



Designation: D 999 – 01

Standard Test Methods for Vibration Testing of Shipping Containers¹

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1. Scope

1.1 These methods cover vibration tests of filled shipping containers. Such tests may be used to assess the performance of a container, with its interior packing and means of closure, both in terms of its strength and of the protection it provides its contents when it is subjected to vibration such as it experiences in transportation. These procedures are suitable for testing containers of any form, material, kind, design of interior packing, means of closure, and any size and weight. They are not intended for determining the response of products to vibration for product design purposes, nor are they intended for tests of products in their operational configuration as other more suitable procedures are available for these purposes.^{2,3}

1.2 The following methods appear:

Method A1—Repetitive Shock Test (Vertical Motion).

Method A2—Repetitive Shock Test (Rotary Motion).

Method B—Single Container Resonance Test.

Method C—Palletized Load, Unitized Load, or Vertical Stack Resonance Test.

1.3 *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 precautionary statements are given in Section 6.

1.4 These methods fulfill the requirements of International Organization for Standardization standards ISO 8318 and ISO 2247. *The ISO standards may not meet the requirements for these methods.*

2. Referenced Documents

2.1 ASTM Standards:

D 996 Terminology of Packaging and Distribution Environments⁴

D 3580 Test Method for Vibration (Vertical Linear Motion) Test of Products⁴

D 4169 Practice for Performance Testing of Shipping Containers and Systems⁴

D 4332 Practice for Conditioning Containers, Packages, or Packaging Components for Testing⁴

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process⁵

2.2 ISO Standards:

ISO 2247 Packaging—Complete, filled transport packages—Vibration test at fixed low frequency⁶

ISO 8318 Packaging—Complete, filled transport packages—Vibration tests using a variable frequency⁶

3. Terminology

3.1 *Definitions*—For definitions of terms used in these test methods, see Terminology D 996.

3.1.1 *double amplitude, n*—the maximum value of a sinusoidal quantity (peak-to-peak).

3.1.2 *octave, n*—the interval between two frequencies having a ratio of two (2).

3.1.3 *power spectral density (PSD), n*—used to quantify the intensity of random vibration in terms of mean-square acceleration per unit of frequency. The units are g^2/Hz ($(\text{m/s}^2)^2/\text{Hz}$), where g is the acceleration of gravity, equal to 386 in./s^2 (9.8 m/s^2). Power spectral density is the limiting mean square value in a given rectangular bandwidth divided by the bandwidth, as the bandwidth approaches zero.

3.1.4 *repetitive shock, n*—impacts of a package on a test platform which occur cyclically from input oscillatory motion.

3.1.5 *resonance, n*—for a system undergoing forced vibration, the frequency at which any change of the exciting frequency, positive and negative, in the vicinity of the exciting frequency causes a decrease in the response of the system.

4. Significance and Use

4.1 Shipping containers are exposed to complex dynamic stresses when subjected to vibration present in all transportation vehicles. Approximating the actual damage, or lack of damage, experienced in shipping may require subjecting the container(s) and contents to vibration inputs.

4.2 Resonant responses during shipment can be severe and

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² Military Standard Environmental Test Methods, MIL-STD-810F, Method 514, Vibration, available from www.dodssp.daps.mil/dodssp.htm.

³ International Electrotechnical Commission Recommendation, Publication 68-2-6, Part 2, Test F: Vibration, Basic Environmental Testing Procedures for Electronic Components and Electrical Equipment, available from American National Standards Institute, Inc., 11 W. 42nd St., 13th Floor, New York, NY 10036.

⁴ *Annual Book of ASTM Standards*, Vol 15.09.

⁵ *Annual Book of ASTM Standards*, Vol 14.02.

⁶ Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

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may lead to package or product failure. Identification of critical frequencies, and the nature of package stresses can aid in minimizing the effect of these occurrences.

4.3 Vibration tests should be based on representative field data. When possible, the confidence level may be improved by comparing laboratory test results with actual field shipment data.

