Vibration Testing

By condensing a lifetime of stress and wear into a short period of time, vibration tests can reveal hidden design weaknesses.

We need to be sure that products can cope with the shocks and stresses of their service life. For example:

- A mobile phone must be able to withstand bouncing around in a backpack as well as being dropped on the floor several times. If it cannot cope with this general day-to-day use, **warranty costs** will explode for the manufacturer resulting in a real risk of **brand deterioration** and of customers looking elsewhere the next time they buy a new phone.

- A satellite has to be able to survive the excessive vibrations from being launched into space. If it is faulty, the investment in the development and building of the satellite may be jeopardized.

Vibration Results Validation

In order to ensure that the products customers receive are intact and fully-functional, it is essential that they can survive the **journey** from when they are boxed at the factory until they arrive at the end destination.

Moreover, beyond merely withstanding short-term physical forces, developers need to ensure that their products will maintain the integrity and quality that represents the brand in the longer term. Product qualification and verification is done through extensive simulation in the development phases, but **simulation is not enough**.

It is also necessary to do physical testing on prototypes and end-of-line items, both to **validate** simulated results and to prove product durability to customers.

Ensuring product integrity

Vibration testing helps manufacturers to ensure **quality, reliability and durability** of complete products and their components.

Vibration tests can reveal design **weaknesses** that would only become apparent during transport, deployment and use – like a helmet hitting the ground.

Some of these tests, such as buzz, squeak and rattle (BSR) on vehicle interiors, can also detect the development of unwanted noise.

For environmental testing such as highly accelerated lifetime testing (HALT) and highly accelerated stress screening (HASS), it is necessary to combine vibration testing with environmental chambers to add the expansion stresses of rapid heating and cooling.

These tests are typically conducted on industrial and electronic components and products, on medical equipment and on military hardware.

Vibration test profiles

Where do the actual vibration test profiles originate?

Customers, end users or manufacturers who incorporate a component into an assembly, often define vibration **test specifications and procedures themselves**. These are typically based on experience and knowledge of which design solutions work well and which don't.

Vibration test can provide a more structured approach to understanding failure modes and defects that are caused by vibration.

Testing according to standards

Many vibration testing profiles are defined by standards developed over many years.
There are a lot of them and they are often dedicated to specific applications and products.
Examples include DIN, ISO, BS, MIL, IEC and ASTM. The use of testing according to standards is especially the case for the aerospace, defence and transportation industries. These include MIL-STD-810, NATO STANAGs and AS/EN9100.

Why Vibration Testing?

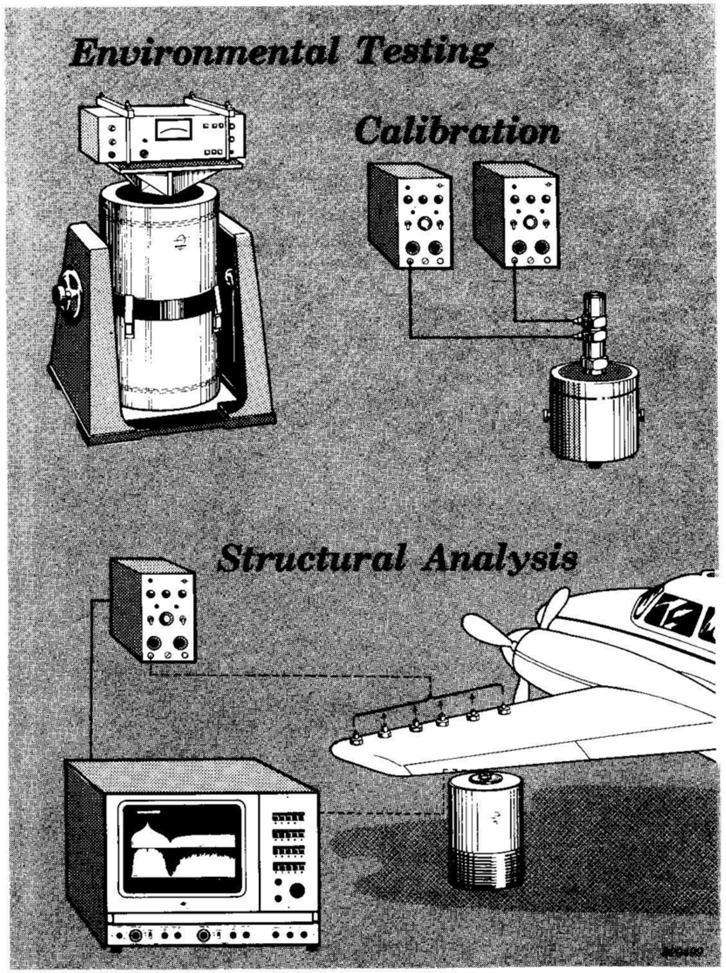
Due to the demands of high speed operation and the use of light structures in modern machinery, static measurements of stress/strain properties are not sufficient. Dynamic measurements are necessary and vibration testing has therefore found widespread use.

