

Institute of Environmental Sciences and Technology

IEST-RP-DTE032.2

Design, Test, and Evaluation Division
Recommended Practice 032.2

Pyroshock Testing Techniques



1827 Walden Office Square, Suite 400 |
Schaumburg, IL 60173 USA
Phone: (847) 981-0100 • Fax: (847) 981-4130
E-mail: iest@iest.org • Web: www.iest.org

This Recommended Practice is published by the Institute of Environmental Sciences and Technology (IEST) to advance the technical and engineering sciences. Use of this document is entirely voluntary, and determination of its applicability and suitability for any particular use is solely the responsibility of the user. Use of this Recommended Practice does not imply any warranty or endorsement by IEST.

This Recommended Practice was prepared by and is under the jurisdiction of Working Group 032 of the IEST Design, Test, and Evaluation Division.

Copyright © 2009 by the Institute of Environmental Sciences and Technology

Second printing, July 2017

ISBN 978-0-9841330-2-4

PROPOSAL FOR IMPROVEMENT: The Working Groups of the Institute of Environmental Sciences and Technology are continually working on improvements to their Recommended Practices and Reference Documents. Suggestions from users of these documents are welcome. If you have a suggestion regarding this document, please use the online Proposal for Improvement form found on the IEST website at www.iest.org.

Institute of Environmental Sciences and Technology
1827 Walden Office Square, Suite 400 |
Schaumburg, IL 60173 USA
Phone: (847) 981-0100 • Fax: (847) 981-4130
E-mail: iest@iest.org • Web: www.iest.org

Pyroshock Testing Techniques

IEST-RP-DTE032.2

CONTENTS

SECTION

1	SCOPE	5
2	REFERENCES.....	5
3	TERMS AND DEFINITIONS	6
4	BACKGROUND AND OVERVIEW	7
5	PYROTECHNICALLY EXCITED NEAR-FIELD SIMULATION	21
6	MECHANICALLY EXCITED MID-FIELD AND FAR-FIELD SIMULATION	23
7	STANDARD SHOCK-TESTING MACHINES WITH CLASSICAL PULSE TESTS (NOT RECOMMENDED)	31
8	MECHANICALLY EXCITED NEAR-FIELD SIMULATIONS.....	31

FIGURE

1	TYPICAL ACCELERATION-TIME HISTORY FOR A PYROSHOCK.....	7
2	ACCELERATION SRS AND TIME HISTORY FOR A NEAR-FIELD PYROSHOCK (DAMPING = 5%).....	9
3	ACCELERATION SRS AND TIME HISTORY FOR A FAR-FIELD PYROSHOCK (DAMPING = 5%).....	9
4	NEAR-FIELD PYROSHOCK DATA WITH ERRONEOUS ACCELEROMETER OFFSET	11
5	NEAR-FIELD PYROSHOCK DATA CORRECTED WITH WAVELETS	13
6	NEAR-FIELD PYROSHOCK DATA REPEATABILITY FOR A PLATE (16 TESTS)	15
7	NEAR-FIELD PYROSHOCK DATA REPEATABILITY FOR A NASA STRUCTURE (48 MEASUREMENTS: SIX LOCATIONS MEASURED FOR EIGHT TESTS).....	16
8	NEAR-FIELD PYROSHOCK NOISE CHANNEL DATA.....	18
9	ORDNANCE-GENERATED PYROSHOCK SIMULATOR	21
10	SCALED TESTS USING REPRESENTATIVE STRUCTURE	22
11	BOUNDED IMPACT TEST METHOD IMPLEMENTED ON A STANDARD DROP TABLE	23
12	FULL-SCALE PYROSHOCK SIMULATION WITH RESONANT SIMULATOR. MEASUREMENTS AT COMPONENT LOCATIONS CONFIRM SIMULATION SUCCESS	24
13	MIPS SIMULATOR	25
14	ACCELERATION SRS AND TIME-HISTORY FROM A TUNED RESONANT FIXTURE (DAMPING = 5%).....	26
15	RESONANT PLATE TEST METHOD (PLATE IS FREELY SUSPENDED)	27
16	RESONANT BAR TEST METHOD (BAR IS FREELY SUSPENDED).....	27
17	TUNABLE RESONANT BEAM TEST METHOD	28
18	TRIAXIAL ACCELERATION MEASUREMENTS FOR THE UNIQUE RESONANT FIXTURE SURVEY WITH THREE-AXES RESPONSE	29

