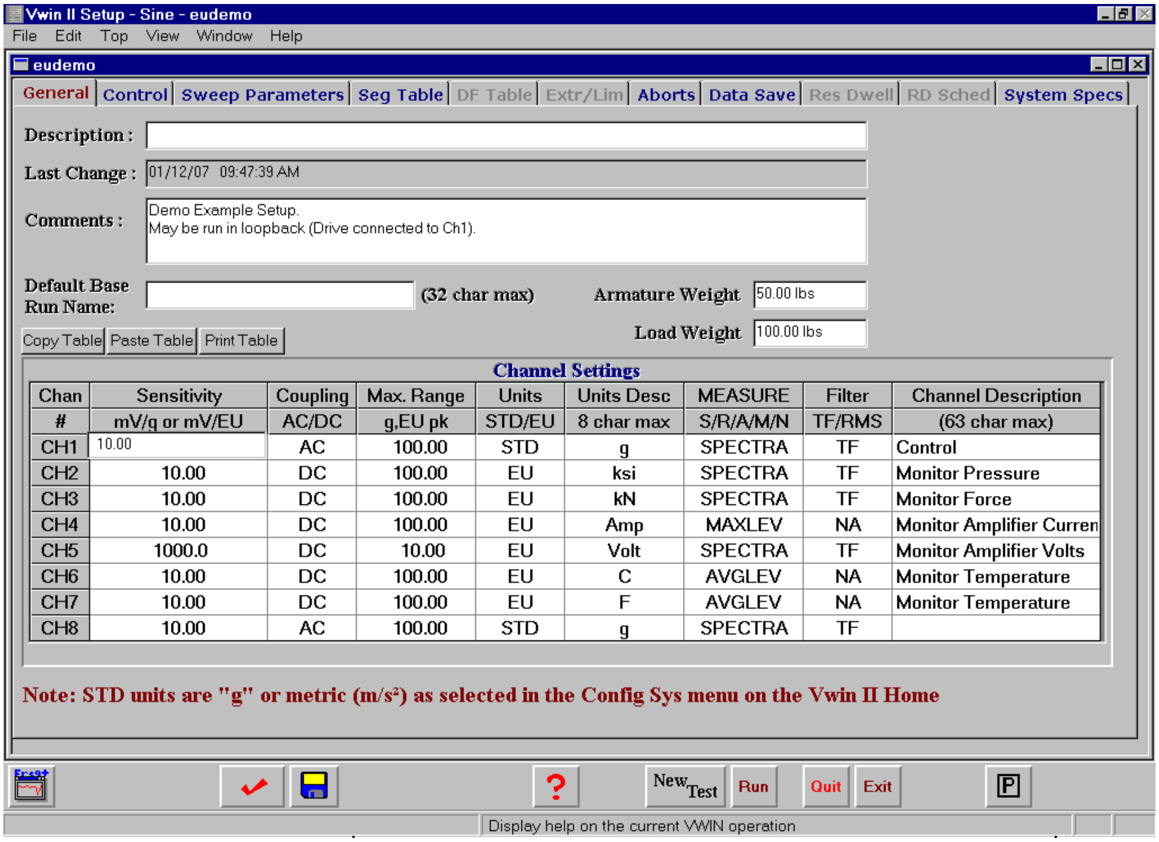
2-7 Axis Naming Representation to Location

The most common accelerometer types are single axis and must be orientated with the axial direction of test. However, it is best pr

When setting up a Measurement Accelerometer there are measurement parameters that should be set in the software. The Typical defaults are as follows:

Parameter	Default Value	Typical Units	Notes
Input Sensitivity	10	mV/g	For Less than 500g loading
Input Coupling	AC		For when the Sine Sweep input signal is known
Maximum analysis channel range	Ideally 2X max expected G value	Variable (g)	Max Setting limited by Input sensitivity
Input Tracking Filters	YES	Input logic	
Input Channel Description	Specific Location, Orientation	Text	Very Important! When you have a set of 100 accelerometers its critical you clearly identify the location and orientation for analysis

2-8 Accel Parameters for Test



Description :

Last Change : 01/12/07 09:47:39 AM

Comments : Demo Example Setup.
May be run in loopback (Drive connected to Ch1).

