BRITISH STANDARD

BS ISO 5344:2004

Electrodynamic vibration generating systems — Performance characteristics

ICS 17.160

British Standards

National foreword

This British Standard reproduces verbatim ISO 5344:2004 and implements it as the UK national standard. It supersedes BS 6140-1:1981 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee GME/21, Mechanical vibration and shock, to Subcommittee GME/21/2, Vibration and shock measuring instruments and testing equipment, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

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Summary of pages

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INTERNATIONAL STANDARD

ISO 5344

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Electrodynamic vibration generating systems — Performance characteristics

Systèmes électrodynamiques utilisés pour la génération de vibrations — Caractéristiques de performance

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 5344 was prepared by Technical Committee ISO/TC 108, *Mechanical vibration and shock*, Subcommittee SC 6, *Vibration and shock generating systems*.

This second edition cancels and replaces the first edition (ISO 5344:1980), which has been technically revised.

Considered responses to all of the proposed substantive changes to ISO 5344:1980 are incorporated in this second edition. Changes favouring the specific design of individual sources were rejected. Regarding endurance testing, a compromise is incorporated, providing a less expensive, but hopefully adequate, assurance of reliability.

Introduction

Users want their equipment to operate for long period without malfunction. A major purpose of this International Standard is to establish procedures to measure performance and to provide ways to ensure the reliability of electrodynamic vibration generation equipment and systems. Some assurance of reliability, but not conclusive, is provided by endurance tests on the vibrator, amplifier and the system as a whole.

If all sources of electrodynamic vibration generation equipment and systems use the same procedures, these procedures define the meanings of the performance statements and reliability statements. Comparisons of the performance and reliability statements of the different sources become useful.

Many of these procedures are suitable for incorporation in a purchase specification to state the acceptance testing to be carried out upon delivery.

Others, particularly those related to endurance testing, are lengthy and expensive, and typically are performed by the source at the end of the product development process, before the start of series production. These procedures typically are used to establish and confirm the rated performance stated in the sales literature. After discussions with the proposed sources, the writer of the purchase specification may propose abbreviated procedures for equipment acceptance testing, or alternatively, may propose to accept written assurances that the full procedures have been performed by the source with mutually satisfactory results.

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Electrodynamic vibration generating systems — Performance characteristics

1 Scope

This International Standard specifies the performance characteristics and performance test conditions for electrodynamic vibration generator systems and provides a list of additional equipment characteristics (see Annex A) that can be declared by the equipment manufacturer. This information can be used by the user or the writer of specifications for equipment for the selection of such a system, taking into account its application.

This International Standard establishes procedures for calculating the system performance of a system comprising an amplifier from one source and a vibrator from a different source. Such a calculated system performance is less precise than performance measured on a system comprising the actual vibrator and amplifier, and a reserve of calculated force is recommended. It can be desirable to specify separately the acquisition of needed vibrator and/or amplifier interface data, particularly if a vibrator or amplifier is to be acquired to add to an existing installation. It can also be desirable to specify the responsibility for the calculation of performance.

This International Standard is applicable to equipment producing sine, random and impulse rectilinear vibration. It is implied that all systems are usable for sine testing at least at a low level, since sine capability is needed for specimen response evaluation and transfer function measurements for random and impulse testing. When random capability is specified, it is implied that some sine capability is also available. Similarly, when impulse capability is specified, it is implied that some sine, but not necessarily random, capability is available.

NOTE Three groups of people are expected to use this International Standard: the supplier of the equipment, the purchaser of the equipment, and the organization that tests the equipment. The supplier of the equipment states that "rated" performance is available, typically as stated in sales literature. The purchaser states the "specified" performance of the equipment that he will accept, typically less than or equal to the rated performance. The test organization "provides" the results of its tests and observations, typically by a written report, which may include the conditions and accuracy of each measurement, and illustrations such as waveforms, performance graphs and tables of values.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2041:1990, *Vibration and shock — Vocabulary*

ISO 15261, *Vibration and shock generating systems — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2041, ISO 15261 and the following apply.

3.1
electrodynamic vibration generator
vibrator
vibration generator which derives its vibratory force from the interaction of a magnetic field of constant value, and a coil of wire contained in it which is excited by a suitable alternating current

[ISO 2041:1990]

NOTE 1 Unless specifically restricted to the moving element, body and base of the vibrator machine, this includes the flexible field, control and drive cables, coolant hoses, field supply, and cooling, demagnetizing, protective and safety systems.

NOTE 2 In this International Standard, the subscript “ v ” is used to indicate vibrator, short for electrodynamic vibration generator. The word vibrator, which has the same meaning, is the term commonly used in industry.

3.2
power amplifier
amplifier
power electronic device capable of providing the voltage and current used to drive the vibrator

NOTE Unless otherwise specified, this includes the cooling, protective and safety systems.

3.3
system
combination of a power amplifier and an electrodynamic vibration generator to provide vibratory force

NOTE The following are excluded from this International Standard, but are included in the more inclusive electrodynamic vibration test facility system:

- the input signal source and control (typically providing controlled sinusoidal, random or shock simulation signals);
- specimen mounting fixtures and auxiliary tables;
- measuring instrumentation (e.g. accelerometers and conditioning and analysis electronics);
- mains electrical power cables and coolant hoses, or piping to and between the power amplifier, vibrator field supply, and vibrator and amplifier cooling supplies;
- air conditioning to remove generated heat not removed by the cooling systems;
- a vibration-isolated inertia block to inhibit the transmission of vibratory forces from the vibrator to the surroundings.

3.4
equipment source
source
supplier of the equipment being acquired or to be used in the system

NOTE 1 When a system is purchased from a single source, that source usually is the manufacturer or his agent. When the components of a system are being purchased from more than one source, the sources are usually the manufacturers of the individual components or their agents. When an organization wishes to acquire a new component (e.g. a switching amplifier) to be combined with an existing component (e.g. a vibrator in the test laboratory of the organization), the source of the vibrator is the vibration test laboratory.

NOTE 2 The vibration test laboratory, or other similar non-commercial source, may have difficulty acquiring the data needed to assure that the resulting system achieves the desired system specifications.

3.5
drive coil

component of the electrodynamic vibration generator, designed to provide, by means of interaction between the alternative current in the drive coil and the static magnetic field, the vibratory force proportional to the drive coil current

NOTE For most electrodynamic vibration generators, the drive coil is attached to the moving element. For transformer coupled vibrators, the drive coil is stationary and is coupled by transformer action to a shorted ring on the moving element.

3.6
linear power amplifier

power amplifier having an output proportional to the input

NOTE 1 Typically, the large linear power amplifiers designed to drive vibrators have low distortion (0,1 % to 0,3 %) when they are new or well maintained, but have high internal power dissipation, so necessitate a way of disposing of the excess heat, and are more expensive than switching power amplifiers.

NOTE 2 Small vibrators are sometimes driven by linear audio-power amplifiers or arrays of linear audio-power amplifiers. Moderately priced units typically have 0,1 % distortion, and higher performance and price units are available with 0,01 % distortion.

3.7
switching power amplifier

power amplifier having an output that switches alternately between a negative value and a positive value at a high frequency

NOTE 1 If the output is positive for a greater fraction of the high frequency cycle than it is negative, the mean output is positive. Filtering, including the effects of the drive coil inductance and the moving mass, serves to smooth the current through the drive coil. The technique results in low internal power dissipation. Switching power amplifiers typically are smaller and less expensive than linear power amplifiers of the same output capability, but may have higher distortion.

NOTE 2 The earlier switching power amplifiers used to drive vibrators had switching frequencies around 40 kHz and distortions of about 5 % to 15 %. Modern switching power amplifiers are available with switching frequencies of about 150 kHz and distortion of about 1,5 % to 5 %. As faster switching transistors become available, higher switching frequencies will be possible, and the distortion will be reduced further. When switching frequencies reach the megahertz region, substantial feedback around the output stage is possible, and the switching amplifier distortion will reach the 0,1 % to 0,3 % range of the linear power amplifiers.

3.8
force

vibratory force resulting from a varying current, in a steady magnetic field, which is applied to the structure of the moving element and the attached specimen

NOTE Due to losses, resonances and travel limitations, not all of this force is available to accelerate the moving element and attached specimen and/or to deflect the moving element suspension springs. The magnitude of the force is defined by the resulting acceleration:

$$F = \left(m_\mathrm{e} + m_\mathrm{t}\right) a$$

where m_e and m_t are the masses of the moving element and attached load, respectively, and a is the resulting acceleration. This definition applies to sine, random and impulse functions of a and F.

3.9
frequency range f_min to f_max

frequency range over which the full rated performance of a variable can be achieved

NOTE 1 Since the frequency range for one variable differs from the frequency range of another variable, the frequency range should be separately specified for each variable and for each load.

NOTE 2 With regard to the force-generating capability, the values of $f_{\min}$ and $f_{\max}$ should be individually specified for both vibrator and system rated sine, random and impulse forces for each of the masses m_{t}, and for the amplifier rated sine, random, and impulse output. If factors other than the force-generating capability limit the frequency range of operation, they should be specified.

