Designation: D 3332 – 99

Standard Test Methods for Mechanical-Shock Fragility of Products, Using Shock Machines[1]

This standard is issued under the fixed designation D 3332; 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 These test methods cover determination of the shock fragility of products. This fragility information may be used in designing shipping containers for transporting the products. It may also be used to improve product ruggedness. Unit or consumer packages, which are transported within an outer container, are considered to be the product for the purposes of these test methods. Two test methods are outlined, as follows:

1.1.1 Test Method A is used first, to determine the product's critical velocity change.

1.1.2 Test Method B is used second, to determine the product's critical acceleration.

1.2 The values stated in either inch-pound or SI units are to be regarded as the standard. The values given in parentheses are for information only.

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.* For specific precautionary statements, see Section 6.

2. Referenced Documents

2.1 *ASTM Standards:*

D 996 Terminology of Packaging and Distribution Environments[2]

D 2463 Test Method for Drop Impact Resistance of Blow-Molded Thermoplastic Containers[3]

D 3580 Test Method for Vibration (Vertical Sinusoidal Motion) Test of Products[2]

D 4332 Practice for Conditioning Containers, Packages, or Package Components for Testing[2]

D 5112 Test Method for Vibration (Horizontal Linear Motion) Test of Products[2]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[4]

E 680 Test Method for Drop Weight Impact Sensitivity of Solid-Phase Hazardous Materials[4]

3. Terminology

3.1 *Definitions*—General definitions for packing and distribution are found in Terminology D 996.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *acceleration of gravity (g)*—386.1 in./s^2(9.806 m/s^2).

3.2.2 *critical acceleration (A_c)*—the maximum-faired acceleration level for a minimum velocity change of 1.57 ΔV_c (see 9.3), above which product failure (or damage) occurs. A product usually has a different critical acceleration for each direction in which it is tested.

3.2.3 *critical velocity change (V_c)*—the velocity change (see 9.2) below which product failure is unaffected by shock-pulse maximum-faired acceleration or waveform. A product usually has a different critical velocity change for each direction in which it is tested.

3.2.4 *damage*—product failure that occurs during a shock test. Damage can render the product unacceptable because it becomes inoperable or fails to meet performance specifications when its appearance is unacceptably altered, or some combination of these failure modes occurs.

3.2.5 *damage boundary*—See Annex A3.

3.2.6 *fairing*—The graphical smoothing of the amplitude of a recorded pulse still containing high frequency components even though electronic filtering may have been performed. This amplitude is used to evaluate the basic recorded pulse features with respect to the specified pulse. (see Figs. A1.1 and A2.1)

3.2.7 *shock pulse programmer*—a device used to control the parameters of the acceleration versus time shock pulse generated by a shock test machine.

3.2.8 *shock test machine drop height*—the distance through which the carriage of the shock test machine falls before striking the shock pulse programmer.

4. Significance and Use

4.1 These test methods are intended to provide the user with data on product shock fragility that can be used in choosing

[1] These test methods are under the jurisdiction of ASTM Committee D-10 on Packaging and are the direct responsibility of Subcommittee D10.15 on Fragility Assessment.

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[2] *Annual Book of ASTM Standards*, Vol 15.09.

[3] *Annual Book of ASTM Standards*, Vol 08.02.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

optimum-cushioning materials for shipping containers or for product design modification.

5. Apparatus

5.1 *Shock Test Machine*:

5.1.1 The machine shall consist of a flat horizontal test surface (carriage) of sufficient strength and rigidity to remain flat and horizontal under the stresses developed during the test. The test surface shall be guided to fall vertically without rotation or translation in other directions.

5.1.2 The machine shall incorporate sufficient carriage drop height to produce the shock pulses given in 9.2 and 9.3. Drop height control shall be provided to permit reproducibility within ±0.25 in. (±6 mm).

