WHITE PAPER

Brüel & Kjær
BEYOND MEASURE

ENGINEERING INFORMATION NOTE
"DOS AND DON'TS" IN VIBRATION TESTING

ABSTRACT

This paper provides guidance on avoiding pitfalls and difficulties commonly encountered during the design, installation and operation of vibration test systems. It is based on the many years of experience had by Brüel & Kjær VTS in the world of vibration, and the plethora of problems that can be encountered during the vibration testing of components and assemblies.

SITE DESIGN

Layout

Position of control room

The control room should, if possible, be positioned within sight of the vibration system. If this is not possible then a CCTV system should be installed to provide a view of the vibrator.

Room access

There should be adequate access both for installation and maintenance of the vibration system, and to allow the easy and safe mounting of payloads and fixtures.

Vibration

Consideration should be given to the vibration, especially at low frequencies, that will be transmitted into the floor during testing. Various mounting options are available to reduce transient vibration, but all have a low-frequency limit. An unsuitable isolation mounting resonance can lead to excessive motion of the vibrator and even damage to the surrounding building.

Location of amplifier

The system amplifier should not be sited directly against a wall as this will restrict the air flow available to cool it; maintenance will also be easier if the amplifier is surrounded by free space. System user manuals contain detailed recommendations on this.

Airglide mounts

When equipment is fitted with 'Airglide' mounts, it is necessary to ensure that the floor has a suitable finish and level as specified in the user manual.

Fan hoses

Extended fan hoses should not be fitted without consulting the engineering team at Brüel & Kjær VTS; any hose extensions could result in the vibrator overheating. For the same reason, sharp bends in hoses should be avoided, and hose arrangements shown in outline drawings should not be modified without consulting Brüel & Kjær VTS.

Floor loading

The floor must be able to bear the load of the vibration system – vibrators and their associated equipment are heavy items.

Position of main isolators

Main electrical isolators and switches should be fitted in an accessible position close to the amplifier. Positioning should comply with relevant safety regulations.

Acoustic noise

Be aware that due to the nature of vibration systems, audible noise is produced by the armature. For larger systems this can often lead to high levels of noise. Careful consideration should be given to the use of sound attenuating structures and soundproof rooms, etc. Vibrator noise levels are specified in the user manuals.

Other equipment
Siting vibration systems next to other heavy equipment can cause problems due to the transmission of vibration or electrical noise.

Environmental

Temperature and humidity
It is advised not to operate Brüel & Kjær VTS equipment outside of the temperature and humidity limits; these are specified in the relevant user manuals.

High altitudes
At higher altitudes, the cooling of the vibrator will be affected by the reduced air density. If this is likely to be a problem, it is recommended to consult the engineering team at Brüel & Kjær VTS for further advice.

Cleanliness
The vibration test system and other associated equipment should not be operated in damp, oily, dirty or dusty environments. Dirt and dust may cause the centre positioning system (where fitted) not to function correctly. Water collection due to damp conditions will cause corrosion of the vibrator and may also lead to electrical short circuits. Oil on or around the vibrator makes the surfaces slippery, creating a hazard for operators, ensuring the surrounding areas are clean and tidy are an essential part of the day-to-day maintenance activities.

Condensation
If the operational temperature and humidity (for instance when operating with a thermal chamber) are such that the temperature of the vibrator armature falls below the dew point, moisture will condense on the armature. This can cause corrosion to the frame and lead to electrical shorts.
These problems can be avoided by:

- The use of a thermal barrier
- Fitting heating elements around the armature/chamber interface
- Directing the warm air expelled by the fan towards the underside of the chamber

Vacuum
When the vibrator is used with an altitude chamber, the chamber will apply suction to the armature. In solutions where an air-cooled vibrator is used, it’s worth noting that the load compensation is based on positive pressure, so special control will be required. In water-cooled vibration test systems, a small vacuum pump is fitted to provide negative pressure on the armature. This, however, works against the vacuum pump for the chamber, which is usually larger.

Thermal expansion
When using a thermal chamber, it is necessary to be aware of thermal expansion and the resulting stresses it can cause; this is particularly important when the chamber is attached to a multi-bearing slip table.

Corrosion of magnesium components
The magnesium alloy used in slip tables, head expanders and other components is susceptible to corrosion, as such the advice on the care and maintenance of a vibration test system in the user manuals should be followed carefully.