EXAMPLE

a) At low frequencies, examples of areas that may cause problem are

- ratio of body mass to moving mass,
- the pedestal-body suspension stroke limitations,
- distortion,
- transverse motion,
- the moving element stroke limitations,
- moving element side load capability, and
- moving element suspension heating.

b) At high frequencies, examples of areas that may cause problems are

- moving element mechanical resonance,
- diaphragmatic effect of the moving element table (diaphragming),
- distortion,
- transverse motion, and
- moving element to load stiffness.

3.10
test mass

m_{t}

mechanical mass used for the testing of systems and electrodynamic vibration generators

NOTE Except for the special case of m_0, the subscript “ t ” indicates the magnitude of the mass by the magnitude of the sinusoidal acceleration achievable with the mass:

m_0 is the special case of zero load, where only the moving element is driven;

m_1 means that 10 m/s^2 ($\approx 1\ g_{\mathrm{n}}$) is achievable;

m_4 means that 40 m/s^2 ($\approx 4\ g_{\mathrm{n}}$) is achievable;

m_{10} means that 100 m/s^2 ($\approx 10\ g_{\mathrm{n}}$) is achievable;

m_{20} means that 200 m/s^2 ($\approx 20\ g_{\mathrm{n}}$) is achievable;

m_{40} means that 400 m/s^2 ($\approx 40\ g_{\mathrm{n}}$) is achievable.

Unless otherwise specified, only m_0, m_{10} and m_{40} are used.

3.11
amplifier test load

$Z_{\mathrm{a,t}}$

electric load of the amplifier, designed to be used when testing as a system is not possible (usually because the amplifier and vibrator sources differ)

NOTE Tests with the loads $Z_{\mathrm{a,t}}$ are used to acquire data for the prediction of system performance. The subscript t indicates the operation mode: s for sine, r for random, and i for impulse. See 7.2 for properties and the calculation of load magnitudes.

3.12
amplifier apparent power

product of the amplifier output current and the amplifier output voltage under specified conditions

NOTE See Note to 7.1.2 for improved size designation.

3.13
standard random spectral shape

random motion spectrum of the following shape, unless otherwise specified:

$$
\begin{array}{lll}
\Phi(f) = 0 & \text{for } f < 20\ \text{Hz}; & \\
\Phi(f) = \left(\dfrac{f}{100}\right)^2 \Phi_0 & \text{for } 20\ \text{Hz} \leqslant f < 100\ \text{Hz} & \text{(20 dB per decade)} \\
\Phi(f) = \Phi_0 & \text{for } 100\ \text{Hz} \leqslant f < 2\,000\ \text{Hz} & \text{(constant)} \\
\Phi(f) < \Phi_0 \left(\dfrac{2\,000}{f}\right)^4 \text{ or } 10^{-4}\Phi_0 & \text{for } f \geqslant 2\,000\ \text{Hz} & \text{(allowable spill-over)}
\end{array}
$$

NOTE $\Phi(f)$ is the magnitude of the acceleration spectral density function, defined as the limit as Δf approaches 0 of $a_{\mathrm{n}}^2/\Delta f$, where a_{n} is the root-mean-square value of a narrow-band random acceleration of bandwidth Δf centred about the frequency f.

3.14
impulse

short-duration waveform used to provide a shock excitation to the specimen

NOTE 1 There should be agreement on the acceleration time history of the impulse to be used before any of the impulse clauses of this International Standard may be used.

NOTE 2 An impulse is specified by an acceleration time history. For electrodynamic systems, the frequency components of the acceleration time history or of the wavelets used to produce an acceleration response spectrum are specified over the frequency range.

NOTE 3 Typically, the high frequency spill-over problems of impulse testing are more severe than for random vibration testing because the high amplifier output, and clipping, generate larger distortion components.

NOTE 4 Vibrators with transformer driver coils sometimes are used for high acceleration impulses. Typically, such vibrators have the advantage of very strong moving elements. As a disadvantage, they have displacement limits that are particularly serious for the smaller vibrators. Moving element cooling of the strongest types of these vibrators is difficult, which may be a problem if the same vibrator is to be used for sine and random testing as well as for impulse testing.

3.15
spill-over

undesired vibration (or signal) in the frequency range higher than the specified frequency range

EXAMPLE For vibration tests specified only to 2 000 Hz, spill-over is vibration excitation above 2 000 Hz.

NOTE Typically, spill-over is caused by loose elements of the moving element or test load, inadequate filtering, or by excessive current distortion.

3.16
distortion

undesired change in the waveform

[ISO 2041:1990]

NOTE 1 Distortion is distinguished from noise and hum, which are dealt with separately in this International Standard.

NOTE 2 For a good electrodynamic vibration generating system, the presence of distortion is a very sensitive indication that something is wrong. Excessive distortion is a signal calling for corrective action. The user is advised to find the problem, and correct it, before running an environmental test that would be invalid. The cause of the distortion may be anywhere, including a loose bolt mounting the specimen to the table, a failed amplifier output transistor, an obstruction in a cooling system, or an attempt to drive the amplifier or vibrator beyond its limits.

NOTE 3 For properly maintained electrodynamic vibration generation systems, a major cause of distortion is non-linearity or clipping in the power amplifier. Some of the low frequency distortion, below 50 Hz to 100 Hz, is typically caused by suspension stiffness non-linearity and/or the non-uniformity of the field in the magnetic gap. In this frequency range, these distortions can exceed those due to power amplifier non-linearity.

NOTE 4 The distortion process generates harmonics of the input signal which excite higher frequency resonances of the specimen. Both distortion products in the operating band, typically 20 Hz to $f_{\max}$, and distortion products which cause excitation above $f_{\max}$ are troublesome (see 3.15).

NOTE 5 Distortion may be specified for any variable of the system: current, voltage, acceleration, velocity or displacement. Current distortion is the most useful distortion measure for vibration test systems. It is used to predict system distortion and spill-over.

NOTE 6 It is tempting to specify the measurement of acceleration distortion directly, but such a measurement is unique to the particular moving element/load combination being measured, and does not provide data that are useful for the prediction of distortion with other table loads.

3.17
standard acceleration due to gravity
g_{n}
value for the acceleration due to gravity as defined for shock and vibration use in ISO 2041

NOTE 1 According to ISO 2041, g_{n} equals 9,806 65 m/s^2.

NOTE 2 In vibration testing, acceleration magnitude is often expressed as a multiple of g_{n}.

4 Structure of this International Standard

4.1 General

Clauses on the electrodynamic vibration generator, power amplifier and system as a whole include subclauses giving information that the specification writer may include in his relevant specification for the acquisition of a complete system or for components of a system.

A single relevant specification is unlikely to include all of the subclauses. For example, if only an amplifier is to be acquired, some of the system subclauses are not necessary, and only a few of the vibrator subclauses are needed for interface information. It is suggested that the writer of a specification read the entire standard before selecting the subclauses needed for a particular application.

4.2 Subclause coding

A code appears after the title of each subclause as an aid to the reader and to the writer of relevant specifications. This code has the form **(X,y)**.

The entry at position **X** specifies the type of acquisition for which the subclause is applicable:

- **A** for all acquisitions,
- **S** only for system acquisitions, and

- **C** only if a component, vibrator or amplifier, is being acquired, but not if both are being acquired.

The entry at position **y** specifies the type of use for which the subclause is applicable:

- **a** for all,
- **s** for sine,
- **r** for random, and
- **i** for impulse.

4.3 Symbol coding

Symbols used frequently in the text are coded as $K_{\mathrm{g,h}}$:

- symbol K means F for force, t for time to temperature stabilization, I for current, V for voltage, Z for amplifier load, and d for distortion;
- subscript g means s for system, v for vibration generator, and a for amplifier;
- subscript h means s for sine, r for random, and i for impulse.

5 Systems

5.1 General

The performance of both vibrators and amplifiers deteriorates as the operating temperature increases. When performance is specified for continuous operation, as is typical for sine and random testing, the performance tests shall be taken after a conditioning heat run to stabilize the temperature of the equipment. Exceptions to continuous operation shall be clearly stated. For example, not all air-cooled systems will operate at high altitudes. Also, for some vibrators, overheating and failure will occur if continuous sine operation is attempted at certain pedestal to body suspension resonances or certain body to moving element suspension resonances.

5.2 System specifications (S,a)

The major characteristic to be specified for an electrodynamic vibration generator system is its force-generation capability for the desired type of use (sine, random or impulse). Be sure to include the mass of the necessary fixtures when calculating the needed force.

The system force generation capabilities shall be specified as follows:

- for sine operation, the specified system force capability with test masses m_{10} and m_{40} is $F_{\mathrm{s,s}}$ (see 5.3.2 and 5.4.2);
- for random operation, the specified system force capability with test masses m_{10} and m_{40} and acceleration spectral density shape of 3.13 is $F_{\mathrm{s,r}}$ (see 5.3.3 and 5.4.3);
- for impulse operation, the specified system force capability with test masses m_{10} and m_{40} is $F_{\mathrm{s,i}}$ (see 5.3.4 and 5.4.4); the impulse acceleration time history to be produced (see 8.6) shall also be specified.

If the power amplifier of the system is large, the system force capability and the vibrator force capability are the same.