5.1.3 The machine shall be equipped to produce shock pulses at the carriage as specified in 9.2 and 9.3.

5.1.4 Means shall be provided to arrest the motion of the carriage after impact to prevent secondary shock.

5.2 *Instrumentation*:

5.2.1 *Acceleration*— An accelerometer, signal conditioner, and data storage apparatus are required to record acceleration-time histories. The accelerometer shall be attached rigidly to the base structure of the product or to the fixture, at or near a point at which the fixture is fastened to the carriage. If the fixture is sufficiently rigid to not distort the shock pulse imparted to the product, the accelerometer may be mounted on the carriage. In some cases, when a product contains heavy resiliently supported masses that will distort the shock pulses severely, it may be necessary to precalibrate the shock machine. The accelerometer is fastened to the carriage in this case, and a rigid mass weighing the same as the product is subjected to a series of shock pulses. The instrumentation system shall have sufficient response to permit measurements in the following ranges.

5.2.1.1 *Test Method A*— 5 Hz or less to at least 1000 Hz.

5.2.1.2 *Test Method B*— 1 Hz or less to at least 330 Hz.

5.2.1.3 *Accuracy*—Reading to be within ±5 % of the actual value.

5.2.1.4 *Cross-Axis Sensitivity*—Less than 5 % of the actual value.

5.2.2 *Velocity*—Instrumentation to measure the velocity change of the shock table is required. This may be a device that integrates the area electronically under the shock pulse waveform. Alternatively, it can be measured by photodiode-type devices that measure shock table impact and rebound velocity. Calculation that assumes the shock pulse to be a perfect geometric figure is usually grossly inaccurate and should not be used.

6. Precautions

6.1 These test methods may produce severe mechanical responses in the test specimen. Operating personnel must therefore remain alert to potential hazards and take necessary safety precautions. The test area should be cleared prior to each impact. The testing of hazardous material or products may require special precautions that must be observed. Safety equipment may be required, and its use must be understood before starting the test.

7. Sampling

7.1 Sampling procedures and the number of test specimens depend on the specific purposes and needs of the testing. Sample size determination based on Practice E 122 or other established statistical procedures is recommended.

8. Conditioning

8.1 If temperature and humidity conditioning is required for the product being tested, refer to Practice D 4332 for standard conditioning procedures. Unless otherwise specified, conduct all tests with the same conditions prevailing.

9. Procedure

9.1 Mount the product to be tested on the carriage of the shock test machine. The product should be supported by a fixture similar in shape and configuration to the cushion that will support the product in its shipping container. The fixture should be as rigid as possible so as not to distort the shock pulse imparted to the product. Fasten the fixture and product securely to the carriage so that it will not leave the surface of the carriage during the shock test.

NOTE 1—The points at which the fixture supports the product are very important because the dynamic response of the product is influenced strongly by the location of these support points

NOTE 2—If the orientation of the product can change during handling impacts, a test may be required for each of the directions in which the input shock can occur. Multidirectional tests are recommended since most products have different fragilities in different orientations.

9.2 *Test Method A—Critical Velocity Change Shock Test*:

9.2.1 *Scope*—This test method is used to determine the critical velocity change (V_c) portion of the damage boundary plot of a product.

9.2.1.1 To ensure that the components of a product only respond to the velocity change of the pulse, a shock pulse having any waveform and a duration (T_p) not longer than 3 ms should be used to perform this test. Pulse durations as short as 0.5 ms may be required when testing small, very rigid products (see Note 3). Shock pulse waveform is not limited since the critical velocity portion of the damage boundary is unaffected by shock pulse shape. Since they are relatively easy to control, shock pulses having a half sine shock waveform are normally used.

NOTE 3—In general: $T_p \leq 167 / f_c$

where:

T_p = maximum shock test machine pulse duration in ms, and
f_c = component natural frequency in Hz.

For example, a component of a product with a natural frequency below 56 Hz can be effectively tested on a shock machine with a 3 ms duration pulse. If the component natural frequency is higher, the pulse duration must be shorter. A 2 ms duration pulse can be used on a component with a natural frequency up to 83 Hz.

9.2.2 *Procedure*:

9.2.2.1 Set the shock test machine so that the shock pulse produced has a velocity change below the anticipated critical velocity change of the product.

9.2.2.2 Perform one shock test.

9.2.2.3 Examine or functionally test the product, or do both, to determine whether damage due to shock has occurred.

9.2.2.4 If no damage has occurred, set the shock test machine for a higher velocity change and repeat the shock test. Acceptable increment size is influenced strongly by the product being tested. For example, an increment of 5 in./s (0.13 m/s) may be appropriate for most products but unacceptable for high-value products.

