Standard Practice for Instrumented Package Shock Testing For Determination of Package Performance[1]

This standard is issued under the fixed designation D6537; 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 practice covers methods for obtaining measured shock responses using instrumentation for an actual or simulated product package system when subjected to defined shock inputs to measure package performance.

1.2 This practice establishes methods for obtaining measured shock data for use with shock and impact test methods. It is not intended as a substitute for performance testing of shipping containers and systems such as Practice D4169.

1.3 This practice will address acceleration measuring techniques. Other ways of measuring shock impacts, such as high speed video, are not covered by this practice.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D996 Terminology of Packaging and Distribution Environments

D3332 Test Methods for Mechanical-Shock Fragility of Products, Using Shock Machines

D4003 Test Methods for Programmable Horizontal Impact Test for Shipping Containers and Systems

D4169 Practice for Performance Testing of Shipping Containers and Systems

D5276 Test Method for Drop Test of Loaded Containers by Free Fall

D5277 Test Method for Performing Programmed Horizontal Impacts Using an Inclined Impact Tester

D5487 Test Method for Simulated Drop of Loaded Containers by Shock Machines

D6055 Test Methods for Mechanical Handling of Unitized Loads and Large Shipping Cases and Crates

D6179 Test Methods for Rough Handling of Unitized Loads and Large Shipping Cases and Crates

2.2 *ISO Standard:*

10012 Quality Assurance for Measuring Equipment[3]

3. Terminology

3.1 *Definitions:*

3.1.1 General definitions for packaging and distribution are found in Terminology D996.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *accelerometer*—a sensor that converts acceleration into a proportional electric signal for measurement.

3.2.2 *coefficient of restitution*—the ratio of the rebound velocity to the impact velocity.

3.2.3 *complex waveform*—acceleration versus time graph representing the responses of many different spring/mass systems when subjected to an impact. Also referred to as a complex shock-pulse.

3.2.4 *faired acceleration*—the amplitude representing the primary or intended response system in a complex shock pulse.

3.2.5 *fairing*—the graphical smoothing of a recorded pulse by visually estimating the amplitude of the primary waveform when high frequency responses are also present.

3.2.6 *peak acceleration*—the maximum absolute value of acceleration which occurred during the shock pulse.

3.2.7 *primary waveform*—acceleration versus time graph representing the response of the spring/mass system of interest when subjected to an impact. Also referred to as a primary shock-pulse.

3.2.8 *pulse duration*—the amount of time the shock acceleration is beyond a reference level. This level is generally taken as 10 % of the pulse peak acceleration (not the zero baseline) to most accurately represent the effective duration and frequency of the pulse.

[1] This practice is under the jurisdiction of ASTM Committee D10 on Packaging and is the direct responsibility of Subcommittee D10.13 on Interior Packaging.

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[2] 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.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.2.9 *velocity change*—the sum of the velocity at impact and the rebound velocity.

4. Significance and Use

4.1 This practice is intended to provide the user with a process to obtain data on package performance when a packaged product is subjected to shock. These measures can be used to quantify or qualify a package system.

4.2 Data from this practice may provide a measure of a package's ability to mitigate the various levels of shipping shock or impact hazards. These measures may be used to prescribe a mode of shipping and handling that will not induce damage to the packaged product or to define the required levels of protection that must be provided by its packaging.

4.3 This practice could potentially be used in conjunction with the data derived from Test Method D3332 (Method B) for optimizing cushion design.

4.4 This practice obtains data at the interface of the product and package (coupled) or element response, depending on the intent of the user (see 10.1 and 10.1.1).

5. Apparatus

5.1 Shock or impact apparatus shall be as described in the established shock or impact method used. Examples of shock and impact apparatuses are described in Test Methods D4003, D5276, D5277, D5487 and D6055.

