Low Frequencies in Vibration Tests

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http://www.ista.org/

Abstract

In vibration testing (both sine and random) inaccuracies in vibration control systems at low frequency can result in the controller calling for significant increases in table amplitude with resulting table control problems and, even, over-stroke. This presentation explores this issue illustrated with real data from two vibration control systems.

Introduction

This paper examines issues around the low frequency components of vibration tests (focussing on random spectra) and the control errors that commonly occur below 3Hz. Whilst acceleration levels below 3Hz are generally very low, amplitudes are high. Errors can cause a significant, sometimes very large, increase in amplitude at low frequency with the potential to cause control problems. Difficulties in control can relate to over-stroke, or to high velocities with servo-hydraulic systems.

The random vibration spectra used in packaging tests typically start at 2Hz or below. This reflects the low frequency energy found in measurements of product transportation.

It could be argued that the component of the test below 5Hz is unimportant because:

- The acceleration levels (and, hence, the forces acting on the test item) are very low
- The pack and product response is *nearly always* linear as the frequencies in question are well below first resonance.

However there are two reasons for a laboratory to give careful consideration to the low frequency component of a test:

- The test calls for the low frequency component. Obvious – yes: but equipment calibration probably does not cover the lower frequencies. From a quality audit perspective there is a need to be seen to do the right thing.
- Although g levels are low, amplitudes are high (as will be shown).
- Measurement errors in the controller feedback loop tend to be negative giving a positive error in drive signal. Thus the already large amplitudes will become larger, sometimes substantially so.

Test Requirements

From ISTA Yearbook and Individual Procedures

Random Vibration Test System complying with the apparatus section of ASTM D 4728-01.

From ASTM D4728 (D999 and D3580 are similar)

5.3 Instrumentation—Accelerometers, signal conditioners, analyzers, data display, storage devices, and the control techniques described in 5.2 are required to measure and control the PSD levels at the table surface. Instrumentation may also be desirable for monitoring the response of the test specimen(s). The instrumentation system shall have an accuracy of ± 5 % across the frequency range specified for the test.

From EN 60068-2-64 / IEC 68-2-64

The indicated acceleration spectral density in the required axis at the check and reference points between f_1 and f_2 shall be within ± 3dB allowing for instrument error referred to the specified acceleration spectral density.

The r.m.s. value of acceleration, computed or measured, between f_1 and f_2, shall be within ± 10% of the r.m.s. value associated with the specified acceleration spectral density.

Start Points for Random Spectra

Table 1 shows the lower frequency control point for a number of commonly used random vibration tests. Also shown is the 3σ peak amplitude for the total test spectrum.

As a controller feedback signal rolls off the lower frequency bands will be more affected than higher frequency bands.

Standard	F_1 (Hz)	g^2_{rms} / Hz at F_1	Peak amplitude total spectrum (mm)
ISTA Series			
1 Series	1	0.0001	12.6
2C Level 1	2	0.00036	12.9
2C Level 2	1	0.00005	10.8
2C Level 3	0.6	0.0009	43
3A Over the road	1	0.0007	25.8
3A Pick up and delivery	1	0.001	31.9
3H Air ride	0.6	0.0009	43
ASTM D4169			
TL2	1	0.00005	10.8
TL1	1	0.0001	15.3

Table 1: Data for common random profiles

Sources of Error in Vibration Measurement

The vibration controller uses a measurement of table acceleration (the control signal) as a feedback signal to ensure the table is being driven as required. To do this the input signal (in the time domain) is converted to a power spectrum in the frequency domain. The table drive signal gain is controlled by a series of narrow band filters: the gain of each filter is corrected according to any errors between the control signal and control spectrum in the frequency domain. The controller assumes the control signal is, itself, error free – i.e. it is a true representation of table vibration.

Common sources of error in the control signal are:

- Low frequency roll-off in accelerometer sensitivity.

Roll-off typically starts somewhere between 1Hz and 5 Hz depending on the accelerometer.

- Low-frequency roll-off from AC coupling.

Accelerometers with on-board electronics are often preferred because of simplicity of use, simplicity of system calibration and low signal noise. However the signal from these accelerometers has a DC offset which must be isolated (usually by capacitative coupling) at the controller input. The input capacitor acts as a high pass filter typically rolling off from between 1Hz and 3 Hz. In principal charge output accelerometers can be DC coupled to the controller but can suffer DC signal drift if the input impedance of the amplifier is set very high. As the input impedance is lowered (to reduce DC drift) the resulting charge decay gives a low frequency roll-off.

Note: other sources of signal error include cable noise, connector noise and fixture / table resonance. These sources of error are typically associated with higher frequency issues and so are not examined in detail here.

