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INSTRUMENTATION AND EQUIPMENT, COMPLEX VIBRATION TEST

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1. GENERAL

1.1. Scope.

This standard covers requirements for complex-wave, random vibration testing with respect to instrumentation, calibration, equipment capability and test methods.

1.2. Definitions.

1.2.1. Complex Signal.

Any signal that is not sinusoidal.

1.2.2. Random Noise.

A fluctuating quantity (such as physical motion, sound pressure, or an electrical signal) whose instantaneous amplitudes vary as a function of time according to a normal (Gaussian) distribution.

1.2.3. Random Vibration Test.

A vibration test using random noise as the input signal.

1.2.4. Acceleration Spectral Density (ASD).

The square of the rms acceleration in a specified frequency band divided by the bandwidth used to measure it (g^2/Hz). The term is sometimes called Power Spectral Density (PSD) or Auto Spectral Density (ASD).

1.2.5. Equalization.

The process whereby the frequency response of a vibration system is adjusted to a flat or shaped spectrum.

1.2.6. Digital Vibration Controller.

Any random vibration control system that equalizes by the process of mathematical manipulation of digitized data and synthesis of random noise for input to the vibration exciter.

1.2.7. Digital Equalizer.

Text deleted.

1.2.8. Fundamental Frequency.

The particular forcing frequency of the vibration-controller sinusoidal drive for input to the vibration exciter.

1.2.9. White Gaussian Noise

White Gaussian noise is random noise with equal energy per unit frequency bandwidth (constant g^2/Hz).

1.2.10. Overall Test Level.

The overall test level is the measurement of rms acceleration at the input accelerometer calculated or measured over the test bandwidth.

1.2.11. Sigma (Standard Deviation).

In vibration theory, the mean value of the vibration is equal to zero; therefore, for a random time history, the standard deviation is equal to the rms level of the random signal. A 3-sigma peak is a peak that is at a level of three times the rms level.

1.2.12. Distortion.

Any frequencies other than the fundamental frequency present on an acceleration input or response signal.

1.2.13. Tolerance.

Tolerances expressed on drawings and specifications are absolute values as defined by 9900000. Measurement equipment meeting the requirements of this standard is considered to be "specified measurement equipment" when applying the measurement procedures of 9900000.

1.2.14. Standard.

A standard is the physical embodiment of a defined unit of measure under specified conditions.

1.2.14.1. Primary Reference Standard.

A primary reference standard is the prime reference of the standard and calibration system for a particular type of measurement. Periodic calibration by the National Institute of Standards and Technology (NIST) assures its consistency with legal standards.

1.2.14.2. Secondary Reference Standard

A secondary reference standard is the standard specified for use at secondary standards laboratories for the calibration of secondary transfer standards (and/or instruments, gages, and testers in special cases).

1.2.14.3. Transfer Standards (Primary and Secondary)

Primary and secondary transfer standards are standards used to transfer values of a given level of accuracy to other standards one step lower in accuracy, or to gages, instruments, or testers.

1.2.15. Input Control Circuit(s).

One or more measuring circuits used to measure the control or input acceleration to the test item.

1.2.16. Measuring Circuits.

Circuits used to measure acceleration input or test item response at various locations. Each circuit consists of the accelerometer, signal conditioner, filter (if used), and output display equipment.

1.2.17. Statistical Degrees of Freedom (DOF).

For estimation of the acceleration spectral density with a time-averaging technique, the number of degrees of freedom is twice the number of averages used in the estimate.

1.2.18. Statistical Error.

The statistical error in the estimation of the acceleration spectral density is a function of the number of statistical degrees of freedom. The statistical error is equal to the reciprocal of the square root of (DOF/2) for a confidence level of 67%.

1.2.19. Frequency Resolution (Delta-F).

The frequency spacing used in the calculation of the acceleration spectral density for control or analysis. Delta-F is equal to the sample rate used for the analysis divided by the data record block size.

1.2.20. Data Window.

A data window is a weighting function by which the data record is effectively multiplied to minimize the effects of the discontinuities at the beginning and end of the data record. A data window usually is a smooth mathematical function that begins and ends at zero within the time segment of the data record. The window is applied to the digitized random waveform prior to the calculation of the Fast Fourier Transform (FFT) to minimize spectral leakage in the calculation of the acceleration spectral density. Examples of common data windows are the Hanning window , the Keiser-Bessel window, and the Blackman-Harris window.