5.2 *Instrumentation:*

5.2.1 *Instrumentation System*—Accelerometer(s), cables, signal conditioner, and a data acquisition system are required to record acceleration versus time histories. The instrumentation system shall have the following minimum properties:

5.2.1.1 Frequency response from at least 2 Hz to at least 1000 Hz.

5.2.1.2 Accuracy reading to be within ±5 % of the actual value.

5.2.1.3 *Accelerometers*—An appropriate accelerometer shall be used that is capable of measuring the acceleration input over the desired amplitude frequency and temperature range. Avoid accelerometers where the mass characteristics of the accelerometer, including any attachments to it (mountings, cables, etc.), will affect the weight or stiffness of the surface to which it is attached.

NOTE 1—A false reading of the mounting structure or unnecessary high frequency responses will occur if the mass of the accelerometer is too large in relation to the mounting surface. The mass characteristics of the accelerometer assembly should be less than $\frac{1}{10}$ th the mass of the structure being measured (**1**).[4]

5.2.1.4 Cross axis sensitivity less than 5 % of actual value.

5.2.1.5 *Cabling*—Use cables that are suitable to the system used. Accelerometer cables should be as lightweight and flexible as possible to avoid mass loading on the accelerometer or structure being tested. Cable length may alter the desired signal depending on the application and type of accelerometer used. Refer to manufacturers' recommendations for appropriate cable type and length because various accelerometer types require special cables and are not necessarily interchangeable.

6. Sampling

6.1 Sampling procedures and the number of test specimens depends on the specific purposes and needs of the testing. Refer to the sampling procedure for the standard test method chosen.

7. Test Specimen

7.1 *Option 1*—Actual contents and package.

7.1.1 Use this option to evaluate the protective capability of the package intended for shipment and when the actual contents are available. Testing a prototype package may yield results that differ from a production manufactured package. Care should be taken to ensure that the construction and materials of the prototype are representative of a production package. Re-testing may be required with a production package to verify earlier test results. (**Warning**—Damage to the test specimen may result from shock or impact testing.)

7.1.2 The contents may or may not be operational or in calibration.

7.2 *Option 2*—Simulated contents and package.

7.2.1 Use this option to evaluate the package when access to the actual contents is prohibitive because of availability, excessive cost or hazardous nature. This option may also be desirable to eliminate or minimize high frequency responses that the actual product may produce.

7.2.2 A mock-up simulating the actual product with respect to dimensions, center of gravity, moment of inertia and other product characteristics may be used.

7.2.3 A dummy load may be used to represent the loading characteristics of the actual product within the package.

7.2.4 Mock-ups and dummy loads are to be fabricated from rigid, non-responsive materials such as wood, plastic, modeling foam, aluminum, or steel, and be durable enough to withstand the intended impacts without failing. A mock-up load may use part(s) of the actual product with modifications to replicate the actual product or be fabricated entirely from other materials.

7.3 Minor modifications may be made to the product or package to accommodate accelerometers, cabling, or to observe the product during the test. Such modifications are allowed as long as they do not affect the test results.

7.4 Care must be taken to ensure that no degradation has occurred to the package if the test packages have been shipped to the test site. If any doubt exists as to the condition of the package, repackage the product in new packaging material before testing.

8. Calibration

8.1 The accuracy of the test equipment must be verified to ensure reliable test data.

8.1.1 System calibration is generally accomplished by having each of the individual components calibrated periodically (**2**).

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

8.2 Verification of calibration must be performed on a regular basis to ensure compliance with all accuracy requirements established in Section 5. Refer to manufacturer's recommendations on calibration schedules. Typically, system verification is performed at least on an annual basis. In no case shall the time interval between verification of system calibration exceed 18 months.

8.3 Contractual regulations may require more periodic calibrations.

8.4 International standards, such as ISO 10012 provide insight and methods for determining re-calibration intervals for most measuring equipment.

8.5 Accelerometers may need to be re-calibrated on a more frequent basis. Factors such as extent of use, environmental or other unusual conditions may require that the accelerometer be re-calibrated before its scheduled due date.