Service and cabling

Availability of services

It is recommended to ensure that all services required for the equipment are available and as specified in the relevant user manuals.

Cabling

The following points should be borne in mind when running cabling:

- All cable lengths should be kept to a minimum, as cables longer than those specified in the user manuals may restrict the performance of a system. If in doubt, consult the engineering team at Brüel & Kjær VTS
- Care should be taken not to apply undue loads and tension to cable terminations
- Ducting for the armature drive and field cables should be ventilated to avoid the possibility of heat build-up, which could restrict performance and cause damage
- Cables should be routed neatly and safely to avoid possible trip hazards
- Power and signal cables should be routed separately to avoid interference problems
- All signal cables should be screened; triaxial cables should be used for analogue signals over long lengths

Further guidance on cabling is given in the relevant user manuals.

Electromagnetic

Safety and RFI earths

It is recommended that safety earths are fitted and used where possible. RFI earths should be used and be of the correct type as specified.

Further guidance on earthing is given in the relevant user manuals.

Mounting the vibrator

The body of the vibrator is constructed from steel to allow for conduction of the magnetic fields. If the body is connected to large steel components other than supplied by Brüel & Kjær VTS, these fields will flow in the connecting parts. This can cause problems with magnetised plates, loss of flux within the vibrator and/or large stray magnetic fields.

Siting of control equipment

If control equipment is sited close to the vibrator, the stray magnetic field may distort the monitor.

Low frequency field

Brüel & Kjær VTS recommends that personnel, particularly those with medical implants, do not enter the danger zone whilst the vibration test system is running.

Further guidance on safe practices and hazards is given in the relevant user manuals.

VIBRATORS

Air-cooled vibrators

Dirt and dust

If the vibrator is operated in dirty and dusty environments, the air vents can become blocked causing the vibrator cooling to become impaired.

Ambient temperature

If the vibrator is operated at high ambient temperatures (above 30°C), the vibrator coils will overheat at full force. The cooler the air, the longer the life of the vibrator will be. If temperatures cannot be kept below 30°C, the vibrator should be de-rated in force.

Air cooling hoses

Hose lengths should be as short as is practical. Where the standard supplied length of hose is deemed too short, the Brüel & Kjær VTS engineering team should be consulted as to the requirements for long ducting lengths. It is worth noting that long ducts can increase the pressure drop seen by the fan, and thus restrict the flow of air to the vibrator.

A kinked or damaged cooling hose can cause a reduction in the flow of air to the vibrator, leading to increased running temperatures, reducing the life of the vibrator.

Air supply

Particularly where air compressors may turn off overnight, consideration should be given to fitting a safety switch to ensure that the vibrator cannot run without an air supply being present.

Air quality

The air supply should conform to ISO 8573-1: class 1.7.1, with a maximum particle size of 0.01 microns and remaining oil content of 0.01 ppm. Water or oil traps should be fitted if deemed necessary.

Water-cooled vibrators

Continuous running

Due to the gradual heating of the body, standard water-cooled vibrators should not be run continuously. Optional body cooling is available for V964 vibrators, which allows for continuous running scenarios.

Cooling unit, oil

Raw water supplied to the cooling unit should always be within specification for flow and temperature. High raw water temperatures or low flow will cause the system to trip as the cooling unit coils will not be able to reject all of their heat. Where the cooling unit is sited either above or below the vibrator, special consideration is required for how the water and oil are returned from the vibrator. If the cooling unit is below the vibrator, siphoning can occur from the vibrator. However, if the cooling unit is above the vibrator, scavenging will be required for the oil. Oil scavenging should also be considered if supply hoses are unusually long. The cooling unit tank must always be full, damage to both the vibrator and the cooling unit may occur if the tank is empty.

Economy tap

When running the vibration test system using the economy tap, the vibrator will not be able to produce full force; full field will be required in order to do this.

Maximizing armature life

Whilst Brüel & Kjær VTS vibration test systems are extremely robust, the armature is a lifed component whereby the high numbers of stress cycles, high stresses and high temperatures will ultimately lead to failure and the need for replacement.
The time taken for an armature to fail depends on:

- Primarily the force level at which it is running
- Secondarily the type of test
- Other factors which will influence its life

As a guide, Brüel & Kjær VTS vibrators have an expected life of over 10,000 hrs when running at 80% force. At force levels below 80% the expected life will be longer; at levels above 80% it will be shorter. This relationship is non-linear, being based on S-N curves which approximate to a straight line only on a log-log scale. Armature life is also affected by the type of test being run as shown below (higher values lead to reduced life):

Type of Test	Value
Sine Sweep	1
Random broad band (20 - 2000 Hz)	1
Shock	1.5
SRS	2
Sine on random	2
Narrow band random	2
Fixed frequency sine	3

Expected armature life can be calculated by dividing this number into the rated life for the force level used.
For instance, the expected life for a fixed frequency sine test run at 80% force is approximately 10,000/3 = 3000 hours.