In the environmental laboratory, vibration testing is performed as part of a company's quality assurance programme together with for example temperature and humidity tests to ensure product reliability. The test object is exposed to a certain vibration level according to a procedure specified by national and international standards.

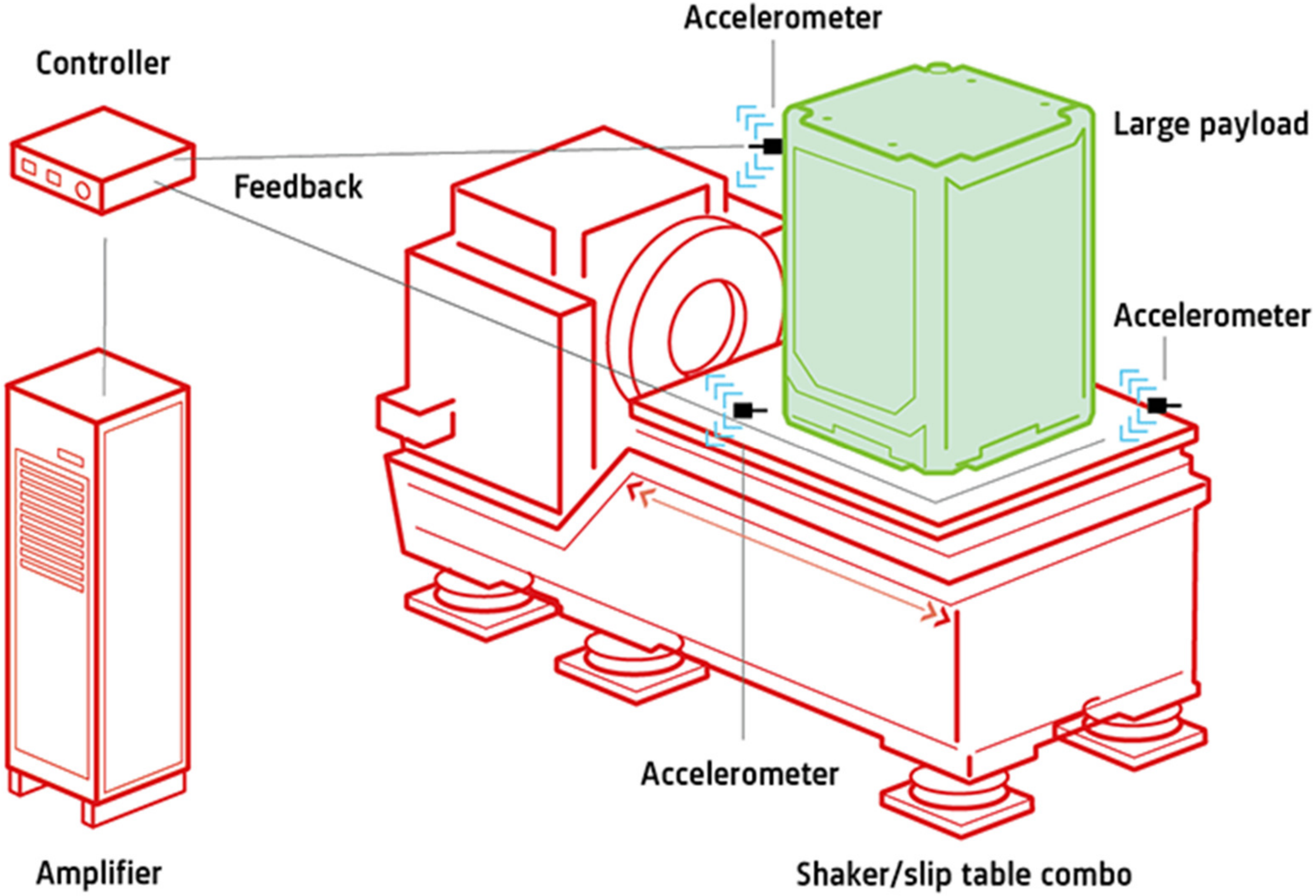
To find the dynamic properties of a structure, the response to a vibrational force is of interest rather than the actual vibration level. This concept is found for instance in determination of the ability to transmit or damp vibrations or in the description of the vibrational modes of a structure at resonances.