9. Conditioning

9.1 Condition the package and components to the conditioning requirements in accordance with the test method being followed. Unless otherwise specified, conduct all tests with the same conditions prevailing.

10. Procedure

10.1 *Total Product Response*—Mount the accelerometer at a location on the product that represents the product as a single mass. This location should be rigid and non-flexible to prevent extraneous responses from being measured, thus distorting or influencing the resulting data. The accelerometer is to be mounted on the product, or simulated product, so that the sensitive axis of the accelerometer is aligned in the direction of the applied shock. Where possible, mount the accelerometer near the product's center of gravity, or along a line passing through the center of gravity for the axis being measured. Measured shock responses from locations other than the center of gravity may be misleading due to item rotation.

NOTE 2—Caution should be used when mounting the accelerometer to the exterior of the product. Damage to the accelerometer can result if there is insufficient distance between the product and the interior of the package upon impact.

NOTE 3—Utilization of more than one accelerometer to record multiple axes or vectors simultaneously can expedite testing when evaluating multiple orientations. Using multiple accelerometers eliminates the need to open the package and reposition the accelerometer after each series of tests. Triaxial type accelerometers work well for most applications where the mounting location is representative of the overall product movement.

NOTE 4—When comparing results of earlier testing, the accelerometer should be mounted in the same location as previous so that data can be compared equally.

10.1.1 *Element or Component Response (Option 1 Only)*—To measure acceleration imparted through the package and through the product's structure to a component or element of interest, follow all accelerometer and mounting recommendations in 5.2.1.4, 10.1, and 10.2. The responses from an element or component might not represent the performance of the cushion system due to the spring/mass characteristics of the element or component.

10.2 *Accelerometer Mounting*—The method of accelerometer mounting can have a significant effect on quality of the data. Looseness or loss of contact between the accelerometer and its mounting surface can cause false or spurious readings. The best and most reliable method is a threaded fastening mounted directly to a smooth surface. Often this is not possible or convenient, however, and methods using various adhesives, cements, magnetic mounts, and waxes can be used with good success. See Appendix X1 for discussion on mounting techniques.

10.2.1 The accelerometer should be mounted so that its sensitive axis is aligned as accurately as possible with the acceleration direction to be measured. Any misalignment will result in an error which is proportional to the cosine of the angle between the accelerometer's measuring direction and the direction of actual motion.

NOTE 5—*Example*—If an accelerometer is mounted at an angle of 10° from the direction of actual motion, it will measure only a component of the acceleration A, equal to $A \times \text{cosine } 10° = A \times 0.985$, which is an error of 1.5 %.

10.3 Document the sensing orientation of the accelerometer in reference to the axis of the product. When the package is assembled the accelerometer orientation may not be readily accessible. Most recording devices require pre-impact setup prior to each test to ensure that the shock or impact event for the desired axis is recorded.

10.4 Make necessary connections from the accelerometer(s) to the signal conditioner. Refer to manufacturer's recommendations for proper connections. Labeling of the cables by channel or axis is recommended if more than one accelerometer is used during testing.

10.4.1 Cables should be securely fastened to the mounting structure with tape, a clamp, or other adhesive to minimize cable whip and connector strain. Cable whip can introduce noise, especially in high impedance signal paths. Cable strain near the electrical connector can often lead to intermittent or broken connections and loss of data. Cables should be fastened to the structure with ample slack equal to or greater than the maximum amount of potential displacement the structure may undergo to avoid damage to the sensor/cable connection. See Fig. 1 for proper cable connection.

