



# Standard Test Method for Random Vibration Testing of Shipping Containers<sup>1</sup>

This standard is issued under the fixed designation D 4728; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers the random vibration testing of filled shipping units. Such tests may be used to assess the performance of a container with its interior packing and means of closure in terms of its ruggedness and the protection that it provides the contents when subjected to random vibrational inputs.

1.2 This test method provides guidance in the development and use of vibration data in the testing of shipping containers.

1.3 Two alternative vibration control techniques are described as follows:

1.3.1 *Method A Closed Loop*—Automatic Equalization (5.2.1, 10.2.1)

1.3.2 *Method B Open Loop*—Data Storage Media (5.2.2, 10.2.2)

NOTE 1—Sources of supplementary information are listed in the Reference section (1–10).<sup>2</sup>

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Specific safety hazard statements are given in Section 6.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

D 996 Terminology of Packaging and Distribution Environments<sup>3</sup>

D 4169 Practice for Performance Testing of Shipping Containers and Systems<sup>3</sup>

D 4332 Practice for Conditioning Containers, Packages or Packaging Components for Testing<sup>3</sup>

### 2.2 ISO Standards:

ISO 13355 Packaging—Complete, filled transport packages

and unit loads—Vertical random vibration test<sup>4</sup>

## 3. Terminology

### 3.1 Definitions:

3.1.1 *General*—Definitions for the packaging and distribution environments are found in Terminology D 996.

### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *bandwidth*—the difference, in Hz, between the upper and lower limits of a frequency band. For the purposes of this test method, the bandwidth may be considered equivalent to the frequency resolution of a spectrum analysis.

3.2.2 *closed-loop*—a condition of control where the input may be modified over time by the effect of the output or response of the system.

3.2.3 *decibel (dB)*—ten times the base 10 logarithm of a ratio of two power like quantities that is, a PSD. Two PSD levels that have a ratio of 2.0 differ by 3 dB. Two PSD levels that have a ratio of 0.5 differ by –3 dB.

3.2.4 *equalization*—adjustment or correction of the amplitude characteristics of an electronic control signal throughout a desired frequency range to maintain a desired vibration output spectrum and level.

3.2.5 *equalizer*—instrumentation used to conduct equalization.

3.2.6 *mean-square*—the time average of the square of a function.

3.2.7 *open loop*—a condition of control where the input of a system is preestablished and is not affected by the output or response of the system.

3.2.8 *overall g rms*—the square root of the integral of power spectral density over the total frequency range.

3.2.9 *periodic vibration*—an oscillation whose waveform repeats at equal increments of time.

3.2.10 *power spectral density (PSD)*—an expression of random vibration in terms of mean-square acceleration per unit of frequency. The units are  $g^2/Hz$  ( $g^2/cycles/s$ ). Power spectral density is the limit of the mean square amplitude in a given rectangular band divided by the bandwidth, as the bandwidth approaches zero.

3.2.11 *random vibration*—an oscillation whose instantaneous amplitude is not prescribed for any given instant in time.

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D10 on Packaging and is the direct responsibility of Subcommittee D10.22 on Physical Test Methods.

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<sup>2</sup> The boldface numbers in parentheses refer to the list of references at the end of this test method.

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 15.09.

<sup>4</sup> Available from International Organization for Standardization, 1 Rue de Varembe', Case Postale 56, CH-1211, Geneva 20, Switzerland.

The instantaneous amplitudes of a random vibration are prescribed by a probability distribution function, the integral of which over a given amplitude range will give the probable percentage of time that the amplitude will fall within that range. Random vibration contains no periodic or quasi-periodic constituent. If random vibration has instantaneous magnitudes that occur according to the Gaussian distribution, it is called "Gaussian random vibration." Gaussian random vibration has the property that the rms level is equal to the standard deviation, or 1 sigma, and that the amplitude will fall within 3 sigma, or 3 times the rms level, 99.7 % of the time.

3.2.12 *root-mean-square (rms)*—the square root of the mean-square value. In the exclusive case of a sine wave, the rms value is 0.707 times peak value.