If the power amplifier is small, the system force capability is less than the force capability of the vibrator.

The system performance tests (see 5.3) apply if the system is to be acquired and tested as a whole, including both the power amplifier and the electrodynamic vibration generator. Typically this is the situation when both the vibration generator and the power amplifier are acquired together from the same source.

When the system is to be acquired as a whole, particularly when the capabilities of the amplifier match the requirements of the vibrator, the system performance tests provide an adequate test of the performance of the amplifier and the vibrator, and individual tests on the amplifier and the vibrator (as components) are not required.

If, however, it is probable that the vibrator will be used with other amplifiers, or that the amplifier is likely to be used with other vibrators, now or in the future, the individual performances of the vibrator and the amplifier should be specified (see 6.2 and 7.3).

Optionally, it may be specified that no-load maximum acceleration current-to-acceleration distortion or fuzz of the vibrator shall not exceed X %, where X typically is 1 to 3 for general-purpose vibration generators used for wide bandwidth sine/random testing. A larger value for X may be allowable for many uses of long stroke vibration generators, particularly those with rolling element guidance.

The system performance tests apply if the components are purchased from the same source.

When the system is to be assembled from components, the components shall be individually specified and tested (see 6.1 to 6.3; 7.1 to 7.3).

When the test procedures are used, the acquisition of accurate interface data from the two sources and the calculation of the system forces shall also be specified.

5.3 System performance

5.3.1 General (S,a)

System performance includes

- force capability for continuous operation (see 8.2),
- displacement capability, between mechanical stops,
- allowable velocity, and
- reliable operation.

The endurance tests (see 8.3) provide some assurance of reliable operation.

The system performance test report shall give the information listed in 5.3.2 to 5.3.4.

5.3.2 System sine performance (S,s)

For the system sine conditioning run (see 8.2.1 and 8.2.2) at the force $F_{\mathrm{s,s}}$ and with the test mass m_{10}, provide the time to temperature stabilization, $t_{\mathrm{s,s}}$, and any abnormalities or deviations from an uneventful run.

For the system sine endurance test (see 8.3) at the force $F_{\mathrm{s,s}}$, provide the actual time duration of the endurance test (at least 10 $t_{\mathrm{s,s}}$ unless otherwise specified). During the test, measure and report the temperatures of the vibrator body iron, moving element, vibrator cooling air/water/oil, room ambient air, coolant-to-vibrator cooling system, cooling air/water to the amplifier and amplifier cooling system, and the maximum and minimum values of the main power voltage. Also provide a description of any abnormalities or deviations from an uneventful test and the results of an after-test inspection to determine if any changes or damage to the vibrator, vibrator cooling system, amplifier or amplifier cooling system have occurred.

Ensure that the system achieves the manufacturer's rated displacement and velocity.

Measure the spill-over acceleration and ensure that the limit specified in 8.4 has not been exceeded.

5.3.3 System random performance (S,r)

For the system random conditioning run (see 8.2.1 and 8.2.3) at the force $F_{\mathrm{s,r}}$ and with the test mass m_{10}, provide the time to temperature stabilization $t_{\mathrm{s,r}}$ and any abnormalities or deviations from an uneventful run.

For the system random endurance test (see 8.3) at the force $F_{\mathrm{s,r}}$, provide the actual time duration of the endurance test (at least 10 $t_{\mathrm{s,r}}$ unless otherwise specified). During the test, measure and report the temperatures of the vibrator body iron, moving element, vibrator cooling air/water/oil, room ambient air, coolant-to-vibrator cooling system, cooling air/water to the amplifier and amplifier cooling system, and the maximum and minimum values of the main power voltage. Also provide a description of any abnormalities or deviations from an uneventful test and the results of an after-test inspection to determine if any changes or damage to the vibrator, vibrator cooling system, amplifier or amplifier cooling system have occurred.

If the manufacturer's rated random displacement and/or velocity are greater than the sine performance rating, confirm that the rated random values have been achieved.

Measure the spill-over acceleration and ensure that the limit specified in 8.3 has not been exceeded.

5.3.4 System impulse performance (S,i)

The system impulse time history test requires generation of the specified acceleration time history by the procedure of 8.6.

For the system impulse endurance test (see 8.3.6) with the mass m_{10}, provide the actual time duration of the system impulse endurance test (at least $10\,t_{\mathrm{s,s}}$ unless otherwise specified), the impulse acceleration time histories at both the start and the end of the tests, any abnormalities or deviations, and the results of an after-test inspection to determine if any changes or damage to the vibrator or amplifier have occurred.

For the system impulse endurance test with the mass m_{40}, provide the actual time duration of the system impulse endurance test (at least $10\,t_{\mathrm{s,s}}$ unless otherwise specified), the impulse acceleration time histories at both the start and the end of the tests, any abnormalities or deviations, and the results of an after-test inspection to determine if any changes or damage to the vibrator or amplifier have occurred.

If the manufacturer's rated impulse displacement and/or velocity are greater than the sine performance rating, confirm that the rated impulse values have been achieved.

Measure the spill-over acceleration and confirm that the limit specified in 8.4 has not been exceeded.

5.4 Calculated system performance

5.4.1 General (C,a)

The calculated system performance requires the amplifier current and voltage capabilities as specified in 7.1 and confirmed by test in 7.3.

Also required are the vibrator force capabilities as specified in 6.1 and confirmed by test in 6.2.

Also required are the vibrator drive requirements as measured in 6.3.

5.4.2 Calculated system sine performance (C,s)

Referring to the amplifier capabilities and the vibrator requirements, two ratios are calculated:

$$K_{\mathrm{i,s}} = \frac{I_{\mathrm{a,s}}}{I_{\mathrm{v,s}}} \quad \text{and} \quad K_{\mathrm{v,s}} = \frac{V_{\mathrm{a,s}}}{V_{\mathrm{v,s}}}$$

The available system force is $F_{\mathrm{s,s}} = K\,F_{\mathrm{v,s}}$, where K is the smaller of $K_{\mathrm{i,s}}$ or $K_{\mathrm{v,s}}$, but is not greater than 1.

5.4.3 Calculated system random performance (C,r)

Referring to the amplifier capabilities and the vibrator requirements, two ratios are calculated:

$$K_{\mathrm{i,r}} = \frac{I_{\mathrm{a,r}}}{I_{\mathrm{v,r}}} \text{ and } K_{\mathrm{v,r}} = \frac{V_{\mathrm{a,r}}}{V_{\mathrm{v,r}}}$$

The available system force is $F_{\mathrm{s,r}} = K\ F_{\mathrm{v,r}}$, where K is the smaller of $K_{\mathrm{i,r}}$ or $K_{\mathrm{v,r}}$, but is not greater than 1.

5.4.4 Calculated system impulse performance (C,i)

Referring to the amplifier capabilities and the vibrator requirements, two ratios are calculated:

$$K_{\mathrm{i,i}} = \frac{I_{\mathrm{a,i}}}{I_{\mathrm{v,i}}} \text{ and } K_{\mathrm{v,i}} = \frac{V_{\mathrm{a,i}}}{V_{\mathrm{v,i}}}$$

The available system force is $F_{\mathrm{s,s}} = K\ F_{\mathrm{v,s}}$, where K is the smaller of $K_{\mathrm{i,i}}$ or $K_{\mathrm{v,i}}$, but is not greater than 1.

6 Electrodynamic vibration generators

6.1 Vibration generator specification (C,a)

The major characteristic to be specified for an electrodynamic vibration generator is its force-generation capability for the desired type of use (sine, random or impulse). Be sure to include the mass of the required support fixtures when calculating the force needed.

The vibration generator force generation capabilities shall be specified as follows:

- for sine operation, the specified vibrator force capability with test masses m_{10} and m_{40} is $F_{\mathrm{v,s}}$ (see 6.2.2);
- for random operation, the specified vibrator force capability with test masses m_{10} and m_{40} and with the acceleration density spectral shape of 3.13 is $F_{\mathrm{v,r}}$ (see 6.2.3);
- for impulse operation, the specified vibrator force capability with test masses m_{10} and m_{40} is $F_{\mathrm{v,i}}$ (see 6.2.4); the impulse acceleration time history to be produced (see 8.6) shall also be specified.

These vibrator maximum force capabilities are available when the vibrator is driven with an amplifier of adequate size. In this International Standard, this amplifier is described as a large amplifier to distinguish it from the amplifier to be used with the vibrator in the actual system, which may have limitations which preclude the availability of these vibrator maximum force capabilities.

If the vibrator is acquired in a system, the vibration generator force generation capabilities shall be specified. The system tests confirm that the vibrator performance is adequate for the system force specified for each type of use.

Optionally, testing of the vibrator as a component may be specified, which is particularly important if the initial system includes an amplifier significantly smaller than the large amplifier, and if a future increase of amplifier size may occur.

Optionally, the maximum value of the full current-to-acceleration distortion may be provided (see 6.3.2).

6.2 Vibration generator performance

6.2.1 General (C,a)

Vibrator performance includes

- force capability for continuous operation (see 8.2),
- displacement capability, between mechanical stops,
- allowable velocity, and
- reliable operation.

The endurance tests (see 8.3) provide some assurance of reliable operation.