Other risk factors, which can lead to a reduction in armature life are as follows:

- High temperature of raw cooling air or water
- Distortion caused by ‘slapping’ components
- High ‘g’ levels
- Humid or dusty environments
- High frequency > fn
- Large displacement
- Horizontal running
- Running under a chamber
- Large overturning moments applied
- High velocity
- Drive high
- Lively payload
- Poor control
- Not keeping reference plots
- Poor maintenance
- Unattended operation
- Large payloads

Maximum armature life will be obtained when these factors are avoided as much as feasibly possible, all while using the vibrator within its specified performance range.

TESTING

Test design

Test dynamics

The combined dynamics of the item under test, fixtures and vibrator armature should be well understood, especially where the payload is large, or the test is severe.

Test frequencies

The vibrator should only be run within both its maximum and minimum frequencies.

Accelerometers

It is recommended to ensure that all accelerometers are rigidly mounted and will not fall off during the test.

Cross-axial motion

Careful monitoring of the cross-axial motion is advised to avoid exceeding vibrator overturning moment capability.

Loads and fixtures

Suitability for purpose

It is essential to ensure that fixtures are suitable for the purpose required of them.

Thermal expansion

All jig design should take account of the effects of thermal expansion. Different materials when fastened together and subjected to changes in temperature will induce stress in the components. Slip tables in thermal chambers are particularly susceptible to thermal expansion whereby bearings can be damaged, particularly if the jig bolts are tightened before the slip plate has reached the working temperature of the chamber.

Torque settings

Inserts and payload bolts should always be tightened to the correct torques as defined in the user manuals. Over tightening these bolts can cause damage to the inserts, under tightening can cause the payload to rattle or work loose resulting in inaccurate measurements being made or damage to the system, or payload.

Load support

Always use the load support system as described in the user manuals.

Accelerometer positioning

Accelerometer positions should be chosen with great care; control accelerometers must not be positioned at vibration nodes. In some cases, this could cause the armature to be become damaged.

Fixing the load

It is recommended to use as many fixing points as possible when attaching a fixture or payload using short fixing bolts rather than long ones, which may resonate during the test.

Control strategy

This section covers some of the basic ideas and concepts relating to vibration control strategies. It explains the need for control accelerometers and gives guidance on where to place them.

Nearly all vibration tests cover a frequency range where mechanical resonances occur in a system comprising the payload, fixturing and vibrator armature. Nearly every vibration test is controlled in terms of acceleration, relying on the fundamental equation force = mass x acceleration (f = ma), if mass remains constant. However, under resonant conditions, the effective mass does not remain constant. For this reason, poor control can lead to under or over-testing of the payload and damage due to overdriving the armature.

The choice of where to control is thus one of the most critical parts of any vibration test. There are no universally suitable control positions, and the positions chosen can mean the difference between damaging the vibration equipment or not. Control positioning can also dramatically affect the accelerations applied to the item under test (payload).

The following principles should be borne in mind:

- All mechanical structures have resonances.
- The larger (dimensionally or more massive) a structure, the lower the resonant frequency.
- For increased mass without increased stiffness, the resonant frequency will reduce.
- For increased stiffness without increased mass, the resonant frequency will increase.
- In a free system when a purely axial resonance occurs, the liveliest points (those moving the most) will always be the ends.

Description of a typical test

A typical vibration test involves three main physical components:

- The vibrator armature
- The fixture
- The payload (item under test)

Consideration must be given to the resonance, not of the individual components, but of the entire system which they comprise.

The armature and the payload are normally fixed with no scope for change, but the fixture can consist of a slip plate or head expander, and often a mounting fixture.

If the entire system were rigid and its resonances fell outside the range of the test, all points on the system would vibrate at the same level and the position of the control accelerometer would be immaterial.

However, for many payloads the size of the fixture in combination with the mass of the payload leads to resonances within the range of the test. It is these resonances which cause the difficulty in selecting control positions.