3.2.13 *sigma drive signal clipping*—a condition where the maximum amplitude of the drive or output signal to a vibration system is limited to a sigma value, or multiple of the rms value. For drive clipping at the 3 sigma level, the maximum amplitude will not exceed 3 times the rms value.

3.2.14 *sinusoidal vibration*—a periodic oscillation having a sinusoidal waveform of only one frequency.

3.2.15 *spectrum*—a definition of the magnitude of the frequency components within a specified *frequency range*.

3.2.16 *statistical degrees of freedom (DOF)*—as related to PSD calculation, the degrees of freedom is a measure of the statistical accuracy of the PSD estimation. The number of DOF is determined by the analysis bandwidth (frequency resolution) and total time of the sample (determined by frequency resolution and number of averages). It is defined by the formula  $DOF = 2BT$ , where  $B$  is the analysis bandwidth in Hz, and  $T$  is the total record length in seconds.

3.2.17 *transfer function*—the dynamic relationship between output and input. In terms of a vibration system, it is the ratio of output response to a constant input over a defined *frequency range*.

#### 4. Significance and Use

4.1 Shipping containers are exposed to complex dynamic stresses in the distribution environment. Approximating the actual damage, or lack of damage, experienced in real life may require subjecting the container and its contents to random vibration tests. In this way, many product and container resonances are simultaneously excited.

4.2 Resonance buildups during random vibration tests are less intense than during sinusoidal resonance dwell or sweep tests. Therefore, unrealistic fatigue damage due to resonance buildup is minimized.

4.3 Random vibration tests should be based on representative field data. When possible, confidence levels may be improved by comparing laboratory test results with actual field shipment effects. Refer to Practice D 4169 for recommended random vibration tests. (See Appendix X1 and Appendix X2 for related information.)

4.4 There is no direct equivalence between random vibration tests and sinusoidal vibration tests. Equivalent tests between sine and random, in a general sense, are difficult to establish due to nonlinearities, damping and product response characteristics.

4.5 Vibration exposure affects the shipping container, its

interior packing, means of closure, and contents. This test allows analysis of the interaction between these components. Design modification to one or all of these components may be used to achieve optimum performance in the shipping environment.

4.6 Random vibration tests may be simultaneously performed with transient or periodic data to simulate known stresses of this type, that is, rail joints, pot holes, etc.

4.7 Random vibration may be conducted in any axis (vertical or horizontal) or in any package orientation. However, different test levels may be utilized for each axis depending on the field environment that is to be simulated.

#### 5. Apparatus

5.1 *Vibration Test System*—The vibration test system (shaker) shall have a vibration table of sufficient strength and rigidity so that the applied vibrations are essentially uniform over the entire test surface when loaded with the test specimen. The vibration table shall be supported by a mechanism capable of producing single axis vibration inputs at controlled levels of continuously variable amplitude throughout the desired range of frequencies. Suitable fixtures and guides to restrict undesired movement of the test specimens shall be provided.

5.2 *Electronic Controls*—Controls shall provide the capability of generating vibration system drive inputs necessary to produce the desired power spectral density at the table surface adjacent to the test specimen. The following methods provide this capability with varying degrees of accuracy and versatility.

5.2.1 *Method A, Closed Loop—Automatic Equalization*—A closed loop controller is required, which allows the operator to enter desired PSD data. The controller automatically generates equalized vibration test system drive signals to achieve the desired PSD thus maintaining closed loop control. The equalized drive signals automatically compensate for specimen and vibration test system characteristics. Typical systems include an analog to digital converter for conditioning feedback signals, a digital to analog converter to produce drive signals, a digital processor with real time analysis capability, random vibration control software programs, a graphics display terminal, hard copy printer, and a hard or flexible, or both, disk drive unit.

NOTE 2—Random vibration systems typically create a drive signal that follows the Gaussian distribution. Many systems have a "drive clipping" capability, which is sometimes employed to protect the vibration system or test specimen from high instantaneous amplitudes that might cause damage.