9.2.2.5 Repeat 9.2.2.2-9.2.2.4, with incrementally increasing velocity change, until product damage occurs. This point is shown as Test No. 7 in Fig. A3.1.

9.2.2.6 Common practice is to define the critical velocity change (V_c) as the midpoint between the last successful test and the test that produced failure. Depending on the purpose of the test, use of the last successful test point before failure may be considered as a more conservative estimate of (V_c).

9.3 *Test Method B—Critical Acceleration Shock Test*:

9.3.1 *Scope*—This test method is used to determine the critical acceleration (A_c) portion of the damage boundary plot of a product.

9.3.1.1 When the critical acceleration of a product is known, package cushioning materials can be chosen to protect it.

9.3.1.2 If no cushioning materials are to be used in the package, it may be unnecessary to perform this test. Only the critical velocity change test may suffice in this case.

9.3.1.3 Trapezoidal shock pulses are normally used to perform this test. Although a true square wave shock pulse is most desirable in theory, it is not possible to obtain infinitely short rise and fall times. On the basis of much testing experience, it has been determined that rise and fall times (see Fig. A2.1) of 1.8 ms, or less, are required. Longer rise and fall times cause the critical acceleration line of the damage boundary curve to deviate from the horizontal, introducing errors into the test results. For the same reason, waveforms having faired shapes that are not trapezoidal should not be used for this test. Their use would cause the critical acceleration line of the damage boundary curve to vary widely as a function of velocity change. For example, if a half sine shock pulse waveform is used, a deeply scalloped critical acceleration line is produced and the test data become meaningless.

9.3.2 *Procedure*:

9.3.2.1 Set the shock test machine so that it will produce a trapezoidal shock pulse having a velocity change of at least 1.57 times as great as the critical velocity change determined in Test Method A (9.2). A factor of 2 or more is normally used for an added safety margin. This is required to avoid the rounded intersection of the critical velocity change and critical acceleration lines. Maximum-faired acceleration level of the first shock pulse should be below the anticipated failure level of the product.

9.3.2.2 Perform one shock test.

9.3.2.3 Examine the recorded shock pulse to be certain the desired maximum-faired acceleration and velocity change were obtained.

9.3.2.4 Examine or functionally test the product, or do both, to determine whether damage due to shock has occurred.

9.3.2.5 If no damage has occurred, set the shock test machine for a higher maximum-faired acceleration level. Be certain that the velocity change of subsequent shock pulses is maintained at or above the level determined in 9.3.2.1. Acceptable increment size is influenced strongly by the product being tested. For example, an increment of 5 g may be appropriate for most products but unacceptable for high-value products.

NOTE 4—See shock machine manufacturer recommendations for setting acceleration levels because this procedure is specific to the type of programmer.

9.3.2.6 Repeat 9.3.2.2-9.3.2.5, with incrementally increasing maximum-faired acceleration, until product damage occurs. This point is shown as Test No. 14 in Fig. A3.1. Common practice is to define the critical acceleration (A_c) as the midpoint between the last successful test and the test that produced failure. Depending on the purpose of the test, use of the last successful test point before failure may be considered as a more conservative estimate of (A_c).

10. Report

10.1 Report the following information:

10.1.1 Reference to these test methods, noting any deviations from the test method.

10.1.2 Complete identification of the product being tested, including type, manufacturer's code numbers, general description of configuration, and its pretest condition.

10.1.3 Method of mounting the product on the carriage of the shock test machine.

10.1.4 Type of instrumentation used and critical settings thereof.

10.1.5 Recordings of the shock pulses that caused product damage.

10.1.6 Record of shock test machine drop height for each shock pulse that caused product damage.

10.1.7 Record of damage, including a photograph of product damage, if visible.

10.1.8 Record of waveform, maximum-faired acceleration, pulse duration, and velocity change of the shock pulses.

10.1.9 Record of conditioning used.

10.1.10 Plots of damage boundaries of the product.

10.1.11 If multiple products are used, record of the sampling methods, average or median test levels, and standard deviations.