These roll-off's associated with accelerometer response and AC coupling will be consistent and, in principal, predictable / measurable. However, in practice:

- Accelerometer calibration has a lower limit, typically between 2Hz and 10Hz
- Controller calibration has a lower limit, typically around 5Hz

Most accelerometers and some controllers have a specification which includes low frequency performance but this often lacks sufficient detail to be really useful.

Practical Examples

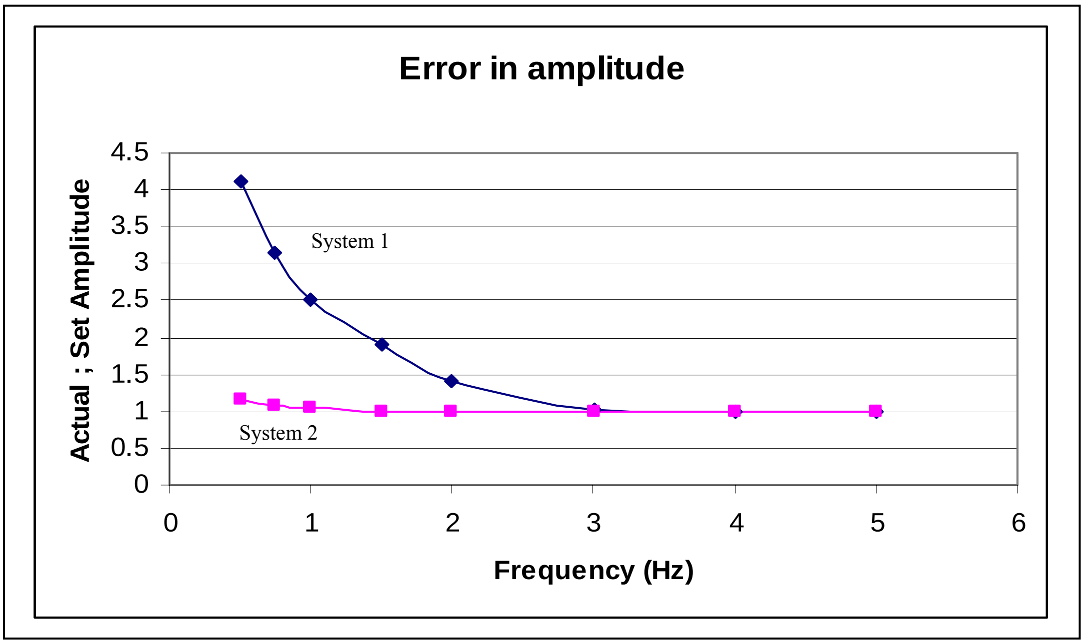
Pira has 2 digital vibration controllers which it uses with servo-hydraulic tables. Both are from international well known suppliers. They are used with ICP type accelerometers.

- System 1: Controller and accelerometer supplied with our most recent vibration table as part of the purchased system.

- System 2: Controller with accelerometer selected and purchased with a specific interest in achieving minimal low frequency roll-off.

To assess low frequency performance we played fixed frequency fixed amplitude low frequency sine tones and measured actual table amplitude, expressing the result as a ratio of programmed amplitude. Table amplitude was measured using a digital height gauge giving us a calibrated measurement system which was, itself, free of low frequency roll-off. We estimated the uncertainty of measurement to be around 3%.

The results are summarised in the two graphs below. System 2 falls just inside the standard requirements for control ± 5% at 1 Hz in amplitude terms, and the power error is within ± 3dB.


Error in amplitude
Actual ; Set Amplitude
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
6
Frequency (Hz)
System 1
System 2