1.2.21. Anti-Aliasing Filters.

Analog low-pass filters that band-limit the analog accelerometer signal to frequencies less than one-half the sampling rate (Nyquist Frequency) before digitizing to prevent aliasing errors in the acceleration spectral density calculations.

1.2.22. Digital Filters.

Digital filters are devices (algorithms) that process a continuous digitized signal and provide an output digital signal that is filtered in some way with respect to the input signal. Digital filters can be designed to achieve virtually any filtering effect that can be expressed as a mathematical function or algorithm. Typical types of digital filters used in vibration testing are low-pass, high-pass, and band-pass filters. Manufacturers of digital vibration control systems employ various versions of digital filters to achieve different objectives within their control architecture.

2. DOCUMENTS

The following documents form a part of this specification to the extent stated herein.

9900000 General Requirements

9958000 Instrumentation and Equipment, Temperature Test

3. REQUIREMENTS

3.1. Instrumentation Accuracy.

3.1.1. Acceleration-Amplitude Measuring Circuits.

Acceleration-amplitude measuring circuits, including the accelerometer and cable, shall have an uncertainty of ±10% or less at all frequencies within the test range.

3.1.2. Single-Filter Narrow-Band Wave Analyzers.

Text deleted.

3.1.3. Digital Controller/Analyzer.

Digital analyzers used for control and analysis of random signals shall have an acceleration spectral density amplitude measurement uncertainty of ±0.5 dB or less throughout the analysis bandwidth. The frequency resolution of the controller/analyzer shall be 12.5 Hz or less.

3.1.4. Digital Wave Analyzer.

Text deleted.

3.2. **Calibration**.

The calibration intervals indicated below apply unless otherwise specified. The Design Agency or integrated contractor responsible for procurement may specify additional calibration and/or modify calibration intervals based on stability, purpose or use, accuracy, and frequency of usage. The following calibration checks, or approved equivalent, shall be considered minimum certification of the overall system accuracies required in 3.1.

3.2.1. Standards.

Deleted.

3.2.2. Pre-test Checks.

The following items (Channel Sensitivity and Noise Level, along with Calibration Compliance) shall be checked before each test:

3.2.2.1. Channel Sensitivity.

The control and response channel(s) sensitivity(ies), in units of mv/g or pC/g, shall be checked for agreement with the sensitivity entered into the digital control system. This check will include the certified accelerometer sensitivity as well as the gain and sensitivity settings of any signal conditioning equipment.

3.2.2.2. Output or Response Circuits

Text deleted.

3.2.2.3. Noise Level

The system noise level must not exceed 0.4 Grms or 20% of the level stipulated in the detailed test specification, whichever is less. This measurement includes acceleration noise on the exciter head as well as electrical circuit noise in operational status, so all exciter components (power supplies, amplifiers, blowers, controllers, etc.) must be interconnected and energized.

3.2.2.4. Single-Filter Narrow-Band Wave Analyzers or Digital Wave Analyzers.

Text deleted.

3.2.3. Twelve-Month Calibration.

The following items should normally be calibrated every 12 months, but the calibration period shall not exceed 15 months. Calibrations shall also be made whenever changes are made to the circuit (elements, repairs, etc.) that affect the sensitivity.

3.2.3.1. Accelerometers.

Calibration shall be performed against a standard with a certified uncertainty of ±3% or less. Accelerometers showing a change in sensitivity of 10% or more between successive calibrations shall be rejected. The following additional requirements shall apply:

a. A single acceleration level of 10 g or greater shall be used in calibration, except where low-frequency displacement limitations restrict acceleration to a lower level.

b. Calibration shall be performed at enough frequencies in the expected test bandwidth to adequately define the accelerometer's frequency response characteristic.

c. Calibration shall be performed at enough temperatures within the range of use to adequately define the accelerometer's temperature response characteristic. The characterization data may then be used to calculate the accelerometer's sensitivity for use at any specific temperature within the characterization range.

d. If the intended operating range has a ΔT of 50°F (28°C) or less, the calibration may be performed at midrange. If the intended use is at a single temperature, then the calibration may be performed only at that temperature. The temperature at each calibration point shall be controlled to within ±10°F (±6°C) of the intended calibration temperature.