19	TRIAXIAL ACCELERATION SRS CALCULATIONS FOR THE UNIQUE RESONANT FIXTURE WITH THE ACTUAL TEST UNIT.....	30
20	KNEE FREQUENCY IN THE SRS FOR THE UNIQUE RESONANT FIXTURE WITH THE ACTUAL TEST UNIT.....	31

TABLE

1	COMPARISON OF PUBLISHED PYROSHOCK DEFINITIONS	8
---	---	---

APPENDIX

A	BIBLIOGRAPHY	32
---	--------------------	----

Pyroshock Testing Techniques

IENT-RP-DTE032.2

1 SCOPE

This Recommended Practice (RP) provides an overview of pyroshock testing concepts and compares provisions from other pyroshock documents. Much of this RP is devoted to acquisition and analysis of pyroshock data because proper time-history data acquisition and test specification development are common test industry problems. To avoid corrupted pyroshock data and resulting inaccurate pyroshock specifications, recommended practices for instrumentation and data acquisition systems are given.

If pyroshock testing equipment is used to simulate the detonation of a pyrotechnic device, a unique, custom design is usually required, with a few exceptions. There is no universal pyroshock testing technique or equipment that can handle all specifications and all dimensions for units under test, whether test units are individual components, subsystems, or complete systems. This RP includes examples of different concepts and equipment configurations and notes any limitations. Several sections are devoted to the design and use of resonant fixtures for pyroshock simulations. Additionally, this RP contains an example of a three-dimensional pyroshock simulation with one impact to a resonant fixture that can provide a realistic simulation of pyroshock and prevent mechanical failure caused by overtesting with single-axis sequential test procedures.

CAUTION: Testing in accordance with this RP may involve hazardous materials, operations, and equipment. This RP does not purport to address all of the safety problems associated with its use. It is the responsibility of the user to consult safety guidelines and establish appropriate safety practices, and to determine the applicability of regulatory limitations prior to use of this RP.

2 REFERENCES

The following documents are incorporated into this RP to the extent specified herein. Users should apply the most recent editions of the references. See Appendix A for informative references cited in this RP and additional resources.

IENT-RD-DTE012: Handbook for Dynamic Data Acquisition and Analysis.

ISO 18431-4: Mechanical vibration and shock—Signal processing—Part 4: Shock-response spectrum analysis

MIL-STD-810: Environmental Engineering Considerations and Laboratory Tests, Method 517, Pyroshock.

NASA-STD-7003: Pyroshock Test Criteria.

2.2 Sources and Addresses

IENT

Institute of Environmental Sciences and Technology
1827 Walden Office Square, Suite 400 |
Schaumburg, IL 60173 USA
Phone: (847) 981-0100
Fax (847) 981-4130
www.ient.org

ISO

In US, documents may be obtained from:
IENT
1827 Walden Office Square, Suite 400 |
Schaumburg, IL 60173 USA
Phone: (847) 981-0100
Fax (847) 981-4130
www.ient.org
Outside U.S.: Documents available from
representative ISO member organization

US Military Standards

Standardization Document Order Desk
700 Robbins Avenue
Bldg. #4, Section D
Philadelphia, PA 19111-5094, USA
<http://dodssp.daps.dla.mil/>

NASA Technical Standards

NASA Headquarters
Washington, DC 20546-0001
Phone: (202) 358-0001
Fax: (202) 358-4338
<http://standards.nasa.gov>

3 TERMS AND DEFINITIONS

damping ratio

For a system with viscous damping, the ratio of the actual damping coefficient to the critical damping coefficient or the fraction of critical damping. $\zeta = c/c_c$ is the symbol typically used.

dB

A decibel for acceleration or an acceleration-based shock response spectrum (SRS) in this case is defined as: $20 \log_{10}(\text{new level/nominal level})$. The nominal level for acceleration is almost always 1 *g*.

dB/octave

A slope used for an acceleration-based SRS. An octave is a doubling in frequency. A pyroshock slope is 9 to 12 dB/octave or 1.5 to 2 decades in amplitude to one decade in frequency.