Default Base Run Name: (32 char max)

Armature Weight 50.00 lbs

Load Weight 100.00 lbs

Channel Settings

Chan #	Sensitivity mV/g or mV/EU	Coupling AC/DC	Max. Range g,EU pk	Units STD/EU	Units Desc 8 char max	MEASURE S/R/A/M/N	Filter TF/RMS	Channel Description (63 char max)
CH1	10.00	AC	100.00	STD	g	SPECTRA	TF	Control
CH2	10.00	DC	100.00	EU	ksi	SPECTRA	TF	Monitor Pressure
CH3	10.00	DC	100.00	EU	kN	SPECTRA	TF	Monitor Force
CH4	10.00	DC	100.00	EU	Amp	MAXLEV	NA	Monitor Amplifier Curren
CH5	1000.0	DC	10.00	EU	Volt	SPECTRA	TF	Monitor Amplifier Volts
CH6	10.00	DC	100.00	EU	C	AVGLEV	NA	Monitor Temperature
CH7	10.00	DC	100.00	EU	F	AVGLEV	NA	Monitor Temperature
CH8	10.00	AC	100.00	STD	g	SPECTRA	TF	

Note: STD units are "g" or metric (m/s²) as selected in the Config Sys menu on the Vwin II Home

Display help on the current VWIN operation

2-9 Accelerometer Physical Test Parameters

2.8 Measurement Accelerometer Physical Mounting and Setup

There are six typical accelerometer types for Accelerometer setup. Each have their advantages in application and variation in performance. The type, and technique chosen will affect the fidelity, and repeatability of the data that can be collected specified in Hz or Cycles Per Minute (CPM). Some of the common types are:

Mounting Technique	Name	Freq Response (+/- 3dB)	Application Notes
Permanent Mount	Stud Mount	Sensor Max response	When properly installed provide the best transmission of the broadest range, and are the most reliable and resilient
Permanent Mount	Stud Mount; Tri-axial	Typically accurate up to 7or 8kHZ	When properly installed provide the best transmission of the broadest range, and are the most reliable and resilient. All three axes can be monitored at that one location
Permanent Mount	Epoxy Pad	10kHz to 15kHz (600000-900000 CPM)	High Repeatability at locations where drilling and tapping are not permitted. Good transmission for High Frequency (5 to 10 KHz)
Adhesive Mount	Flat Magnet with Target (Target is	10kHz (600000CPM)	High Repeatability at locations where drilling and tapping are not permitted.

	permanent)		Performance Installation Dependant
Portable Mount	Quick Disconnect (Threaded)	Up to 6.5 KHz (390000CPM)	Increases Data Collection Speed, Maintains consistent data collection locations
Portable Mount	Curved Surface Magnet	Up to 2kHz (120,000CPM)	Increases Data Collection Speed, Maintains consistent data collection locations
Portable Mount	Probe Tip	500 Hz (30,000) CPM	Difficulty in repeatability not meant above 500 Hz

