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14. ABSTRACT

This TOP provides guidance for the laboratory simulation of pyrotechnic shock tests via resonant fixtures. The pyrotechnic event is characterized by short transient excitations (less than 4 msec) of high amplitude (3000 g's) and high frequencies (10 kHz). The transients are typically induced by the activation of missile ordnance components such as explosive bolts, cable cutters, pyrovalves, flexible linear shape charges, and primer cords. This document describes instrumentation, test fixture design, and data collection and processing procedures required to achieve a successful test program. The focus will be on metal to metal impact testing of resonant fixtures tuned to the appropriate test specification.

15. SUBJECT TERMS

Shock	Pyrotechnic Shock	Environmental Test
Shock Data Analysis	Resonant Fixtures	Missile Ordnance
Pyroshock	Shock Response Spectrum	Flight Safety Components

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TEST OPERATIONS PROCEDURE

Test Operations Procedure 5-2-521 20 November 2007
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PYROTECHNIC SHOCK TEST PROCEDURES

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1. SCOPE.

This TOP contains information specific to far-field pyrotechnic shock testing of missiles, rockets, and related components. Techniques for mechanically excited pyrotechnic shock testing along with generally recommended test specifications, facility requirements, appropriate instrumentation, test procedures, and data reporting are also within this document.

1.1 Purpose.

The purpose of this TOP is to establish guidelines and procedures such that pyrotechnic shock (hereafter known as pyroshock) testing can be performed in a uniform manner and result in accurate and repeatable tests.

1.2 Application.

a. These test procedures are specifically targeted at missiles, rockets and their components, however, the procedures may be applied to other items as well.

b. The procedures are applicable for far-field mechanically excited pyroshock testing.

1.3 Limitations.

a. This TOP can only provide an overview of far field pyroshock testing procedures. Specific test items and or test requirements should be examined individually and the test procedures should be tailored accordingly.

b. This TOP does not specifically describe near-field pyrotechnically excited techniques, Mechanical Impulse Pyroshock Simulators (MIPS), pyroshock with drop-table testing, or tunable resonant beams.

c. While many types of pyroshock test equipment is available this TOP is chiefly limited to resonant impact fixtures which are mechanically excited by a pendulum hammer.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

a. The specific test facilities and test equipment required to perform a pyroshock test is dependent upon the test requirements and the item under test. Facilities should allow for ample working space, adhere to all local fire regulations and provide an overall safe working environment. Information pertaining to any on site hazards should be documented and made available to any site visitors. Standard Operating Procedures should be kept current and updated with the facility’s latest capabilities.

b. Hazardous test items (explosives) require facilities approved for such operations and approved for the quantity of explosives under test. All personnel should have appropriate explosives training for handling and setup of test items. Remotely controlled test equipment in accordance with each test center's safety regulations should be used to conduct the pyroshock test. Closed circuit video systems permit observation of explosive items under test.

c. Facilities to perform non-destructive inspections such as x-ray, ultrasonic, magna-flux, eddy current, etc. may be required before and after pyroshock tests to validate test item integrity.

d. Temperature conditioning equipment capable of providing temperatures between 71°C and -54°C may be required for pyroshock tests that are specified to be conducted at temperature extremes. Conditioning may take place with the test item in a chamber for a designated soak time or the item may be conditioned on the resonant beam test equipment. Figure 1 shows a possible conditioning shroud design. Test runs and proper "tuning" of the resonant beam must be performed at the temperature specified in the test requirement. The facility personnel should be fully qualified to provide temperature conditioning safely.

Figure 1. Open Temperature Conditioning Shroud Encompassing Entire Pyroshock System

2.2 Instrumentation.

Pyroshock testing will require the following instrumentation and may require other equipment in order to monitor the integrity of the items under test.

a. Accelerometers

b. Signal Conditioners

c. Digital Recording System

d. Data Processing System with hardcopy output capability

2.3 Tolerances.

The test level tolerances are usually specified in the test requirements. Generally accepted test level tolerances for pyroshock testing are ± 6 dB.

2.4 Instrumentation Accuracy and Calibration.

The instruments and test equipment used to control or monitor the test parameters shall have an accuracy of at least one-third the tolerance for the variable to be measured. For example, if the tolerance for acceleration is 10 percent then the accuracy shall be 3.33 percent. The instruments and test equipment shall be calibrated to laboratory standards whose calibration is traceable to National Institute of Standards and Technology standards. Instruments should have been calibrated within the past year and verified to be in good working order prior to testing. The calibration records shall be maintained by the test laboratory.

3. REQUIRED TEST CONDITIONS.

3.1 Test Planning.

3.1.1 General.

Proper test planning should be conducted prior to any testing performed. The following paragraphs describe areas of concern when developing a test plan. Test plans should be properly tailored to accommodate individual test requirements and specifications. It is important to try and understand the overall function of the test item and the configuration and stresses the item may see during operation.

3.1.2 Test Objectives/Criteria.

Clear and obtainable test objectives and test item criteria should be defined when developing a test plan. The objective should state the level of intensity of the environment provided during testing and the criteria should provide the means of assessing if the test item meets the required performance and/or structural integrity specifications.

3.1.3 Test Item Inspection Procedures.

Visual, functional, and possibly radiographic inspections of the test items should be made prior to pyroshock testing. Ensure that all vitally important functions are operational and that there are no areas of concern about the unit tested.

3.1.4 Test Item Configuration.

It is preferred that the test item be configured in the most likely operating position. Mounting points should allow the input frequency to resonate through the test item similarly as to how they would pass during a full scale operation. The physical dimensions, mass, center of gravity, operational state, configuration, and orientation of the test item is vital information required to develop the appropriate test procedures. If possible it is recommended that the test item be operational and/or with electronics turned on and monitored during pyroshock testing in order to identify any intermittent failures even if the item is not expected to be on during real world pyroshock exposure.