4.4 Exposure to vibration can affect the shipping container, its interior packaging, means of closure, and contents. These tests allow analysis of the interaction of these components. Design modification to one or more of these components may be utilized to achieve optimum performance in the shipping environment.

4.5 *Methods A1 and A2, Repetitive Shock Tests*, are suitable for tests of individual containers that are transported unrestrained on the bed of a vehicle and may be suitable for tests of containers that might be subjected to repetitive shocks due to magnification of vibrations in unit loads or stacks.

NOTE 1—Methods A1 and A2 produce different vibration motions, and therefore, will generate different forces which may result in different damage modes and intensities. Results from these two methods may not correlate with one another.

4.6 *Method B, Single Container Resonance Test*, tests or determines the ability of an individual container and its interior packaging to protect the contents from transportation vibration, particularly when the container and its contents might exhibit resonant responses.

NOTE 2—Individual products that are palletized might be better tested using Method C.

4.7 *Method C, Palletized Load, Unitized Load or Vertical Stack Resonance Test*, covers the determination of the presence and the effects of resonance in palletized loads and multiple-unit stacked loads, and whether or not the strength of the containers is sufficient to withstand dynamic loads when stacked.

4.8 Any or all of these test methods may be employed, as determined by the appropriate performance specification, with test intensities, frequency ranges, and test durations as called for in the specification. Although these tests do not simulate the shipping environment, they are intended to create the damage-producing potential of the shipping environment. Results of any one of these methods may differ from the results of the others.

5. Apparatus

5.1 *Method A1—Repetitive Shock Test (Vertical Motion):*

5.1.1 *Vibration Test Machine*, with a platform having a horizontal surface 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 platform shall be supported by a mechanism that vibrates it so the motion is approximately a vertical sinusoidal input. (A rotary motion of the platform is not acceptable.) The double amplitude displacement of the vibration shall be fixed at or controlled to 1 in. (25 mm), and the frequency shall be variable within the range from 2 to at least 5 Hz (cycles per second). The vibration test machine shall be equipped with fences, barricades, or other restraints to keep the test specimen from falling off the

platform without restricting its vertical motion.

5.2 *Method A2—Repetitive Shock Test (Rotary Motion):*

5.2.1 *Vibration Test Machine*, with a platform having a horizontal surface 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 platform shall be supported by a mechanism that vibrates it so that the motion is a rotational input with the vertical component approximately sinusoidal. The double amplitude displacement of the vibration shall be fixed at 1 in. (25 mm), and frequency shall be variable from 2 to at least 5 Hz (cycles per second). The vibration test machine shall be equipped with fences, barricades, or other restraints to keep the test specimen from falling off the platform without restricting its vertical motion.

5.3 *Methods B and C—Resonance Tests:*

5.3.1 *Vibration Test Machine*, with a platform having a horizontal surface 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 platform shall be supported by a mechanism capable of producing vibration in the vertical linear plane at controlled accelerations or displacements, or both, over a controlled continuously variable range of frequencies. (A rotary motion of the platform is not acceptable.) Suitable fixtures and attachment points shall be provided to rigidly attach the test container to the platform for Method B. Restraints shall be provided to restrain the horizontal motion of the test specimens on the platform without restricting the vertical motion of the specimen(s), for Method C.

5.4 *Instrumentation*—Accelerometers, signal conditioners, and data display or storage devices are required to measure and control the accelerations at the test surface in Methods B and C. Instrumentation may also be desirable for monitoring the response of the containers and packaged items. The instrumentation system shall have a response accurate to within $\pm 5\%$ over the range specified for the test. Accelerometers should be small and light weight enough as to not influence the response of the item being measured nor influence the results of the test. Detailed information on suitable instrumentation may be found in the *Shock and Vibration Handbook*.⁷

5.5 *Conditioning Apparatus*—Adequate facilities shall be provided for conditioning test specimens at selected humidity and temperature prior to or during the test, or both, in accordance with the requirements of the applicable specification.