5.2.2 *Method B, Open Loop—Data Storage Media—Data storage media* open loop control systems enable prerecorded equalized PSD data to be produced, as long as the combined transfer function of the specific record/playback device (that is, FM tape, digital tape, floppy disk drive, or CD-ROM drive), vibration system and load configuration was incorporated in the media's original preparation. Typical systems include a record/playback or playback device, prerecorded data storage media, a means of controlling the overall gain of the vibration system drive signal, and a true rms meter to monitor the overall g rms level of the vibration table. The playback device shall have adequate frequency response and dynamic range to reproduce the vibration spectrum to the tolerances defined in

this test method. Ideally, data storage media should be equalized using Method A for each specific test specimen to ensure that the dynamic response of the actual specimen(s) does not cause significant differences between the actual PSD test levels and the desired test levels. Equalization with a very stiff ballast weight equivalent in mass to the test item is sometimes employed as a more practical approach. Exercise caution, however, since the open loop system will not compensate for actual specimen responses.

5.2.3 The digital real time analysis, whether used for Method A or to equalize data storage media for Method B, shall provide a minimum of 60 statistical degrees of freedom, and a maximum analysis bandwidth of 2 Hz.

5.3 *Instrumentation*—Accelerometers, signal conditioners, analyzers, data display, storage devices, and the control techniques described in 5.2 are required to measure and control the PSD levels at the table surface. Instrumentation may also be desirable for monitoring the response of the test specimen(s). The instrumentation system shall have an accuracy of  $\pm 5\%$  throughout the frequency range specified for the test.

## 6. Safety Precautions

6.1 This test method may produce severe mechanical responses of the test specimen(s). Therefore, fences, barricades, and other restraints must have sufficient strength and must be adequately secured. Operating personnel must remain alert to the potential hazards and take necessary precautions for their safety. Stop the test immediately if a dangerous condition should develop.

## 7. Test Specimens

7.1 The test specimen shall consist of the container as intended for shipment, loaded with the interior packaging and the actual contents for which it was designed. Blemished or rejected products may be used if the defect will not affect test results and if the defect is documented in the report. Dummy test loads are acceptable if testing the actual product might be hazardous or cost prohibitive. If a dummy load is used, an assessment must be made, after the test is completed, as to whether or not the actual test item would have passed or failed. Sensors and transducers should be applied with minimum possible alteration of the test specimen to obtain data on the container or packaged item. When it is necessary to observe the contents during the test, holes may be cut in noncritical areas of the container.

7.2 Whenever sufficient containers and contents are available, it is highly desirable that replicate tests be conducted to improve the statistical reliability of the data obtained.

## 8. Calibration and Standardization

8.1 The accuracy of instrumentation and test equipment used to control or monitor the test parameters should be verified prior to conducting each test to ensure that desired test levels and tolerances are maintained.

8.2 The specified PSD data and resulting RMS acceleration level should be based on other test standards, Appendix X1, or derived from actual field measurements or published PSD data made on typical transport vehicles under representative conditions of speed, load, terrain, road surfaces, etc. Field measure-

ments must be accurately recorded with equipment having adequate frequency response and dynamic range to prevent attenuation or noise contamination of the acceleration energy levels. Multiple independent field measurements must be sampled to assure representative test levels. This data must then be reduced to PSD format and equalized for proper control of the vibration system. In the absence of specified PSD data it is recommended that the appropriate profile from Fig. X1.1, be used.

8.3 Shaker table input levels to the test specimen provide the only common benchmark for repeatability between various test systems. Therefore, control analysis based on monitoring table motion rather than actual package response is recommended. This table feedback signal is generated by an accelerometer mounted directly to the table. Accelerometer mounting location should be next to the test specimen or directly below it on the underside of the table.

8.4 The shaker's drive signal must be equalized as described in 5.2 to compensate for test specimen dynamics, the test system's transfer function, and the control system's transfer function.

8.4.1 The power spectral density of the random vibration test profile shall not deviate from the specified requirements by more than  $\pm 3$  dB in any frequency analysis band over the entire test frequency range, except that deviations as large as  $\pm 6$  dB will be allowed over a cumulative bandwidth of 10 Hz. In addition, the overall g rms level shall not deviate more than  $\pm 15\%$  from the specified level during the test.