3.1.5 Atmospheric Conditions.

Standard ambient conditions, as shown below, would be the preferred conditions for pyroshock testing; however, test specifications may call for other controlled conditions. The test specifications should be accommodated and appropriate adjustments should be made.

a. Temperature: 25 ± 10°C (77 ± 18°F)

b. Relative Humidity: Uncontrolled room ambient

c. Atmospheric Pressure: Site pressure

3.2 Test Specifications.

It is highly recommended that pyroshock test specifications be developed from measurements gathered during full scale operations where the test item is meant to be deployed. Data should be recorded from locations near the mounting points of the test item. There are generally many ways to specify pyroshock tests including the Fourier spectrum and the energy spectrum; however, the Shock Response Spectrum (SRS) is the most common representation of the test environment. The SRS is defined as the computation of the peak responses of a series of uniformly damped single degree of freedom systems (spring, mass, and damper) to an applied transient waveform. The spectra are to be determined for positive and negative maximum accelerations (either maximum absolute or equivalent static), generally at Q = 10 (critical damping of 5%) and at least 1/6 octave frequency intervals. The shock response may be expressed as absolute acceleration or equivalent static acceleration versus natural frequency. Further discussion of SRS principles is provided in Appendix A and in more detail in International Test Operations Procedure (ITOP) 1-1-050[1*].

[*] Superscript numbers correspond to those in Appendix D, References.

3.3 Test Preparation.

3.3.1 Test Equipment Selection.

Test equipment selection is based on the type and size of test item. Each setup has its limitations. The typical resonant beam fixture is shown in Figure 2. Overall length of the resonant beam must be calculated to conform to the knee frequency found in the required test profile. The material properties of the beam and impact hammer will also affect the profile of the shock. Aluminum is the most common material used but steel could also be substituted or there could be a combination of a steel impact plate and aluminum beam depending on the frequency response required. The resonant fixture is applicable to high amplitude, high frequency pyroshock simulations. See Appendix B for additional resonant fixture information.

3.3.2 Test Axes.

The test axes (X, Y, Z) and directions (positive and negative) may be defined in the test specification or may need to be assigned during test planning (assumes one SRS). The orientation relationship has to match the desired input levels or else the tester runs the risk of over or under testing the item.

Figure 2. Typical Resonant Beam Test Fixture Suspended With Test Item Attached (2 orientations)

3.3.3 Number of Shocks.

The typical pyroshock test specification requires 3 shocks in each axis in each direction (18 total). This number could vary depending upon the test item's field application. Oftentimes, the test can be completed with 3 shock applications in one orientation (e.g., the x-axis). This is dependent upon the resonant fixture design, test item response, and test specification. The resonant beam fixture shown in Figure 2 often responds equally in each direction and in each axis. Perform practice runs with dummy test items to fully characterize the resonant beam response before installing the test article.

3.3.4 Accelerometer Locations.

The reference axis is defined as the axis along the line of impact and in most cases will be the only one to reach the test specification level. The remaining two axes likely will not be within the frequency range and acceleration levels required by the test specification. These are considered to be the off axis responses and should be part of the recorded data. Therefore; accelerometers should be mounted in each major axis of the resonant beam (triaxial acclerometer configuration) and in close proximity to the test item. The transducer monitoring shock levels along the line of impact will be considered the control reference.

3.3.5 Combined Environment Testing.

Missile components must operate in the various environments around the world to include high altitude or space conditions. Thus, performing pyroshock testing at extreme temperatures may be requried. This temperature stress will influence the behavior of the resonant beam and will result in differing shock response profiles when the same beam is tested at hot and cold temperatures. Calibration shocks should always be performed at the designated temperature.

3.4 Instrumentation and Data Acquisition Equipment.

Instrumentation and data aquisition equipment is required to measure the shock profile and surrounding environments which can be recorded, analyzed and archived in electronic format.

a. Transducers. Piezoelectric and piezoresistive accelerometers are the transducers of choice for most pyroshock measurements. It is important to identify an accelerometer with the ability to measure high level shocks, have a resonance frequency of 100 kHz or more, and a maximum acceleration limit of 200,000 g's or more. The transducers should contain a current calibration sticker over the test frequency and acceleration range. Additionally, strain gauges, velocity gauges, displacement devices, and laser velocimeters may be used where appropriate. All sensors should be lightweight, especially when trying to measure test item responses of low mass components. The use of accelerometer mounting blocks should be avoided where possible. When required, the mounting blocks shall be made of aluminum, magnesium, or beryllium and shall be no greater than 19 mm (0.75 inches) cubed. When mounting the accelerometer block it is important to note the orientation of the transducers in reference to test item; i.e., the X axis of the mounting block should be aligned to the X axis of the test item to within 5 degrees. Dental cement or high strength adhesive may be used for low level shock applications. For high level shocks (5000 g's and above) it is recommended that the block be both bolted and glued to the structure. The block mounting surface should have a surface finish of 0.41 µm (16 microinches) or better. The accelerometer mounting surface should be flat to within ±12.7 µm (0.0005 inches).

b. Signal Conditioners. The signal conditioning system consists of amplifiers, filters, and associated cabling.

(1) Amplifiers are used to increase the magnitude of the transducer output signal. In particular, charge amplifiers convert a charge input, coming from a piezoelectric transducer, into a voltage output. Amplifiers that provide signal conditioning should be checked to verify the correct excitation voltage is being supplied to the transducer. Gain on the charge amplifier should be set to a level that will provide a strong return signal, but also do not overload or over-range any of the recording equipment. Overloading can be identified through indicator lamps found on most charge amplifiers and DAT recorders. Clipping can be seen by capturing and viewing a shock pulse on an oscilloscope. Clipping will produce a signal that resembles a square wave.

(2) Filters are used to limit the frequency bandwidth of the signal. Low pass filters attenuate the high frequencies and pass the lows. Filters can be analog or digital and in many cases both will be used. Generally, analog low pass filters are used as anti-aliasing filters and are placed before the analog to digital converter (ADC). Filters become very important when dealing with pyroshock due to the possibility of resonance and the high frequencies that are achieved. One of the best analog filters used for anti-aliasing is the elliptic filter. It has the sharpest rejection (up to 100 dB/octave) and near linear phase up to the cutoff frequency. Other filters, such as Bessel or Butterworth filters, may be suitable for some applications. Further filter guidance may be found in IEST-RP-DTEO 12.2[2]. For SRS computations, it is recommended that the half-power point cutoff frequency of the anti-aliasing filter should be 1.5 times the highest SRS natural frequency to be analyzed. Digital filters, on the other hand, are used in digital analysis systems where the data has already been sampled into the digital domain.

(3) Cable selection should depend upon the: cable length; impedance of the transducer, cable, and electronics; magnetic and capacitive background noise coupling; physical test environment; and type of transducer and signal conditioner. Low noise cabling should be used at all times for piezoelectric transducers. For piezoelectric transducers, the charge amplifier is dependent on the feedback capacitance and therefore is effected by cable length running from the transducer to the amplifier. Proper identification of cables and cable routing are important in complicated test setups.

c. Data Recorders. Data recording equipment includes strip chart recorders, digital storage oscilloscopes, digital audio tape recorders, and computer controlled on-line digital storage devices. The recording device should be selected based on the shock test specification and these characteristics; data capacity (e.g., 1 to 6 hours), number of channels (e.g., 4 to 28), frequency response (e.g., ± 0.5 dB out to 60 kHz), dynamic range (e.g., 30 to 70 dB), and playback ability. It is highly recommended that all shock data be recorded in some format for further evaluation.