Choosing control position

Control accelerometers are needed to:

- Control the acceleration into the payload.
- Ensure the vibrator is not damaged.

The most obvious reason for control accelerometers is to limit the acceleration into the payload. If the payload is large and/or the frequency range is high, at some point one or more resonances will occur. This can be seen as the difference in acceleration levels over the fixture.

If only one accelerometer position is used on a test, the control loop only ensures control of acceleration at this position. If this position coincides with a resonance node (a point at which there is little or no movement), then the rest of the structure could be accelerating a hundred times or more than the control level. As the location of nodes changes with frequency, finding a point where they will not occur is difficult; it is for this reason that several accelerometers positions should be used.

The best area to place accelerometers with least risk of finding a node, is at the end of the system. On a slip table this would be on the end of the plate, furthest away from the vibrator.

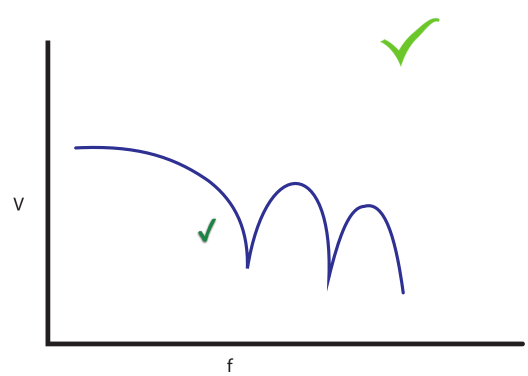
When using even one accelerometer, resonances can be spotted. If a flat sine sweep is required, then the control acceleration will also be flat. Looking at the drive from the controller will show the dynamics of the system; this drive is the signal which the controller outputs to the amplifier. A drop in the drive indicates a resonance, and a rise in the drive indicates an anti-resonance. Anti-resonances indicate that the control accelerometer is placed on a node.

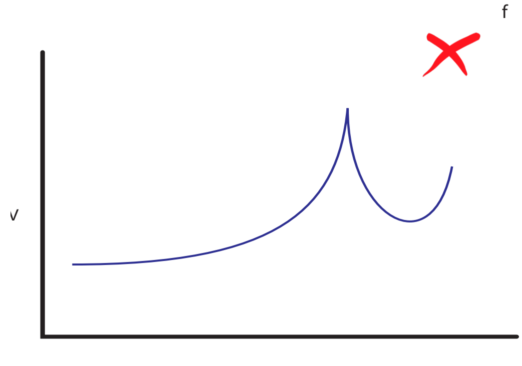
The drive signal is directly proportional to the output from the amplifier to the vibrator. The vibrator will respond to this input from the amplifier to produce force. This follows that if the drive is high, then the force the vibrator is producing will also be high. Anti-resonances are the most dangerous to the vibrator, as the force the vibrator will be producing, will be far higher than the simple calculation of force = mass x acceleration (f = ma).

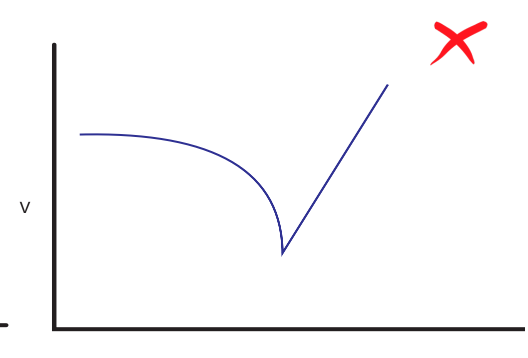
The drive signal is the most useful piece of information about the vibrator as it demonstrates how good the control strategy is, as well as the force that the vibrator is producing.

The drive signal should not rise above the nominal level for the test if the structure were rigid. Control positions should be changed or more added if this is the case.

Examples of good and bad drive plots are shown below in figures 1, 2 & 3.







Choosing locations for monitoring

It may not be possible to always put a control accelerometer at the end of the system; if this is not possible, then monitors should be placed with notching levels set so that damage to the vibrator does not occur.

Random vs sine testing

There is a difference between sine and random testing in how the vibration system protects itself. Under sine testing the amplifier monitors the voltage and current supplied to the vibrator, stopping the test if either exceeds the pre-set trip levels. Should the test be a high level test and the control position at a node, the drive power may increase past the trip level causing the system to shut down.