6. Safety Precautions

6.1 These test methods may produce severe mechanical responses of the test specimens. Therefore, fences, barricades, and other restraints must have sufficient strength and must be adequately secured. Operating personnel must remain alert to 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

⁷ Harris, C. M., *Shock and Vibration Handbook*, McGraw-Hill, New York, NY, 1988, Chapter 16.

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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 is recorded prior to the test. Dummy test items should be used for developmental testing when necessary, but may not be used for final acceptance testing.

NOTE 3—Surrogate material may be used when actual product is unacceptable for use (for example, package testing for hazardous materials).

7.2 Sensors and transducers may be applied with the 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.

7.3 Whenever sufficient containers and contents are available, it is highly desirable that five or more replicate tests be conducted to improve the statistical reliability of the data obtained (see Practice E 122).

8. Conditioning

8.1 Condition test specimens prior to the test or during the test, or both, in accordance with the requirements of the applicable specification. When no conditioning requirements are given, and the container materials are climatically sensitive, a conditioning atmosphere is recommended (see Practice D 4332 for standard and special conditions).

9. Procedure

9.1 Methods A1 and A2—Repetitive Shock Tests:

9.1.1 Place the test specimen on the test machine platform in its normal shipping orientation. Attach restraining devices to the platform to prevent the specimen from moving horizontally off the platform and to prevent excessive rocking, without restricting the vertical movement. Adjust the restraining devices to permit free movement of the test specimen of approximately 10 mm (0.4 in.) in any horizontal direction from its center position.

9.1.2 Start the vibration of the platform at a frequency of about 2 Hz, and steadily increase the frequency until some portion of the test specimen repeatedly leaves the test surface. To ensure that the test specimen receives a continuing series of repetitive shocks, a shim with a 1.6 mm ($1/16$ -in.) thickness and a width of 50 mm (2.0 in.) shall be used to determine when the test specimen is leaving the test platform by inserting it under the package, a minimum of 100 mm (4.0 in.), and moving it intermittently along one entire length of the package. Use a shim of sufficient length to ensure operator safety, taking care to keep the shim flat on the vibration platform.

9.1.3 Continue the test at this frequency for a 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 may be stopped momentarily to inspect for damage.

9.1.4 If the container might possibly be transported in any other orientations, test at least one container in each possible orientation for the full specified test duration.

NOTE 4—When no test duration is specified, a test duration of 1 h is recommended. Practice D 4169 may also be referred to for test durations.

9.1.5 Inspect the container and its contents and record any damage or deterioration resulting from the test.

9.2 Method B—Single Container Resonance Test:

9.2.1 Fasten the test specimen, in its normal shipping orientation, securely to the platform of the vibration equipment so that the specified vibration condition is transmitted to the outer part of the container. Mount the accelerometer to either the top or bottom of the platform, as close to the test item as possible, (insuring the accelerometer is not damaged by the product) or in a location that produces data representative of table motion. Monitor the amplitude and frequency data achieved on the platform to ensure that the desired test conditions are produced.

9.2.2 Determine resonance frequency or frequencies in one of two ways: sine sweep or random input.

9.2.2.1 *Resonance Search Using Sine Sweep*—Adjust the vibration test apparatus to produce the specified constant acceleration amplitude (zero-to-peak) over the specified range of frequencies. Starting at the lowest frequency, sweep the frequency of the vibration at a continuous logarithmic rate of 0.5 to 1.0 octaves per minute to the upper frequency limit and back to the lower limit. Repeat this complete cycle twice, recording all the resonant responses of the test specimen. These resonance frequencies can be determined in a variety of ways, including auditory (listening to the response), visual (a stroboscope or video system may be beneficial aids), or with an accelerometer.

NOTE 5—Resonance frequency or frequencies may differ between sweep up and sweep down. The natural frequency of the test specimen is approximately midway between the apparent resonance frequency (ies) found on the sweep up versus the sweep down.

NOTE 6—If no test severity is specified, an acceleration amplitude of 0.25 g 's – 0.5 g (2.45 m/s^2 – 4.9 m/s^2) (zero to peak) over the frequency range from 3 to 100 Hz is often sufficient to excite resonance. Practice D 4169 also may be referred to for test level and duration recommendations.

