Sine-on-random vibration testing

Introduction

In nature, purely sinusoidal vibration is a rare phenomenon. A much more common phenomenon is sinusoidal motion coupled with background random motion having a broadbanded frequency range. Consequently, in vibration testing, it is becoming increasingly popular to use a test based on a sinewave superimposed on a random waveform – sine-on-random testing. This type of test produces a better simulation of the real world, which is the aim of the vibration-test engineer.

Vibration-testing systems based around large broadband controllers have the facility for sine-on-random testing by adding the particular software option. More moderately priced broadband controllers can provide a shaped random-vibration spectrum complying with the standards, but have no facility for sine-on-random testing. However, by using a broadband controller together with a sine controller, sine-on-random testing can be simply attained. A most suitable sine controller for this application is the Vibration Exciter Control Type 1050.

This Application Note describes a technique for using the Vibration Exciter Control Type 1050, with a broadband controller, for sine-on-random testing. Both instruments operate in the usual way. However, the Type 1050 must be used with the Slave Filter Type 5888; and the outputs from the two controllers must be added together by using a simple resistor network. To maintain full control over the random spectrum, a notch filter can be used to filter out the sine component from the feedback signal. However, whether the notch filter is used or not, the 1050's control of the sine signal will be unaffected by the random signal. And the control over the random spectrum will far exceed that demanded by the test standards.
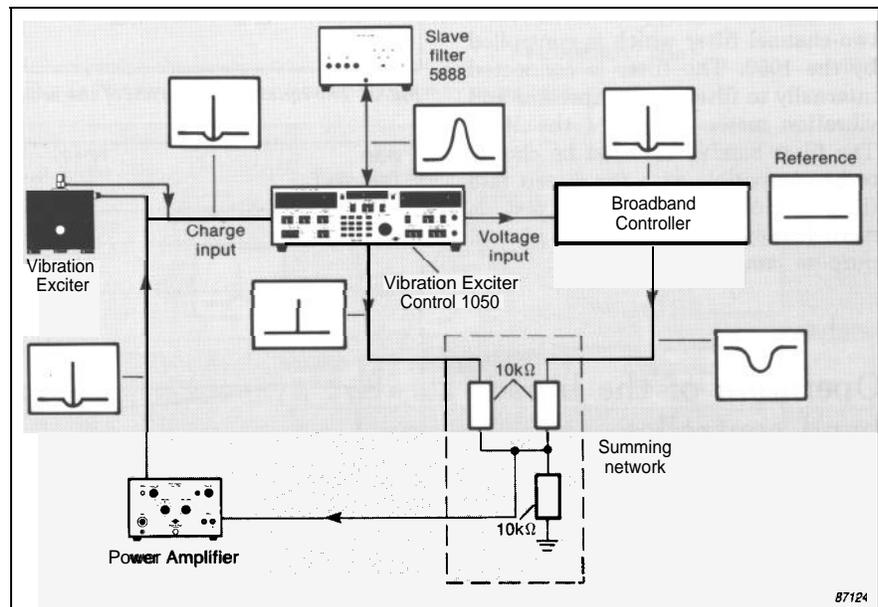

Fig. **1. Instrumentation interconnections for sine-on-random testing. Included are the frequency spectra for the signals at each stage of the system.**

System operation

Figure 1 is a block diagram showing the connections between the instruments in the system. At each stage of the system, the signal shape is shown to aid understanding of the system.

Firstly, let's examine the way in which the system operates; later we'll consider the operation of the sine and broadband controllers separately.

The 1050 produces a very pure sine signal, and the broadband controller produces a broadband random noise signal. These two signals are simply added together by using a resistor network, and the resulting signal is supplied to the vibration exciter, via a power amplifier, in the usual manner. To accurately control the level of both the sine component and random noise produced by the vibration exciter,

each part of the signal must be controlled by the appropriate controller. That is, the sine signal must be supplied to the compressor of the 1050, and the random signal must be supplied to the equalizer of the broadband controller.