In the calibration of vibration transducers a comparison is made between the transducer to be calibrated and a reference transducer at a prescribed vibration level.

To produce a defined vibration an electromagnetic vibration exciter (also called a shaker) is used. This converts an electric signal into a mechanical movement, controlled to maintain a certain vibration level or force.



Testing system

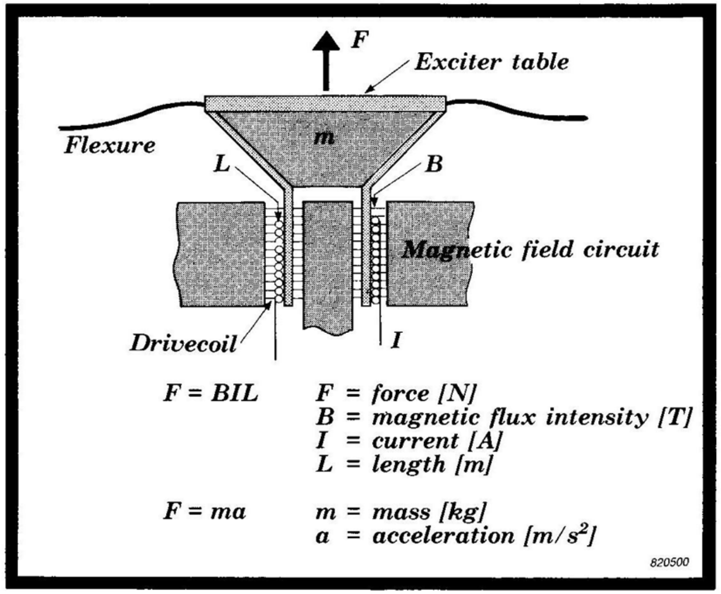


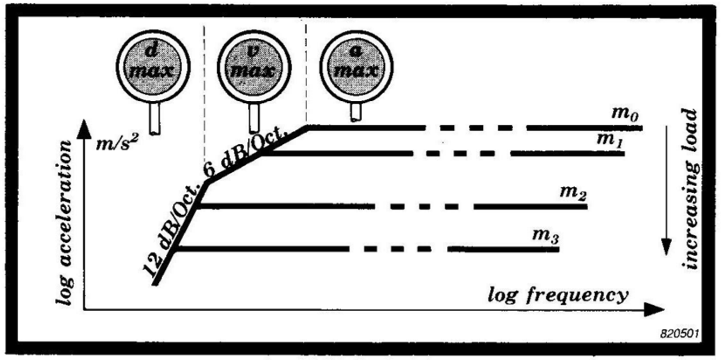
How Does an Exciter Work?

In principle the electromagnetic vibration exciter operates like a loudspeaker, where the movement is produced by a current passing through a coil in a magnetic field. The force used to accelerate the moving element is proportional to the drive current and the magnetic flux. Therefore by controlling the current, the vibration level of the exciter can be controlled.

In small exciters the magnetic field is produced by a permanent magnet, whereas in the larger ones electromagnets are necessary. The maximum current and the load determines the acceleration level which can be obtained. At low frequencies, however, this acceleration level will decrease due to displacement limitations of the moving element. Resonances in the moving element will set the upper frequency limit.