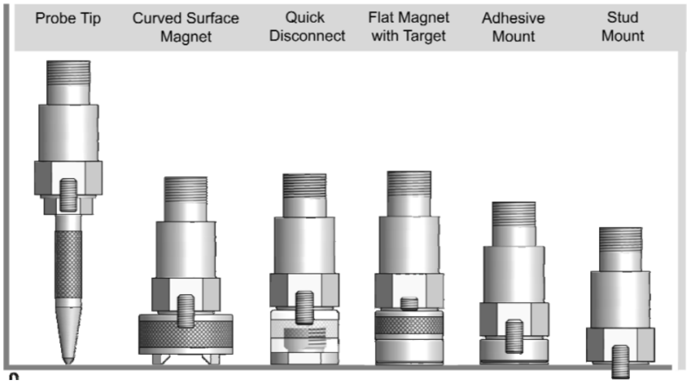
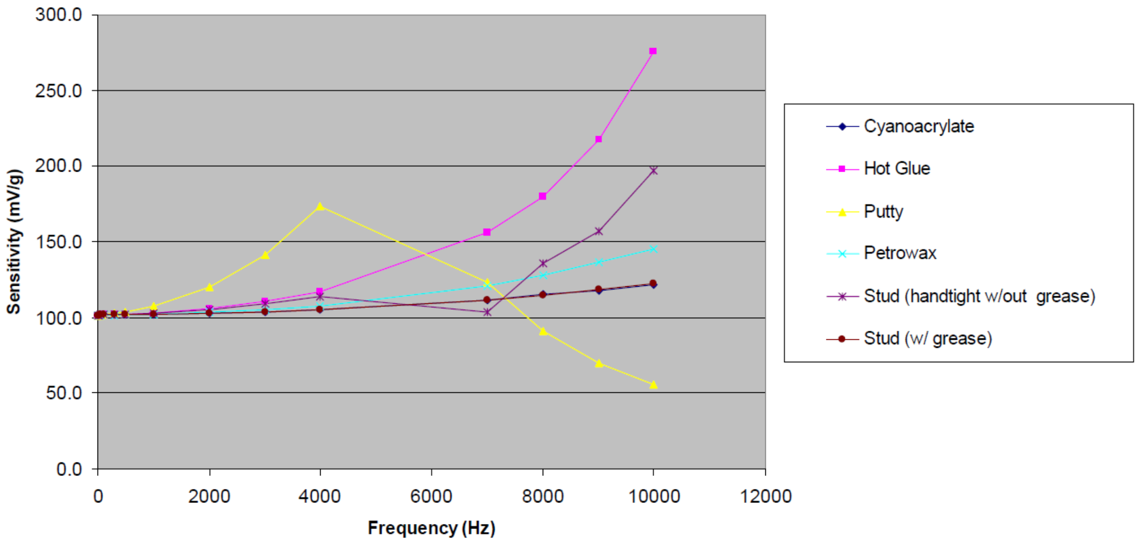


Figure 2-10 Accelerometer Uni-axial types[2]

Choice of mounts can be critical depending on the Analyst needs for data fidelity. With help from the Analyst (with support from FEA analysis) detailed direction on Stiffness, Additional Mass, Contact Area, and Location should be provided. Regardless of type and installation method, Surface preparation (ie grit blasting or bonding glue) should be researched in order to obtain proper contact. For example, epoxy pads (and mating surface) should have the smooth contact surface cleaned with an appropriate cleaner (ie alcohol wipes) in order to not have surface contamination affect contact adhesion.
Below is a representation of the accelerometer performance affect relative to mounting condition.



2-11 Mounting Condition effect on Accelerometer response

General Caution should be used in mounting and handling Accelerometers. Shocking the sensor while handling could invalidate the data, its calibration, or permanently damage the Accelerometer Part.

2.9 Measurement Accelerometer Transmission note

Generic for all Accelerometers there exists a finite regime with which they are useful for data collection. This is called the transmission region and is defined in the product specification sheets. This characteristic is set for life of the Accelerometer (if left undamaged). Even within the transmission region the Accelerometer performs non-linearly. Therefore, for best measurement results the part should be calibrated. Most companies have either an internal calibration group that can perform this task, or they can accept the calibration done by the vendor.