In the case of missile component tests, test records may need to be retained for possible re-evaluation at a later date (one year or more).

d. Analysis Equipment. Analysis software can be purchased to compute the SRS from the acceleration time history. The SRS plots can be viewed almost immediately depending on the software being used and computer processing speed. Transducer specifications and scaling factors must be known in order to provide the analysis software with the proper parameters to run the calculations. A sampling rate of at least 10 times the highest SRS computation frequency is required if an interpolation algorithm is not used. If an algorithm is used, then the sampling rate can be as low as 4 times the highest SRS computation frequency.

3.5 Test Controls.

Calibration runs must be performed using the appropriate test equipment described above to attain the desired shock specification. A mass simulator or dummy load shall be substituted for the test item during these calibration runs. The simulator shall be of equal weight, weight distribution, and size of the actual test item that it is replacing. The simulator can be quite elaborate (possibly a previously failed test item) or just a piece of metal. Obtain at least three consecutive shocks within the tolerance requirements before installing the test item. Recording the last calibration run as a proof of input would be helpful if something unexpected were to occur during actual testing.

4. TEST PROCEDURES.

4.1 General.

Once the shock test specification and test equipment have been determined perform calibration runs with the shock fixture and dummy/mass simulator in place. The following procedures shall be performed for all pyroshock tests.

4.2 Test Conduct.

a. The resonant beam should be suspended such that when impacted it has some freedom for translation. Restraints such as bungee cords should be used to control extreme movements. Adding cords or applying more tension will also provide a means of adjusting the intended shock profile.

b. Mount the test item simulator onto the test fixture (adapter plate) and to the resonant beam and note test axis. The item should be mounted in a fashion representative of how it is to be mounted during full scale operation. The beam should be level and labeled in terms of X, Y, and Z coordinates (to include positive and negative directions).

c. Torque all bolts to the appropriate values.

d. Install accelerometers onto the fixture. A transducer should be used to monitor each major axis of the beam (i.e., triaxial accelerometer). Accelerometers should be placed in the approximate locations that they were in when test specification data was collected, usually close to the mounting points of the test item. Note the serial number of transducers used and the corresponding axis they will be monitoring. The accelerometers should be level with respect to the major axis of the resonant beam and with the pendulum impact hammer's line of impact.

e. Ensure the data acquisition system is functioning and recording data properly. Check for correctly designated channel labels, properly connected cables, and that accelerometers are properly adjusted for measurement (i.e., gain and bandwidth on charge amplifiers are set correctly). The amplifiers should be auto-balanced prior to conducting the pyroshock test. Use proper grounding technics to minimize any data line noise.

f. The impact hammer drop height should be measured and properly adjusted to provide the required shock profile. Use a remotely activated quick release hook to facilitate the test (drop the impact hammer). This is required when dealing with hazardous items.

g. Calibration shocks should be performed until the correct waveform can be consistently reproduced and performed within test specification tolerances (about three times in a row). Final adjustments can be made by adding damping (rubber padding) to the impact area of the beam and or adding damping mass (plumber's puddy) to the resonant beam. Some test specifications require additional test apparatus adjustments such as changing the impact hammer material or mass. The final calibration shock should be recorded and saved as the proof of input for the pyroshock test to be performed.

h. Remove the test simulator and install the actual test item onto the fixture. Visual inspection of the test item should be performed noting any physical damage or irregularities.

i. If temperature conditioning is required, pre-condition the item as specified in the test requirements (e.g., 12 hour soak). This may be done on the shock test equipment or in a separate climatic chamber prior to test. If shock testing cannot be done with a temperature shroud installed, the test requirements should specify the amount of time the item is allowed out of a temperature chamber before re-conditioning is required (generally no more than 5 minutes).

j. Perform any pre-test performance checks of the test item if required. The item should be functioning properly. All test item performance data should be recorded.

k. If required, the test item should be left in its operational state (Power on) during the application of the shock..

l. After all data acquisition equipment has been checked and personnel have evacuated to a safe location apply the pyroshock.

m. Assess the quality of the shock transient waveform and the resulting SRS data. Examine the data from all test axes. Record test item performance data and note any intermittent failures or irregularities.

n. For explosive items, wait the required safety hold time (~20 minutes) to ensure no latent reactions will occur. Once the wait time is over visually examine and assess the health of the test item.

o. If test item is in satisfactory condition, repeat steps 4.2.a through 4.2.n for the total number of required shocks and all required test item orientations.

p. Perform post-test inspections and performance checks of the test item upon completion of all shock tests.

4.3 Data Verification Procedures.

All shock data signals shall be visually examined for any anomalies such as those described below. Further guidance may be found in IEST-RP-DTEO 12.2.

a. Obvious wild points, signal dropouts, or signal clipping.

b. Signal termination that is indicative of accelerometer failure or unbonding/separation from the structure.

c. Sharp, randomly occurring noise spikes that could be caused by loose connectors or ground loops.

d. Zero shifts caused by saturation of the accelerometer or signal conditioning system.

e. One-sided clipping of the signal, e.g., positive values may be much larger than negative values.

f. For pyroshock data measurements where there is no net velocity change, the velocity signal should look like a low pass filtered version of the acceleration signal having zero velocity at the end of the measurement. If the mean velocity exceeds the peak to peak range of the oscillating portion of the velocity signal, then the data is to be considered invalid. If there is a net velocity change there should be a velocity value at the end of the measurement approximately equal to the net velocity change of the structure. The data is considered invalid if the velocity change differs by more than 200 percent.

4.4 Data Analysis Procedures.

a. The signal to be analyzed should begin and end at a data point near zero before and after the transient event. All other data before and after the event shall not be used in the SRS calculation.

b. If the background noise is substantial, the average value of the signal prior to the transient event should be taken as the zero value of the signal.

c. In most cases the damping ratio shall be equal to 0.05 which is equivalent to Q = 10. Other values may be used if the damping characteristics of the test item are known.

d. For pyroshock data, compute the SRS of the background noise, preferably before the transient event. The data is invalid at those frequencies where the noise SRS is within 6 dB of the transient SRS values.

e. For measurements in which there is no net velocity change, force the transient signal to have zero net velocity change before SRS computation.

f. For measurements in which there is a net velocity change due to the shock, force the signal to have a velocity of zero at the start of the transient event before SRS computation.

g. Perform positive and negative SRS computations. Data is invalid if the positive and negative SRS values exceed a difference of more than 6 dB.