Fourier transform; discrete Fourier transform (DFT)

The representation of a time-history by a harmonically related series of sines and cosines. The digitally sampled time-history is represented by the DFT.

g

The acceleration of gravity: 9.8 m/sec (386 in./sec, or 32.2 ft/sec).

g-level

Acceleration time-history amplitude of a pyroshock as measured by an accelerometer calibrated in *g*'s.

knee frequency

The dominant frequency in a pyroshock SRS, at which the slope for the SRS changes from an approximate +9 dB/octave slope to an approximately horizontal slope with peaks at the major local structural frequencies. All pyroshock SRS have a knee frequency, even if not properly measured or quantified.

maximax SRS

The maximum of the positive and negative primary and of the positive and negative residual.

Nyquist frequency

The highest frequency identified in a DFT, equal to one-half of the sample rate.

pseudo-velocity

A widely used approximation for a relative velocity SRS is given by the relative displacement SRS multiplied by $2\pi f_n$. For hard impact and pyroshock transients, a relative velocity or pseudo-velocity SRS generally covers a much narrower dynamic range than either an absolute acceleration or a relative displacement SRS.

pyroshock (also called pyrotechnic shock)

The result of an explosive event, such as an explosive charge to separate two stages in a multi-stage rocket, and the resulting high-frequency (as high as 1 MHz), high-magnitude material stress phenomenon that propagates throughout the structure.

pyroshock, far-field

Pyroshock sufficiently distant from the pyrotechnic source that significant energy has transferred into the lower frequency structural response. Far-field pyroshock contains lower frequency and lower *g*-level energy than mid-field pyroshock; most of the energy is usually concentrated at one or a few frequencies at 3 kHz or less that correspond to dominant structural mode(s). Additionally, some energy is dissipated by friction, material deformation, and heating and is not manifested in the lower structural frequency response.

pyroshock, mid-field

Pyroshock at a distance from the pyrotechnic source where significant energy is still contained in material stress-wave propagation, but some energy has transferred into the lower frequency structural response. Mid-field pyroshock contains lower frequency and lower *g*-level energy than near-field pyroshock; most of the energy is usually concentrated at frequencies between 3kHz and 10 kHz.

pyroshock, near-field

Pyroshock close to the pyrotechnic source, at a point before significant energy is transferred to the modal structural response. This type of pyroshock is dominated by material stress-wave propagation from the source, and contains very high frequency and very high *g*-level energy, which is distributed over a wide frequency range and is not generally dominated by a few selected frequencies.

Q

The quality factor, $1/2\zeta$. Typically, $Q = 10$ for an acceleration-based pyroshock SRS.

shock response spectrum (SRS)

The maximum response of a single-degree-of-freedom system to a shock input, plotted as a function of the

natural frequency of the system with a constant damping value. The response and the input may be acceleration, velocity, or displacement. The damping value used for an SRS specification may affect the ability to meet that specification. Typically the maximum of the positive and negative SRS (maximax) is plotted, but many specifications require the positive SRS and negative SRS to be calculated separately and shown on the same log-log plot. In all cases, the SRS should be calculated according to ISO 18431-4.

single degree of freedom

Motion described by a single coordinate.

slew rate

The maximum slope or rate of change of a sinusoidal wave form.