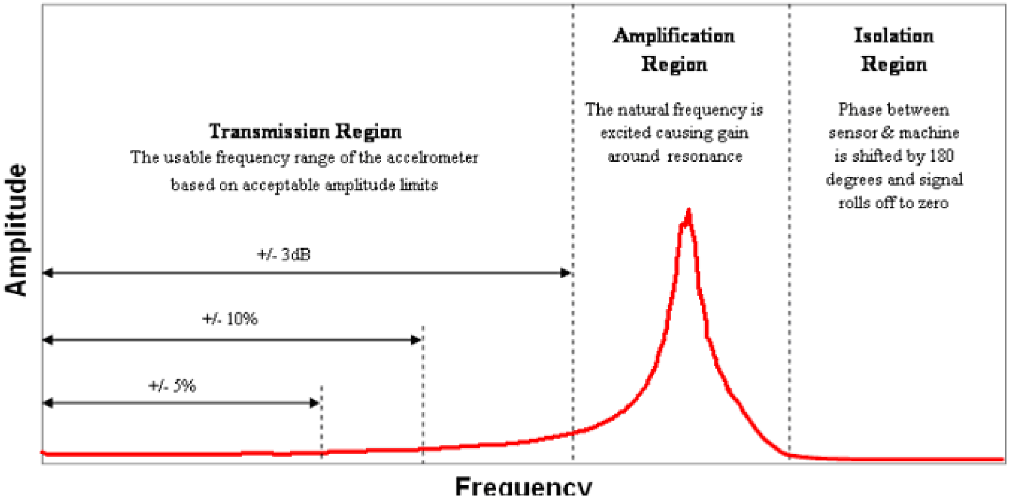
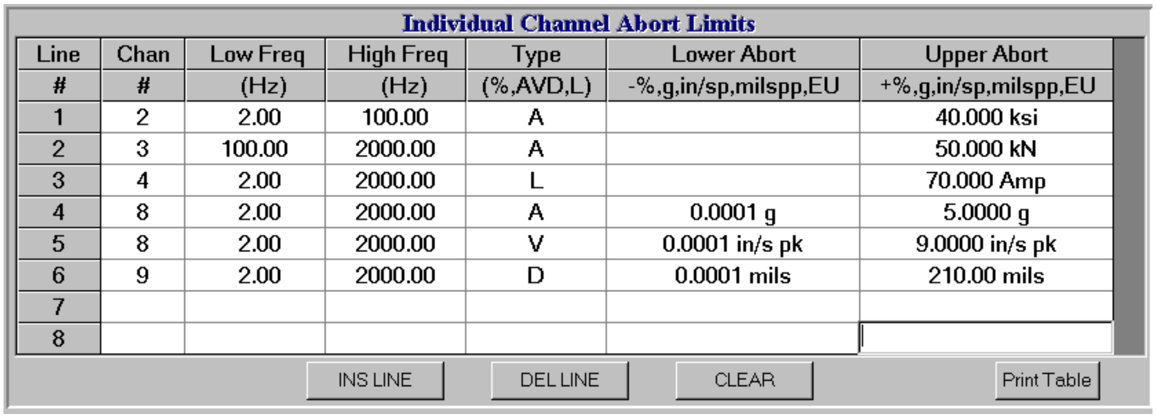


Figure 2-12 Transmission, Amplification (about the Accel's own resonance) and Isolation regimes [2]

2.10 Measurement Accelerometer Channel inputs



Individual Channel Abort Limits

Line #	Chan #	Low Freq (Hz)	High Freq (Hz)	Type (%,AVD,L)	Lower Abort -%,g,in/sp,milspp,EU	Upper Abort +%,g,in/sp,milspp,EU
1	2	2.00	100.00	A		40.000 ksi
2	3	100.00	2000.00	A		50.000 kN
3	4	2.00	2000.00	L		70.000 Amp
4	8	2.00	2000.00	A	0.0001 g	5.0000 g
5	8	2.00	2000.00	V	0.0001 in/s pk	9.0000 in/s pk
6	9	2.00	2000.00	D	0.0001 mils	210.00 mils
7						
8						

2-13 Measurement Accelerometer Entries

NOTE: The low abort limit check can be especially useful to detect broken cables, faulty accelerometers, intermittent system conditions or other potentially dangerous situations which cause a low level input. Situations like a bad accelerometer wire leading to low signal, 60 Hertz frequency noise, or Improper mounting conditions may occur leading to low signal or causing the System to trip and stop test.