The vibration is measured by using an accelerometer mounted on the exciter table. The output signal from the accelerometer is connected to the charge input of the Type 1050, and the input sensitivity is set accordingly. This same signal is supplied to the voltage input of the broadband controller. As this signal comes directly from the preamplifier output of the Type 1050, before any bandpass filtering, the signal supplied to the broadband controller is the sine-on-random signal.

Operation of the Vibration Exciter Control Type **1050**

The value of the signal supplied to the compressor of the Type 1050 is the RMS value of the sine-on-random signal. In order for the compressor to keep the level of the sine component constant, it must operate on the sine signal alone. Consequently, the input signal must be filtered using a band-pass filter.

The best filter to use with the 1050 is the Slave Filter Type 5888, as it is a two-channel filter which is controlled by the 1050. The filter is connected internally to filter the compressor and vibration meter signals of the 1050. The filter bandwidth must be chosen to be compatible with the sweep rate (if a swept-sine-on-random test is run). However, 3% is a good general purpose bandwidth.

Operation of the broadband controller

The input section of most modern broadband controllers is an FFT analyzer. The analyzer compares the measured spectrum to a reference spectrum (line by line) and calculates the output spectrum necessary to produce the desired reference spectrum. This output spectrum is transformed to a time signal, by using an inverse FFT, and is converted to an analogue signal, which is added to the sine wave by the resistor network.

Because the corrective output signal must compensate for the latest input signal, the FFT analyzer updates the frequency spectra exponentially with an adjustable time constant.

When the spectrum of the sine-on-random input to the broadband generator is measured, the sine component is represented by a small number of lines instead of one, due to leakage error. The output spectrum corresponds to the inverse of the input spectrum – it exhibits a notch represented by the same number of lines as the sine component. Consequently, after the sine signal has been added to the notched signal, the resulting sine-on-random signal has a dip on either side of the sine component. The width of the notch is dependant on the reso-
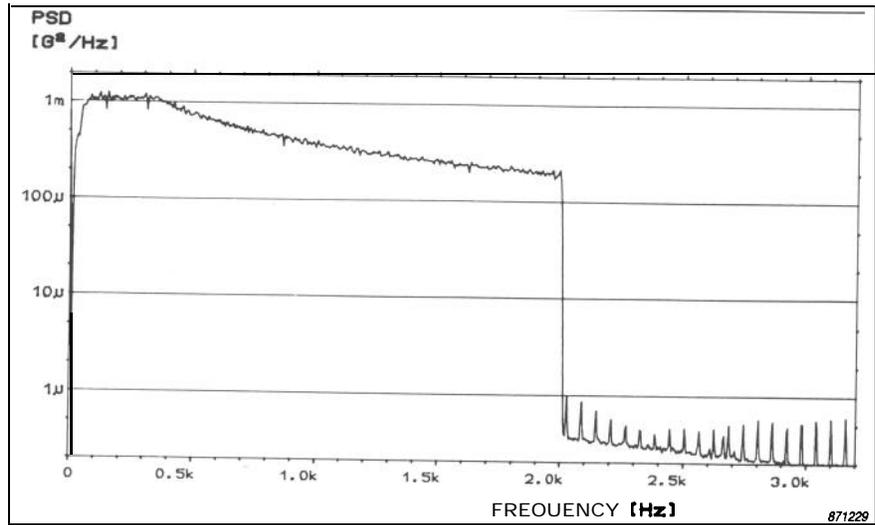