NOTE 6—Avoid routing cables along floors or walkways where they may be stepped on or become contaminated. Also avoid routing cables near AC power wires. If necessary to cross AC power lines, do so at right

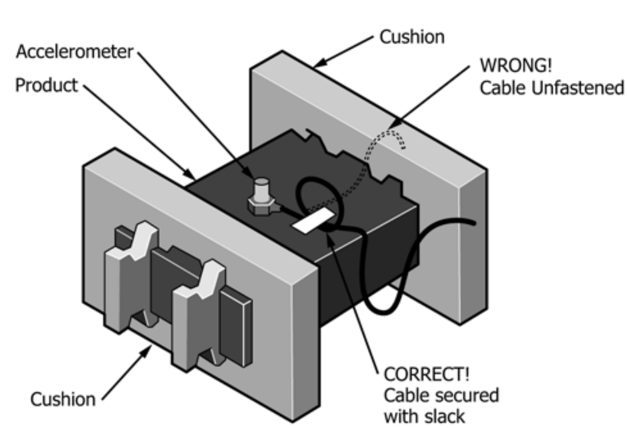

FIG. 1 Right and Wrong on Cable Routing

angles. Do not kink, bend sharply, or place cable in tension.

10.5 Assemble the package in accordance with the specimen option chosen.

10.6 Close and secure the package in the same manner as specified for shipment.

10.7 Prepare the recording device in accordance with the manufacturer's instructions. Typically this would include presetting the trigger threshold level to a value lower than the expected response of the product during impact. Some systems will require that the scale also be pre-set. Finally the system needs to be set to capture or acquire data.

10.8 Perform the shock event per the established shock and impact method. Typical shock and impact test procedures are described in Test Methods D4003, D5276, D5277, D5487, D6055, D6179 and Practice D4169.

10.9 Where desired and capable, data should be saved for later retrieval or archival purposes.

10.10 Repeat as needed to complete total number of shock impacts per pre-established test sequence.

11. Interpretation of Results

11.1 *Interpretation of Shock Waveform*—The recorded shock event contains several elements that can be used to qualify or quantify a package. The elements (peak acceleration, filtered or faired peak acceleration, pulse duration, and velocity change) are shown in Fig. 2. Several texts offer more detailed discussion on shock waveform analysis (**2**,**3**,**4**).

11.1.1 Peak acceleration is simply the maximum absolute value of acceleration (that is, either positive or negative) which occurred during the shock pulse.

11.1.2 Filtered or faired peak acceleration is the maximum absolute value of acceleration (that is, either positive or negative) taken from a shock pulse after modification by techniques of fairing or filtering as described in 11.2.1 and 11.2.2.

11.2 *Fairing and Filtering*—Often shock response pulses from package testing result in complex waveforms with multiple frequencies present. These are generally high frequency noises overriding the primary shock pulse. Fairing and filtering are techniques of removing this unwanted high frequency noise without changing the primary pulse, resulting in a more accurate depiction of the desired shock data.

11.2.1 Fairing is a graphical smoothing of the pulse by estimating and drawing a line midway between the positive and negative peaks of the overriding high frequency noise.

11.2.2 Low-pass filtering is the process of eliminating or reducing high-frequency noise by electronic circuitry or by data calculation. However, it is important not to filter at such a low frequency that the shape, amplitude, or duration of the primary waveform is changed. The filter cutoff frequency should be at least five times greater than the fundamental pulse frequency (**5**, **6**).

NOTE 7—*Example*—For a 15 ms half sine pulse, the duration of a full sine wave would be 0.015 times 2 = 0.030 s. The reciprocal of this gives the frequency; 1 divided by 0.030 = 33.33 Hz. 5 times 33.33 Hz = 166.65 Hz, which is the minimum recommended filter frequency for that pulse.

11.2.2.1 In-line hardware filters permanently alter the signal displayed on the readout device. Software (calculation) filters can usually be removed or changed if the pulse has been stored in its original form.