5. DATA REQUIRED.

The following shock test data are required.

a. Test item pre-test operational data.

b. Details of the spectral profile and damping (Q).

c. Test equipment description.

d. Test item orientation.

e. Number of shocks in each axis.

f. Data recordings to include acceleration time history and SRS plots of each accelerometer.

g. Temperature time histories (if applicable).

h. Test item post-test operational data.

i. Description of any failures.

j. Documentary photographs of the test setup.

6. PRESENTATION OF DATA.

6.1 Acceleration Time History Plots.

All accelerometer data channels shall be processed into acceleration time history plots for reporting purposes. An example of a pyroshock acceleration time history is provided in Appendix A.

6.2 Shock Response Spectrum Plots.

SRS plots of the accelerometer data are required.. The maximax spectrum plot is normally computed and presented. An example SRS computed from an acceleration time history is shown in Appendix A.

APPENDIX A. BACKGROUND

1. General. High amplitude and high frequency transient shocks may occur on airborne missile components due to events such as in flight ejection of covers or launch vehicle separation. Missiles can also be subjected to high level shocks prior to firing due to gunfire on the missile launcher platform. This shock environment can be quite severe and is caused by a pyrotechnic device or a mechanical metal to metal impact (spring release). The shock waveform is characterized by a rapid rise in acceleration level to several thousand g's in less than 2 msec.

2. Effect of the Environment. Typical test item failures to be identified when the equipment is subjected to the pyroshock environment are:

a. Intermittent electrical contacts

b. Touching and shorting of electrical parts

c. Seal deformation

d. Optical misalignment

e. Cracking and rupturing

f. Structural deformation

g. Shearing of fasteners

3. Shock Response Spectrum. The SRS is defined by the maximum response of a series of uniformly damped single degree of freedom systems to an applied transient waveform. The single degree of freedom system consists of a rigid mass attached to a base by a massless linear spring and a viscous damper. The SRS is computed from acceleration versus time signals and is displayed as peak response acceleration versus natural frequency. Figure A-1 shows a representative pyroshock acceleration time history and Figure A-2 its corresponding SRS.

a. The SRS can be described by the primary, the residual, or the maximum absolute or maximax spectra. Further guidance may be found in ITOP 1-1-050. These spectra are defined as follows:

(1) the primary or initial spectrum (positive and negative) is the peak response which occurs during application of the pulse.