8.4.2 The maximum equalizer analysis bandwidth allowed is 2 Hz and the minimum DOF is 60. This applies when running closed loop Method A and when equalizing data storage media for Method B.

8.4.3 For Method B, the recommended time constant for the true rms meter is 1 to 2 s.

8.4.4 The equalizer analysis bandwidth may need to be less than 2 Hz, depending on the slope of the PSD between adjacent breakpoints. Very steep slopes require smaller bandwidths to maintain control to  $\pm 3$  dB.

8.4.5 If sigma drive signal clipping is used, the clipping level used shall not be less than 3.0 sigma.

## 9. Conditioning

9.1 Test specimens shall be conditioned prior to test or during test, or both, in accordance with Practice D 4332. When no specific conditioning requirements are given, and container materials are moisture sensitive, a standard conditioning atmosphere of  $23 \pm 2^\circ\text{C}$  ( $73.4 \pm 3.6^\circ\text{F}$ ) and  $50 \pm 2\%$  relative humidity is recommended, for a minimum of 24 h prior to performance of test(s).

## 10. Procedure

10.1 *Set-up of Test Specimen on Vibration Table*—Place the unit(s) to be tested in its normal shipping orientation so that the desired vibration condition (vertical or horizontal) is transmitted to the outer container. The specimen center of gravity should be as near as practicable to the center of the table. The specimen may be either securely fastened to the vibration table or allowed to vibrate freely. In the latter case, attach restraining devices to the vibration table to prevent excessive rocking and

movement off the vibration table. Adjust the restraining devices to permit free movement of the specimen of approximately 10 mm (0.4 in.) in any horizontal direction from its centered position. Unit loads, stacked columns, or single units should be tested in this manner. Only shipping units that will actually be securely fastened during shipment, for example, on a flatbed trailer, should be securely fastened during the test.

10.2 *Start Up Procedure*—Provision shall be made that the vibration levels do not overshoot the PSD profile on start up. This is important since random vibration will produce relatively large, low frequency displacements in an unpredictable sequence.

10.2.1 For Method A, it is recommended that tests be initiated at least 6 dB below full test level and incremented in one or more subsequent steps to full test level. This enables the closed loop control system to complete its equalization at lower test levels and provides the operator adequate opportunity to visually verify that the test specimen and fixture are receiving a realistic test, prior to full test level exposure.

10.2.2 For Method B, the test should be brought up to full test level gradually, using the system overall gain control.

10.3 Conduct the random vibration test for the length of time stated in the applicable specification, if any, or for a predetermined period, or until a predetermined amount of damage may be detected. The test duration is the time at full test level. Time spent during start up is not included.

10.4 Test levels are often increased over the actual field data to shorten the test time. Any attempt to do so should be done with caution. Use of “equivalence” techniques of this type may assume linearity of specimen response to test input which is, in fact, not likely.

10.5 When shipping information becomes available for the test item, the test duration or PSD profile should be modified based on observed damage levels. For example, if the laboratory test does not produce a realistic level of damage, then adjustments should be made.

## 11. Report

11.1 Report the following information:

11.1.1 A reference to this test method,

11.1.2 Identification and description of the test specimens, including the container, the interior packaging, the product (give size, weight, and any other pertinent details), and photographs (before and after) of the test items, where possible,

11.1.3 If unitized loads are tested, description of the unitized load, the height of the stack, the unitizing method employed, and photographs (before and after) of the test items, where possible,

11.1.4 Purpose of the test and the applicable performance specification, if any,

11.1.5 Rationale for the random vibration PSD levels’ pertinence including a detailed description of the measurement and analysis techniques utilized,

11.1.6 Details of the test method, test levels analysis bandwidth, DOF, drive clipping, and durations used,

11.1.7 Verification of compliance with the test method, including a plot of the actual vibration table input PSD, or descriptions of any deviations,

11.1.8 Number of replications of each test,

11.1.9 Atmospheric conditions to which the specimens were subjected, both prior to test and during test,

11.1.10 Any other tests the specimens were subjected to prior to this test,

11.1.11 Description of the apparatus and instrumentation used,

11.1.12 Results of the tests, and a comparison between damage levels observed as a result of the test versus actual damage observed in transportation, if historical data exists,

11.1.13 Descriptions and photographs of any damage or deterioration to the containers or their contents as a result of the tests,

11.1.14 All significant resonant responses and any observations that may assist in correct interpretation of results or lead to improvements in design of container, interior packaging or product, and

11.1.15 Statement of whether or not the specimens complied with the requirements of the applicable specification.

## 12. Precision and Bias

12.1 No information is presented about either the precision or bias of this test method for producing damage due to random vibration since the test result is nonquantitative.