11. Precision and Bias

11.1 *Precision*—The within-laboratory or repeatability standard deviation is largely dependent on the particular item being tested. A research report[5] describes an interlaboratory test program of three types of items (in packages) for a critical velocity change shock test. The repeatability standard deviations were 6.7, 14.7, and 21.5 in./s (0.17, 0.37, and 0.55 m/s). Other items may have more or less variability. The between-laboratory or reproducibility standard deviation was 5.7 in./s (0.15 m/s).

11.2 *Bias*—No justifiable statement can be made on the bias of these test methods since a true value cannot be established by an accepted referee method.

12. Keywords

12.1 fragility; products; shock; shock machine

[5] Supporting data have been filed at ASTM Headquarters. Request RR: D10-1004.

ANNEXES

(Mandatory Information)

A1. HALF-SINE SHOCK PULSE VELOCITY CHANGE, USING INTEGRATING INSTRUMENTATION

A1.1 *Integrating Instrumentation*—Integrate the area under the curve from the point at which the acceleration level first leaves the zero axis in a positive direction to the point at which the acceleration next returns to zero (see Fig. A1.1).

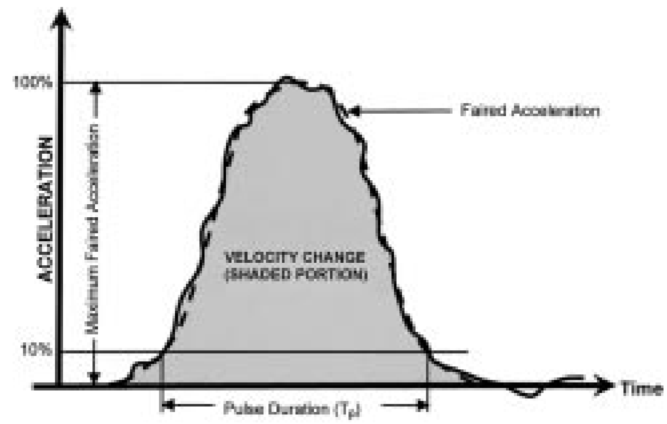

FIG. A1.1 Half-Sine Shock Pulse Diagram

A2. TRAPEZOIDAL SHOCK PULSE VELOCITY CHANGE USING INTEGRATING INSTRUMENTATION

A2.1 *Integrating Instrumentation*—Integrate the area under the curve from the point at which the acceleration level first leaves the zero axis in a positive direction to the point at which the level next returns to zero (Fig. A2.1).

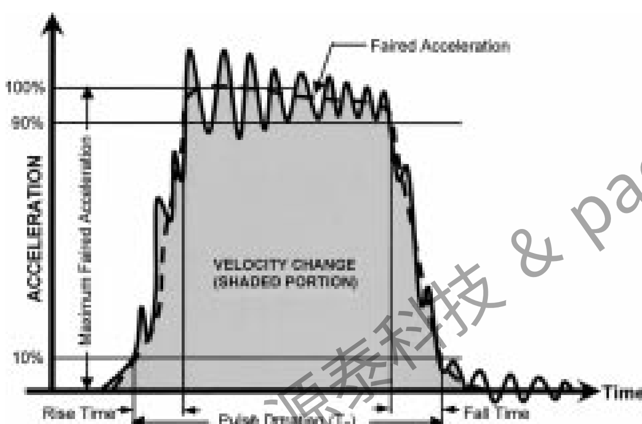

FIG. A2.1 Trapezoidal Shock Pulse Diagram

A3. DAMAGE BOUNDARY

A3.1 Sensitivity to shock of a product is dependent on three parameters of the shock pulse: shock pulse shape, shock-pulse velocity change, and shock-pulse maximum-faired acceleration. For a given product, the interrelation of these three parameters is shown by damage boundary, as plotted in Fig. A3.1.

A3.2 Product damage will occur for shock pulses having peak acceleration and velocity change values falling in the shaded area. Shock pulses having values outside the shaded area will not damage the product. For most products, the damage boundary will be different for each direction in which the shock occurs.

A3.3 The example plotted in Fig. A3.1 is based on tests conducted in accordance with Test Methods A and B. A sample of the product was subjected to half-sine shock pulses in accordance with Test Method A.