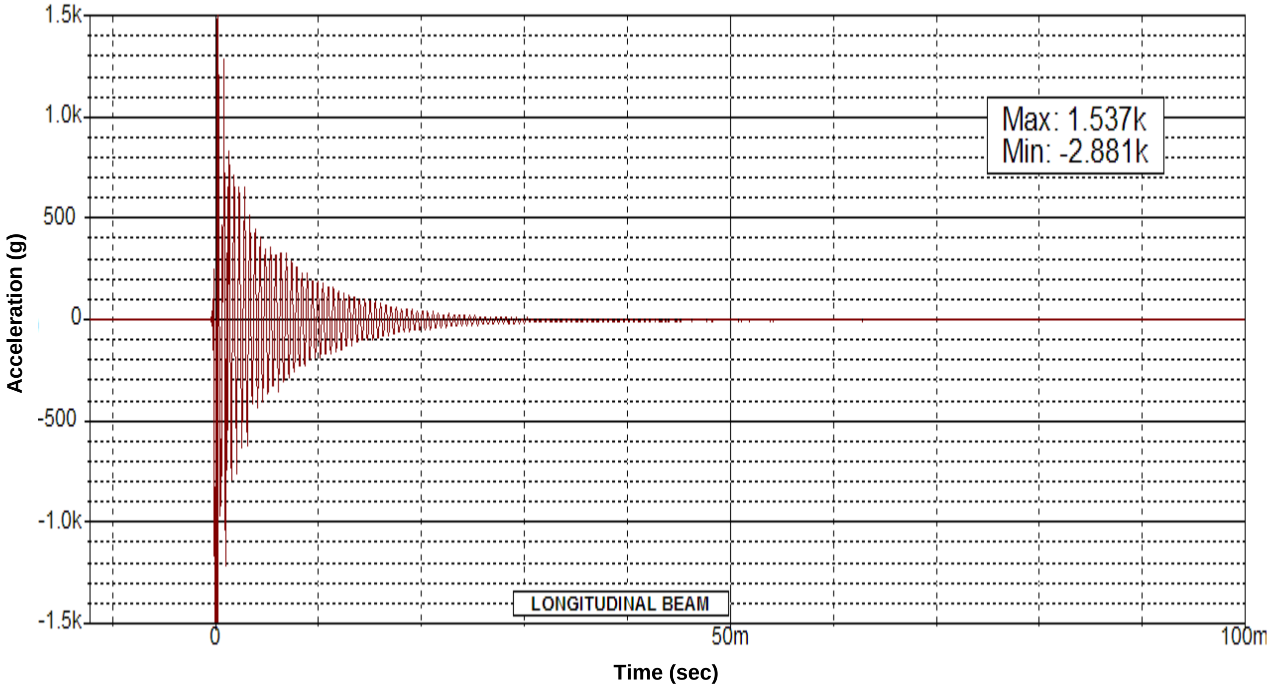

Figure A-1. Acceleration Time History Plot

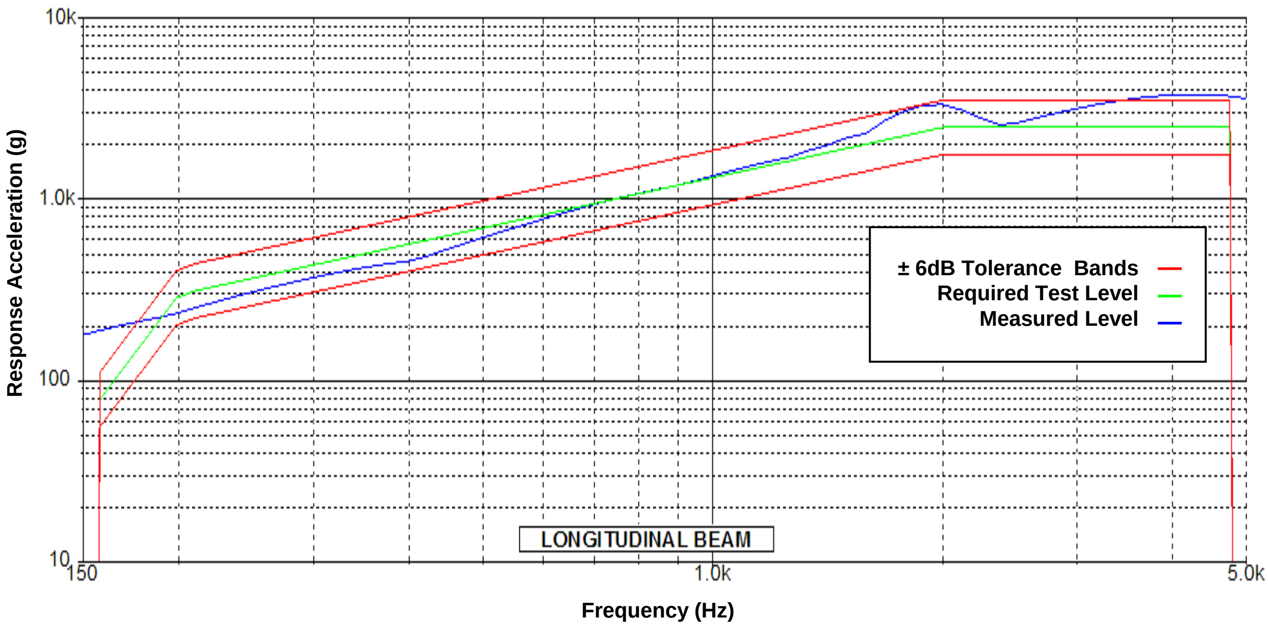

Figure A-2. SRS Plot

(2) the residual spectrum (positive and negative) is the peak response after the pulse has subsided (ringing).

(3) the maximax spectrum is the envelope of the absolute maximum values of primary or positive residual spectra (occurring any time in either direction).

b. It is the maximax spectrum that is most commonly used to specify SRS tests. It is expressed as a peak acceleration response versus natural frequency plot.

c. Although not always done, the transient duration should also be defined for this type of test specification. This is important when trying to simulate the field data transient with laboratory test equipment. A comparison of the field and laboratory acceleration time histories is recommended in order to ensure the test item is appropriately stimulated.

4. Common Errors in SRS Signal Processing.

a. Knowledge of the Data Acquisition System. It is important to understand the amplitude and phase response characteristics of the data acquisition system. Generally, one component dominates the system response. For example, let's assume the filter is dominant. Phase and amplitude response should be known so that the collected data is well within the passband region of the filter. Errors due to signal distortion can be removed with digital processing techniques only if the system response characteristics are known. Take the time to understand the system and the processing techniques to be utilized. Further guidance may be found in reference 2 concerning data validation and processing techniques.

b. Sampling Rates. The sampling rate must be high enough to accurately describe the response of the SRS oscillators. It is recommended that SRS computations be performed with a sampling rate that is 10 times the highest frequency of interest. This will reduce errors in the maximum response of the highest frequency oscillator to less than 5 percent.

c. Filtering Misconceptions.

(1) The type of filter used to process the data can introduce errors into the SRS computation. Filter characteristics such as roll-off sharpness, amplitude and phase linearity, and amplitude flatness can influence SRS accuracy. This is especially true near the filter cut-off frequency.

(2) Filter leakage can introduce SRS errors. A filter may be used to remove unwanted high frequencies. It is assumed that the influence of the high frequency components is removed when filtering. This is not necessarily true as the high frequency portion may contain low frequency components and thus influences the SRS.

(3) The filter cut-off frequency can also influence the SRS plot. Try to use the passband region of the filter. Data in the transitional region will not be completely attenuated and will influence the SRS. This influence is also dependent upon the sharpness of the filter roll-off. A sharp roll-off will reduce the size of the transition region and thus, the power content of the frequencies in this region will be attenuated more.

d. Erroneous Data Effects.

(1) Examine the raw data for high amplitude short duration spikes possibly caused by cable slap or solenoid activated devices. Do not process this data indiscriminately. For example, filtering this data with a 3 kHz low pass filter will result in time histories that look like real data. Thus, computing the SRS of filtered spike type data will result in a significant increase (error) in power content of the high frequency portion of the spectrum.

(2) Examine the raw data for DC shifts. The SRS computation of DC shifted data results in an error over the low frequency portion of the spectrum. The low frequency region will appear to have a flat response. Make sure that the signal begins and ends at zero before SRS computation.

APPENDIX B. RESONANT FIXTURES

1. Laboratory test simulation of pyrotechnic shock events can be accomplished using metal-to-metal impact techniques to generate high g-level transients in metal plates, fixtures, or resonant beams.

2. Pyrotechnic shock simulation can be done with the resonant beam test apparatus shown in Figure B-1. The design of an aluminum resonant beam is based upon the equation:

$$L = \frac{c}{2f_i}$$

where:

L = length of the beam (m)
c = speed of sound (4991 m/sec for aluminum)
f_i = first fundamental frequency of longitudinal mode

The beam fundamental frequency is chosen to coincide with the knee frequency of the SRS. For example, the length of an aluminum beam requiring a 2000 Hz knee frequency is:

$$L = 4991/(2 \text{ x } 2000) = 1.24 \text{ m}$$

The SRS profile can be further shaped with the addition of a damper mass to “tune” the beam.

3. Alternative designs to the resonant beam may be required to accommodate intracately shaped test items. Whether a computer simulation of the fixture resonating at the desired frequency is necessary will depend on the complexity of the fixture. Figures B-2 and B-3 are alternative designs that have been used in testing.