3.2.3.2. Acceleration Amplitude Measuring Circuits.

The complete acceleration amplitude measuring circuit, with the exception of the accelerometer and cable, but including the signal conditioner and digital signal analyzer (if used to measure overall rms level), shall be calibrated for amplitude linearity and frequency response against a reference standard with a certified uncertainty of ±1% or less from 10 Hz to maximum test frequency. The minimum amplitude linearity check of the circuits shall be made at two voltage amplitudes having a ratio of at least 5:1, and at voltage levels equivalent to acceleration levels greater than 1 g. The frequency response measurement of the circuits shall be determined for at least five frequencies covering the range from 30 to 3000 Hz or maximum test frequency, whichever is greater.

If testing is performed below 10 Hz, then the frequency response at the lowest test frequency shall also be checked with a standard having a certified uncertainty of ±5% or less.

For hydraulic actuators, the frequency response shall be determined for at least three frequencies covering the range from 2 Hz to the upper frequency limit of the system.

3.2.3.3. Single-Filter Narrow-Band Wave Analyzer.

Text deleted.

3.2.3.4. Multiple-Filter Narrow-Band Wave Analyzer.

Text deleted.

3.2.3.5. Digital Signal Analyzers.

The digital signal analyzers shall be calibrated for amplitude linearity, frequency response and frequency accuracy against an AC, sinusoidal reference standard with a certified uncertainty of ±1% or less in amplitude and frequency from 30 Hz to the maximum test frequency. The minimum amplitude linearity check shall be made at two voltage amplitudes having a ratio of at least 10:1, and at voltage levels equivalent to acceleration levels greater than 0.7 Grms. The frequency response measurement shall be determined for at least five frequencies covering the range from 30 Hz to the maximum test frequency.

The correlation between the ASD level and the sinusoidal input is determined by the data window used by the analyzer. Each data window type has a coherent gain and equivalent noise bandwidth (ENBW) that can be used to determine the input level. When the sinusoidal input frequency is set at an analyzer frequency line, the equation is

$$\text{Grms} = [\text{ASD} \times \text{ENBW} \times \Delta F]^{1/2}$$

where Grms = rms level of the sinusoidal input (expressed in g's)

ASD = Acceleration Spectral Density (g^2/Hz)

ENBW = Equivalent Noise Bandwidth (DFT bins)

ΔF = frequency resolution of analyzer (Hz)

If the manufacturer does not provide information on the data window, then the ENBW can be determined by direct measurement.

3.3. Vibration Machine Capability.

The following items should normally be checked every 12 months, but shall be checked at least every 15 months and after every major repair of the vibration-machine exciter and power supply.

3.3.1. Transverse Motion.

The unfiltered transverse acceleration of the unloaded (bare armature) vibration exciter shall not exceed 30% of the filtered input acceleration when the machine is run at 20-g input (not to exceed maximum velocity, displacement or maximum power) from 20 Hz to the maximum test frequency or 3000 Hz, whichever is less. The measurement shall be made at or near the center of the exciter top with the accelerometers orthogonal to each other. The data from the latest transverse motion survey shall be made available to the Design Agency upon request.

3.3.2. Waveform Distortion.

A waveform distortion survey shall be made at 75% or greater of the maximum system force rating, except that the velocity and displacement may also be limited to 75% of the rated maximums. The survey shall be made with no load and with the accelerometer located at or near the center of the table top, or with the test fixture or load weight on the vibration machine with the accelerometer at or near the center of the table top. Total harmonic distortion (THD) vs frequency measurements shall be made in no more than 50-Hz intervals over the test frequency range or from 20 to 3000 Hz, whichever is less, and at any other frequencies necessary to ensure mapping all areas where the distortion is in excess of 10% within the above frequency range.

In addition to the above distortion measurements, the first major structural resonance (commonly referred to as axial) shall be determined so that distortion measurements can be made at the submultiples (one-half and one-third) of this frequency. If the design characteristics of the exciter indicates more than one structural resonance, i.e., a response peak equal to or greater than, but not greater than 6 dB below the first major resonance peak, then distortion measurements shall also be made at one-half and one-third of these resonances.

Measured distortion (THD) shall not exceed 25% at frequencies one-half and one-third (submultiples) of the above described major resonance(s) and at only one other additional frequency between 1 and 2 kHz. At all other frequencies the THD shall not exceed 15%. The data from the latest distortion survey shall be made available to the Design Agency upon request.