9.2.2.2 *Resonance Search Using Random Vibration Input*—As an alternative to using sine sweep for identifying resonance frequency or frequencies of a packaged product, it may be faster to use random vibration input, where a wide frequency input band excites all of the natural frequencies of a packaged product simultaneously. Please see Test Method D 3580 for further discussion of using random vibration input. To utilize this methodology, it is necessary to attach an accelerometer, or accelerometers, to the product to monitor maximum response frequencies. It is also necessary to attach an accelerometer to the platform to assure the platform motion is representative of the desired PSD input spectrum. Mount a transducer in such a way as to identify the resonant frequency or frequencies of the package in the direction of the table motion.

9.2.2.3 The minimum frequency range should be from 3 to 100 Hz at a minimum power spectral density (PSD) level of 0.005 g^2/Hz (0.049 $(m/s^2)^2/Hz$), or a spectrum known to be appropriate. Note that this spectra does not represent any particular real world environment but simply allows one to identify package natural frequencies within the area of forcing frequencies found most often in transportation. Start the vibration system such that the PSD levels do not overshoot the

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desired spectrum during startup. Initiate the test at least 6dB below full level and increment in one or more subsequent steps to full test level. Allow the control system to stabilize sufficiently to represent a stable spectrum shape and level. Compare the input with the response. Record the resonance responses of the test item.

NOTE 7—It should be noted that some existing vibration test equipment has limited frequency range capability and additional equipment may be needed to cover the entire recommended frequency range.

9.2.3 Dwell for the specified length of time at each resonant frequency determined in 9.2.2.1 (limited to a maximum of the four most severe resonances), or until damage to the container is noted, whichever occurs first. Adjust the frequency of vibration as necessary to maintain resonance.

NOTE 8—If no dwell time is specified, a dwell of 15 min is recommended. Practice D 4169 may also be referred to for test durations.

9.2.4 Repeat the procedures of 9.2.1, 9.2.2.1, and 9.2.3 with the container oriented in those orientations that might be expected to occur in distribution.

9.2.5 Inspect the container and its contents and record any damage or deterioration resulting from the test.

9.3 *Method C—Palletized Load, Unitized Load, or Vertical Stack Resonance Test:*

9.3.1 Place the full-size unitized or palletized load(s) of test specimen(s) on the test machine platform to a height equal to that used in the mode of shipment. It is best to test the load exactly the way it is prepared for normal shipment, that is, stretch wrap, banding, stacking configuration, etc. A single vertical column of containers may be used if vertical stacking alignment is used in shipping. Attach restraining devices to the platform to prevent the specimen(s) from horizontal movement off the platform, and to prevent toppling and excessive rocking. Adjust the restraining devices to permit free movement of the test specimen(s) of approximately 10 mm (0.4 in.) in any horizontal direction. Attach the accelerometer to the platform as close as possible to the test specimen(s), but protected so that it will not be contacted.

9.3.2 Determine resonance point(s) in one of two ways: sine sweep or random input.

9.3.2.1 *Resonance Search Using Sine Sweep*—Adjust the vibration test apparatus to produce the specified constant acceleration amplitude (zero-to-peak) over the specified range of frequencies. Starting at the lowest frequency, sweep the frequency of vibration at a continuous logarithmic rate of 0.5 to 1.0 octaves/min to the upper frequency limit, and then back to the lower limit. Repeat this complete cycle twice, and record all the resonance responses of the test load. These resonance frequencies can be determined in a variety of ways, including auditory (listening to the response), visual (a stroboscope or video system may be beneficial aids), or with an accelerometer located on an upper package in the stack.

NOTE 9—Multiple-unit loads likely are to exhibit several resonant responses.

NOTE 10—Resonance frequencies may differ between sweep up and sweep down. The natural frequency of the test specimen is approximately midway between the apparent resonance frequency found on the sweep up versus the sweep down.