A3.3.1 Tests numbered 1 through 7, with both drop height and acceleration increasing successively, were performed. Failure occurred in the seventh test, establishing the vertical critical velocity change line midway between the sixth and seventh test levels (see 9.2.2.6).

A3.3.2 Then another sample or a repaired sample of the product was subjected to trapezoidal shock pulses in accordance with Test Method B (9.3). Each trapezoidal shock pulse had a velocity change of more than two times the critical velocity change (V_c) determined previously. Each trapezoidal shock pulse had a faired acceleration level incrementally higher than the previous shock pulse. Failure occurred in the fourteenth test, establishing the horizontal critical acceleration line (A_c) midway between the thirteenth and fourteenth test levels (see 9.3.2.6).

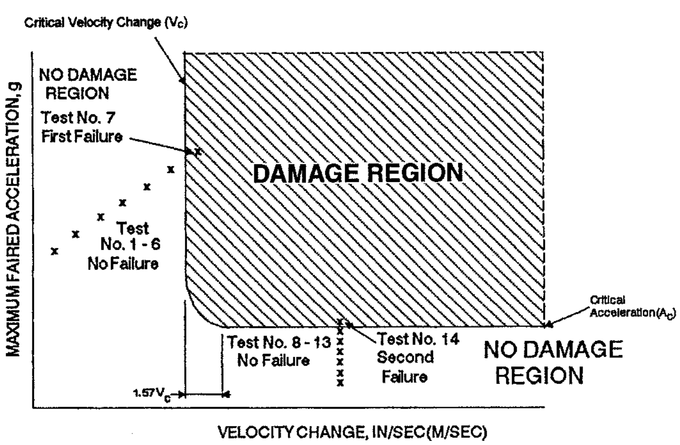

FIG. A3.1 Damage Boundary

A3.4 Three results can be determined when the damage boundary is plotted:

A3.4.1 If the velocity change that the product will undergo in shipment is below the critical velocity change (V_c), no cushioning is required.

A3.4.2 If the critical velocity change (V_c) is below the velocity change that the product will be subjected to during unpackaged product handling, the product should be modified to increase its critical velocity change. Examples of unpackaged product handling are movement of the finished product on a production line, before packaging and customer handling, and installation upon receipt. In these cases, the test will have shown that the unmodified product is too fragile to be handled in its normal production or in-use environment.

A3.4.3 If the velocity change that the product will undergo in shipment is above the critical velocity change (V_c), package cushioning would be required to prevent damage.

A3.4.4 The actual shape of the pulse transmitted to the product by the cushion is usually not known. The pulse shape depends on the dynamic force-versus-deflection characteristics of the cushion and will vary for different cushion materials, cushion deflections, etc. The damage boundary of a trapezoidal-shock pulse envelops damage boundaries produced by other waveforms. For this reason, shocks transmitted by some cushion materials will be less severe than those produced by the trapezoidal-shock pulse test. None will be more severe than those produced by the trapezoidal shock pulse. Therefore, the test in accordance with Test Method B (9.3) introduces a safety factor.

A3.4.5 As shown in Fig. A3.1, the corner at which the critical velocity change and critical acceleration lines intersect is rounded. To avoid inconclusive test results, the critical acceleration test is conducted at velocity changes at least two times the critical velocity change of the product. In this way, the rounded region of the damage boundary is avoided.

A4. EFFECT OF MULTIPLE SHOCKS

A4.1 Test Methods A and B require that the product being tested be subjected to a series of shocks of incrementally increasing severity. Most products are not affected by this multiplicity of tests. However, some products will fail prematurely due to cumulative effects. When a second sample of such a product is subjected to a single shock pulse at the same level that caused the first sample to fail, it will not fail. It will fail only when it is subjected to even higher level shocks. For a product of this type, it is important to determine the probable number of shocks that it will be subjected to in shipment. The test data will have to be corrected if significantly fewer shocks than those used in the test are anticipated. Multiple samples of such a product are usually tested.