The performance of an exciter is presented in a diagram, showing the maximum acceleration as a function of frequency. With double logarithmic scales the displacement limit will be represented by a straight line with a slope of 12 dB/octave. A velocity limit is often also found, especially with the larger exciters, and this is indicated by a line with a slope of 6 dB/octave.

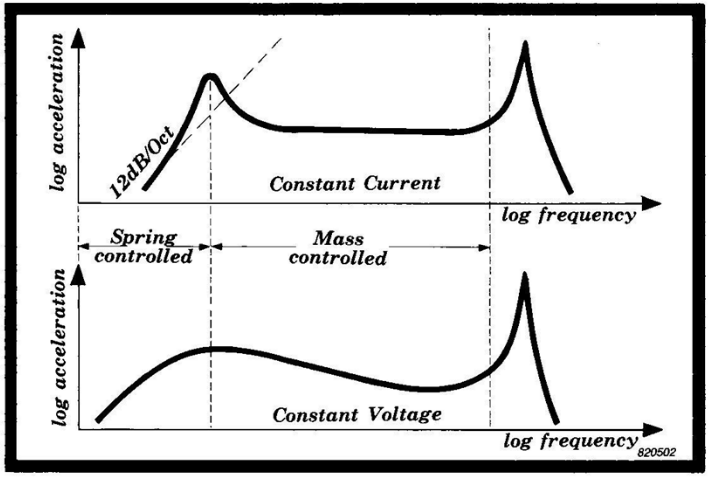




The Power Amplifier

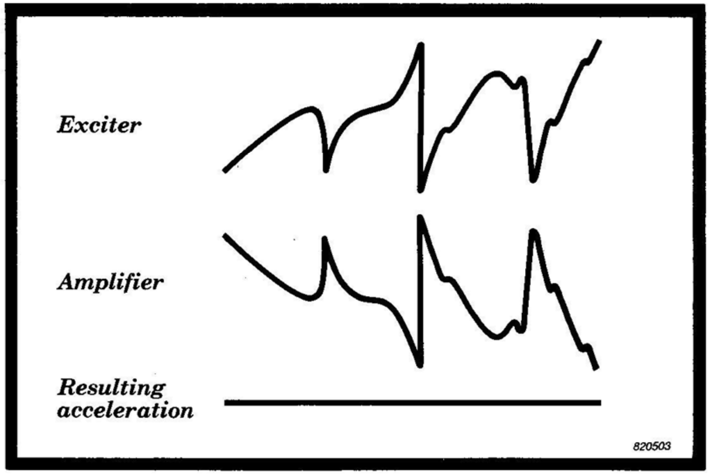
The frequency response for an exciter driven by a constant current will show three regions of different nature. The first two regions represent the spring-mass system of the moving element and its suspension with a resonance of typically 20 Hz. In the third region, typically above 5 kHz for big exciters, axial resonances in the moving element will occur, setting the upper operational frequency of the exciter.

A response curve for an exciter with a constant voltage input will show the same regions of control, but the lower resonance is considerably damped, giving an easier control of the level. The voltage control, obtained by a low impedance amplifier is normally preferred. In some cases, however, a current control will be advantageous, primarily when the exciter is used as a force generator or where non-feedback control is required using the mid frequency range of the exciter. This demands a high impedance output and therefore amplifiers will often have selectable impedance outputs.



The Exciter Control

The use of a vibration exciter assumes a constant vibration level at the table. The frequency response curve is not flat, it contains resonances, and other resonances will be introduced when a test object is mounted on the exciter. When used throughout a frequency range the gain of the amplifier must consequently vary with frequency. This gain is set by a controller, receiving feedback information from the test object. The main elements of an exciter control must therefore be a frequency generator, a vibration meter and a level controlling circuit.