4 BACKGROUND AND OVERVIEW

Pyroshock (also called pyrotechnic shock) testing may be required for test items, subsystems, and full-scale or complete systems that must withstand an explosive event, such as an explosive charge to separate two stages in a multi-stage rocket, and the resulting high-frequency (as high as 1 MHz), high-magnitude material stress phenomenon that propagates throughout the structure. Pyroshock was once considered a relatively mild environment due to the relatively low velocity change (as compared to impact mechanical shock) and high-frequency content involved. Although pyroshock rarely damages structural members, pyroshock can easily cause failures in electronic test items that are sensitive to the high-frequency pyroshock energy.

Many flight failures have been attributed to pyroshock compared to other types of shock or vibration sources. In one case, an extensive database of the failures due to pyroshock has been compiled.¹ The types of failures caused by pyroshock commonly include relay chatter, separation of small-circuit test items, and the dislodging of contaminants (e.g., solder balls) that cause short circuits. Designers should rely on testing of systems and components exposed to pyroshock because of the absence of adequate analytical techniques to predict high-frequency structural response. Implementation of a qualification test program can reduce failures caused by pyrotechnic shock.

Figure 1 shows a typical pyroshock acceleration-time history and displays the general characteristics of a pyroshock. The initial pyroshock acceleration magnitude may be as high as 200,000 *g* or higher, as it is a function of the measurement technique and digital signal processing as well as the source type and size or strength, intervening structural path characteristics (including structural type and configuration, joints, fasteners, and other discontinuities), and distance from the source to the response point of interest. The pyroshock acceleration-time history is a decaying oscillatory acceleration transient that decays to a few percent of the maximum within a few (typically no more than 20) msec. The characteristics of the pyroshock acceleration-time history, i.e., the magnitude and frequency content, vary with the distance from the pyroshock event. As discussed in this RP, the pyroshock frequency content is assessed with the shock response spectrum (SRS). In this document, three types of pyroshock

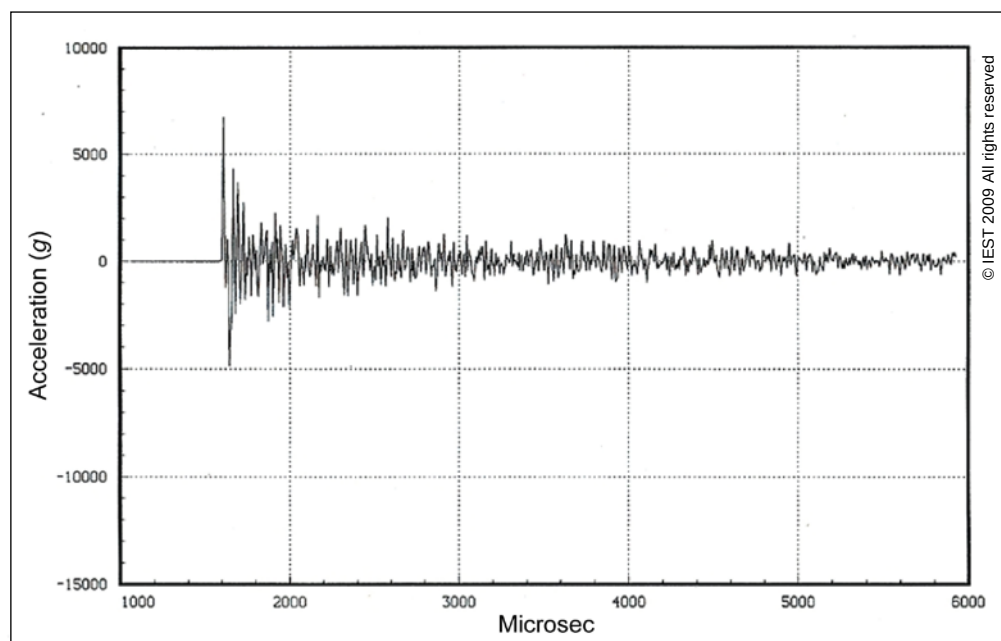


Figure 1—Typical acceleration-time history for a pyroshock.

are distinguished: *near-field*, *mid-field*, and *far-field*. Although the differences among the three types of pyroshock are not always clearly defined for a particular structure, the major differences are defined here in terms of their corresponding test techniques. The three types of pyroshock should be used as guidelines and not rigid definitions of acceleration amplitude or SRS frequency characteristics. The acceleration time history and resulting SRS for a laboratory simulation are a function of several parameters as discussed earlier. Thus, the specification of a pyroshock test is generally defined from measured data for a particular test item and configuration.