## 13. Keywords

13.1 distribution environment; random vibration; shipping container; vibration; vibration control

(Nonmandatory Information)

X1. SAMPLE PSD TEST PROFILES

X1.1 Sample PSD test profiles in Fig. X1.1, Fig. X1.2 and Fig. X1.3 are provided for *informational purposes only*. They do not purport to accurately describe a specific transportation mode or distribution environment. The user of random vibration must verify accuracy and applicability of any data of this type prior to its use.

X1.2 Fig. X1.1 illustrates that there are relative differences in vibration intensity and frequency content for various types of commercial transportation.

X1.2.1 Fig. X1.1 has evolved from a compilation of field measurements made by several organizations over a period of time.

X1.2.2 Whereas the data in Fig. X1.1 averages vibration intensities measured under various loading conditions, suspension types, road conditions, weather conditions, travel speeds, etc., it does not represent the environment that exists in any specific transportation environment. Exact situations must be verified by the user of this method.

X1.2.3 Transients caused by pot holes, rail joints, takeoff/landing, etc. are not reflected in Fig. X1.1.

X1.2.4 The profiles of Fig. X1.1 are utilized in Practice D 4169 as the Assurance Level II test definitions.

X1.2.5 The profiles of Fig. X1.1 are presented in Table X1.1.

X1.3 Fig. X1.2 illustrates the differences that may exist due to truck trailer suspension and trailer loading. These sample test profiles are from Ref (8), and are composites for trucks traveling on interstate expressways at 55 mph.

X1.3.1 Curve A is for a leaf spring trailer with 20 000 lb (9 072 kg) load.