3.4. Test Methods.

3.4.1. Location of Input Control Accelerometer(s).

Accelerometers used for input control shall be mounted on the fixture as close as possible to a test-item mounting point without touching the test item unless otherwise stipulated by the detailed specification.

3.4.2. Accelerometer Mounting Methods.

The attachment method for accelerometers shall be one of the following methods, or the transmissibility across the auxiliary hardware used must be proved by actual test to be between 0.98 and 1.02 over the test frequency range.

a. Direct attachment by threaded fasteners to the surface being monitored, using the torque values specified by the accelerometer manufacturer.

b. Direct bonding by adhesive (dental cement, cyanoacrylate adhesive, or rigid epoxy adhesive) to the surface being monitored.

c. Direct attachment by threaded fasteners to an adapter no greater than ½-in thick, using the torque values specified by the accelerometer manufacturer. The adapter is then bonded to the surface being monitored as indicated in subparagraph b.

3.4.3. RMS Acceleration Measurements.

The overall rms acceleration level of the test input signal shall be continuously measured. The vibration control system's rms abort level for test shutdown shall be set to the rms tolerance stated in the detailed specification.

It should be noted that multipoint control strategies, such as averaging, response limiting, external control, etc., will affect the rms acceleration at each input control location. With response limiting, for example, the rms acceleration level at the input control can be less than the calculated overall rms level. In the case where response limiting is specified, only an upper rms abort level is required. When the control system provides a computed composite rms level during multipoint control, the composite level may be used for test monitoring and abort control.

3.4.4. Transverse Motion.

If a pre-test requirement by the detailed specification, transverse motion shall be checked before the test by conducting a sine or random investigation at a level prescribed in the detailed specification. The levels in both axes perpendicular to the test axis at the control point(s) should not exceed the specified values in the test axis. When conducted with a random input, the total rms value of the ASD in both axes perpendicular to the test axis should not exceed 50% of the overall rms value for the specified axis. In the case of larger test items and/or flexible fixtures, it may be difficult to achieve these values, and cross-axis response limiting strategies may be prescribed in the detailed specification. The transverse motion results, if required, shall be made available to the Design Agency upon request.

3.4.5. Waveform Distortion.

Text deleted.

3.4.6. Surveillance During Tests.

During the time any vibration test is in progress, the vibration equipment and the test item behavior shall be monitored by trained personnel. At minimum, an operator shall observe the control ASD and the rms level. The closed-loop drive update shall be enabled on the vibration controller to maintain the specified equalization levels and the required overall rms acceleration level.

Personnel may leave the test unattended for brief breaks only if the vibration controller is capable of monitoring test quality and is able to log actions and then abort the test if undesirable events occur.

3.4.7. Equalization Levels.

3.4.7.1. Sine-Wave Equalization.

Text deleted.

3.4.7.2. <u>Random Wave Equalization</u>.

Equalization shall consist of demonstrating that the control PSD is within the limits stated in the detailed specification. Minimum proof of the equalization shall consist of a plot of the control PSD with test limits and an indication of the overall acceleration level. The proof of equalization record(s) may be made anytime during the test or at the end of the test. On all tests the rms acceleration during the test shall be monitored. Unless otherwise specified, the random level used for equalization shall be at least 6 dB down from the test level, and the total vibration time required to equalize the test specimen shall not exceed 500% of the required test duration.

It should be noted that multipoint control strategies such as averaging, response limiting, external control, etc., may require additional equalization time at test levels less than the full level. There may also be the need to have equalization steps above the -6 dB level for systems demonstrating any nonlinear behavior. Proof of equalization for multipoint control strategy tests shall include documentation sufficient to show that the test fully complied with test requirements.

3.4.8. <u>Narrow-Band Analysis</u>.

Text deleted.

3.4.9. <u>Combined Temperature / Vibration Test.</u>

The guidance and requirements of this Process Standard apply, as do most of those of 9958000 except that it is sometimes not practical to require that (1) the test item occupy less than one-third of the chamber volume, or (2) to insist that a temperature distribution survey be made at least once every 12 months. Therefore, these requirements may at times have to be waived. Once stabilization is obtained, the temperature of the test item, monitored at the skin or on the fixture to which the test item is attached, should be controlled within ±5°F (±3°C) of the specified value. The thermocouple used to monitor this temperature should indicate the skin temperature of the test item or fixture and not necessarily the temperature of the air surrounding the test item, unless the test item is generating heat.