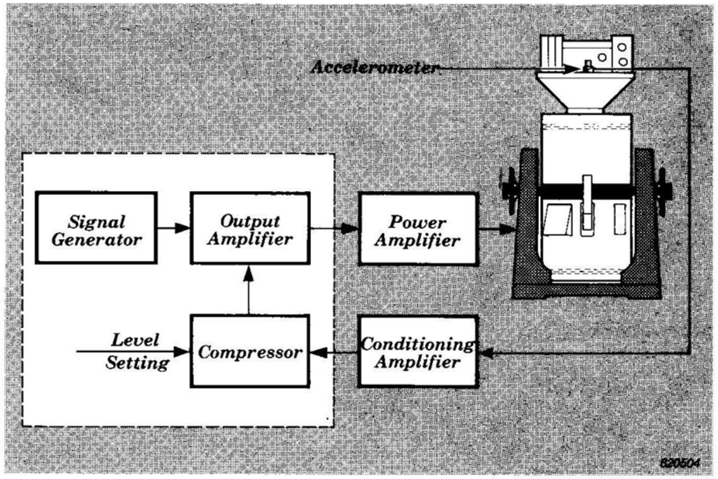


Basic Exciter Instrumentation

A basic set-up consists of an exciter, a power amplifier, an exciter control, an accelerometer or force transducer and a conditioning amplifier.

The exciter is selected primarily according to the force or acceleration required, but other parameters may be important such as its ability to take up side loads, the transverse vibration and the distortion of the waveform.

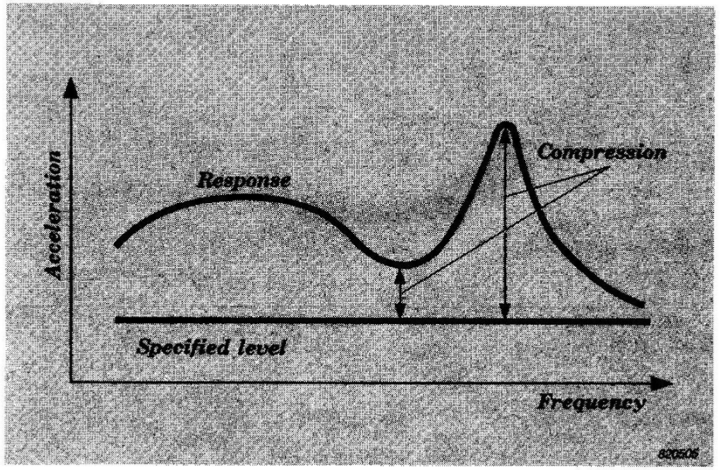
The exciter is isolated from its base by springs, in most cases giving sufficient protection from environmental vibration when bolted directly on the floor. However, to reduce the vibration transmitted to the building by exciters used for high level applications, the exciter must be mounted on resilient material or a seismic block.



Sine Excitation

Sine signals, swept or at a single frequency, are by far the most commonly used excitation inputs: the control is relatively simple, a large amount of reference material exists, and the response signals are easy to measure. When the signals are swept, a feedback control, known as a compressor is applied. The demand to the compressor is that it should be fast enough to react to low damped resonances even at high sweep rates. A dynamic range of at least 80 dB and compressor rates up to 1000 dB/sec are normally found.

Sine signals are described by their frequency and amplitude. In vibration testing the amplitude is normally in terms of peak values (displacement as peak-peak) with frequencies ranging between 2 and 10,000 Hz.



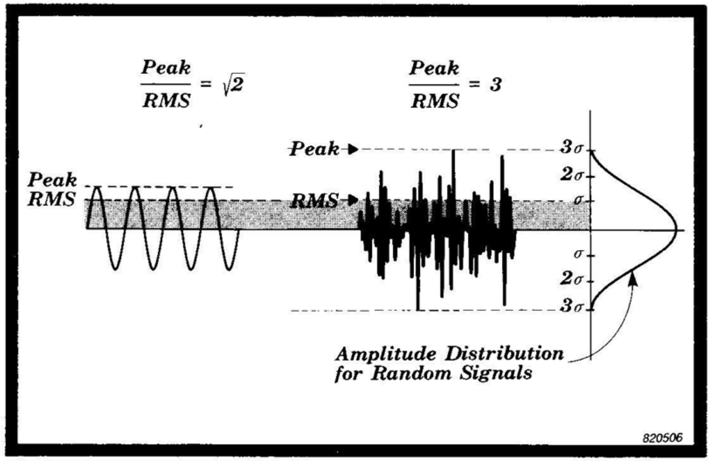
Random Excitation

A random signal used in vibration testing has a continuous spectrum, with amplitudes varying according to a Gaussian distribution. Within the specified frequency range any amplitudes should be present, but in practice the generators and amplifiers will give limitations. In vibration testing it is generally demanded that a random signal should contain peak-values of three times the RMS value.