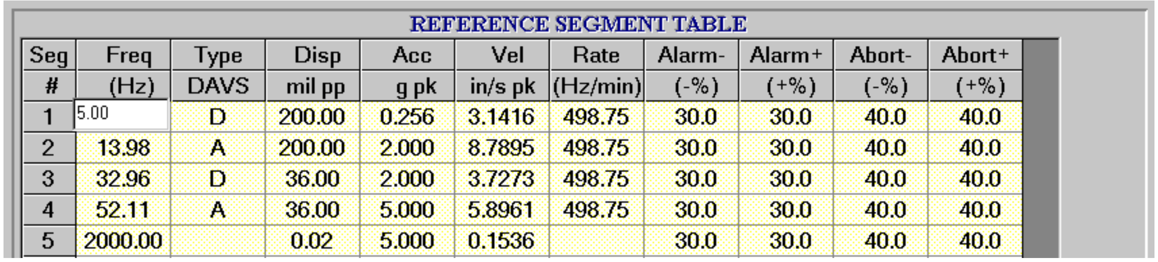
Parameter	Default Value	Typical Units
Channel #	Assigned channel to Accelerometer	#
LOW FREQ, HIGH FREQ	Variable selection based on need. Usually the	Hz

	Frequency test range input in the Sine Sweep	
TYPE%	Variable for Acceleration (A), Velocity (V), Displacement (D), Level (G)	Variable (g)
Abort	% about nominal value (0 db reference), usually 40%	Input logic

2-14 Measurement Accelerometer Parameters

2.11 Sine Sweep Input Parameters

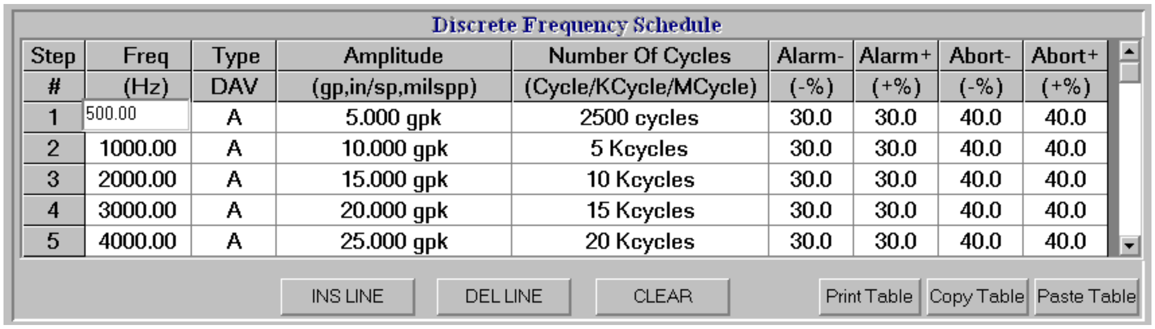
As was stated prior Frequency range of interest, Displacement, Acceleration, Velocity, and Rate (Duration) must be known parameters. This particular piece of software is representative of the suggested input options, as well as the ability to adjust the sweep rate around areas of interest (mostly focused on resonance).



REFERENCE SEGMENT TABLE

Seg #	Freq (Hz)	Type DAVS	Disp mil pp	Acc g pk	Vel in/s pk	Rate (Hz/min)	Alarm- (-%)	Alarm+ (+%)	Abort- (-%)	Abort+ (+%)
1	5.00	D	200.00	0.256	3.1416	498.75	30.0	30.0	40.0	40.0
2	13.98	A	200.00	2.000	8.7895	498.75	30.0	30.0	40.0	40.0
3	32.96	D	36.00	2.000	3.7273	498.75	30.0	30.0	40.0	40.0
4	52.11	A	36.00	5.000	5.8961	498.75	30.0	30.0	40.0	40.0
5	2000.00		0.02	5.000	0.1536		30.0	30.0	40.0	40.0