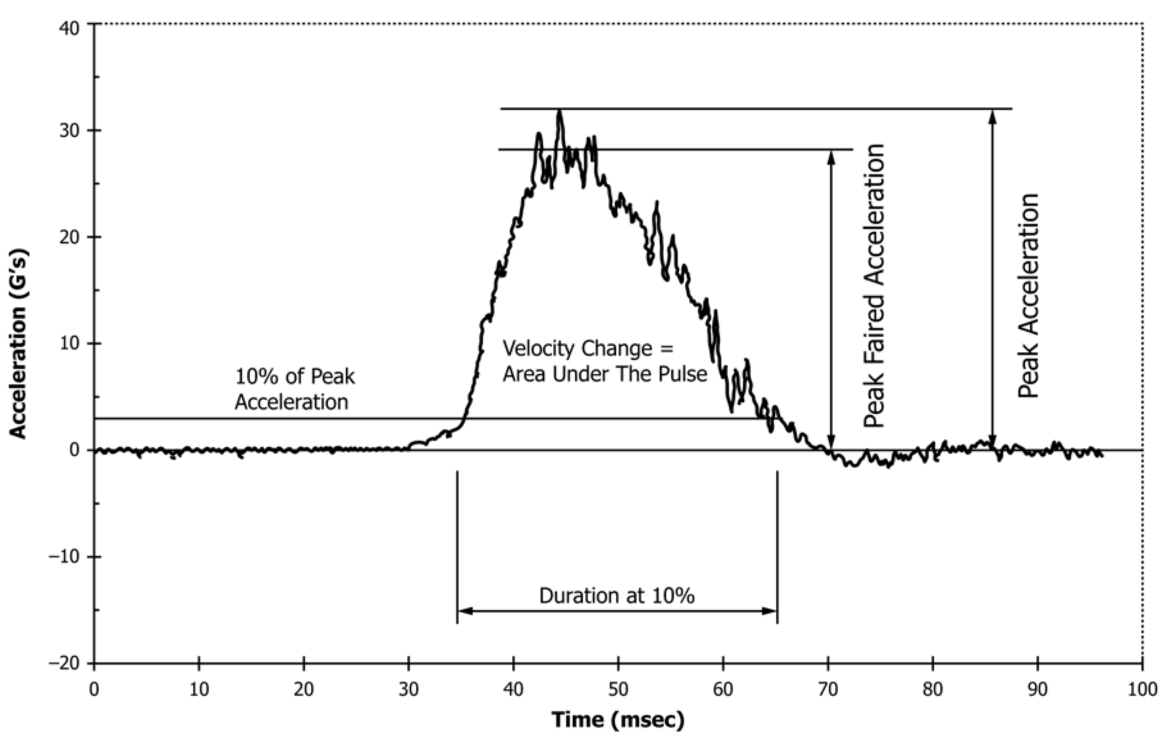

FIG. 2 Parameters for a Classic Shock Pulse of a Cushioned Item

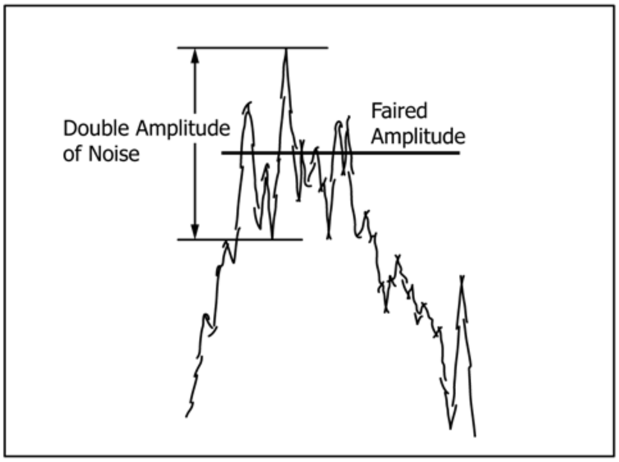

FIG. 3 Fairing Technique

11.2.3 Sometimes unwanted noise remains on the pulse even after proper filtering. It is permissible to graphically fair a filtered pulse to obtain a more accurate primary shock-pulse depiction.

11.3 Pulse duration is the amount of time the shock acceleration is beyond a reference level. This level is generally taken as 10 % of the peak acceleration as defined above (not the zero baseline) to most accurately represent the effective duration and frequency of the pulse.