The performance of this clause is specified for a vibrator to be acquired as a component. Optionally, it may be specified for a vibrator to be acquired in a system.

This performance is demonstrated with a large amplifier. The performance test report shall provides the information listed in 6.2.2 to 6.2.4.

6.2.2 Vibrator sine performance (C,s)

For the vibrator sine conditioning run (see 8.2.1 and 8.2.2) at the force $F_{\mathrm{v,s}}$ and with the test mass m_{10}, provide the time to temperature stabilization $t_{\mathrm{v,s}}$ (see 8.2.2) and any abnormalities or deviations.

Immediately after the sine conditioning run, take the data of 6.3.2 using the mass m_{10}.

Change the test mass to m_{40}, repeat the conditioning run until the same temperatures are achieved, and take the data of 6.3.2 using the mass m_{40}.

For the vibrator sine endurance test (see 8.3) at the force $F_{\mathrm{v,s}}$, provide the actual time duration of the endurance test (at least 10 $t_{\mathrm{v,s}}$ unless otherwise specified). During the test, measure and report the temperatures of the vibrator body iron, moving element, vibrator cooling air/water/oil, room ambient air, and the coolant-to-vibrator cooling system. Also provide a description of any abnormalities or deviations and the results of an after-test inspection to determine if any changes or damage to the vibrator or vibrator cooling system have occurred.

Confirm that the vibrator achieves the manufacturer's rated displacement and velocity.

6.2.3 Vibrator random performance (C,r)

For the vibrator random conditioning run (see 8.2.1 and 8.2.3) at the force $F_{\mathrm{v,r}}$ and with the test mass m_{10}, provide the time to temperature stabilization $t_{\mathrm{v,r}}$ (see 8.2.3) and report any abnormalities or deviations.

Immediately after the random conditioning run, take the data of 6.3.4 using the mass m_{10}.

Change the test mass to m_{40}, repeat the conditioning run until the same temperatures are achieved, and take the data of 6.3.4 using the mass m_{40}.

For the vibrator random endurance test (see 8.3) at the force $F_{\mathrm{v,r}}$, provide the actual time duration of the endurance test (at least 10 $t_{\mathrm{v,r}}$ unless otherwise specified). During the test, measure and report the temperatures of the vibrator body iron, moving element, vibrator cooling air/water/oil, room ambient air, and coolant-to-vibrator cooling system. Also provide a description of any abnormalities or deviations and the results of an after-test inspection to determine if any changes or damage to the vibrator or vibrator cooling system have occurred.

If the manufacturer's rated random displacement and/or velocity are greater than the sine performance rating, confirm that the rated random values have been achieved.

6.2.4 Vibrator impulse performance (C,i)

The vibrator impulse time history test requires the generation of the specified acceleration time history by the procedure of 8.6.

Provide the m_{10} vibrator impulse current and voltage time history waveforms for the specified acceleration time history with the test mass m_{10}.

Provide the m_{40} vibrator impulse current and voltage time history waveforms for the specified acceleration time history with the test mass m_{40}.

For the vibrator impulse endurance test with the mass m_{10}, provide the actual time duration of the vibrator impulse endurance test (at least $10\,t_{\mathrm{v,s}}$ unless otherwise specified), the impulse acceleration time histories at both the start and the end of the test, any abnormalities or deviations, and the results of an after-test inspection to determine if any changes or damage to the vibrator have occurred.

For the vibrator impulse endurance test with the mass m_{40}, provide the actual time duration of the vibrator impulse endurance test (at least $10\,t_{\mathrm{v,s}}$ unless otherwise specified), the impulse acceleration time histories at both the start and the end of the test, any abnormalities or deviations from an uneventful test, and the results of an after-test inspection to determine if any changes or damage to the vibrator have occurred.

If the manufacturer's rated impulse displacement and/or velocity are greater than the sine performance rating, confirm that the impulse values have been achieved.

6.3 Vibrator drive requirements

6.3.1 General (C,a)

With the vibrator driven with a large amplifier, the vibrator current and voltage drive requirements shall be provided at the full specified vibrator forces for the specified types of use (sine, random and/or impulse).

The vibrator drive requirements of this clause are specified for a vibrator to be acquired as a component. Optionally, they may be specified for a vibrator to be acquired in a system.

6.3.2 Vibrator sine drive requirements (C,s)

Immediately after the sine conditioning run (see 6.2.2, 8.2.1 and 8.2.4) with the test mass m_{10}, make a one octave per minute sweep at the full specified displacement, velocity, and $F_{\mathrm{v,s}}$ force in the agreed frequency range. Provide the acceleration at the top centre of the test load, the drive coil root-mean-square current, and the drive coil root-mean-square voltage for the calculation of the m_{10} curves of 6.3.3.

Change the test mass to m_{40}, repeat the conditioning run until the same temperatures are achieved, and run another one octave per minute sweep at the full specified displacement, velocity, and $F_{\mathrm{v,s}}$ force, in the agreed frequency range. Provide the acceleration at the top centre of the test load, the drive coil root-mean-square current, and the drive coil root-mean-square voltage for the calculation of the m_{40} curves of 6.3.3.

The maximum current required for either sweep is the vibrator sine current requirement $I_{\mathrm{v,s}}$ for the force $F_{\mathrm{v,s}}$. The maximum voltage required for either sweep is the vibrator sine voltage requirement $V_{\mathrm{v,s}}$ for the force $F_{\mathrm{v,s}}$.

Remove the test load, repeat the conditioning run until the same temperatures are achieved, and run another one octave per minute sweep at the full specified displacement, velocity, and force $F_{\mathrm{v,s}}$, in the agreed frequency range. Provide the moving element acceleration, the drive coil root-mean-square current, and the drive coil root-mean-square voltage for the m_0 curves of 6.3.3.

Carry out a signal purity test (fuzz test). During this no-load run, carefully listen to the acoustic output of the vibrator and observe the motion by an oscilloscope display to detect any noise, distortion, or bunches of a high-frequency signal (fuzz) on the acceleration wave. Any fuzz or distortion over 2 % of the acceleration fundamental shall be reported. A common cause of no-load fuzz is a poor or loose connection on the moving element or moving element suspension.

6.3.3 Vibrator transfer function curves (C,s)

Provide the current-to-acceleration $H_{\mathrm{i}}(f)$ and voltage-to-acceleration $H_{\mathrm{v}}(f)$ transfer function curves for the vibrator with masses m_0, m_{10} and m_{40}, similar to those illustrated in Figure 1, from the data of 6.3.2.

These curves are for a temperature-stabilized vibrator, and are most useful for sine and random testing. If required, similar curves may be specified for a cold vibrator, as is most useful as a starting point for impulse testing. As a rough approximation, the cold condition curves may be approximated from the hot curves: For $H_{\mathrm{i}}(f)$, multiply the entire curve by 1,05. For $H_{\mathrm{v}}(f)$, multiply the midband values by 1,25, tapering to 1,0 at f_{s} and f_{t}.

6.3.4 Vibrator random drive requirements (C,r)

At the end of the random conditioning run (see 6.2.3, 8.2.1 and 8.2.3) at the vibrator specified random force $F_{\mathrm{v,r}}$ with the test mass m_{10} and the acceleration spectral density shape of 3.13, provide the driver coil root-mean-square random current and root-mean-square random voltage.

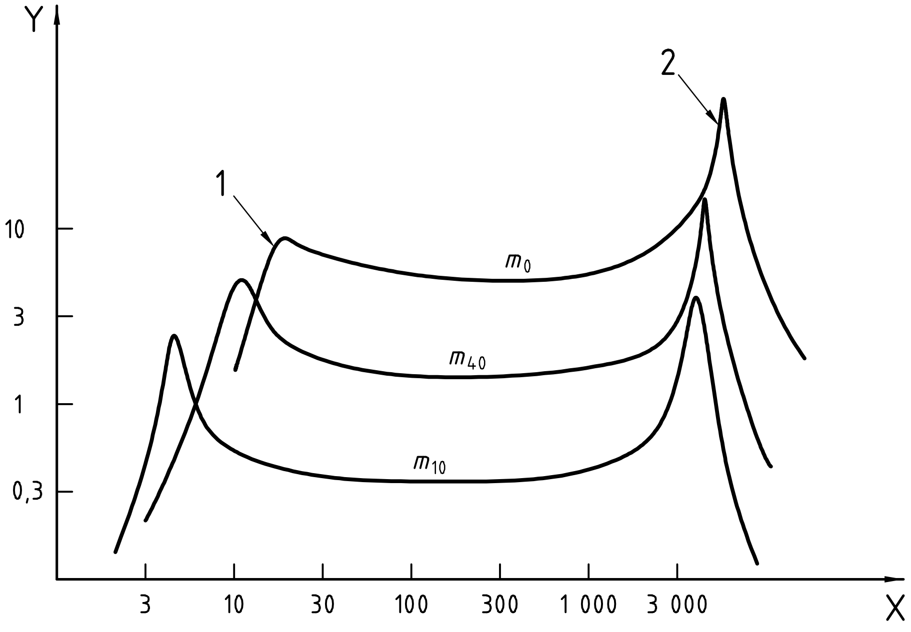
Change the test mass to m_{40}, repeat the random conditioning run at the vibrator specified random force $F_{\mathrm{v,r}}$ and the acceleration spectral density shape of 3.13, until the same temperatures are achieved, and provide the driver coil root-mean-square random current and root-mean-square random voltage.