A near-field pyroshock test requires frequency control up to and above 10 kHz for amplitudes greater than 10,000 *g*. A pyrotechnically excited simulation technique is usually appropriate, although in some cases a mechanically excited simulation technique may be used.

A mid-field pyroshock test requires frequency control from 3 kHz to 10 kHz for amplitudes less than 10,000 *g*. A mechanically excited simulation technique other than shaker shock is usually required.

A far-field pyroshock test requires frequency control no higher than 3 kHz for amplitudes less than 1000 *g*. A shaker shock or a mechanically excited simulation technique is appropriate.

Other references, such as NASA-STD-7003 and MIL-STD-810G, Method 517, also define pyroshock regions. Generally, in these documents, pyroshock is described by frequency content, acceleration amplitude (*g*), distance from the source, test item structure, or structural response. Acceptable criteria in the different documents depend on the type of excitation source and numerous parameters. Table 1 gives a general summary of NASA-STD-7003 and MIL-STD-810G,

Method 517 pyroshock definitions, along with the definitions in this document. The pyroshock definitions in this RP are consistent with the definitions in MIL-STD-810G, Method 517.

Near-field pyroshock occurs close to the pyrotechnic source, at a point before significant energy is transferred to the modal structural response. This type of pyroshock is dominated by a high-magnitude material stress phenomenon that propagates from the source, and contains very high frequency and very high *g*-level energy, which is distributed over a wide frequency range and is not generally dominated by a few selected frequencies. Although the near-field distances given in NASA-STD-7003 are appropriate for the general size of NASA structures, the distances restrict the definitions to particular sizes. For example, the NASA definition of near-field as >5000 *g* at 2.5 to 15.2 cm (1 to 6 in.) from the source implies a large structure with significant structural damping because 5000 *g* is a very low value for near-field pyroshock. Explosive quantities as small as 5 mg can create accelerations of almost 80,000 *g* at distances of 2.5 to 15.2 cm (1 to 6 in.) for small structures.² NASA-STD-7003 recommends “in a good aerospace system design, there should be no pyroshock-sensitive hardware exposed to a near-field environment, so that no near-field testing will be required.” NASA-STD-7003 includes requirements for structures intended for human occupation, but this near-field recommendation also applies to unmanned structures. There are many components in near-field locations for applications other than NASA structures. Some components are deliberately put in the near field in order to monitor events occurring during the pyrotechnic shock. Near-field pyroshock measurements are now generally routine, due in large part to advances made in utilizing piezoresistive accelerometers, with and without resilient mounting (called mechanical filter), and using laser Doppler vibrometers.²⁻⁵

Table 1—Comparison of published pyroshock definitions.

Document	Region	Acceleration Amplitude (<i>g</i>)	Frequency (Hz)	Distance from Source	
				Intense Source	Mild Source
NASA STD 7003	Near-field	>5000	>100 k	<6 in.	<1 in.
	Mid-field	1000–5000	>10 k	6–24 in.	1–6 in.
	Far-field	<1000	<10 k	>24 in.	>6 in.
IEST-RP-DTE032 and MIL-STD-810G, Method 517	Near-field	>10,000	≥10 k		
	Mid-field	<10,000	3 k–10 k		
	Far-field	<1000	≤3 k		