In random testing the amplifier monitors r.m.s. voltage and current in a similar manner. However, if control is at a node and the drive increases around that node, the amplifier will not shut down as long as the overall voltage and current remain below trip level. This remains true even though the vibrator may be producing more force than required.

A further complication is that, at the resonant frequency of the armature itself (normally around 2,000 Hz) there is a large amount of 'free energy'. Little voltage and current is required to drive the armature at this frequency and it is possible to damage the armature by overdriving the vibrator (exceeding its limits in both force and acceleration) without causing amplifier shutdown.

Placing a control accelerometer at the end of the system will protect against this danger as this end moves in a similar manner to the armature at the other end.

Good practice

Following good practice as described below (common for any type of testing, sine, random, shock etc) will maximise the life of the equipment:

1. Always fit an accelerometer at the end of the system to either control or, if this is not possible, monitor with limits set at the maximum theoretical acceleration using the f = ma calculation.
2. Large slip tables may require several control accelerometers positioned at the end as the corner of the plate will be vibrating at a different level to the centre, and at higher frequencies.
3. Run low-level sine sweeps over the entire testing frequency range to characterise the fixture and payload. This could be low-level random if sine is prohibited. Low-level means approx. –12 dB of the full test level.
4. Review the drive to ensure there are no rises past the nominal drive level.
5. Use the results to modify the control strategy if required.
6. Look at the out of band energy during random running as this can indicate other problems: the bandwidth should be at least 1.5 times the highest control frequency.
7. Where this energy is large or at the same level as the controlled energy, this indicates potential problems with the test and an investigation should be conducted before continuing.
8. If problems occur, look at the real time trace of acceleration as this may show problems not seen in the frequency domain.
9. If all looks OK, proceed to the test level.

This will ensure that the vibrator is protected as far as possible against damage. If these precautions are not taken, immediate damage may not occur, but forcing the vibrator to provide more than its designed force or acceleration levels will lead to reduced life.

Controllers usually offer a range of control strategies (single point, average, weighted average, extremal etc). The best from a vibrator protection point of view is extremal, but if this is not practical, and average or single point is employed, the monitor at the end of the system must be fitted with a limit. If this end point were included in a two-point average, where the other point drops to zero, the vibrator would have to provide double the force required by an extremal strategy.

Summary
Control accelerometers are used to protect the vibrator as well as control the test level. It is recommended to use the drive plot to assess the control strategy and protect the vibrator. Random vibration can mask control problems where sine sweeps wouldn't run.
Always control or monitor at the end (liveliest) parts of the system.
Consider the whole system not just the item under test.
Do not assume the characteristics of a system, always establish them by investigation.
Ensure that the dynamic characteristics of the system are known before testing at full level.

Slip tables

Mating surface
Any mating surfaces should be correctly connected, with no fretting of the surfaces. Surfaces should be flat and smooth, and bolted together using short bolts at close spacings.
Where a drive connection is fitted to the armature, it is recommended to ensure that all inserts are used, and the structure is dynamically rigid to the highest drive frequency.

Design of the jugs and fixtures
Design of jigs should consider the slip plate overturning moment given in the user manual, as exceeding this will cause damage to the bearings. When designing jigs to fit on the slip plate, try to cover all available bearings as this will give the best overturning moment restraint.
When designing jigs for slip plates, it is worth understanding that the slip plate is only stiff in the three axes, but flexible in the three rotations. Jigs should be designed to add to the stiffness of the slip plate.

Attaching jigs and fixturtes
Flatness of jigs and fixtures is critical. Uneven or bowed jigs can cause binding of the bearings within the slip plate and rubbing of the slip plate against the granite table base. Fixing bolts should have a length as specified in the user manuals. Bolts that are too long will damage the slip plate; bolts that are too short may not fully engage in the insert.

Thermal expansion
Jig design should take account of the effects of thermal expansion. Different materials when fastened together and subjected to changes in temperature will induce stress in the components.
Slip tables in thermal chambers are particularly susceptible whereby the bearings can be damaged if jig bolts are tightened before the slip plate has reached the working temperature of the chamber.

Armature connection
Where possible all armature inserts should be used to attach driver bars or fixtures. Using only a few can cause the inserts to pull out, or the dynamics of the armature to change.

Operations

Users of equipment

Only trained personnel should use the equipment, if training is required then contact Brüel & Kjær VTS for details of courses in vibration testing.