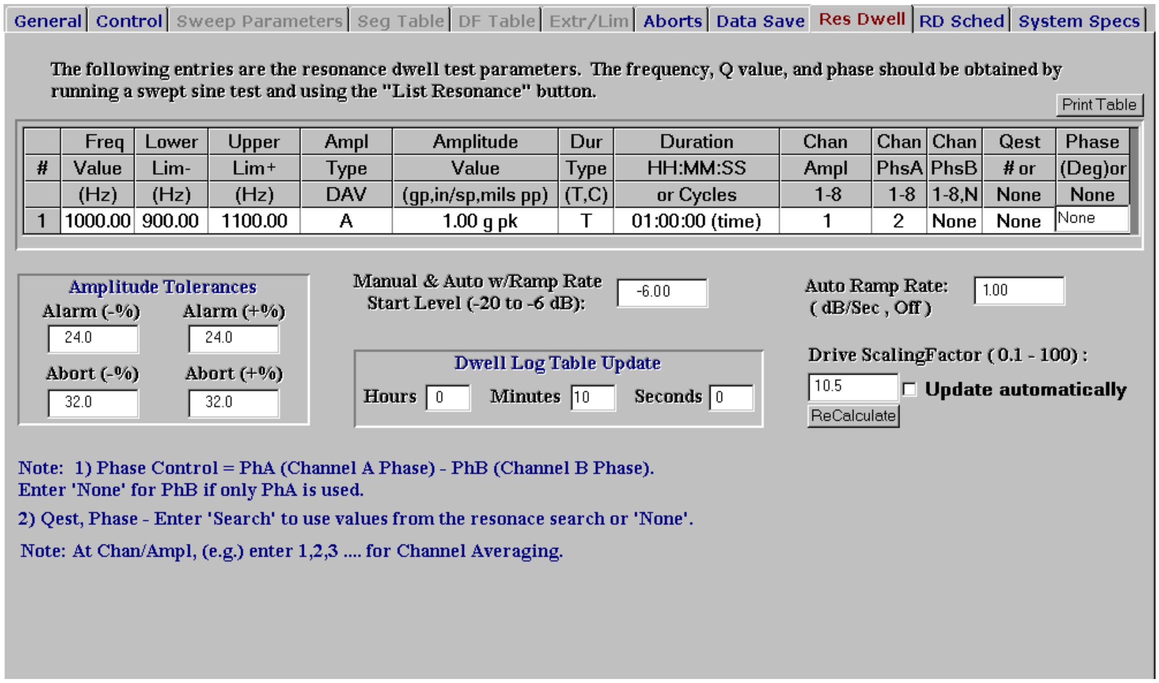
2-15 Representation of Sine Sweep reference input table[6]



Discrete Frequency Schedule

Step #	Freq (Hz)	Type DAV	Amplitude (gp,in/sp,milspp)	Number Of Cycles (Cycle/KCycle/MCycle)	Alarm- (-%)	Alarm+ (+%)	Abort- (-%)	Abort+ (+%)
1	500.00	A	5.000 gpk	2500 cycles	30.0	30.0	40.0	40.0
2	1000.00	A	10.000 gpk	5 Kcycles	30.0	30.0	40.0	40.0
3	2000.00	A	15.000 gpk	10 Kcycles	30.0	30.0	40.0	40.0
4	3000.00	A	20.000 gpk	15 Kcycles	30.0	30.0	40.0	40.0
5	4000.00	A	25.000 gpk	20 Kcycles	30.0	30.0	40.0	40.0

2-16 Sine Sweep When Test is Scheduled for Time[6]



The following entries are the resonance dwell test parameters. The frequency, Q value, and phase should be obtained by running a swept sine test and using the "List Resonance" button.