A4.2 If only a few samples of the product are available, a simplified calculation technique may be used to determine the effect of multiple shocks. After the tests of the first sample, successive samples are tested at shock levels beginning near the failure level of the first sample. Three to five new or repaired test items are often used for each test orientation and for each part of the damage boundary (V_c and A_c). The failure level is then defined as the average (arithmetic mean) of the midpoints between the last tests and the test that produced failure (excluding the first sample, which failed prematurely due to cumulative effects). This procedure is less accurate than that described in A4.3.

A4.3 A test procedure known as the "up-and-down" or "staircase" method is well suited for use in product fragility testing. Several specimens are tested sequentially, with the test specimen being discarded or repaired after each individual shock test. The first specimen is tested at the estimated failure point. If it fails at that shock level, the next specimen is tested at a level that is a fixed increment lower. If it passes, the specimen is tested at a shock level that is incrementally higher. The shock input for each test is thus determined by the previous test result.

A4.3.1 At the completion of a fixed number of tests, often ten or more, an average or median value and the standard deviation are calculated. This procedure is repeated for each orientation and each part of the damaged boundary (V_c and A_c) that is of interest. When possible, analyze the data for normality (reasonable conformance with Gaussian probability distribution).

A4.3.2 Several texts **(1-3)**[6] describe this procedure and computations in detail. In addition, Test Methods D 2463 and E 680 also describe this procedure.

A4.4 The effect of multiple shocks should be considered, even if only a single sample of the product is available for testing. If the product is complex, usually some sub-element of the product will fail first. Even though the product may be a prototype, additional sub-elements are frequently available to replace the one that was damaged. The procedure of A4.2 may be used in this case.

A4.4.1 If all parts of the product are one-of-a-kind, a correction factor allowing for the effects of multiple tests may have to be used. Such a factor will vary widely for different types of products. As more product samples become available, the test results should be refined using the procedures of either A4.2 or A4.3.

[6] The boldface numbers in parentheses refer to a list of references at the end of this standard.

A5. SHOCK RESPONSE SPECTRUM ANALYSIS IN FRAGILITY TESTING

A5.1 Package cushioning which is designed so that it transmits no more than the critical acceleration A_c (as determined by Test Method B and as recommended in A3.4.3) may be somewhat conservative. That is, it may be possible to design the cushion to transmit a somewhat higher acceleration yet still not cause damage to the product. This is because of the differences in pulse shape and characteristics between the fragility test and actual package cushion performance. Shock Response Spectrum (SRS) analysis can provide a tool for safely reducing the amount of conservatism. Complete details and descriptions of SRS may be found in the literature **(4-9)**.

A5.2 SRS analysis calculates the response of a large number of theoretical, single-degree-of-freedom spring-mass systems to a given shock pulse. An SRS plot is a graph of the absolute value of the maximum response accelerations of each spring-mass system, plotted at their various natural frequencies. Fig. A5.1, Fig. A5.2, and Fig. A5.3 show the SRS from a nominal 30 G, 11 ms shock machine half sine, shock machine