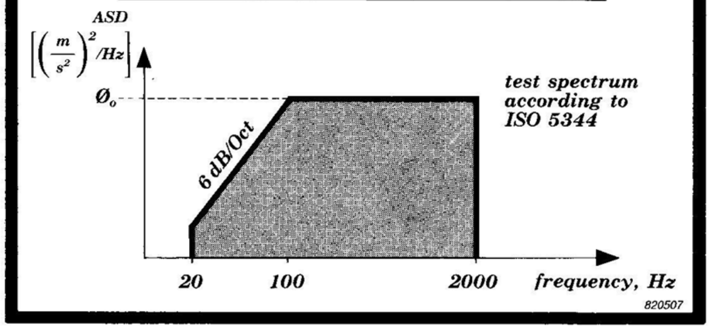
The force produced by an exciter is mainly limited by the heating effect of the current, i.e. the RMS value, whereas the power amplifier rating is influenced by the peak values. To give the same force the amplifier must therefore be larger when used with random than with sine excitation.

The random spectrum is described by its power spectral density or acceleration spectral density, ASD $[(m/s^2)^2/Hz]$. To shape and control this, the vibration must be analyzed by a narrow band analyzer and compressor loops applied to each bandwidth. Digital techniques based on Fourier transforms are normally used and the control is achieved using a computer, a process called equalization.

The random capacity of an exciter is specified as the maximum acceleration spectral density at different loads of a spectrum, shaped according to the International Standard, ISO 5344.



$f\,[Hz]$	<20	$20-100$	$100-2000$	>2000
$\text{Ø}\left(\frac{m}{s^2}\right)^2/Hz$	0	$\left(\frac{f}{100}\right)^2 \text{Ø}_o$	Ø_o	0



Fixtures

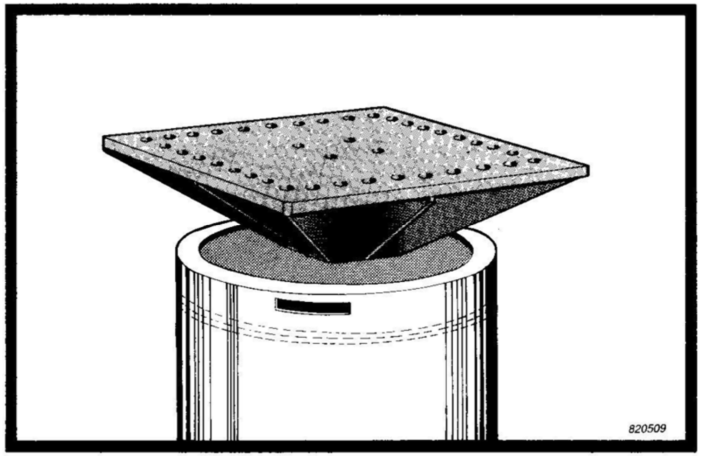
In cases where the test object cannot be mounted directly on the exciter table a fixture, sometimes of a rather complex nature, is required for fastening the object. The fixture must be stiff enough to transmit the generated force or motion uniformly to the test object, thus not introducing any resonances. It is important to check the design by measuring the vibration levels on the surface of the fixtures by means of accelerometers. All resonances must lie outside the test frequency range.