#	Freq Value (Hz)	Lower Lim- (Hz)	Upper Lim+ (Hz)	Ampl Type DAV	Amplitude Value (gp,in/sp,mils pp)	Dur Type (T,C)	Duration HH:MM:SS or Cycles	Chan Ampl 1-8	Chan PhsA 1-8	Chan PhsB 1-8,N	Qest # or None	Phase (Deg)or None
1	1000.00	900.00	1100.00	A	1.00 g pk	T	01:00:00 (time)	1	2	None	None	None

Amplitude Tolerances

Alarm (-%) 24.0
Alarm (+%) 24.0
Abort (-%) 32.0
Abort (+%) 32.0

Manual & Auto w/Ramp Rate Start Level (-20 to -6 dB): -6.00

Auto Ramp Rate: (dB/Sec , Off) 1.00

Dwell Log Table Update

Hours 0 Minutes 10 Seconds 0

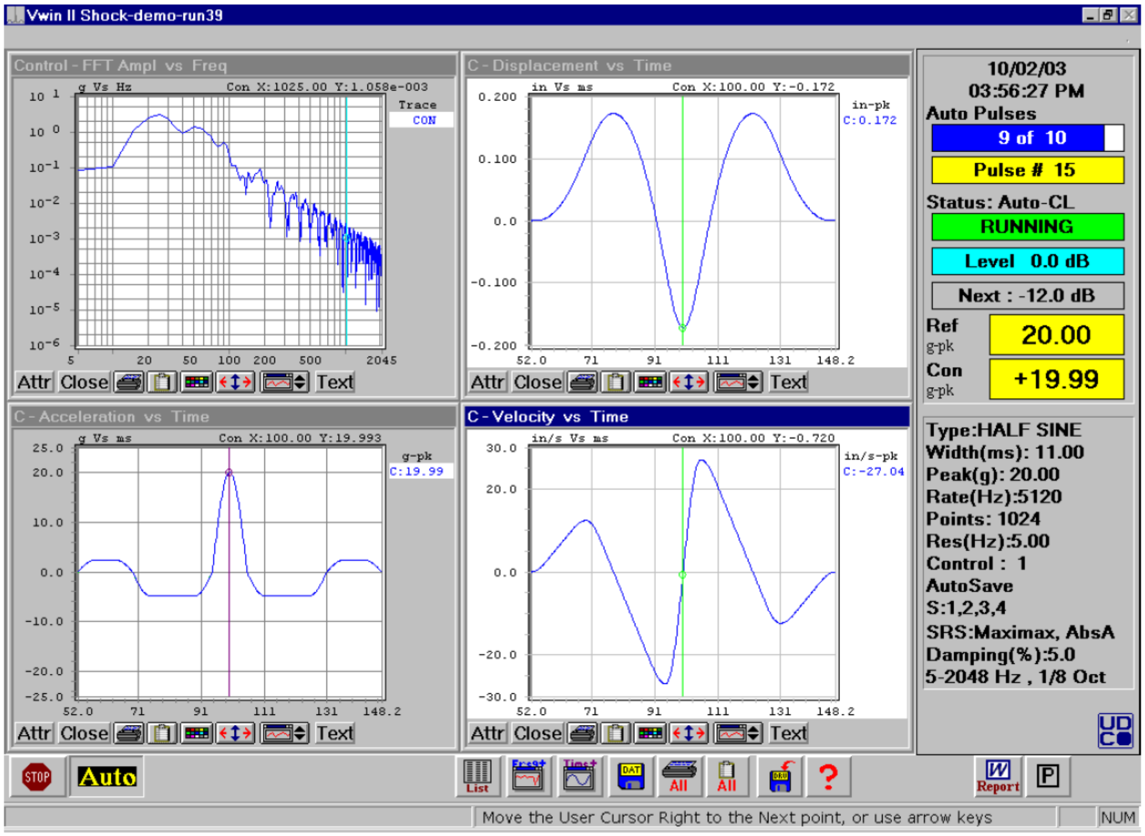
Drive ScalingFactor (0.1 - 100) : 10.5

☐ Update automatically

Note: 1) Phase Control = PhA (Channel A Phase) - PhB (Channel B Phase).
Enter 'None' for PhB if only PhA is used.
2) Qest, Phase - Enter 'Search' to use values from the resonace search or 'None'.
Note: At Chan/Ampl, (e.g.) enter 1,2,3 .... for Channel Averaging.