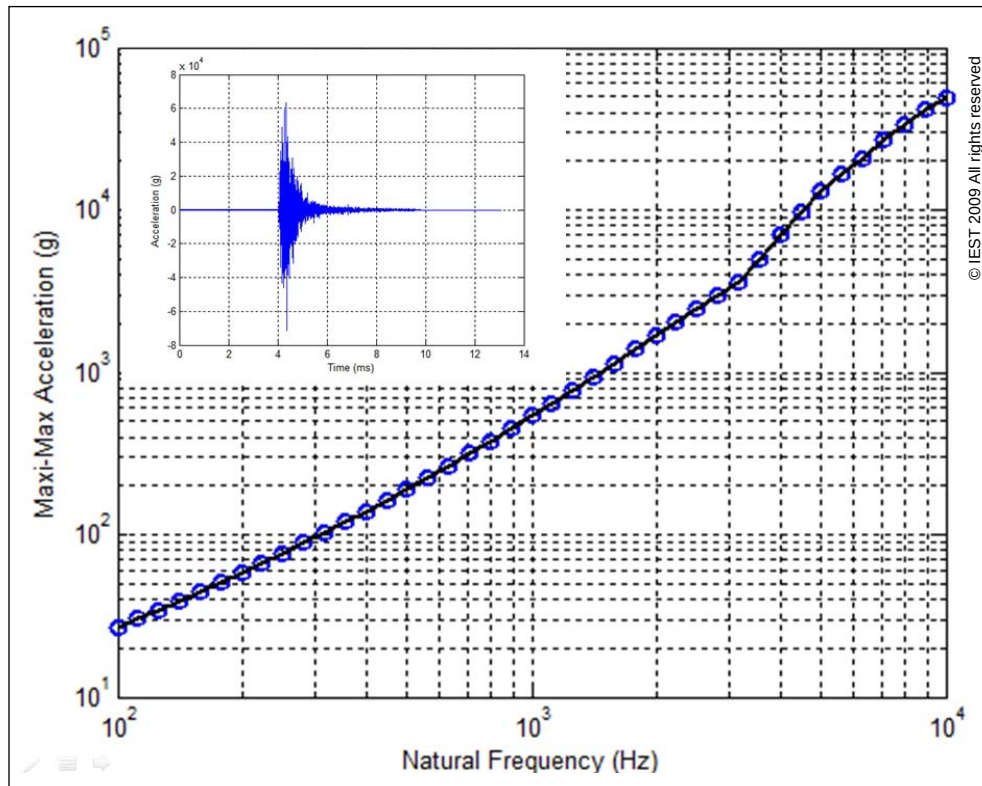


Figure 2—Acceleration SRS and time history for a near-field pyroshock (damping = 5%).