The maximum current required for either conditioning run is the vibrator random current requirement $I_{\mathrm{v,r}}$ for the force $F_{\mathrm{v,r}}$. The maximum voltage required for either conditioning run is the vibrator random voltage requirement $V_{\mathrm{v,r}}$ for the force $F_{\mathrm{v,r}}$.

6.3.5 Vibrator impulse drive requirements (C,i)

The vibrator impulse current requirement $I_{\mathrm{v,i}}$ for the impulse force $F_{\mathrm{v,i}}$ is the m_{40} vibrator impulse current time history of 6.2.4, unless m_{10} is specified (see 8.6).

The vibrator impulse voltage requirement $V_{\mathrm{v,i}}$ for the impulse force $F_{\mathrm{v,i}}$ is the m_{40} vibrator impulse voltage time history of 6.2.4, unless m_{10} is specified (see 8.6).



Key

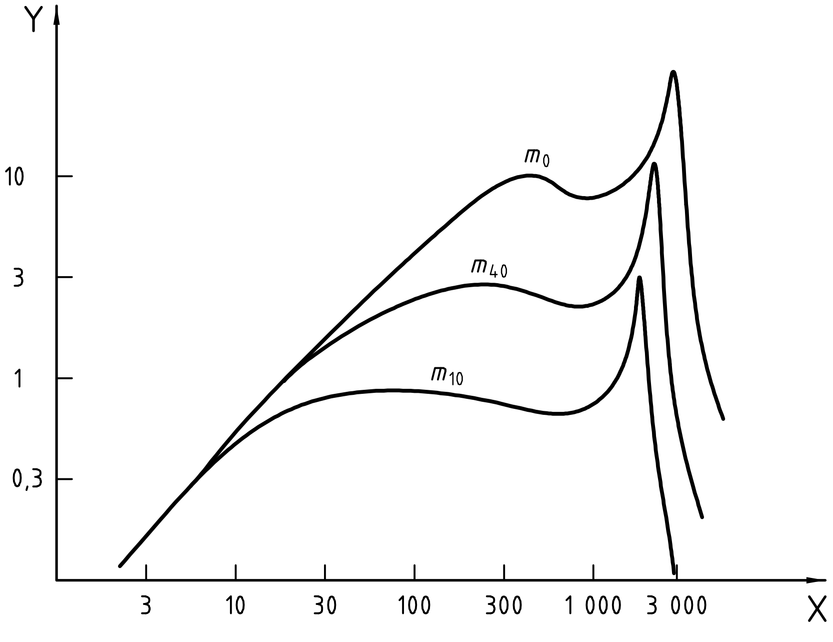
X frequency, Hz

Y transfer function, m/(s^2·A)

1 mechanical resonance of moving element suspension

2 mechanical resonance of moving elements

a) **Acceleration per unit current in the drive coil**



Key

X frequency, Hz

Y transfer function, m/(s^2·V)

b) **Acceleration per unit voltage across the drive coil**

Figure 1 — Typical electrodynamic vibration generator transfer functions

6.4 Vibrator maintenance (A,a)

Vibrator maintenance is required if the vibrator is to continue to provide the specified performance.

Recommended periodic care includes the inspection and/or replacement of air, water and oil filters, water electrodes, distilled water, water tower water/glycol, flexible cables and hoses to the vibrator, to the field coils and to the moving element, and the removal of accumulated dust and dirt, particularly in the cooling air path.

Recommended periodic care also includes inspection and/or repair of the body-to-moving element suspension/guidance, and load-to-moving element mounting point inserts.

Vibrator maintenance is particularly required if the acceleration waveform differs significantly from the current waveform. Such differences are usually caused by cavitations in the liquid coolant or loose parts associated with the moving element and failure typically follows.

For a vibrator in regular use, it is suggested that no-load, maximum acceleration, slow sine sweeps be scheduled monthly, with the results recorded. See the fuzz test of 6.3.2. A properly maintained vibrator should not introduce distortion or fuzz into the acceleration waveform. A month-to-month degradation of performance, especially an increase of no-load fuzz, suggests the need for preventive maintenance.

Vibrator maintenance should be provided by qualified personnel.

7 Power amplifiers

7.1 Amplifier specification (C,a)

7.1.1 Main characteristics

The amplifier current and voltage capabilities shall be specified as follows:

- for sine operation, the specified amplifier current is $I_{\mathrm{a,s}}$ and voltage is $V_{\mathrm{a,s}}$ (see 7.2.2);
- for random operation, the specified amplifier current is $I_{\mathrm{a,r}}$ and voltage is $V_{\mathrm{a,r}}$ (see 7.2.3);
- for impulse operation, the specified amplifier current is $I_{\mathrm{a,i}}$ and voltage is $V_{\mathrm{a,i}}$.

Unless otherwise specified, the specified impulse current time history $I_{\mathrm{a,i}}$ is the specified vibrator drive coil current time history when the vibrator is producing the desired acceleration time history with the mass m_{40} (see 7.2.4 and 8.6).

7.1.2 Minimum size amplifier

If a system is being acquired for a specific type of use (sine, random and/or impulse) and if only the minimum size amplifier for that type of use is required, the size of the amplifier need not be specified. It is understood that the specified amplifier current and voltage are the maximum required current and voltage for the specified vibrator at the specified force for the specified type of use.

The system tests confirm that the amplifier performance is adequate. Optionally, testing of the amplifier as a component may be specified.

The minimum amplifier size is that needed for the desired system force with the specified vibrator. For each type of use, the amplifier current and voltage are specified, which should equal the maximum required vibrator current and voltage for the specified force.

Optionally, an oversize amplifier may be specified. For each type of use, the amplifier current and voltage shall be specified, which should be equal to or larger than the maximum required vibrator current and voltage for the specified force.

If an oversize amplifier is being acquired in a system, the system testing confirms only the minimum amplifier size. The amplifier shall also be tested as a component.

NOTE Amplifier size is frequently designated in terms of power, or apparent power, or kVA, i.e. terms which suggest a size equal to the product of output current and output voltage. None of these terms is useful to designate the size of an amplifier for an electrodynamic vibrator system. More guidance would be provided by a list of the four most critical parameters, where $I_{\mathrm{a,s}}$ and $V_{\mathrm{a,s}}$ are the values of sinusoidal current and voltage available, and $I_{\mathrm{a,r}}$ and $V_{\mathrm{a,r}}$ are the values of random current and voltage available, with the amplifier loaded with the inductive loads of 7.2.

7.1.3 Impedance matching

Not all vibrators operate at the same impedance level. Some require high currents and low voltages and others require low currents and high voltages. The use of impedance-matching transformers should be explored before writing a specification for an amplifier to be switched from one vibrator to another.

7.2 Amplifier test loads

7.2.1 General (C,a)

Amplifier test loads are used to test the amplifier as a component. They are expensive to construct, so they are usually used only when an appropriate vibrator is not available.

Resistive test loads are not suitable for the testing of amplifiers to drive vibrators. For either a linear amplifier or a switching amplifier, resistive loads do not simulate the internal dissipation of the amplifier in normal use. Some switching amplifiers require an inductive load for proper operation.

Unless otherwise specified, the values of the resistive and inductive components of the amplifier test loads are selected such that the current lags the voltage by 60° ± 3 %.

The amplifier sine and random test loads should be provided with cooling adequate to maintain both the resistive and inductive components of the impedance within 3 % of the specified impedance during all tests. For the larger sizes, circulating water cooling is typically used. The cooling requirements are usually determined by the requirements of the conditioning and endurance tests (see 8.2.1 and 8.3.1).

In the middle of an amplifier's frequency range, its operation is not frequency sensitive. This makes it possible to use the same inductor for both the amplifier sine test load and the amplifier random test load by changing the test frequency.

The amplifier impulse test load has different requirements from the amplifier sine and random test loads (see 7.2.4 and 8.6). The cooling problems are less severe, but the amplifier impulse test load impedance shall match the inductance and resistance of the vibrator.

7.2.2 Amplifier sine test load (C,s)

To make sure that the amplifier can provide, at the same time, under the most adverse loading, both an adequate voltage output and an adequate current output, the amplifier sine test load shall have an impedance

$$Z_{\mathrm{a,s}} = \frac{V_{\mathrm{a,s}}}{I_{\mathrm{a,s}}}$$

when driven with a sinusoidal current at a frequency between 200 Hz and 1 000 Hz.

7.2.3 Amplifier random test load (C,r)

To make sure that the amplifier can provide, at the same time, under the most adverse loading, both an adequate voltage output and an adequate current output, the amplifier random test load shall have an impedance

$$Z_{\mathrm{a,r}} = \frac{V_{\mathrm{a,r}}}{I_{\mathrm{a,r}}}$$

when driven with a narrow-band random current at a centre frequency between 200 Hz and 1 000 Hz.

The filter used to generate the narrow-band random signal shall have a bandwidth b of between 3 % and 5 % of the centre frequency, and skirts steep enough that the signals at frequency multiples are at least 50 dB below the centre frequency signal. The demodulation filter shall have a time constant greater than $300/b$.