2-17 Sweep Rate control about a particular Frequency of interest[6]

2.12 Response Data Analysis Post Processing



10/02/03
03:56:27 PM
Auto Pulses
9 of 10
Pulse # 15
Status: Auto-CL
RUNNING
Level 0.0 dB
Next : -12.0 dB
Ref g-pk 20.00
Con g-pk +19.99

Type:HALF SINE
Width(ms): 11.00
Peak(g): 20.00
Rate(Hz):5120
Points: 1024
Res(Hz):5.00
Control : 1
AutoSave
S:1,2,3,4
SRS:Maximax, AbsA
Damping(%):5.0
5-2048 Hz , 1/8 Oct

Move the User Cursor Right to the Next point, or use arrow keys

2-18 Displacement, Velocity, and Acceleration relative to the Control Accel[6]

Software Controller Packages allow a variety of Post processing and Accelerometer reporting to show if the tests met response requirements.

Readouts of Accelerometer Responses to input can also be displayed in a variety of ways. One way is similar to the above figure or in a more tabular format for post processing.

REFERENCES

[1] Kevin Napolitano, and Daniel Linehan [Multiple Sine Sweep Excitation for Ground Vibration Tests], Proceedings of the IMAC-XXVII Society for Experimental Mechanics Inc, February 9-12, (2009).

[2] Connection Technology Center "Learn Basic Vibration Monitoring with CTCs Vibration Univeristy," <https://www.ctconline.com/__ctc_university.aspx?one=1 > (2012).

[3] Dr. Paul Ibanez ANCO Engineers, Inc., "An Introduction to Shake Tables for Seismic Testing of Equipment And Glossary of Vibration Terminology," ancoengineers.com, October 1st,(2008).

[4] http://shodhganga.inflibnet.ac.in/bitstream/10603/2274/11/11_chapter%203.pdf, ch.3 Page 54

[5] Unholtz-Dickie Corporation, Fixture Design Notes

[6] Unholtz-Dickie Corporation, VWIN II / VWIN XL / VWIN VIBRATION CONTROLLER OPERATING MANUAL

[7] "Ask the expert tacking the mystery out of the power spectral density function" https://www.endevco.com/news/archivednews/2010/2010_08/f1.html

DEFINITIONS

Slip Table	A term mainly used in the aerospace and automotive industry, "slip table" is essentially synonymous to "shake table top". When using electro-dynamic actuators a horizontal table is often implemented by having a flat metal plate supported by an oiled granite or cast iron flat surfaced base. Hence the term "slip table". The term is sometimes used to mean any shake table top, even those guided on bearings or flex plates.
Sine Sweep	A sine sweep is a signal that changes from one frequency to another in a uniform way. The transition can be fast (some times called a "Chirp") or slow (possibly taking hours). It can be increasing or decreasing in frequency, and it may be repeated many times. The rate of change can be linear (the same number of Hz per unit time) or "logarithmic" (the same percentage change per unit time. Note that a "logarithmic" sweep is a misnomer, as the sweep is actually exponentially increasing or decreasing. Sine sweeps are extensively used in shake table testing to provide vibratory
Sampling Theorem	The Shannon sampling theorem says that the sampling rate must be at least twice the highest frequency in the sampled signal. Otherwise the high frequency content in the signal will "alias" and look like low frequency energy, thereby corrupting the information in the digital signal. In practice, the sampling rate should be 3-10 times the highest

	frequency, to obtain optimal results.
Power Spectral Density and Acceleration Spectral Density	PSD, also called acceleration spectral density (ASD), is widely used in random vibration testing applications and is intended primarily as a tool for cancelling out the effect bandwidth of a frequency spectrum. PSD is a unit of measure, described in terms of energy per "filter", used to identify and denote energy strength deviations. It is possible to obtain the total energy within a specific frequency range by taking the root sum squared of the PSD points within the specified range. Proper computation of PSD is achieved directly via FFT spectrum analysis and then transforming it, taking into account actual analyzer filter bandwidth. [7]