Designation: D4728 – 17

Standard Test Method for Random Vibration Testing of Shipping Containers[1]

This standard is issued under the fixed designation D4728; 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 (ε) 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 vibration inputs.

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

NOTE 1—Sources of supplementary information are listed in the Reference section (**1-11**).[2]

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, health and environmental practices and determine the applicability of regulatory limitations prior to use.* Specific safety hazard statements are given in Section 6.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D996 Terminology of Packaging and Distribution Environments

D4169 Practice for Performance Testing of Shipping Containers and Systems

D4332 Practice for Conditioning Containers, Packages, or Packaging Components for Testing

D7386 Practice for Performance Testing of Packages for Single Parcel Delivery Systems

2.2 *ISO Standards:*

ISO 13355 Packaging—Complete, filled transport packages and unit loads—Vertical random vibration test[4]

2.3 *ISTA Standards:*[5]

ISTA Procedure 1G Packaged-Products 150 lb (68 kg) or Less (Random Vibration)

ISTA Procedure 3A Packaged-Products for Parcel Delivery System Shipment 70 kg (150 lb) or Less

ISTA Procedure 3H Products or Packaged-Products in Mechanically Handled Bulk Transport Containers

3. Terminology

3.1 *Definitions:*

3.1.1 *General*—Definitions for the packaging and distribution environments are found in Terminology D996.

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.

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[1] This test method is under the jurisdiction of ASTM Committee D10 on Packaging and is the direct responsibility of Subcommittee D10.21 on Shipping Containers and Systems - Application of Performance Test Methods.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this test method.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

[5] Available from International Safe Transit Association (ISTA), 1400 Abbot Road, Suite 160, East Lansing, MI 48823-1900, http://www.ista.org.

*A Summary of Changes section appears at the end of this standard

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

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

3.2.9 *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.

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

3.2.11 *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.

3.2.12 *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.

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

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

3.2.15 *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.

3.2.16 *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 D4169 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.

5.2.1 *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, printer, and a data storage 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 The digital real time analysis 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 ±5 % across 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 measurements 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 Appendix X1, 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 ± 3 dB in any frequency analysis band over the entire test frequency range, except that deviations as large as ±6 dB will be allowed over a cumulative bandwidth of 10 Hz. In addition, the overall *g* rms level shall not deviate more than ±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.

8.4.3 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 ±3 dB.

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

9. Conditioning

9.1 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 D4332 for standard and special conditions).

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. Unit loads, stacked columns, or single units should be allowed to vibrate freely unless they will actually be securely fastened during shipment, crates on a flatbed trailer for example. When the specimen is not secured to the table, restraining devices should be attached to the vibration table to prevent potential movement of the specimen 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.

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 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.

10.3 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

APPENDIXES

(Nonmandatory Information)

X1. REFERENCES FOR PSD TEST PROFILES

X1.1 One approach to random vibration testing for truck shipments can be found in Practice D4169. This employs a sequence of three separate PSD profiles, representing different probabilities of occurrence in actual shipment.

X1.2 PSD profiles for air and rail shipments can be found in Practice D4169, with profiles at different levels representing different assurance levels.

X1.3 Test profiles specific to small parcel delivery can be found in Practice D7386.

X1.4 ISO 13355 has a single PSD profile for transport test which represents mainly truck shipments.

X1.5 Reference (**2**) MIL-STD-810G, Method 514.6 Vibration, Annex C has recommended PSD profiles for truck shipment, including vertical, longitudinal, and transverse directions separately.

X1.6 The ISTA 1 and 2 Series Procedures, ISTA Procedure 1G as an example, have a basic "integrity test" PSD profile for truck transport.

X1.7 ISTA Procedure 3A has "general simulation" PSD profiles for "over-the-road trailer" and "pick-up and delivery vehicle."

X1.8 ISTA Procedure 3H has "general simulation" PSD profiles for "steel spring truck," "air-ride truck," and "rail."

X2. SAMPLE PSD VIBRATION DATA

X2.1 References **(3-11)** provide many examples of transport vibration PSD data. The user of random vibration must verify accuracy and applicability of any data of this type prior to its use.

REFERENCES

(1) Harris and Crede, *Shock and Vibration Handbook*, McGraw-Hill Co., New York NY, 1976.

(2) "Method 514.6 Vibration," *Environmental Test Methods and Engineering Guidelines MIL-STD-810G*, Department of Defense, October 2008.

(3) Ostrem, F. E., and Godshall, W. D., "An Assessment of the Common Carrier Shipping Environment," *General Technical Report FPL 22*, U.S. Forest Product Laboratory, 1979.

(4) Andress, E. A., "Generation of a Transportation Vibration Test Specification," *DRC-009 11/81*, Scientific Atlanta, Spectral Dynamics Division, 1981.

(5) Tustin and Mercado, *Random Vibration in Perspective*, Tustin Institute of Technology, Inc., Santa Barbara, CA, 1984.

(6) Singh, S. P., Antle, J. R., and Burgess, G. G., "Comparison Between Lateral, Longitudinal, and Vertical Vibration Levels in Commercial Truck Shipments," *Packaging Technology and Science*, Vol 5, pp. 71–75, 1992.

(7) Singh, S. P., and Marcondes, J., "Vibration Levels in Commercial Truck Shipments as a Function of Suspension and Payload," *ASTM JOTE*, November 1992.

(8) "Study of the Shock and Vibration Environment in Boxcars," *Report No. DP 7-92*, Association of American Railroads, November 1992.

(9) "A Technical Summary of the Intermodal Environment Study," *Report No. DP 3-91*, Association of American Railroads, April 1991.

(10) Singh, J., Singh, S. P., and Joneson, E., "Measurement and Analysis of US Truck Vibration for Leaf Spring and Air Ride Suspensions, and Development of Tests to Simulate these Conditions," *Packaging Technology and Science*, Vol 19, pp. 309–323, 2006.

(11) Braunmiller, U.,"Source Reduction by European Testing Schedules (SRETS)," Final Report EUR 19090, Office for Official Publications of the European Communities, 1999.

SUMMARY OF CHANGES

Committee D10 has identified the location of selected changes to this standard since the last issue (D4728-06(2012)) that may impact the use of this standard. (Approved September 1, 2017)

(1) Added D7386 reference to 2.1.
(2) Added 2.3 references to ISTA standards.
(3) Deleted 3.2.7 and 3.2.9.
(4) Replaced all of Appendix X1, deleted all figures and tables, added references to standards that have random test profiles. Note that the reference to current version of D4169 means that truck vibration profiles are significantly changed. Refer to D4169-14 and older for the historical truck profiles, still in wide use.
(5) Replaced all of Appendix X2, deleted all figures, referred to the reference list for example vibration data.
(6) Revised reference (2) to current version.
(7) Deleted reference (3).
(8) Added references (10) and (11).