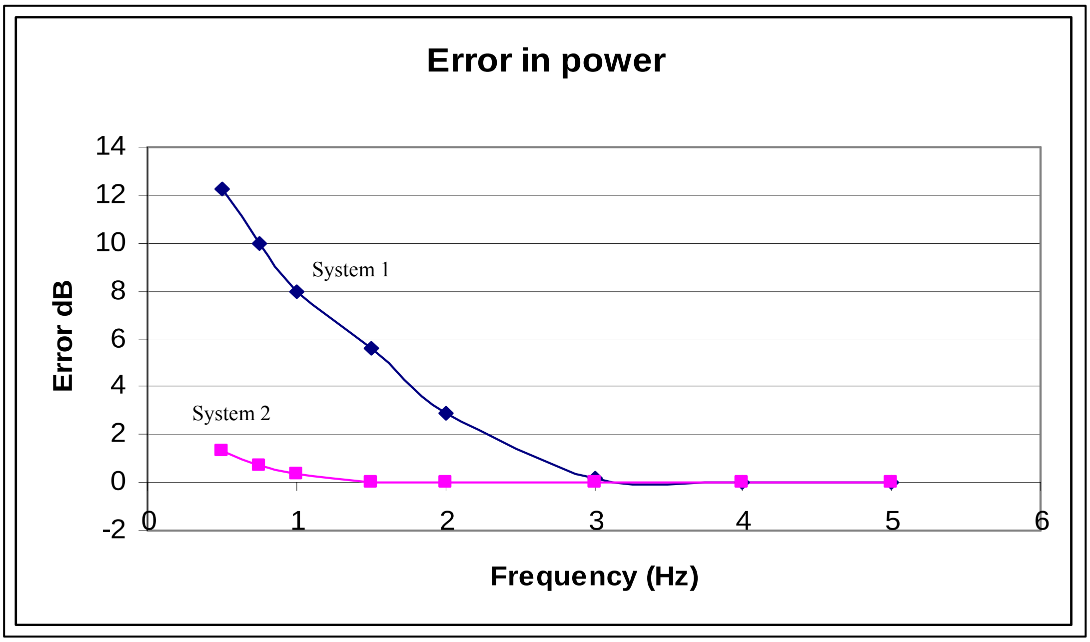

Error in power
Error dB
14
12
10
8
6
4
2
0
-2
0
1
2
3
4
5
6
Frequency (Hz)
System 1
System 2

Table 2 shows 3σ peak amplitude as a function of narrow frequency band and for the total test spectrum. Note the amplitudes do not add linearly.

Tables 3 and 4 show the effect on amplitude of low frequency roll-off for the 2 vibration systems defined above. The roll-off has a greater effect on the lowest frequency band.

Standard	Peak Amplitude 0 - 1Hz	Peak Amplitude 1 – 2 Hz	Peak amplitude 2 – 3 Hz	Peak amplitude total spectrum
ISTA Series				
1 Series	0	9.5	7.4	12.6
2C Level 1	0	0	7.1	12.9
2C Level 2	0	7.2	6.9	10.8
2C Level 3	33.7	27.4	12.6	43
3A Over the road	0	20.5	15.6	25.8
3A Pick up and delivery	0	25.2	20.3	31.9
3H Air ride	33.7	27.4	12.6	43
ASTM D4169				
TL2	0	7.2	6.9	10.8
TL1	0	11.2	10.8	15.3

Table 2: 3σ peak amplitude as a function of narrow frequency band and for the total test spectrum

Standard	Peak Amplitude < 1Hz	Peak Amplitude 1 – 2 Hz	Peak amplitude 2 – 3 Hz	Peak amplitude total spectrum
ISTA Series				
1 Series	0	27.8	17.8	30.2
2C Level 1	0	0	14.7	18.2
2C Level 2	0	20.7	15.0	23.3
2C Level 3	124	79.4	28.8	144
3A Over the road	0	59.8	35.4	66
3A Pick up and delivery	0	73.3	45.9	81
3H Air ride	124	79.4	28.8	144
ASTM D4169				
TL2	0	20.7	15.0	23.3
TL1	0	29.3	21.6	33.2

Table 3: 3σ peak amplitude as a function of narrow frequency band and for the total test spectrum corrected for roll-off for system 1.

Standard	Peak Amplitude < 1Hz	Peak Amplitude 1 – 2 Hz	Peak amplitude 2 – 3 Hz	Peak amplitude total spectrum
ISTA Series				
1 Series	0	10.2	8.1	13.1
2C Level 1	0	0	7.2	13
2C Level 2	0	7.7	6.9	11.0
2C Level 3	38.1	29.4	12.9	47.5
3A Over the road	0	22.1	16.22	27
3A Pick up and delivery	0	27.2	21.07	33.4
3H Air ride	38.1	29.4	12.9	47.5
ASTM D4169				
TL2	0	7.7	6.9	11.0
TL1	0	10.9	9.9	15.7

Table 4: 3σ peak amplitude as a function of narrow frequency band and for the total test spectrum corrected for roll-off for system 2.

Conclusions

Common test spectra require test amplitudes of 11 – 43 mm. The roll-off in feedback signal of a widely used vibration controller and ICP type accelerometer causes an increase in test amplitudes to 18 to 144 mm. Because the effect of roll-off increases at lower frequencies the effect is not consistent between spectra. The amplitudes and velocities of some of these spectra are sufficient to give control problems.

A carefully selected controller and accelerometer gives much smaller errors in amplitude, but in some cases the error still falls outside the tolerances defined in test standards.

Laboratories undertaking the tests with high amplitude (2C L3, 3A over-the-road, 3A pick-up and delivery and 3H air) are recommended to undertake a detailed assessment of the low frequency response of their vibration monitoring and control system.