Equipment manual

Users should familiarise themselves with the equipment manuals including any special addendums.

Before test checks

Do ensure that the vibrator and other equipment is working correctly before starting tests.

Test failure

Any failure should be recorded, and efforts made to analyse its causes before repeating the test. Doing so will avoid repeated failures caused by the same problem. Where appropriate, pass details of failures to the Brüel & Kjær VTS engineering team including drive and profile plots.

Fixed frequency tests

The vibrator may not run at full performance during fixed frequency tests, as frequencies may coincide with vibrator resonances. This may cause failure to achieve the desired test level and/or damage to the vibrator.
For more information on this, see 'Maximising armature life' earlier in this paper.

System characterisation

To determine the correct control positions for the tests to be run, the system should be characterised by running low-level sine sweeps; characterisation plots can be kept for future reference.

Vibrator specification

The vibration test system and other related equipment should only be run within specification, as detailed in the user manuals.

Test masses

The exact mass of the payload and fixture should be known before starting the test. This will avoid overdriving the vibrator.

Advice from Brüel & Kjær VTS

Advice about vibration testing is readily available and should be consulted in case of doubt about a specific test.

MAINTENANCE

Programming of maintenance
Regular checks and maintenance activities should be carried out as recommended in the user manuals. Maintenance should always be carried out by suitably trained personnel.

Calibration
Items such as accelerometers which control test levels should be checked regularly to ensure that they are calibrated and working correctly.

Drive and field cables
All drive and field cable connections should be checked for tightness, as loose connections can inject transients into the test item.

Oil and water supplies
To maximise the life of the vibration test system, oil and water should be changed at the intervals recommended in the user manuals.

Air supply
The air supply should always be within specification, as dirty or wet air can cause the pneumatic regulators to stick.

Replacement parts
To avoid problems caused by stoppages, a stock of spare parts should always be maintained as recommended in the user manuals. Brüel & Kjær VTS approved parts should always be used as many are safety critical, and most will affect the performance of the equipment.

Lifting equipment
Adequate lifting facilities must be available both for mounting payloads and for servicing the vibration test system.

Cleanliness
The equipment, and all areas surrounding it, should be kept as clean as possible.
Do always keep the vibrator clean as swarf can damage the top seals, and if pulled into the vibrator body, can cause electrical shorts, damaging the vibrator.

Cables
Cables should always be routed so as not to obstruct walkways. No cables should be left where they can be walked on.

VIBRATORS AND SLIP TABLE MOUNTING

A key element in the design of a vibration test system is the mounting of the vibrator and any slip table.
A vibrator or combo may be isolated from the floor by mounting it on air-bags, which offer the lowest possible isolation frequency (typically 2 Hz).
Alternatively, the vibrator and any slip table may be rigidly attached either to the floor or to a seismic block, which may itself be isolated.

Air-isolated vibrator

All rigid bodies have six modes of vibration, oscillation in the three linear axes (X, Y, Z) and rotation in the three rotation axes (XX, YY, ZZ), with the frequency of each mode depending on the stiffness and the mass or inertia in its axis. Air isolation ensures that there is a rigid body mode of the vibrator body in the thrust direction at the isolation frequency.

A vibrator may be air isolated in two distinct ways:

- Under the vibrator – the body if base-mounted, the vertical members if trunnion-mounted.
- Close to the centre of rotation – Lin-E-Air isolation.

A major advantage of the Lin-E-Air isolation system is that the vibrator can be used horizontally to
drive a slip table.
Both approaches have the advantage that the vibrators dynamic force is not applied to the floor (though the static mass of the vibrator, which may be large, must also be considered).
While simple air-isolation transmits no dynamic moments to the floor, Lin-E-Air isolation transmits some moments to the floor, depending on their frequency.
A disadvantage of air-isolation is that because only the body of the vibrator reacts to the thrust force generated, body motion can occur if there is considerable force generated at low frequencies; this can result in a deduction in the available displacement.
With air-isolation, a large seismic block below the vibrator is not necessary, although an installation will always benefit from a reasonably sized seismic block to absorb vibration transmitted into the floor due to overturning moments.

Air-isolation under the vibrator

As this approach gives no guidance, the six modes of vibration described above will be determined by the mass and inertia of the vibrator as well as the stiffness and location of the airbags. All six modes will be low as described above.
This approach relies on reaction against the mass or inertia of the vibrator body, as it is effectively floating in all axes. Care must be taken however, to avoid excessive displacement of the body.