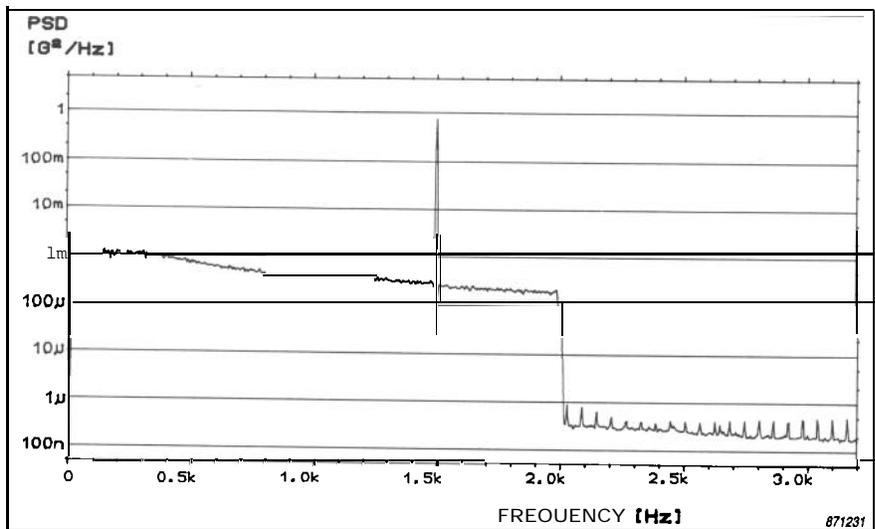Fig. 2. The equalized spectrum of the broadbanded random signal.

Fig. 3. The sine signal superimposed on the broadbanded random spectrum. The notch around the sine component is evident because the plot was obtained using the Dual-Channel Frequency Analyzer Type 2032. This analyzer has a resolution which is higher than the that of the broadband controller.
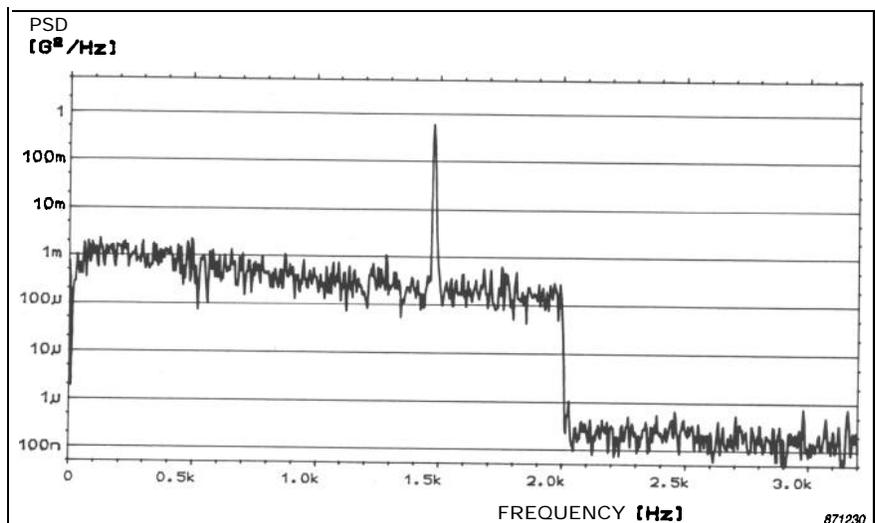

Fig. 4. The swept-sine spectrum, using exponential averaging. The random signal appears to fluctuate more due to the low number of averages used. The sine component is smeared because it is swept through the spectrum.

lution of the analyzer and in practice has little effect. In any case, the amplitude of the dip will not exceed the amplitude fluctuation of the spectrum.

Most broadband controllers feature an adjustable safety limit around the desired level of random noise, for instance adjustable by +/-20dB. If the measured input spectrum exceeds these limits, the controller will resort to "stand-by" or "abort". Under almost all circumstances a sine wave will exceed these limits and cause a test abortion. Therefore, the safety limits should be set so that they are insensitive to the sine frequency.

Using a notch filter to filter the sine component from the sine-on-random signal

One channel of the slave filter can be modified to act as a notch filter instead of a bandpass filter. As the sine component is filtered out before being supplied to the broadband controller, the notch filter enables full use of the safety limits in the broadband control. The instrumentation and the spectra of the signals are shown in Fig. 6.