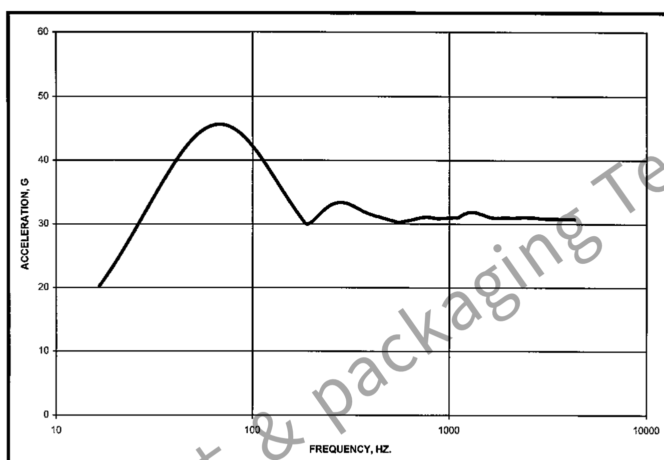

FIG. A5.1 SRS of Nominal 30G, 11 ms Shock Machine Half Sine Pulse

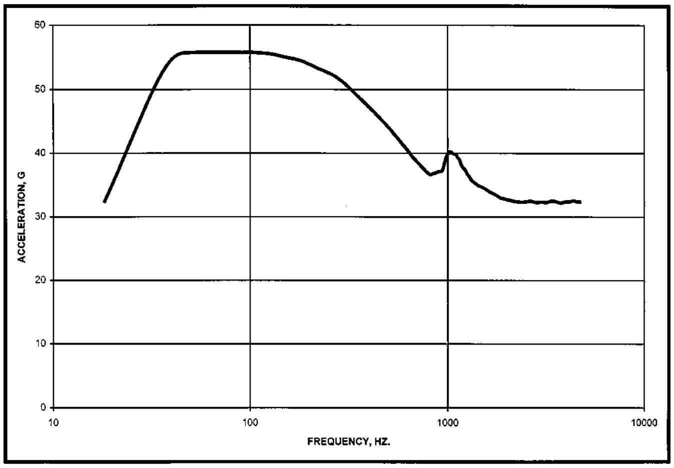

FIG. A5.2 SRS of Nominal 30G, 11 ms Shock Machine Trapezoidal Pulse

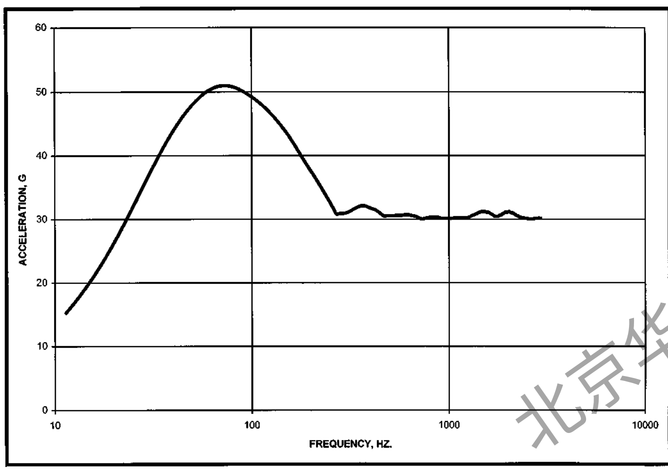

FIG. A5.3 SRS of Nominal 30G, 11 ms Actual Cushion Shock Pulse

trapezoid, and actual cushion shock pulse, respectively. Although there are different types of SRS analysis, most-commonly used is the "composite" or "maximax" analysis, which computes the absolute maximum response of each spring-mass model regardless of whether that maximum occurs during or after the input pulse.

A5.3 Typically, SRS analysis includes effects of damping on the spring-mass systems, and the user is asked to specify an amount (as a percent of or relative to critical damping). If zero damping is specified, the calculated responses will be their greatest. Zero damping, however, is not possible for real products and systems, although in most actual situations damping is low. Therefore most SRS analyses use damping values of 5 to 10 % (0.05 to 0.1). It is important to keep damping values the same throughout all portions of the procedures described below.

A5.4 The frequency range of the SRS analysis should extend from approximately 0.5 to approximately 10 times the frequency of the applied shock pulse. This is sufficient to characterize and indicate the significant responses to that pulse.

A5.5 To use SRS, conduct a Critical Acceleration test as described by Test Method B (note that, in accordance with 5.2.1, the measuring accelerometer should be mounted so as to sense the shock input to the product). Calculate, from unfiltered data, the SRS of the shock pulse that caused damage to the product. This is S_c, the "critical" SRS plot, which becomes the design target for the package cushioning. Instead of designing the cushioning to transmit no more than the critical acceleration A_c, design the cushioning such that it transmits a shock pulse with an SRS of less than S_c (lies below S_c at every frequency on the SRS plot). The peak acceleration of this shock pulse will often exceed A_c.

A5.6 If the natural frequency of the damaged component or subassembly is known (from a vibration test such as Test Methods D 3580, D 5112, or through some other means), the procedure can be more precise. The SRS of the shock pulse transmitted by the cushioning need only lie below S_c in a frequency range of approximately ½to 2 times the damaged component's natural frequency. In other frequency regions the cushion SRS may exceed S_c.

A5.7 Similarly, if it is known (through test or other means) that the product does not have potential for damage in some frequency regions, the cushion SRS may exceed S_c in those regions.

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