Lin-E-Air

A Lin-E-Air isolation system comprises airbags as described above which, along with the vibrator body mass, dictate the resonant frequency in the thrust axis, and the guidance system comprised of shafts and ball bushings to restrict the other rigid body modes.
This maximises the frequency of five vibration modes whilst minimising the sixth which is in the axis of the thrust direction. The frequencies of the other modes depend on the vibrator bearings, their housings, and the stiffness of the shaft.
Although intended to be as high as possible, the frequencies of these modes will always

be in the frequency range of the vibrator as the mass and inertias are so large.
Any moment applied by the attached payload to the vibrator, is transmitted by the vibrator, Lin-E-Air bearings and vertical supports onto the floor, providing the moment is applied below the rigid body frequency for its direction. Above this frequency the moment will not be transmitted to the floor and thus the system is effectively isolated.
If the moment is applied near the rigid body frequency, then the resultant amplification may significantly increase the loading of the bearings. To avoid damaging the bearings, care must be taken to control motion in the rigid body modes, for instance by monitoring the accelerometers on the vibrator.
If the vibrator is used with a head expander, consideration needs to be given to the effect testing tall payloads with high overturning moment will have on the Lin-E-Air guide shafts.

Solid trunnion vibrator

The vibrator is rigidly supported by vertical members which allow the vibrator body to be rotated from horizontal to vertical and bolted in either configuration; these support members are fixed to a seismic block.
In theory, this approach prevents body displacement, as all forces generated by the vibrator are transmitted to the seismic block, and in addition, the thrust force of the vibrator, its static mass and any dynamic moments applied to it.
In practice the support members are never completely rigid through the entire frequency range, and there will be rigid body modes of the vibrator body due to the stiffness of the vibrator supports. However, these modes will occur at much higher frequencies than with Lin-E-Air trunnions as the structure is inherently stiffer.

Slip table

For normal payloads, there are two main approaches to operating a vibrator with a slip table:

1. Air-isolated combo (slip table on the same structure as the vibrator)
2. Separate slip table mounted on a seismic base

Where payloads have a large mass and/or inertia, the vibrator and slip table can be mounted on a shared seismic block as described in the following section.

Combo

As the combo base is isolated from the floor by airbags, moments applied to the slip plate are reacted only by the inertia of the base; however, for all but the largest payloads this is a very practical approach.
The largest Brüel & Kjær VTS vibrators such as the V984 and V994, typically used for satellite or military product testing, are usually installed onto purpose-built seismic blocks as described below. Where it is impractical to install such a block, or the vibration system needs to be movable, combos based on these vibrators can be supplied, with some performance trade-off compared with a rigidly mounted system.

Seismic base slip table

The slip table is supplied on a small seismic base which sits on the floor, normally supported by jacking screws and thus not completely isolated from the floor. As the slip table is separate from the vibrator, it relies on the mass of the base to react against the moments applied. The floor between the vibrator and the base needs to be basically sound but does not necessarily need to be a seismic block.

Seismic blocks

Seismic blocks are normally used where payloads have large mass and/or inertia as the block can be very large and provide a stable base for the payload to react against.
The vibrator and any slip table are then mounted together on a massive reinforced block which is normally isolated to separate it from any surrounding buildings (including the one housing the vibration test system) or may be directly fixed to the bedrock.
The slip table is rigidly mounted to the block, and the vibrator is mounted on the same block, either solid mounted or air-isolated as described above. In either case as the slip table is rigid to the block, any moments applied to it will be reacted by the whole block.
Isolating the vibrator puts less force into the block, which means it does not need to be as large as with a solid vibrator, however, displacement may be limited when running a low frequency, high force test.
For any installation, but particularly when the vibrator is solid mounted, it is very important to locate the vibrator over the centre of gravity of the seismic block, this avoids rocking the block when the vibrator is operated vertically. Any induced rocking of the block may in turn excite rocking modes in the vibrator or payload.
The mass required for a seismic block is usually around ten times the maximum system force; the block for V994 system with 3m slip table would be approximately 10m long x 4.5m wide x 3m deep. As many other factors must be considered in the design of the block, this is best undertaken by a specialist company.
Vibration transmitted through a seismic block can cause problems if sensitive equipment is to be assembled or installed near the vibration system; its effect on building structures must be considered, plus health and safety issues from vibration and noise.
Further objections to the use of a seismic block are that it may be difficult to install due to site limitations, ground conditions or cost, and that the fixed mass prevents easy relocation of the vibration system.