However, in practice, the notch filter's bandwidth can be only as narrow as 10%. Consequently, in addition to eliminating the sine component from the sine-on-random signal, it introduces a dip positioned around the sine component's frequency. The broadband controller compensates for this dip, producing a hump. This results in a sine-on-random signal having a sine component on top of a hump. This contrasts with the situation resulting from no notch filter in the feedback loop to the broadband controller – a sine-on-random signal with a sine component on top of a dip.

Including a notch filter in the way described above does not result in a flatter frequency spectrum. However, by using the notch filter, the sine-on-random set-up can be used in those cases for which it is unacceptable to switch off any of the safety limits of the broadband controller.
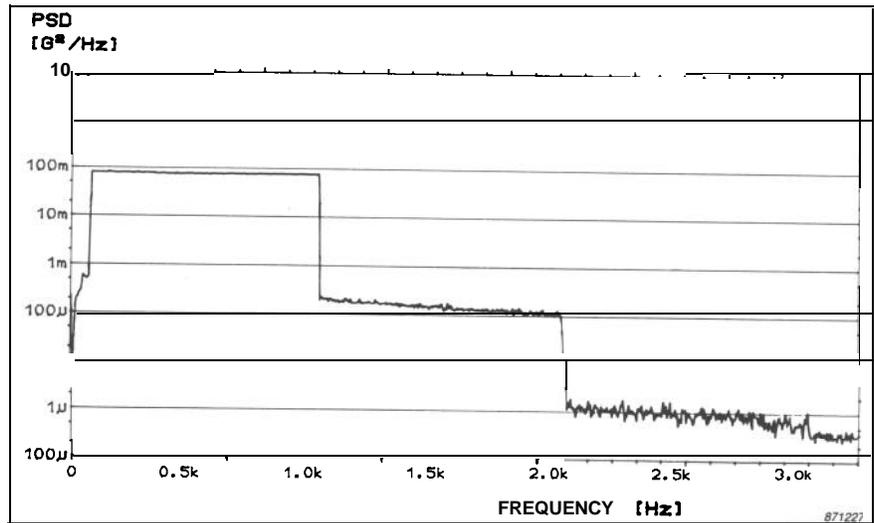

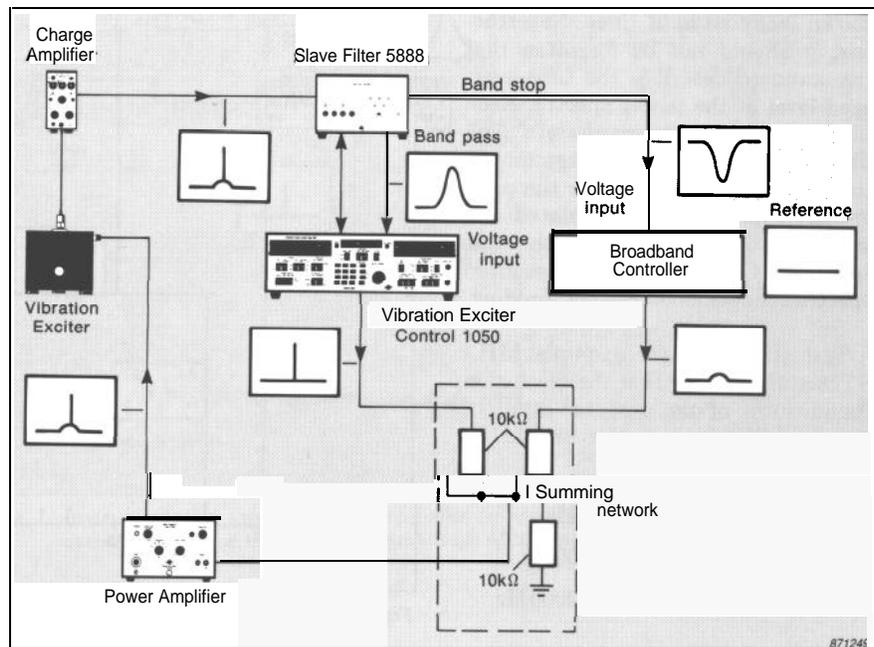Fig. 5. The constant swept-sine level shown by using peak averaging.