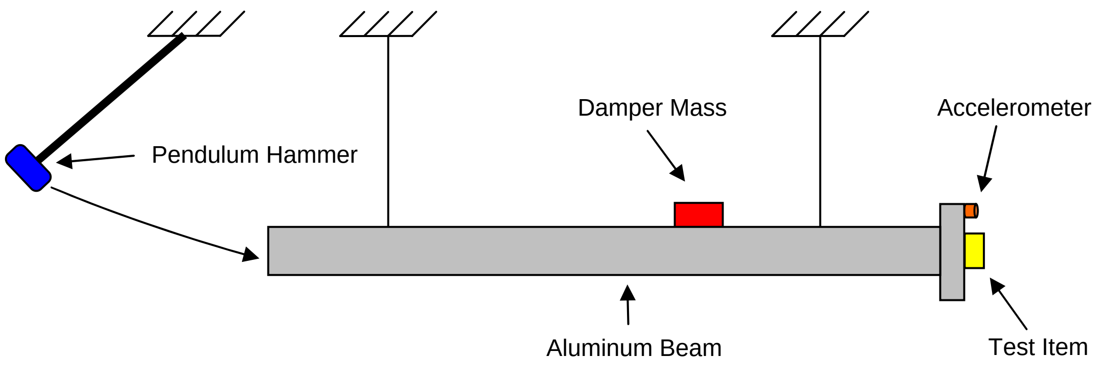

Figure B-1. Resonant Beam Setup

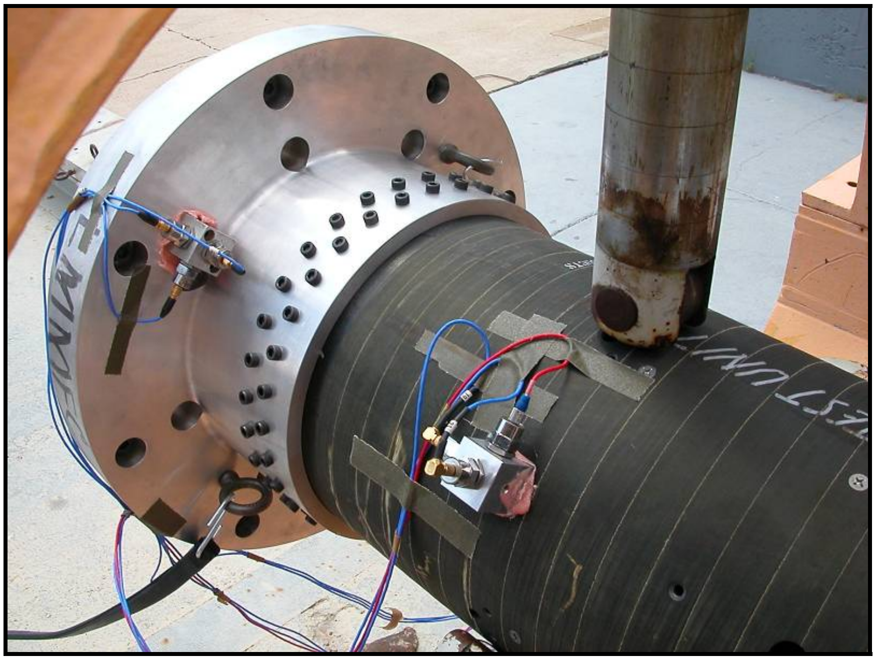

Figure B-2. Cylindrical Aluminum Resonant Impact Fixture With Transducers and Test Item

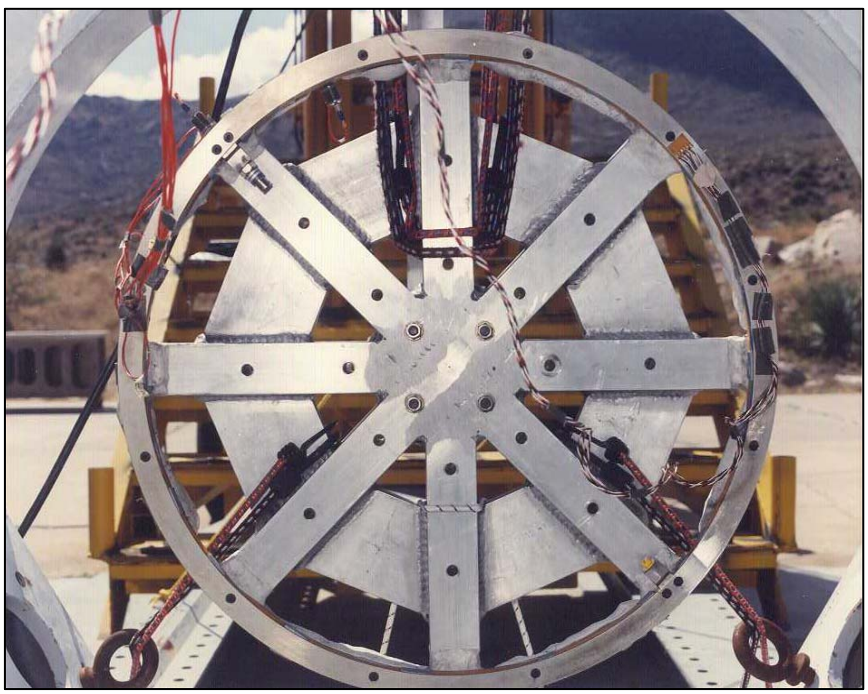

Figure B-3. Resonant Fixture With Linear Shape Charge Ring Test Item

APPENDIX C. GLOSSARY

ACCELERATION. The rate of change of velocity with time, usually along a specified axis, usually expressed in g or gravitational units.

ACCELEROMETER. A device (i.e., sensor, transducer, or pickup) for converting acceleration to an electrical signal.

ALIASING. When the sample rate, f, is less than 2 times the highest frequency in the data, the frequency is ambiguously represented. The frequencies above f /2 will be folded back into the lower frequencies to produce erroneous results.

ANALOG-TO-DIGITAL CONVERTER (ADC). An electronic device used for converting analog signals to digital form, either binary code or binary-coded-decimal. An ADC is usually used in conjunction with a multiplexer which selects a particular analog signal and with a sample-and-hold amplifier which stores an instantaneous analog voltage. The ADC digitizes (see DIGITIZE) that voltage into N discrete levels, where $N = 2^n$ and n is the number of bits of resolution in the device. For dynamic waveforms, the sampling frequency must be high enough to avoid aliasing errors.