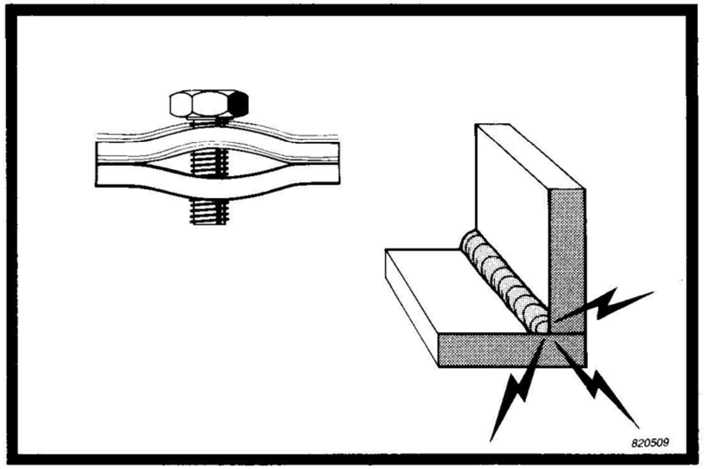
The natural frequency of a construction will be almost the same whether the material is steel or aluminium and as the total weight of test object and fixture is a restricting factor in the application of an exciter, aluminium will normally be the best choice.

To obtain a high resonance frequency, it will always be necessary to over-dimension the structure, so no considerations normally have to be taken concerning the mechanical strength.

For minimizing the weight of the fixture it can be constructed of relatively thin plates, supported by braces. The plates are of simple geometric shapes with responses easy to calculate. Much care should be taken in assembling: bolts can introduce spring/mass effects, welding can introduce internal stresses.

If resonances cannot be avoided the damping can be increased by laminating with a damping material such as rubber or by filling cavities with foamed plastic.





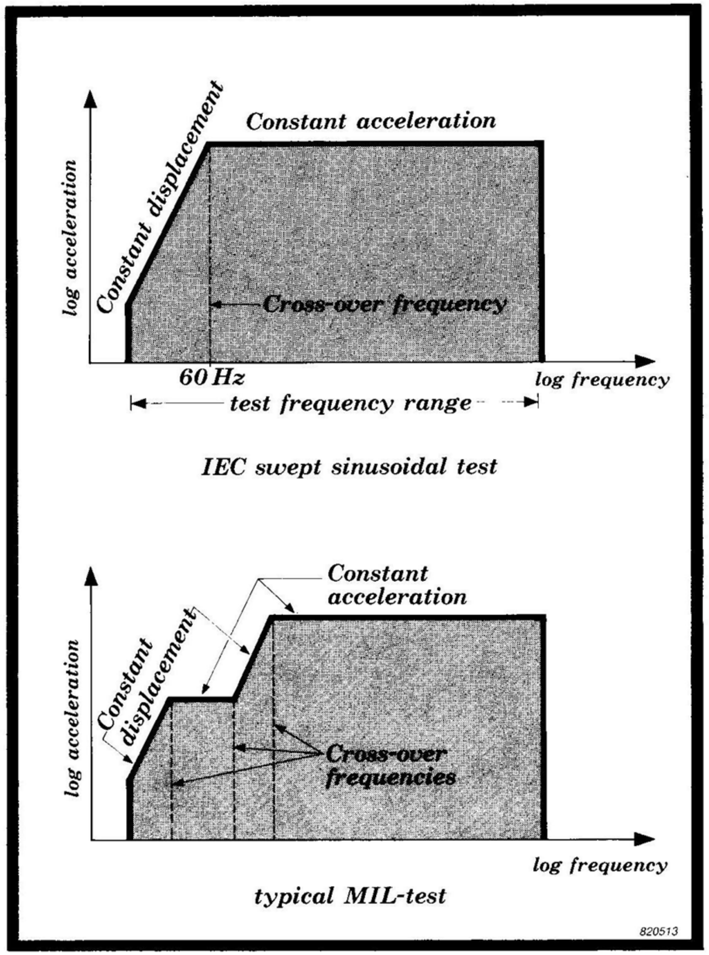
Endurance Conditioning

During the endurance conditioning the specimen is subjected to a vibration, which in severity, i.e. frequency range, level and time, should ensure that it can survive in the real environment. Dependent on these, the conditioning is performed by sine sweeping, sine testing at the resonance frequencies or at other pre-determined frequencies, or by random vibration.

Swept Sine Testing

In the swept sine test the signal to the exciter is continuously swept back and forth over the appropriate frequency range. The main control parameter is the acceleration level, but below a certain frequency (the cross-over point) a constant displacement is chosen. In the IEC-test the cross-over frequency is 60 Hz and the levels of displacement and acceleration are chosen to change continuously from one parameter to another. Other standards, e.g. the military standards, may demand further changes of level or of vibration parameter.