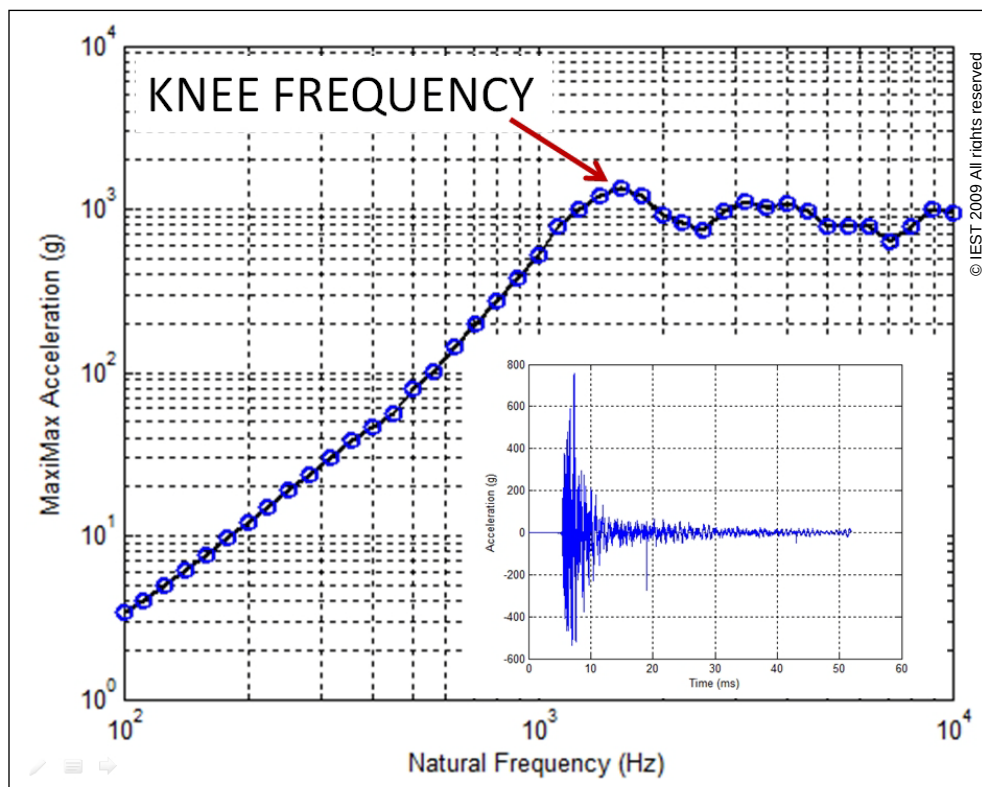


Figure 3—Acceleration SRS and time history for a far-field pyroshock (damping = 5%).

Mid-field pyroshock is characterized by a combination of material stress wave propagation and structural resonances. A frequency content of 3 kHz to 10 kHz can usually be obtained with one of the resonant fixture testing techniques discussed in this RP and is similar to the NASA-STD-7003 description. Far-field pyroshock occurs at a greater distance from the source, where significant energy has transferred into the lower frequency structural response. Far-field pyroshock contains lower frequency and lower g -level energy than near-field and mid-field pyroshock. Most of the far-field energy is usually concentrated at one or a few frequencies that correspond to dominant structural mode(s). A frequency content of ≤ 3 kHz can usually be obtained with one of the resonant fixture testing techniques discussed in this RP or a shaker shock.

4.1 Acceleration-time history data

Ideally, the pyroshock acceleration-time history data used to develop the qualification test specification should be measured during a full-scale or complete-system pyroshock test in which the actual pyrotechnic device or devices are initiated. If the actual hardware is not available, the full-scale or complete-system test should be performed with hardware that is structurally similar to the actual hardware. In program development, the actual hardware is rarely available early in the development stage, so mock hardware is often used. As a minimum requirement, the mock hardware should be the same weight and have the same attachment points as the actual hardware. However, in many cases the hardware weight distribution becomes critical because it governs both the amplitude and the frequency content of the measured acceleration response at the base of the mock hardware, so that a different amplitude and frequency will be observed with the actual hardware. A control point measurement should be specified close to each test item or subassembly of interest, preferably at the attachment point, to measure the input pyroshock. Since full-scale or complete-system testing is expensive, data from a similar application may be used to develop qualification test specifications. This practice may result in over-test or over-design if a large margin is added to the test specification to account for uncertainty in the data. If this practice is used, the test specification should be revised when better full-scale or complete-system data become available.

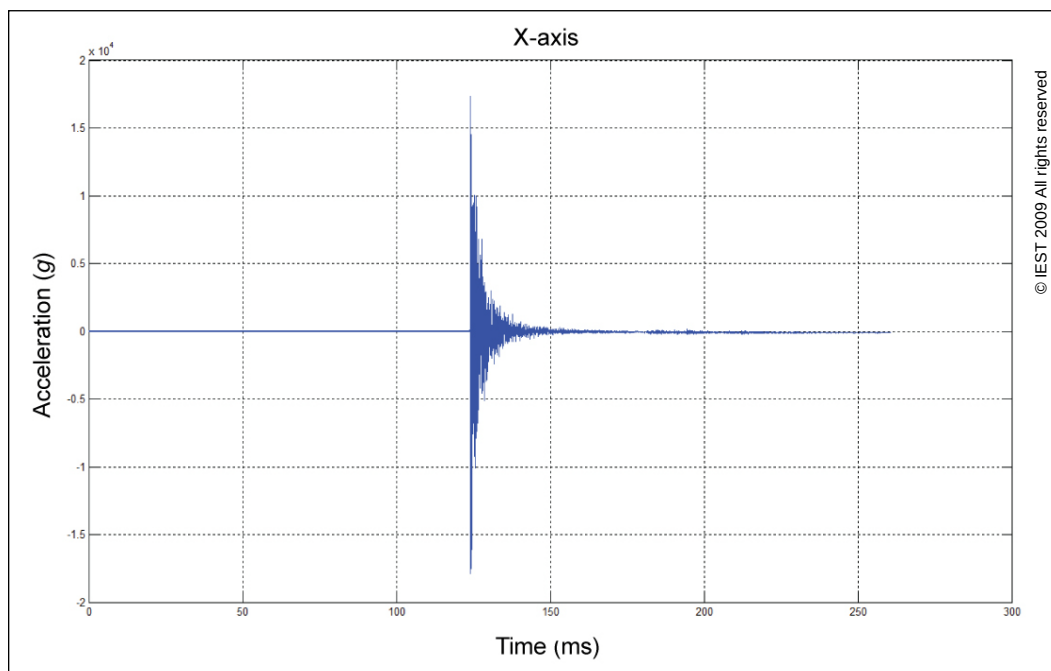
4.2 Wide-band acceleration time-history data