AVERAGE, ARITHMETIC. An averaging technique which indicates the average value after N summations:

$$\hat{x} = \frac{1}{N}\sum_{i=0}^{N-1} x_i$$

CALIBRATION FACTOR (also called SCALE FACTOR). Data acquired by an ADC is in terms of binary counts representing some fraction of a specified full-scale voltage input. The Calibration Factor (CF) is the multiplier that must be applied to the digitized (see DIGITIZE) value to convert it to engineering units. For example, an acceleration signal of 5 g/v is to be digitized by a 12-bit (11 bits + sign) ADC having a full input of
10 V. The Calibration Factor is

$$CF = 5\frac{g}{volt} \times \frac{10V}{2^{11} counts} = 24.414 \times 10^{-3} g/count$$

An ADC count of 1562 would then be equivalent to

$$(1562) \times (24.414 \times 10^{-3} g) = 38.135g$$

CENTER FREQUENCY. A characteristic of a bandpass or band reject filter or a constant percentage filter of these types, the center frequency is the geometric mean of the upper, f_U, and the lower, f_L, cutoff frequencies:

$$f_c = \sqrt{f_L f_U}$$

For a constant bandwidth filter, the center frequency is the arithmetic mean (<u>see</u> AVERAGE, ARITHMETIC) of the upper and lower frequencies:

$$f_c = \frac{1}{2}\left(f_L + f_U\right)$$

<u>CLIPPING.</u> The term applied to the generally undesirable (but sometimes intentional) circumstance when an output signal is limited in some sense by the full scale range of an amplifier, ADC, or other device. Clipping may be hard, that is, when the signal is strictly limited at some level; or it may be soft in which case the clipped signal continues to follow the input at some reduced gain. Clipping makes sense on an input signal to the power amplifier if the distribution of the signal (random) has very high peaks and damage of transistorized equipment could occur.

<u>CRITICAL DAMPING COEFFICIENT.</u> Critical damping is the smallest amount of damping at which a system will respond to a step function without overshoot (<u>see</u> DAMPING). The critical damping coefficient for a linear, viscously damped, single-degree-of-freedom mechanical system is defined as

$$C_c = 2\sqrt{km} = 4\pi m f_n$$

where:

k = spring constant
m = mass
f_n = undamped natural frequency.

<u>CUTOFF FREQUENCY.</u> The frequency at which the rolloff skirt of the filter shape is down from the nominal unity gain passband level by a specified amount.

<u>DAMPING.</u> Dissipation of oscillatory or vibratory energy with motion or with time.

<u>DAMPING RATIO.</u> For a linear, viscously damped, single-degree-of-freedom, mechanical system, the ratio of the actual damping coefficient, C, to the critical damping coefficient, C_c, is called the damping ratio ζ,

$$\zeta = \frac{C}{C_c} = \frac{1}{2Q} \approx \frac{1}{2}\frac{B_{3dB}}{f_n}$$

$$C_c = 2\sqrt{km} = 4\pi \ m f_n$$

where:

k = spring constant
m = mass
f_n = undamped natural frequency
Q = Quality factor
B_{3dB} = half power frequency bandwidth

DECIBEL (dB). A measurement unit which denotes the ratio of the magnitude squared of a quantity with respect to an arbitrarily established reference value of the quantity, expressed as 10 times the logarithm to the base 10 of the ratio.

$$dB = 10 \log_{10} \frac{V^2}{V_{ref}^2} = 20 \log_{10} \frac{V}{V_{ref}}$$

DIGITAL-TO-ANALOG CONVERTER (DAC). The process of producing a (quasi) continuous analog signal from discrete quantized levels. The result is a continuous waveform designed to match as closely as possible a previously sampled signal or a synthesized result. Usually, it is followed by a low pass filter.

DIGITIZE. The process of converting an analog measurement of a quantity into a numerical value.

DISTORTION. In mechanics, any unwanted motion. In electronic measurements, any unwanted signal.

DYNAMIC RANGE. For spectrum measurements, the ratio in dB, between the overload level and the minimum detectable signal level (above the noise) within a measurement system. The minimum detectable signal of a system is ordinarily fixed by one or more of the following: noise level, low level distortion, interference, or resolution level. For transfer function measurements, the excitation, weighting, and analysis approaches taken can have a significant effect on resulting dynamic-range.

FAST FOURIER TRANSFORM (FFT). One of a collection of algorithms for computing discrete Fourier transforms (DFT's) in an optimum fashion. The fast Fourier transform (FFT) algorithm reduces the number of complex multiplications required to compute the transform. This is accomplished by factoring the weighted trigonometric summations required in the computation of the discrete Fourier transform into a sequence of shorter weighted summations by taking advantage of the periodicity's and symmetries of the periodic weighting factors and of the transform itself.

FILTER, ANTI-ALIASING. A filter used to remove the signals whose frequencies exceed one half the sample rate, $f_S/2$. Ideal filters are not realizable so that the cutoff frequency, transition band, and out-of band rejection need to be considered.

FILTER, BAND-PASS. A filter which passes all signal information between two cutoff frequencies and sharply attenuates all signal information outside that range.

FILTER, BAND-REJECT. A filter which attenuates all information between two cutoff frequencies and passes all signal information outside that range.

FILTER, BUTTERWORTH. A filter having flat passband and moderately sharp cutoffs, but also moderately nonlinear phase response. Commonly used for acquisition of data from random processes.

FILTER, CHEBYSHEV. Similar to the Butterworth filter; achieves faster rolloff near cutoff, but at the expense of significant passband ripple and a nonlinear phase response.

FILTER, DIGITAL. A weighted sum that can be defined as

$$g_m = \sum_{n=-N}^{N} b_n f_{m-n} - \sum_{n=1}^{N} a_n g_{m-n}$$

where:

g_m are the filter output samples
f_m are the filter input samples
b_n and a_n are the filter weights or coefficients.

If all the weights, a_n, are zero, the filter is called a nonrecursive filter. If one or more of the weights, a_n, are nonzero, the filter is called a recursive filter. If any of the weights, b_n, are nonzero for $n < 0$, the filter is said to be nonrealizable since future values of the input samples, f_m, will be required. If all the filter weights, b_n, are zero for $n < 0$, the filter is said to be realizable. If we define a digital unit impulse as

$d_n = 0 \qquad n \neq 0,$
$d_o = 1/\Delta t$

where:

Δt is the sampling interval, then the response of a digital filter to this impulse is called the impulse response of the filter. The impulse response for any nonrecursive filter will be finite for any finite N. Hence, nonrecursive filters are sometimes called finite impulse response filters. Recursive filters are called infinite impulse response filters because the impulse responses are not necessarily finite.

FILTER, HIGH-PASS. A filter which passes all signal information above the cutoff frequency, and sharply attenuates everything below that frequency.

FILTER, LOW-PASS. A filter which passes all signal information below the cutoff frequency, and sharply attenuates everything above that frequency.

FILTER RIPPLE. The peak-to-peak variation, in dB, of the gain of the filter in the passband.

FILTER ROLLOFF RATE. The best straight line fit to the slope of the filter transmissibility characteristic in the transition band, usually expressed in dB per octave.