The narrow-band random current $I_{\mathrm{a,r}}$ and narrow-band random voltage $V_{\mathrm{a,r}}$ used with the amplifier random test load $Z_{\mathrm{a,r}}$ shall have the same magnitudes as the wide-band random current and voltage used to drive the vibrator to the acceleration spectral density shape of 3.13.

7.2.4 Amplifier impulse test load (C,i)

The design and fabrication of the amplifier impulse test load requires prior generation of the desired impulse acceleration time history by the procedure of 8.6, and the measurement and recording of the required vibrator current and voltage time histories.

Before fabricating the actual impulse test load, measure the response of a simulated impulse test load and optimize the simulated load. Apply a low level scaled version of the required vibrator voltage time history to the amplifier with a simulated series resistance-inductance load and measure the load voltage and current time history. Adjust the values of the simulated resistance and the simulated inductance until the load voltage and current peaks, and the low frequency voltage and current wave shape are the same as for the simulated vibrator voltage and current time histories. An exact match over the entire vibrator voltage time history may not be possible because the vibrator inductance and resistance vary with frequency.

From the optimized simulated load, an actual impulse test load is calculated and fabricated. It has the value $Z_{\mathrm{a,i}}$.

Since force is proportional to current, it is important that the current time history be accurately reproduced. It is important that the peak voltage be reproduced, because the reproduction of voltage peaks without clipping is a primary amplifier requirement for impulse production.

The $I_{\mathrm{a,i}}$ value used with $Z_{\mathrm{a,i}}$ is the specified $I_{\mathrm{a,i}}$ of 7.1.1, which has the same current time history as measured and recorded with the vibrator producing the desired impulse acceleration time history. The $V_{\mathrm{a,i}}$ value used with $Z_{\mathrm{a,i}}$ is the specified $V_{\mathrm{a,i}}$ of 7.1.1, which has the same voltage peak and low frequency wave shape as the vibrator recorded voltage time history, but may not have the same wave shape over the entire time history.

7.3 Amplifier performance

7.3.1 General (C,a)

Amplifier performance includes

- current and voltage capability for continuous operation (see 8.2),
- satisfactory distortion and spill-over (see 8.4 and 8.5), and
- reliable operation.

The endurance tests of 8.3 provide some assurance of reliable operation.

This performance is demonstrated for the specific amplifier being acquired. The performance test report includes the following.

7.3.2 Amplifier sine performance (C,s)

For the amplifier sine conditioning run (see 8.2) with the amplifier test load $Z_{\mathrm{a,s}}$ (see 7.2.2) and the specified root-mean-square sine current $I_{\mathrm{a,s}}$ and voltage $V_{\mathrm{a,s}}$ (see 7.1.1), provide the time to temperature stabilization $t_{\mathrm{a,s}}$ (see 8.2.4) and any abnormalities or deviations from an uneventful conditioning run.

For the amplifier sine distortion test (see 8.5) for the amplifier with the amplifier test load $Z_{\mathrm{a,s}}$ at the specified root-mean-square current and voltage, provide the total amplifier sine distortion $d_{\mathrm{a,s}}$ (see 8.5.5) and the magnitude of each harmonic component in excess of 1,0 %. Distortion in excess of the spill-over limits of 8.4 shall be noted.

For the amplifier sine endurance test (see 8.3) for the amplifier with the amplifier test load $Z_{\mathrm{a,s}}$ at the specified root-mean-square current and voltage, provide the actual time duration of the endurance test (at least $10\,t_{\mathrm{a,s}}$ unless otherwise specified). Provide the minimum and maximum temperatures of the cooling air/water to the amplifier and amplifier cooling system, minimum and maximum values of the mains power voltage, any abnormalities or deviations, and the result of an after-test inspection to determine if any changes or damage to the amplifier or amplifier cooling system have occurred.

7.3.3 Amplifier random performance (C,r)

For the amplifier random conditioning run (see 8.2) with the amplifier test load $Z_{\mathrm{a,r}}$ (see 7.2.3) and the specified root-mean-square narrow-band random current $I_{\mathrm{a,r}}$ and voltage $V_{\mathrm{a,r}}$ (see 7.1.1, 7.2.3), provide the time to temperature stabilization $t_{\mathrm{a,r}}$ (see 8.2.3) and any abnormalities or deviations from an uneventful conditioning run.

For the amplifier random distortion test (see 8.5) for the amplifier with the amplifier test load $Z_{\mathrm{a,r}}$ at the specified root-mean-square narrow-band random current and voltage, provide the total amplifier random distortion $d_{\mathrm{a,r}}$ (see 8.5.5) and the magnitude of each harmonic component in excess of 1,0 %. Distortion in excess of the spill-over limits shall be reported.

For the amplifier random endurance test (see 8.3) for the amplifier with the amplifier test load $Z_{\mathrm{a,r}}$ at the specified root-mean-square narrow-band random current and voltage, provide the actual time duration of the endurance test (at least $10\,t_{\mathrm{a,r}}$ unless otherwise specified), the minimum and maximum temperatures of the cooling air/water to the amplifier and amplifier cooling system, minimum and maximum values of the mains power voltage, any abnormalities or deviations from an uneventful test, and the result of an after-test inspection to determine if any changes or damage to the amplifier or amplifier cooling system have occurred.

7.3.4 Amplifier impulse performance (C,i)

The amplifier impulse time history test requires prior generation of the desired impulse acceleration time history by the procedure of 8.6, measurement of the required vibrator driver coil current and voltage time histories, and the prior fabrication of the amplifier impulse test load $Z_{\mathrm{a,i}}$ by the procedure of 7.2.4.

In the amplifier impulse time history test, the specified impulse current time history $I_{\mathrm{a,i}}$ is applied to the impulse test load $Z_{\mathrm{a,i}}$. The impulse current and voltage time history waveforms are provided in the performance report.

For the amplifier impulse endurance test (see 8.3.7) for the amplifier delivering a repetitive sequence of specified impulse time histories $I_{\mathrm{a,i}}$ to the impulse test load $Z_{\mathrm{a,i}}$, provide the actual time duration of the impulse endurance test (at least $3\,t_{\mathrm{a,s}}$ unless otherwise specified), the impulse current and voltage time history waveforms at both the start and the end of the test, any abnormalities or deviations, and the results of an after-test inspection to determine if any changes or damages to the amplifier have occurred.

For the amplifier impulse distortion test (see 8.5) for the amplifier with the test load $Z_{\text{a,i}}$ with the gated sinusoidal wave train of 8.5.8, provide the total amplifier impulse distortion $d_{\text{a,i}}$ (see 8.5.9) and the magnitude of each harmonic component in excess of 1,0 %. Distortion in excess of the spill-over limits of 8.4 shall be reported.

7.4 Amplifier maintenance (A,a)

Amplifier maintenance is required if the amplifier is to continue to provide the specified performance. Recommended periodic care includes the replacement of air and water filters, water electrodes, distilled water, filter capacitors, hoses, water tower water/glycol, and the removal of accumulated dust and dirt, particularly near high voltage components and in cooling air passages.

For an amplifier in regular use, it is suggested that maximum output voltage distortion measurements be recorded monthly. Month-to-month degradation of performance suggests the need for preventive maintenance.

Maintenance should be provided by qualified personnel.

8 Tests and measurements

8.1 General

Tests to be specified and performed on systems, vibrators and amplifiers are described in Clauses 5, 6 and 7. This clause describes other considerations relating to these tests.

Prior to writing the purchase specification, the purchaser of the equipment and the source of that equipment, typically the manufacturer, need to reach an agreement as to the specific tests to be performed, and acceptable test reports provided, for the specific items of equipment to be purchased. For example, the purchaser may choose to accept reports describing the manufacturer’s endurance tests on a similar item of equipment as an acceptable alternative to the performance and reporting of specific endurance tests specified in Clauses 5, 6 or 7.

8.2 Conditioning before data runs

8.2.1 General

When performance is specified for continuous operation, as is typical, the performance data shall be taken immediately after a conditioning heat run to stabilize the temperature of the equipment.

Since the durations of impulse tests are short, impulse performance tests shall be taken on cold equipment (within 10 °C of room temperature) to maximize the available force.

Make conditioning heat runs with the equipment operating at maximum dissipation. For vibrator or system heat runs, this is at specified force, first with m_{10} and then with m_{40}. For an amplifier heat run, this is at specified current and voltage into $Z_{\text{a,s}}$ or $Z_{\text{a,r}}$ as appropriate.

Unless otherwise specified, cooling for the vibrator and amplifier shall be adjusted for typical warm weather conditions: low altitude air warmer than 35 °C and/or heat exchanger water warmer than 15 °C.

Make temperature measurements, preferably with adhered thermocouples, at two locations on the vibrator and two locations on the amplifier. On the vibrator, make measurements of the body iron temperature near the load attachment end, and of the moving element temperature near the load as near as is possible to the driver coil diameter. On the amplifier, make measurements of the power transformer iron temperature and of the output power transistor heat exchanger temperature.