Fig. 6. Instrument interconnections for sine-on-random testing (with notch filter). Included are the frequency spectra for the signals at each stage of the system.
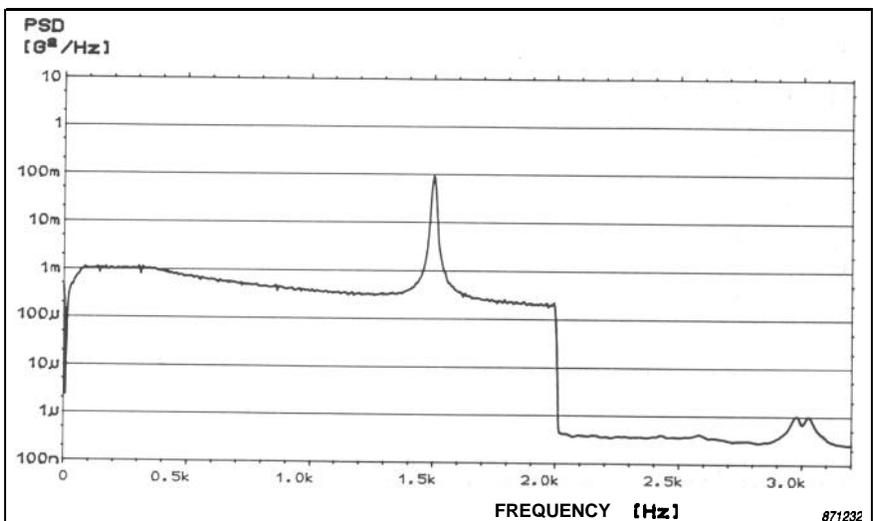

Fig. 7. The equalized spectrum of the broadbanded spectrum (a notch filter was used in the feedback path). No sine component is present; the bump is caused by the notch filter.

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What kind of frequency spectrum should we use for the sine-on-random test?

A test spectrum is defined in terms of its power spectral density (PSD). This is sometimes called acceleration spectral density (ASD) and is shaped as defined in relevant test standards.

Often, the test standard only defines the relative shape of the spectrum in addition to the total acceleration RMS level. The total acceleration RMS level is the square root of the PSD integrated over the whole frequency range. As an example, Fig. 9 shows a spectrum defined by MIL-STD-810D. The spectrum is shown using straight lines. Nevertheless, it should not be forgotten that the standard describes the time-averaged level of the power spectra. Each instantaneous spectrum doesn't look like Fig. 9, but has very large amplitude fluctuations. Only after the power spectrum has been calculated and averaged, does it approach the test spectrum. Consequently the measured spectrum depends on the BT-product.

Test standards, for example MIL-STD-810D, specify that the resolution (bandwidth) of the analyzer input of the broadband controller should be better than the following:

25 Hz, between 20 and 200 Hz

50Hz, between 200 and 1000Hz

lOOHz, between 1000 and 2000Hz

According to MIL-STD-810D, the analysis should consist of at least 50 non-overlapping averages.