NOTE 11—If no test severity is specified, an acceleration amplitude of

0.25 g (2.5 m/s²) (zero to peak) over the frequency range from 2 to 100 Hz is recommended. Practice D 4169 also may be referred to for test level recommendations.

9.3.2.2 *Resonance Search Using Random Vibration Input*—As an alternative to using sine sweep for identifying resonance frequency or frequencies of a unitized, palletized, or stacked load, it may be faster to use random vibration input, where a wide frequency input band excites all of the natural frequencies of the test specimen simultaneously. Please see Test Method D 3580 for further discussion of using random vibration input. To utilize this methodology, it is necessary to attach an accelerometer or accelerometers to an upper package in the stack to monitor the maximum response frequency or frequencies. This transducer should be mounted on the outside of the specimen to capture the resonance frequency of the load versus the resonance information of the interior of the individual package. It is necessary to attach an accelerometer to the platform to assure the platform motion is representative of the desired PSD input spectrum.

9.3.2.3 The minimum frequency range should be from 3 to 100 Hz at a minimum power spectral density (PSD) level of 0.005 g²/Hz (0.049 (m/s²)²/Hz), or a spectrum known to be appropriate. Note that this spectra does not represent any particular real world environment but simply allows one to identify stack natural frequencies within the area of forcing frequencies found most often in transportation. Start the vibration system such that the PSD levels do not overshoot the desired spectrum during startup. Initiate the test at least 6dB below full level and increment in one or more subsequent steps to full test level. Allow the control system to stabilize sufficiently to represent a stable spectrum shape and level. Comparing the input with the response, record the resonance responses of the test load.

9.3.3 Dwell for the specified length of time at each resonant frequency determined in 9.3.2 (limited to a maximum of the four most severe resonances), or until damage is noted in the load, whichever occurs first. Adjust the frequency of the vibration as necessary to maintain resonance.

NOTE 12—If no dwell time is specified, a dwell time of 15 min is recommended. Practice D 4169 may be referred to for test durations.

9.3.4 Inspect the container(s) and contents and record any damage or deterioration resulting from the test.

10. Report

10.1 The report shall include the following:

10.1.1 Identification and description of the test specimens, including the container, the interior packaging, and the product (give size, weight, and any other pertinent details).

10.1.2 If Method C is used for unitized loads, describe the unitized load and the height of the stack, and the unitizing method employed.

10.1.3 Purpose of the test and the applicable performance specification, if any.

10.1.4 Sequence of test methods and the test intensities, frequencies, and durations used. State whether random or swept sine input was used to determine resonance frequencies. If random, report the spectrum used.

10.1.5 Verification of compliance with the test method or describe any deviations.

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- 10.1.6 Number of replications of each test.
- 10.1.7 Atmospheric conditions the test specimens were subjected to, both prior and during the test.
- 10.1.8 Any other test the specimens were subjected to prior to this test.
- 10.1.9 Description of the apparatus and the instrumentation used, including the date of last calibration.
- 10.1.10 Detailed descriptions and photographs of the fixturing used in the test.
- 10.1.11 Results of the test.
- 10.1.12 Descriptions and photographs of any damage or deterioration to the containers or their contents as a result of the test(s).
- 10.1.13 State whether the damage created in the laboratory testing replicates actual field damage to the container and contents.
- 10.1.14 All resonant responses and any observations that may assist in correct interpretation of results or lead to improvements in the design of the container, interior packaging, or product.

10.1.15 Statement of whether or not the specimen(s) complied with the requirements of the applicable specification.

11. Precision and Bias

11.1 Precision:

11.1.1 No information is presented about the damage-producing ability of these methods, since the results are usually nonquantitative.

11.1.2 Based on limited data from one laboratory, the within-laboratory repeatability standard deviation for the primary resonance may be below 1 Hz, depending on the item tested. Higher order resonances may have more variability.

11.2 *Bias*—The procedures in these methods have no bias because there is no accepted reference material or procedure.

12. Keywords

12.1 repetitive shock; resonance; shipping container; stack resonance; vibration

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