To obtain the time to temperature stabilization, record temperatures as a function of time. Make calculations of the temperature rise rates, $\Delta T/\Delta t$, where T is the temperature and t is the time. The temperature rise rates will increase to maximum, then decrease. The time to temperature stabilization is defined as that time when all of the temperature rise rates have decreased to 5 % of their maximum values. The time to temperature stabilization is recorded for use as a time base for the endurance tests of 8.3. For a system or a vibrator, it is an adequate approximation that the time to temperature stabilization for m_{40} is the same as measured for m_{10}.

8.2.2 System or vibrator sine conditioning

Carry out conditioning at the sinusoidal specified force at the frequency of maximum dissipation, typically between 200 Hz and 300 Hz. The time to temperature stabilization is $t_{\mathrm{s,s}}$ or $t_{\mathrm{v,s}}$.

8.2.3 System or vibrator random conditioning

Carry out conditioning at specified random force, with the standard random spectral shape of 3.13. The time to temperature stabilization is $t_{\mathrm{s,r}}$ or $t_{\mathrm{v,r}}$.

8.2.4 Amplifier sine conditioning

Carry out conditioning with the specified sine current and sine voltage with the amplifier loaded with $Z_{\mathrm{a,s}}$. The time to temperature stabilization is $t_{\mathrm{a,s}}$.

8.2.5 Amplifier random conditioning

Carry out conditioning with the specified narrow band random current and voltage with the amplifier loaded with $Z_{\mathrm{a,r}}$. The time to temperature stabilization is $t_{\mathrm{a,r}}$.

8.3 Endurance tests

8.3.1 General

Endurance tests provide some assurance of reliability, but are not conclusive. Equipment that performs well during the following minimum endurance tests is unlikely to have major design or manufacturing flaws.

The duration of the sine and random endurance tests are 10 × the times to adequate temperature stabilization of the corresponding conditioning tests of 8.2.1. The vibrator or system endurance test is performed first with the test mass m_{10} and then with the test mass m_{40}.

When the times to temperature stabilization, $t_{\mathrm{g,h}}$, are large, the endurance test times may be limited to the shorter of $10\,t_{\mathrm{g,h}}$ or 25 h after temperature stabilization. The writer of the relevant specification may include a requirement that the source provide a report describing all endurance test procedures, all results, current and voltage waveforms at the start and end of the tests, and any abnormalities or deviations from an uneventful run.

As in 8.2.1, unless otherwise specified, the environment is adjusted for typical warm weather, low altitude conditions.

8.3.2 System or vibrator sine endurance test

This test is a repetitive sequence of cycles. Each cycle is composed of a 30-min run at full specified force at maximum dissipation, as in 8.2.1, followed by a one octave per minute sweep at the specified displacement, velocity, and force from f_{min} to f_{max}. Repeat the cycles for an endurance test duration of not less than $10\,t_{\mathrm{s,s}}$ or $10\,t_{\mathrm{v,s}}$ (see 8.2.2) for the test mass m_{10} and again for the test mass m_{40}.

8.3.3 System or vibrator random endurance test

Carry out this test at the specified random force, with the standard random spectral shape of 3.13, for an endurance test duration not less than $10\,t_{\mathrm{s,r}}$ or $10\,t_{\mathrm{v,r}}$ (see 8.2.3) for the test mass m_{10} and again for the test mass m_{40}.

8.3.4 Amplifier sine endurance test

Carry out this test with the specified sine current and voltage (see 7.1.1) with the amplifier loaded with $Z_{\mathrm{a,s}}$ for an amplifier endurance test duration not less than $10\,t_{\mathrm{a,s}}$ (see 8.2.4).

8.3.5 Amplifier random endurance test

Carry out this test with the specified narrow-band random current and voltage (see 7.1.1) with the amplifier loaded with $Z_{\mathrm{a,r}}$ for an amplifier random endurance test duration not less than $10\,t_{\mathrm{a,r}}$ (see 8.2.5).

8.3.6 System or vibrator impulse endurance test

The test is a repetitive sequence of cycles. At the start of each cycle, switch on the field supply and allow it to stabilize for about 1 min, then generate a single full-force impulse time history. Switch off the field supply off, and allow the vibrator allowed for 10 min to end the cycle. Repeat the sequence of cycles for a time duration of not less than $10\,t_{\mathrm{s,s}}$ or $10\,t_{\mathrm{v,s}}$ (see 8.22). Carry out the test first with the vibrator loaded with the test mass m_{10}, and again with the test mass m_{40} (see 8.6).

8.3.7 Amplifier impulse endurance test

The test is a repetitive sequence of cycles. Each cycle is an impulse at the specified amplifier impulse current and voltage time histories (see 7.1.1, 7.2.4 and 7.3.4), followed by a 1 min period for the amplifier to cool. Repeat the sequence of cycles for a time duration not less than $3\,t_{\mathrm{a,s}}$ (see 8.2.4). Carry out the test with the amplifier loaded with the load $Z_{\mathrm{a,i}}$ (see 7.2.4 and 8.6).

8.4 Spill-over limits

For system sine testing with masses and, unless otherwise specified, the maximum allowable current spill-over of any harmonic is 1 % of the maximum current below 2 000 Hz and the maximum allowable acceleration spill-over of any harmonic is 10 % of the maximum acceleration below 2 000 Hz.

For system random or impulse testing with masses m_{10} and m_{40}, unless otherwise specified, the maximum allowable random current spectral density (impulse current spectrum) spill-over above 2 000 Hz is

$$\Phi_{\mathrm{a}} = \Phi_{\mathrm{b}} \left(\frac{2\,000}{f}\right)^{4} \text{ or } 10^{-4}\Phi_{\mathrm{b}}$$

where Φ_{b} is the random current spectral density (impulse current spectrum) below 2 000 Hz.

For amplifier sine, random and impulse distortion testing with amplifier test loads $Z_{\mathrm{a,s}}$, $Z_{\mathrm{a,r}}$ and $Z_{\mathrm{a,i}}$, unless otherwise specified, the maximum allowable current spill-over of any harmonic is 1 % of the maximum current below 2 000 Hz.

8.5 Distortion tests

8.5.1 General

A major purpose of these distortion tests is to confirm that the system, vibrator and/or amplifier are adequate, i.e. large enough to generate the specified accelerations and/or currents and voltage. Distortion increases rapidly as excessive drive is attempted, and a distortion limit of 1 % to 3 % may be used as an indication of the maximum available output.

In 8.5.5 to 8.5.9, simplified techniques are used to provide reasonable estimates that the system and/or components is/are large enough, using amplifier test loads and simplified waveforms at frequencies, or in frequency bands, corresponding to normal worst-case conditions.

The distortion of any vibration test system variable, applicable for sinusoidal operation, and with limitation to random and impulse operation as well, is

$$d = \frac{\sqrt{\left(x_2^2 + x_3^2 + x_4^2 \ldots + x_n^2\right)}}{x_1}$$

where x_1 is the root-mean-square magnitude of the fundamental component and x_2, x_3, x_4,..., x_n are the root-mean-square magnitudes of the undesired harmonic components, where all of the harmonic components of significant magnitude are included.

NOTE 1 Some distortion measuring instruments replace the denominator by the total root-mean-square magnitude of the variable:

$$\left(x_1^2 + x_2^2 + x_3^2 + x_4^2 + \ldots + x_n^2\right)^{1/2}$$

Unless the distortion is large, typically 10 % or more, the difference between the two definitions is negligible.

NOTE 2 Some distortion measuring instruments include hum components in the numerator of the above equation, where hum components are at the fundamental, sub-multiples and multiples of fixed system frequencies, such as the power and switching frequencies. Although undesired, these hum components are not distortion in the above sense, and should be excluded from the measurement if any hum components are of significant magnitude to affect the value of d .

Make sine and random system distortion tests at the specified force after conditioning heat runs to stabilize the temperature of the equipment.

Carry out impulse system distortion tests at a specified force on equipment at room temperature, i.e. 20° to 40 °C.

Make sine, random and impulse system distortion tests with both test masses m_{10} and m_{40} . The larger of the two distortion measurements is the system distortion.

If, during measurements of system current distortion, the resonances of the moving element and load cause large distortion values, the input signal to the amplifier under rated conditions may be recorded, the vibrator field turned off, and the current distortion measurement repeated. If lower, it may be used.

Carry out amplifier sine and random distortion tests at the specified sine and random current after conditioning heat runs to stabilize the temperature of the amplifier.

Make amplifier impulse distortion tests at the specified impulse current with the amplifier at room temperature, i.e. 20 °C to 40 °C.

Distortion tests on the system are used to determine whether the system meets the spill-over limits of 8.4 and avoids undesired excitation in the operating band, typically 20 Hz to 2 000 Hz. Distortion tests on the power amplifier with test loads are primarily carried out to predict whether a system using the amplifier will meet the same limits.

In the following distortion measurements, d is calculated with adequate accuracy if only the harmonic components in excess of 0,3 % are included. Note that all harmonic components in excess of 1,0 % shall be reported. The output voltage of the amplifier shall be visually monitored during all distortion tests and all irregularities shall be reported. If voltage waveform clipping occurs, the circumstances resulting in such clipping shall be reported.