11.4 Velocity change is the first integral of the acceleration-versus-time data and can graphically be represented by the area under the shock pulse. Velocity change is determined by integrating (or calculating area) from the point at which the acceleration data first leaves the zero axis at the beginning of the pulse to the point that it returns to the zero axis at the end of the pulse.

11.4.1 *Interpretation of Multiple Axes Waveforms*—When using more than one accelerometer to record multiple axis or vectors simultaneously, the individual waveforms can be interpreted using the techniques in 11.1, 11.2, and 11.3. Additionally when three accelerometers or a triaxial accelerometer are mounted 90° from each other, the magnitude of the vector sum, or resultant, can be calculated. See Appendix X2 for calculations and discussion.

11.5 Verify that the recorded data is valid by comparing the impact velocity to the recorded velocity change of the shock event. The velocity change cannot be less than the impact velocity when the coefficient of restitution (*e*) equals zero and cannot be more than twice the impact velocity when the coefficient of restitution (*e*) equals one. If the velocity change does not meet these conditions, check the recording system for errors and repeat the impact event.

NOTE 8—*Example*—A 30 in. drop has an impact velocity of 152 in. /s. Therefore, the velocity change cannot be less than 152 in./s or greater than 304 in./s.

12. Report

12.1 Report the following information:

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

12.1.2 Required information in accordance with test procedure used,

12.1.3 Complete identification of the product being tested. Include product type, manufacturer's code numbers, general description of configuration, and its pretest condition. Include fabrication method where simulated products were used,

12.1.4 Complete description of the package under test. Include package dimensions; its complete structural specifications; kinds of materials; description and specifications for blocking and cushioning, if used; spacing, size and kind of fasteners; method of closing and strapping, if any; and the tare and gross weights,

12.1.5 The number of specimens tested and date(s) of test,

12.1.6 Conditioning parameters,

12.1.7 Shock or impact test apparatus used, include detailed description of package mounting method where used,

12.1.8 Type of instrumentation used and critical settings thereof, including dates of last calibration, manufacturer's names, model numbers, and sampling rates. Details of any modifications thereto, if known, shall be included,

12.1.9 Location of accelerometers and mounting method used per impact.

12.1.10 The test procedure used,

12.1.11 A description of prescribed sequence, if used,

12.1.12 The height of drop or record of test input,

12.1.13 Desired data from the acceleration versus time waveform(s) per shock or impact event, for example, peak acceleration, faired or filtered acceleration,

12.1.14 A representative sample of the graphical data for each phase of testing.

12.1.15 Filter type, specifications, and filter frequency per impact.

12.1.16 *Optional*—Condition of specimen after test.

12.1.17 Variation from recommended procedures.

13. Keywords

13.1 acceleration; acceleration measuring; accelerometer; cushioning; fairing; instrumentation; instrumented; package; performance; shock; shock testing

APPENDIXES

(Nonmandatory Information)

X1. MOUNTING CONSIDERATIONS

X1.1 Some mounting techniques such as direct threading, certain adhesives and cements will permanently alter the product physically or cosmetically.

X1.2 Any materials superimposed between the surface to be measured and the accelerometer can potentially act as a mechanical filter and therefore reduce the high-frequency capability of the measurement. In general, smooth surfaces and stiff adhesives are adequate for frequencies up to 1,000 Hz (**1**).

X1.3 For threaded accelerometer mounting, hand tighten the sensor/mountings to the test object. Secure the sensor by applying the manufacturer's recommended mounting torque by using a torque wrench. Under torquing the sensor may not adequately couple the device, while overtorquing may result in stud failure or false data.

X1.4 *Adhesive Mounting*—Adhesive mounting is often used for temporary installation or where the test object surface cannot be adequately prepared for stud mounting. Adhesives such as hot glue and wax work well for temporary mounts whereas two-part epoxies and quick bonding gels provide a more permanent mount. Excess adhesive should be displaced by firmly pressing down on the accelerometer or mounting base.

NOTE X1.1—Adhesive mounted sensors often exhibit a reduction in high frequency range. In general, smooth surfaces and stiff adhesives will provide the best frequency response. Generally, temporary adhesives are recommended more for low frequency (up to 1000 Hz) structural testing at room temperature.