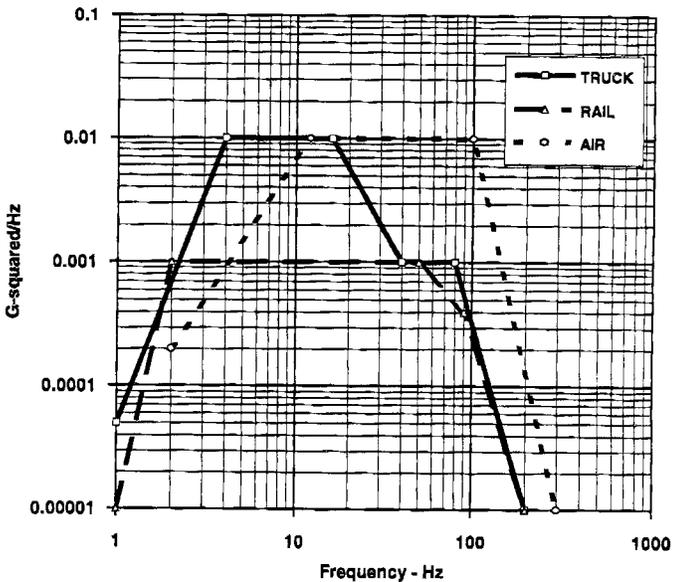


FIG. X1.1 Sample Commercial Transport Vibration Test Profiles

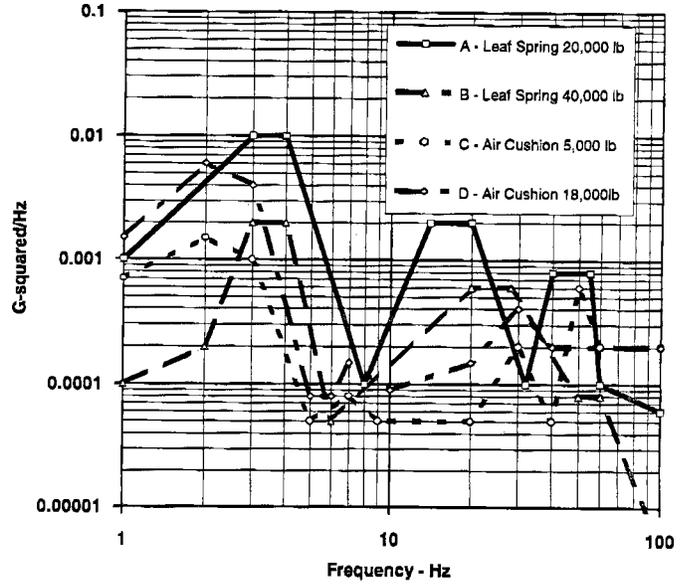


FIG. X1.2 Sample Truck Vibration Test Profiles

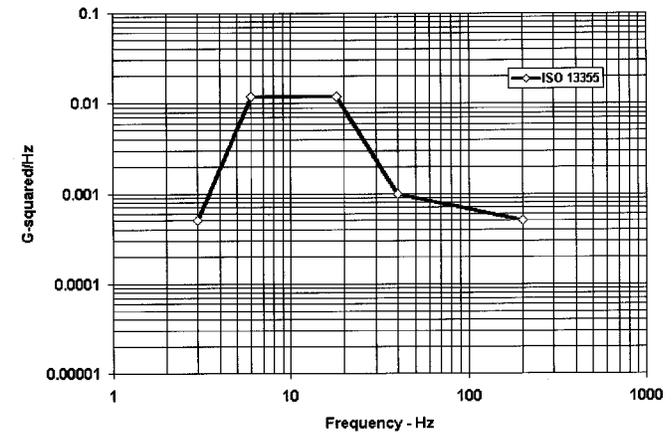


FIG. X1.3 ISO 13355 Vibration Test Profile

TABLE X1.1 Fig. X1.1 Profiles (Practice D 4169 Assurance Level II)

Truck		Rail		Air	
Frequency Hz	Level $g^2/Hz$	Frequency Hz	Level $g^2/Hz$	Frequency Hz	Level $g^2/Hz$
1	0.00005	1	0.00001	2	0.0002
4	0.01	2	0.001	12	0.01
16	0.01	50	0.001	100	0.01
40	0.001	90	0.0004	300	0.00001
80	0.001	200	0.00001		
200	0.00001				
Overall Level, $g$ rms	0.52		0.29		1.05

X1.3.2 Curve B is for a leaf spring trailer with 40 000 lb (18 144 kg) load.

X1.3.3 Curve C is for an air cushion trailer with 5 000 lb (2 268 kg) load.

X1.3.4 Curve D is for an air cushion trailer with 18 000 lb (8 165 kg) load.

X1.3.5 The profiles of Fig. X1.2 are presented in Table X1.2.

X1.4.1 The profile of Fig. X1.3 is presented in Table X1.3.

TABLE X1.2 Fig. X1.2 Profiles

Curve A		Curve B		Curve C		Curve D	
Frequency Hz	Level g <sup>2</sup> /Hz	Frequency Hz	Level g <sup>2</sup> /Hz	Frequency Hz	Level g <sup>2</sup> /Hz	Frequency Hz	Level g <sup>2</sup> /Hz
1	0.001	1	0.0001	1	0.0007	1	0.0015
3	0.01	2	0.0002	2	0.0015	2	0.006
4	0.01	3	0.002	3	0.001	3	0.004
8	0.0001	4	0.002	5	0.00005	5	0.00008
14	0.002	6	0.00005	7	0.00008	6	0.00008
20	0.002	20	0.0006	9	0.00005	7	0.00015
32	0.0001	28	0.0006	20	0.00005	10	0.00009
40	0.0008	50	0.00008	30	0.0002	20	0.00015
55	0.0008	60	0.00008	40	0.00005	30	0.0004
60	0.0001	100	0.000005	50	0.0006	40	0.0002
100	0.00006			60	0.0002	100	0.0002
				100	0.0002		
Overall Level, g rms	0.26		0.14		0.14		0.17

X1.4 Fig. X1.3 provides the test profile from ISO 13355 for reference, where it is described as an indicative power spectral density that can be used to simulate generic (mainly road) transportation.