FILTER TRANSITION BAND. The difference in frequency between the filter cutoff frequency and the point at which the gain reaches the first peak of the out-of-band ripple.

FILTER TRANSMISSIBILITY CHARACTERISTIC (FILTER SHAPE). The magnitude of the frequency response function of a filter relating the output to the input of the filter.

FOURIER TRANSFORM. A bilateral transformation typically used to convert quantities from time domain to frequency domain and vice versa, usually derived from the Fourier integral of a periodic function when the period grows without limit, often expressed as a Fourier transform pair. In the classic sense. a Fourier transform takes the form of

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt$$

where:

$f(t)$ = continuous time waveform
$F(\omega)$ = Fourier transform
ω = analysis frequency expressed in radians/sec

In the discrete or sampled sense, this can be expressed as

$$F_k = \sum_{n=0}^{N-1} f_n e^{\frac{-j2\pi}{N}kn}$$

where:

f_n = samples of time waveform

n = running sample index
N = total number of samples or "frame size"
k = finite analysis frequency, corresponding to "FFT bin centers"
F_k = discrete Fourier transform, and can be associated with the frequencies, $\omega_k = 2\pi k/(N\Delta t)$.

FREQUENCY. The reciprocal of the period in seconds (1/T). Usually specified in hertz (Hz), meaning cycles per second (cps).

FREQUENCY RANGE. The frequency range (bandwidth) over which the performance of the device remains within acceptable limits. Typical analyzers have selectable ranges. As applied to analyzers it usually refers to upper frequency limit of analysis, considering zero as the lower analysis limit.

FREQUENCY RESPONSE. The portion of the frequency spectrum which a device can cover within specified limits of amplitude error.

FUNDAMENTAL FREQUENCY. The number of cycles per second of the lowest-frequency component of a complex, cyclic motion.

HALF POWER BANDWIDTH, 3 dB (B_{3dB}). The interval between the upper and lower frequencies at which the filter attenuates an applied signal by 3 dB (see DECIBEL) with respect to the gain at the center frequency of the filter.

HARMONIC. A frequency component which is an integer multiple of the fundamental component of a complex spectrum. Harmonic components often represent unwanted distortion and are classified by their level and harmonic number (multiple of the fundamental).

INPUT. The mechanical motion, force, or energy applied to a mechanical system or an electrical signal.

LINEAR SYSTEM. A system is linear if for every element in the system the response is proportional to the excitation. This definition implies that the dynamic properties of each element in the system can be represented by a set of linear differential equations with constant coefficients and that, for the system as a whole, superposition holds.

MECHANICAL IMPEDANCE. The ratio of force to velocity, where the velocity is a result of that force only.

NATURAL FREQUENCY, f_n. The frequency of an undamped system's free vibration. Or the frequency of any of the normal modes of vibration.

NET VELOCITY CHANGE. Pyroshock acceleration signals can be checked for validity by examining the instantaneous velocity signal. The velocity signal is calculated by integrating the acceleration signal. The net velocity change is the difference between the value of the velocity at the end of the signal, V_{end}, and the velocity at the beginning of the signal, $V_{initial}$. Thus the net velocity change is: $\Delta V = V_{end} - V_{initial}$. Note, $\Delta V = 0$ for structures having no net velocity change. Structures having a net velocity change, such as deployable satellites, shall have an ending velocity signal approximately equal to the net velocity change as the initial velocity is forced to zero.

NOISE. Any unwanted signal. This term can also be used to denote a random signal source.

NYQUIST FREQUENCY. One-half the sampling frequency, that is 1/2 of $1/\Delta t$. The Nyquist frequency establishes maximum frequency which can be present in the data and still avoid aliasing (see ALIASING).

OCTAVE. An increase in frequency by a factor of two. The number of octaves, n, between two frequencies, f_1 and f_2 is given by $f_2 = 2^n f_1$ where $f_2 > f_1$ or

$$n = 3.3219 \log_{10} \frac{f_2}{f_1}$$

PEAK-TO-PEAK VALUE. The algebraic difference between extreme values.

PERIOD. The smallest interval of time in which a cyclic vibration repeats itself.

PIEZOELECTRIC TRANSDUCER. One which depends upon deformation of its sensitive crystal or ceramic element to generate electrical charge and voltage.

PIEZORESISTIVE TRANSDUCER. One which depends upon the deformation of its sensitive resistive element.

RANGE. A statement of the upper and lower limits over which an instrument works satisfactorily.

RESOLUTION. The discernible difference between one value and adjacent values in a measurement. In a digital signal analyzer it usually refers to the smallest time or frequency increment that can be discerned. In frequency domain measurements the frequency resolution is also called delta f, (Δf), and is equal to the analysis bandwidth divided by the number of spectral lines measured. Since only periodic signals can be resolved to within Δf, the "effective noise bandwidth" of a digital analyzer is probably a more meaningful measure of resolving ability in the frequency domain.

RESONANCE. The enhancement of the response of a physical system to an excitation. The resonant frequencies are usually defined as those frequencies where a small change in the frequency of excitation in either direction will cause the system response to decrease. The term resonant frequency is also used (sometimes erroneously) to denote the imaginary coordinate of the poles of a transfer function, the undamped natural frequencies of a system, and the damped natural frequencies.

RESPONSE SIGNAL. The signal from a “response sensor” measuring the mechanical response of a mechanical system to a shock pulse.

SENSITIVITY. The ratio between electrical signal (output) and mechanical quantity (input) of a mechanical-to-electrical sensor or pickup.

SHOCK PULSE. A transmission of kinetic energy into a system in a relatively short interval compared with the system’s natural period. A natural decay of oscillatory motion follows which is usually displayed as a time history.

SHOCK RESPONSE SPECTRUM (SRS). The maximum response of a series of Single Degree-of-Freedom (SDOF) systems as a function of the natural frequency of each oscillator.

SIGNAL CONDITIONER. An amplifier following a sensor, prepares the signal for succeeding amplifiers, transmitters, readout instruments, etc. and may also supply sensor power.

SIGNAL-TO-NOISE RATIO. A measure of signal quality. Typically, the ratio of voltage or power of a desired signal to the undesired noise component measured in corresponding units.

TRANSDUCER. A device that is actuated by power from one system and supplies power to a second system. In vibration, a transducer usually converts vibrational energy to electrical energy. The voltage output of a vibration transducer is usually proportional to acceleration, velocity, or displacement. The actual power extracted from the vibrating system is usually kept very small.

APPENDIX D. REFERENCES

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