X1.4.1 Care should be used in selecting and testing an adhesive when you are concerned about possible discoloration or damage to the test structure's surface finish. Test the adhesive first on a hidden location or a sample of the structure's finish. Temporary adhesives like Petro or Bee's wax offer a good solution for quick installation in room-temperature applications where the forces are vertical. Where higher temperatures or damage to the surface may occur, apply a piece of tape, such as aluminized mylar, to the test structure first and then mount the accelerometer with an adhesive. After the test, the tape can be easily removed with no damage to the surface finish of the structure. (**Warning**—The high temperatures associated with hot melt adhesives may affect some accelerometers. Refer to accelerometer and hot melt adhesive specifications for suitability prior to testing.)

NOTE X1.2—Selection of a tape is important. If the adhesive backing is not strong enough to hold the forces of the accelerometer, the tape will pull away from the surface, resulting in erroneous data. If the tape backing is too strong, it may leave a residue or remove the surface coating.

X1.5 *Stud Mounting*—This mounting technique requires smooth, flat contact surfaces for proper operation and is recommended for permanent or secure installations, or both. Stud mounting is also recommended when testing at high frequencies. A very thin layer of silicone grease between the accelerometer and mounting surface is recommended for good high frequency responses.

X1.6 *Screw Mounting*—When installing accelerometers onto thin walled structures, a cap screw passing through a hole of sufficient diameter is an acceptable means for securing the accelerometer to the structure. The screw engagement length should always be checked to ensure that the screw does not bottom into the accelerometer base.

X1.7 *Magnetic Mounting*—Magnetic mounting provides a convenient, temporary attachment to magnetic surfaces. This option is only recommended where the accelerometer will be subjected to vertical forces. Forces other than vertical may cause the accelerometer to break free from the mounting surface. Earth magnets are recommended because of their high strength, thus providing better high frequency response. Flat magnets work well on smooth, flat surfaces, while dual-rail magnets are required for curved surfaces.

X1.7.1 Mount the magnet/sensor assembly to the prepared surface by "rocking" or "sliding" it into place.

NOTE X1.3—Careless magnetic mounting of the sensor to the object has the potential to generate very high and potentially damaging "*g*" levels. Some sensors have built-in shock protection to overcome potential damage.

X2. CALCULATING THE MAGNITUDE OF THE VECTOR SUM

X2.1 *Magnitude of the Vector Sum*—When three accelerometers or a triaxial accelerometer are mounted 90° from each other, the magnitude of the vector sum, or resultant, can be calculated using the following formula for each instant in time:

$$a_r = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad \text{(X2.1)}$$

where:

a_r = magnitude resultant,
a_x = acceleration of x axis,
a_y = acceleration of y axis, and
a_z = acceleration of z axis.

Some data acquisition software will automatically calculate the maximum resultant of all three axes.

X2.2 Because the peak acceleration of any of the measured axes may not occur at the same time in the shock event, the maximum resultant for the shock event may not coincide with any of the peak acceleration values either (see Table X2.1). The resultant analysis is best applied to those impacts that are intentionally non-flat (that is, corner or edge). The use of a vector resultant is not a substitute for non-flat impacts because the resultant of such an impact will be lower than the resultant of an equivalent flat drop.

TABLE X2.1 Example Resultant Computation

Time (m/s)	a_x (G)	a_y (G)	a_z (G)	Resultant a_r (G)
6	7.2	6.5	3.6	10.35
7	12.0	7.8	5.0	15.16
8	16.0	9.0	**11.0**	21.40
10	17.0	10.0	9.0	**21.68**
12	**17.4**	10.7	7.0	21.59
14	14.0	13.0	6.6	20.21
16	11.0	**14.0**	6.0	18.79
18	10.0	12.0	5.0	16.40
20	8.0	9.0	4.0	12.69
22	6.0	7.0	3.0	9.70

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