The measured spectrum must be within certain amplitude limits of the reference spectrum. These are also defined in the standards. The signal must be stationary within the analysis time. Obviously, a swept-sine-on-random signal will not be stationary during the analysis time. However, if the frequency spectra are averaged using exponential averaging with a short time constant, then the sine wave can be seen as a moving line with a trailing skirt.
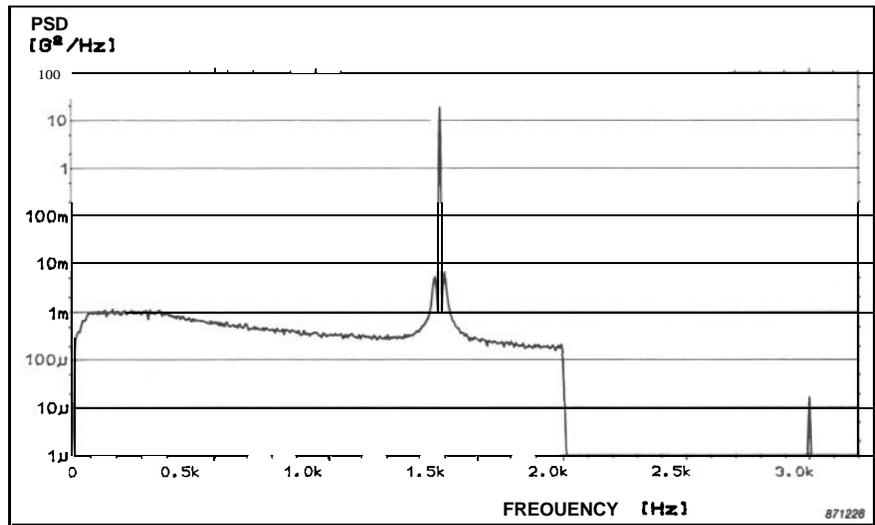

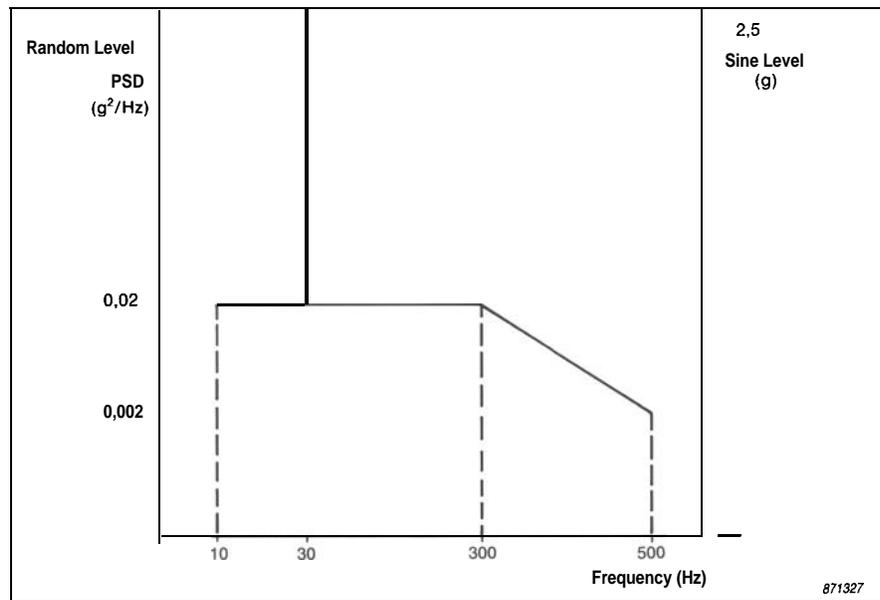*Fig. 8. The sine signal superimposed on the broadbanded random spectrum.*

Fig. 9. An example of a suitable test spectrum, **as** *defined by MZL-STD-8lOD.*

The test should be documented using an analyzer having the same resolution as the broadband controller used in the test. If an analyzer having a better resolution is used, a number of peaks and notches might be seen, which the broadband controller couldn't equalize. Such an analyzer would also reveal the dip in the random spectrum around the sine signal.

Documentation

The documented spectra are examples of measurements made on a Vi-bration Exciter Type 4809 (bare table) using an accelerometer to provide the feedback signal. The sine signal was generated and controlled by a Vibration Exciter Control Type 1050. The broadbanded spectrum was generated and controlled by a Solartron 1210 Random Vibration Controller. The measurements were made with a Dual-Channel Signal Analyzer Type 2032 using a frequency range of 0 to 3,2 kHz and a resolution of 4 Hz. The bandwidth of the Solartron controller is 6Hz.