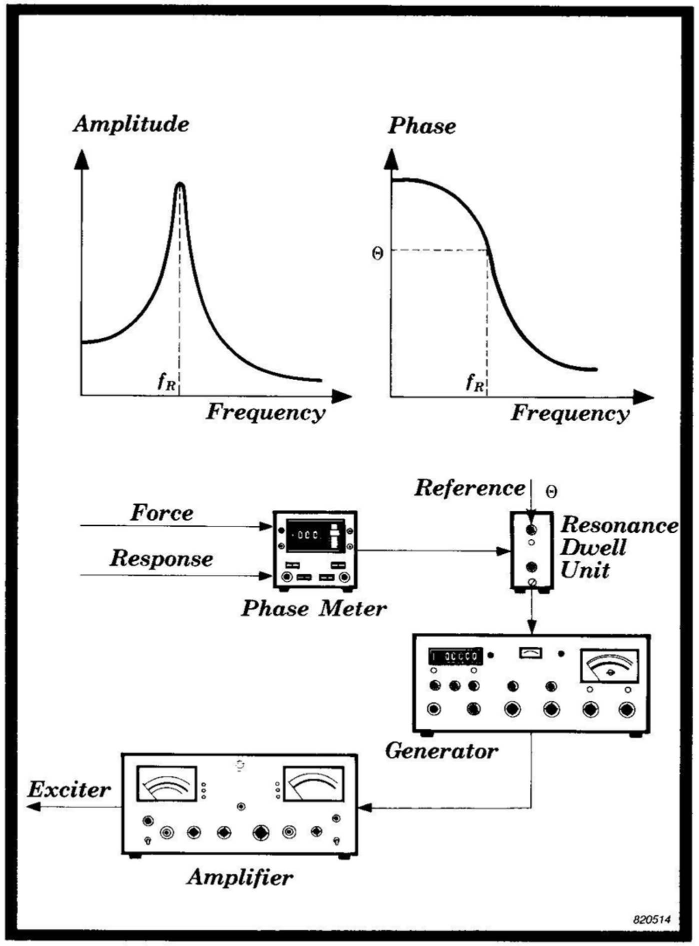
Therefore, the exciter control used for environmental sine testing, has at least two measuring channels with integrators to calculate the displacement and velocity levels from the acceleration level measured by the control accelerometer. There must also be a switching facility, to change the measuring channel at the cross-over frequency.



Conditioning at Single Frequencies

If the expected environment is dominated by one or a few discrete frequencies, the endurance conditioning is most realistically performed only at these frequencies, often as fatigue testing to break-down of the material.

Specimens showing some clearly evident resonances can successfully be tested at these resonances. Due to changes in the structure during the test, the resonance frequency is likely to move and in order to change the excitation frequency automatically, a resonance dwell unit is used. It works on the fact that at resonance the phase angle between the excitation and the response signals will change drastically. It is therefore possible to consider the phase angle as characteristic of the resonance, and it is measured and used as a reference in a servo loop controlling the excitation frequency.



Random Testing

Although sine testing is by far the most widely used vibration test due to the relatively low price and simple instrumentation, a random excitation will better simulate the real environment. In sine testing only a single resonance will be excited at a time and any mutual influence of resonances will not be detected. Another advantage of the random testing is that the time of endurance is shorter because it acts on all resonances at the same time.

A random test is specified by its acceleration spectral density spectrum (ASD), which is shaped by an equalizer and controlled by the total acceleration RMS level of the spectrum.

The high price and complexity is an obstacle for the wider use of random test systems and compromises using excitation without automatic equalization, e.g. by recording a spectrum on a tape, are met when the demands to the reproducibility are small.

One approach combining a simple feed-back control with many of the advantages of the random spectrum is the swept narrow band technique. In a standard sine control the single frequency signal is substituted by a random band and the overall vibration level is controlled by the compressor. With a fairly narrow bandwidth the control is satisfactory even for low damped resonances.