PREDICTIVE TEST METHODOLOGIES

Keeping a set of reference plots for a vibrator gives a valuable indication of whether there are any problems about to arise from the vibrator. This can help with planning maintenance within busy test schedules.
It can also indicate which of the many tests you run are stressing the vibrator the most.
All vibrators produce different characterisation plots and as such it is important to keep a reference set and copies of the same performance throughout the life of the vibrator.
When reviewing the latest plots with reference to the previous ones, differences can be looked at and implications can be drawn.

Recording a character of a vibrator

- Always use the same equipment set-up. If there are any changes, run the same test with the old set-up and again with the new, noting any differences due to the control equipment.
- Run the vibrator in the vertical axis.
- Ensure that the vibrator is run from cold.
- Fit a tri-axial accelerometer to the centre insert of the armature.
- Set a profile in the controller for a 5mm peak-to-peak constant displacement crossing into a 2 gn constant acceleration sine sweep across the entire frequency range of the vibrator.
- Use peak control with a 1 octave per minute sweep rate.
- Record the drive, control and the cross axis in both directions.

- Define the highest frequency that can be run with that control position, by looking at the drive and ensuring that the drive does not rise past the nominal level seen at 200Hz.
- Run a high-level sweep at 20% of Displacement, Velocity and Acceleration through the frequency range as defined previously.
- Record the drive, control, cross axis in both directions and the total harmonic distortion plotted through the frequency range. Use the same measurement technique for the analysis of distortion.

Once these plots have been taken they should be kept in a file and repeated at sensible intervals through the vibration test system life. These intervals should be determined by the usage of the vibrator and the practical level of testing that can be performed.
As a guide Brüel & Kjær VTS would recommend taking these plots at monthly periods, or after any significant high-force testing that has occurred.
These plots can reveal several things, mostly about the health of the armature and suspension. Changes to these plots over time will indicate that these parts are becoming worn or old but will not necessarily mean that they need to be changed. The fact that they are changing will indicate that they need to be monitored and possibly inspected visually.
The speed of change will indicate whether a failure is imminent. Changes tend to happen slowly to start with and then accelerate just before failure. Armature problems can mean either a failure in the coil, or within the frame. It is more common for the coil to fail than the frame.

What to look for

Control plot
Ideally the plot will be flat, if it is not flat then it could indicate there is a control problem. There is very little that can be determined from the control plot alone.

Drive plot

- This should look the same as the previous 2g drive plot in level, shape and that any resonant frequencies are the same.
- The most important piece of information is the first resonant frequency seen on the plot. A record of this frequency should be kept and plotted over time. The variation can then be readily seen. There is normally an initial change with any unused armature, i.e. the frequency drops by 2-5%, then stabilising with little further change until the armature starts to fail. Large changes could indicate an imminent failure of the armature.
- The shape should be the same as before. It is an indication of a problem if there are more ‘bumps’ or ‘dips’ on this plot than before. Large changes in combination with a resonant frequency drop indicate an imminent failure of the armature.
- The basic level should be the same as before. If not, it can indicate either a control problem or loss of field.

Cross axis plot
This is the most difficult to interpret plot as it will vary with the temperature of the vibrator suspension. To interpret this, you should look at the base level of the cross axis and see that it is approximately the same as before. Any peaks that occur should be logged in frequency and level and plotted through time. Brüel & Kjær VTS would recommend taking 4 peaks to plot for any vibrator, normally the highest, but spread

through the frequency range, this may mean taking lower peaks at the lower frequencies. Large changes mean that the suspension is getting worn and should be visually inspected.

Distortion plot

Although this is a different measurement to the cross axis, the same way of looking at it occurs. Take the previous plots and look at the base level shape to the curve. Check to make sure that the new plot matches this, whilst also checking the peaks are not changing primarily in level, but also in frequency. Changes in the base level or increased peak levels can indicate either a problem with the armature or the suspension.
Refer to the other plots to identify the problem.

Other factors

Other factors can cause problems which would look like a failing armature, these are:

- Loose accelerometer cables.
- De-coupling either under the insert or under the accelerometer.
- Anything loose on the armature, inserts, screws etc.
- Excessive noise pick-up.

As with any test procedure over time, consistency is the most important thing, ensuring that as many things as possible are kept the same.

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