TABLE X1.3 Fig. X1.3 Profile (from ISO 13355)

Frequency HZ	Level g <sup>2</sup> /Hz
3	0.0005
6	0.012
18	0.012
40	0.001
200	0.0005
Overall Level, g rms	0.59

X2. SAMPLE PSD VIBRATION DATA

X2.1 Sample PSD vibration data in Fig. X2.1 and Fig. X2.2 are provided for informational purposes only. They do not purport to accurately describe a specific transportation mode or distribution environment. The user of random vibration must

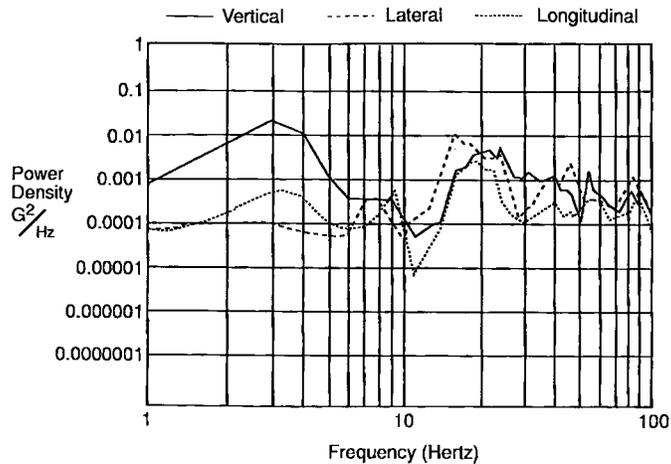


FIG. X2.1 Sample Truck Vibration Data

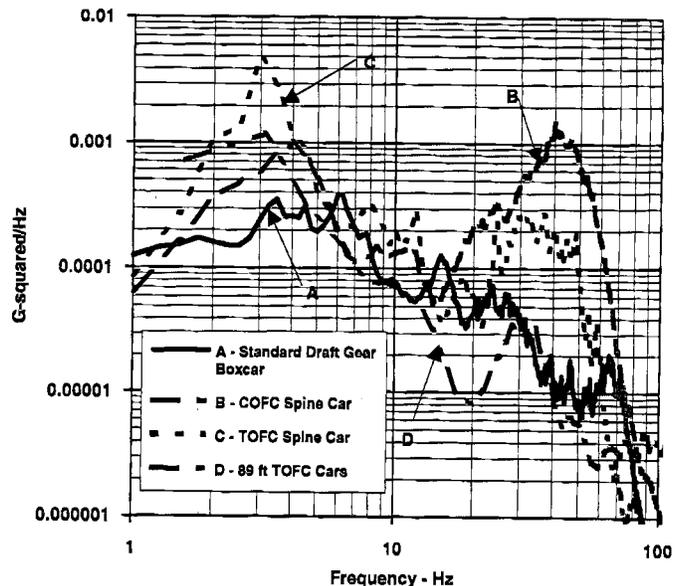


FIG. X2.2 Sample Rail Vibration Data

verify accuracy and applicability of any data of this type prior to its use.

X2.2 Fig. X2.1 illustrates the differences that exist between the vertical, lateral, and longitudinal directions of a truck trailer. This actual data, from Ref (7), represents a leaf spring trailer with a 40 000 lb (18 144 kg) load traveling at 55 mph on a concrete interstate expressway.

X2.3 Fig. X2.2 illustrates the differences that exist between different types of rail transport. These samples are from Refs.

(9) and (10), and represent data averaged over several trip segments of varying length and speeds.

X2.3.1 Curve A is for a standard draft gear boxcar, measurement in the middle of the car.

X2.3.2 Curve B is for articulated “Container-on-Flatcar” (COFC) spine cars, single stack, five units.

X2.3.3 Curve C is for articulated “Trailer-on-Flatcar” (TOFC) spine cars, five units.

X2.3.4 Curve D is for an 89 ft long TOFC car.

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