8.5.2 System sine distortion

System sine distortion $d_{\mathrm{s,s}}$ is a measure of the distortion of the acceleration at the top centre of the test mass measured with frequency tracking instrumentation over a one octave per minute sweep from f_{min} to f_{max}, utilizing a sinusoidal vibration control having adequate accuracy to keep the load acceleration from varying more than 3 % from the specified value.

System sine distortion should be measured at full specified displacement, velocity and force with the test mass m_{40}.

8.5.3 System sine distortion curves

If, during the sweep test of 8.5.2, the magnitude of any single harmonic of the system sine distortion exceeds 1 % of the maximum acceleration below f_{max}, curves showing the maximum values of the distortion components in the f_{min} to 10 000 Hz band shall be provided.

8.5.4 System sine acceleration distortion

System sine acceleration distortion is a measure of the distortion of the acceleration at the top centre of the test mass, measured as in 8.5.2.

8.5.5 Amplifier sine distortion

Amplifier sine distortion $d_{\mathrm{a,s}}$ is a measure of the amplifier current distortion with the load $Z_{\mathrm{a,s}}$. Drive the amplifier with a low distortion sinusoidal signal at a frequency between 200 Hz and 1 000 Hz where both full specified current and full specified voltage are obtained.

8.5.6 System random distortion

System random distortion $d_{\mathrm{s,r}}$ is a measure of the random acceleration distortion at the top centre of the test mass. Measure the distortion with a narrow-band random output at a frequency between 200 Hz and 1 000 Hz where the same root-mean-square current, root-mean-square voltage, and gaussian distribution of amplitudes occur as for the system-specified wide-band random output. A narrow bandwidth simplifies the distortion measurement (see 7.2.3).

8.5.7 Amplifier random distortion

Amplifier random distortion $d_{\mathrm{a,r}}$ is a measure of the random current distortion with the load $Z_{\mathrm{a,r}}$. Measure this distortion as in 8.5.6, except that the amplifier specified root-mean-square random current and root-mean-square random voltage are used.

8.5.8 System impulse distortion

System impulse distortion $d_{\mathrm{s,i}}$ is a measure of the impulse acceleration distortion at the top centre of the test mass. Measure this distortion with a short, typically 1 ms to 10 ms, gated sinusoidal wave train output with frequency adjusted to have the same peak voltage and peak current as the impulse peak voltage and peak current. A sine signal is used to simplify distortion measurement.

8.5.9 Amplifier impulse distortion

Amplifier impulse distortion $d_{\mathrm{a,i}}$ is a measure of the amplifier impulse output current distortion into the load $Z_{\mathrm{a,i}}$, using the procedure of 8.5.8.

8.6 Impulse generation

The desired impulse time history should be generated using the actual system and load. The procedure can be expedited by first making a measurement of the transfer function between the amplifier input and the load acceleration. Using this transfer function and the desired load acceleration time history, calculate an amplifier input time history that is expected to generate the desired output acceleration time history.

To confirm and/or refine the required amplifier input time history, apply a low-level scaled version of the calculated input time history to the amplifier input and record the acceleration time history.

Analyse the resultant acceleration time history and make any needed refinements to the amplifier input time history before the full level impulse is applied to the load. If the amplifier and vibrator are to be acquired from different sources, the two following steps are required.

a) At the vibrator source, perform the above process with the vibrator, test mass m_{10}, and a large amplifier. When the acceleration and displacement time histories are satisfactory, make simultaneous recordings of the driver coil voltage and current time histories. Repeat the process for the test mass m_{40}. Carry out full impulse force tests with both m_{10} and m_{40} to confirm the vibrator impulse force capability.

b) At the amplifier source, using the above m_{40} vibrator voltage and current time history, fabricate an amplifier impulse test load $Z_{\mathrm{a,i}}$ that approximates the vibrator impedance and provides the same peak voltage when the load is driven with the above m_{40} drive coil current time history. The load $Z_{\mathrm{a,i}}$ is used to confirm the amplifier impulse current capability, for amplifier impulse endurance tests, and for the amplifier impulse distortion measurements (see 7.2.4 and 7.3.4). If the test mass m_{10} more closely approximates the actual loads to be impulse tested, use of the m_{10} vibrator current and voltage time histories to make $Z_{\mathrm{a,i}}$ rather than the m_{40} vibrator current and voltage may be specified.

Note that the vibrator and amplifier impulse performance and the amplifier impulse distortion measurement are unique to this specific impulse acceleration time history.

Annex A
(informative)

Additional equipment characteristics

A.1 General

Users have differing needs, and electrodynamic vibration generation systems differ between manufacturers. The writer of a purchase specification may wish to ask potential equipment suppliers to provide statements about additional equipment characteristics. If requested, the manufacturer shall provide the information listed in A.2 to A.20.

A.2 Mass of the moving element, m_e

This mass is defined by the manufacturer (see 3.8) and is used in his definitions of the force produced. This is the mass of the moving element structure including, in some cases, parts of the masses of the supporting suspension, connecting leads, and coolant within the coil conductor and leads.

A.3 Moving element attachment interface

A description of the attachment interface of the moving element should include detailed information of the materials, dimensions, and position(s) of the force take-off point or, in the case of a test table, all the fastening locations. This is preferably provided in the form of a dimensioned drawing which includes, for example, whether the inserts are raised or flush. Information on the mounting torque of the fixing bolts, and the allowable axial load may also be provided. If means are provided to prevent damage to the moving element from the accidental use of over length fixing bolts (perhaps mechanically fusable inserts), such means shall be described.

A.4 Flatness of the mounting surface

The allowable deviation from a flat surface shall be specified, either of the test table or of the tops of the raised inserts.

A.5 Static load

The allowable static load shall be stated, both with the force axis vertical and with the force axis horizontal, and how this load affects the allowable travel.

A.6 Suspension resonance frequency

This is the resonance frequency of the moving mass on its supporting spring and is typically between 5 Hz and 30 Hz.

A.7 Electrical resonance frequency

This is the frequency at which the current in the drive coil is in phase with the voltage, and the electrical impedance is a minimum.

A.8 Resonance frequency of the moving system

This is the lowest frequency, above the electrical resonance frequency, at which the phase of the table acceleration is 90° from the phase of the drive current, and is usually above 1 500 Hz. Typically, the useful upper limit of the operating frequency range is about 1,5 times this frequency.

A.9 Non-uniformity of axial motion of the test table

This is the variation in vibratory motion across the table surface or between the tops of the raised inserts as a function of frequency.

A.10 Transverse motion of the test table

This is measured at the load fixing locations on an unloaded table as a function of frequency.

A.11 Test masses, m_t

In order to test the performance of a vibration test system, the manufacturer uses a set of masses (see 3.10) which are ideally dynamically “dead”. Information on these masses can normally be supplied and will include the geometry, flatness, material(s) and fixing locations.

A.12 Stray static magnetic field

An electrodynamic vibrator will inherently produce a stray magnetic field above the moving element table. In the region of the specimen to be tested, this magnetic field should be stated for an unloaded table, typically as an axial function of the distance from each mounting location, including both axial and radial components. If a degaussing coil is used, this shall be stated.

A.13 Stray alternating magnetic field

In the region of the specimen to be tested, this magnetic field shall be stated for an unloaded table, typically as an axial function of the distance from each mounting location, including both axial and radial components, with full rated current in the drive coil, over the full frequency range. If an alternating current degaussing coil is used, this shall be stated, and any resulting reduction in force or increase of amplifier current or voltage shall be specified. Note that these data are expensive to provide, so should only be requested if the specimen is sensitive to such fields.

A.14 Background acceleration noise

This is the acceleration noise of the unloaded table or force take-off, without drive, under normal operating conditions with the amplifier, the field supply, and the cooling system connected and operating. The wide band, or random, components shall be stated separately from the periodic components. The magnitude and time history of any acceleration transients due to the operation of internal protection devices and on-off sequencing devices shall be provided.

A.15 Vibrator pedestal

This is a device used to support the body of the vibrator, which often includes the means of orienting the table from vertical to horizontal with positioning stops, and sometimes also the means to lock out the vibrator body isolation system.

A.16 Vibrator body resonances

If a vibrator body isolation system is provided, the resonant frequencies of the body mass on the isolation springs with the force axis horizontal and with the force axis vertical shall be stated.

A.17 Sound pressure level of the emitted acoustic noise

This shall be measured for the vibrator and any provided hydraulic and cooling system, at full rated acceleration of the unloaded table (sine, random and impulse), over the full vibration generator frequency range, in one-third-octave acoustic bands, in at least four directions including a measurement on the axis. The test method shall be stated.

A.18 Table temperature

This is the stabilized temperature of the unloaded test table under continuous full-force conditions.

A.19 Installation information

This includes the dimensions and mass of all components to be handled, the services required (such as electric power, cooling water or air, exhaust air or discharge water, air conditioning, compressed air), together with a description of all cables, hoses and special tools needed.

A.20 Seismic block

For a large vibrator without an isolation system, a description should be provided of a suitable block recommended for support of the vibrator, including the mass, dimensions, material specifications, and isolation means between the block and the surrounding concrete or earth. If the material of the block is reinforced concrete, the internal steel structure should be described.

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