Once the acceleration time-history data have been acquired, the wideband data should be scrutinized to verify data quality^{6,7} (see IEST-RD-DTE012). The data should be free of zero-shifts and offsets. Acceleration

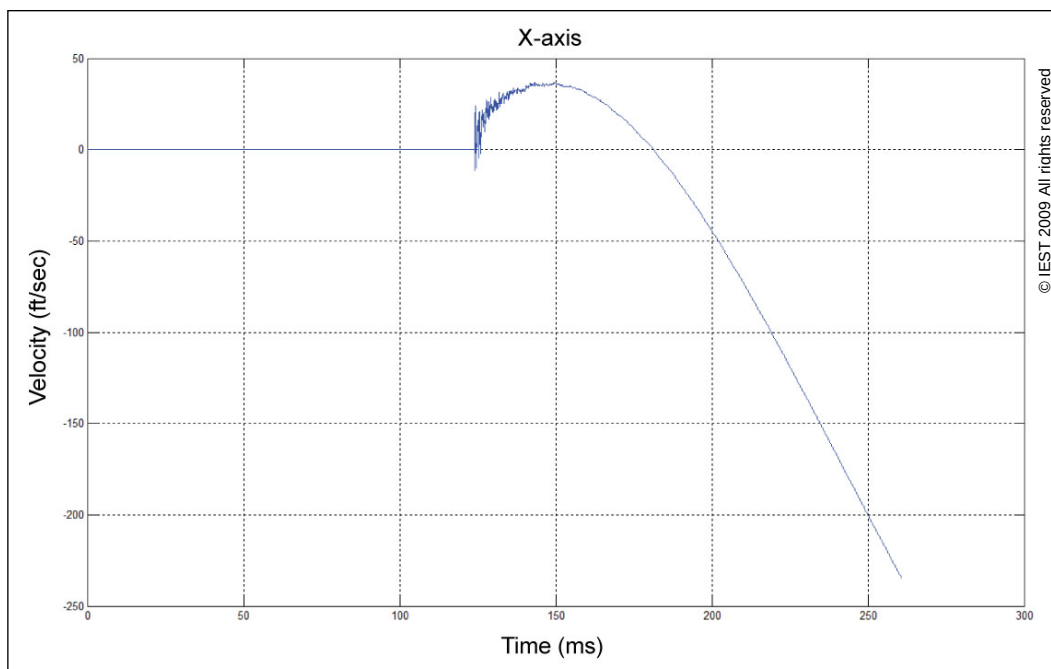
and velocity time-histories should be integrated, and the results examined to determine that the resulting velocity and displacement are consistent with test conditions. Data may be corrected using wavelets or other techniques.⁸ The time-history data should be digitally low-pass-filtered at a designated cutoff frequency after the data are acquired; a cutoff frequency of 20 kHz is typical for mid-field and far-field pyroshock. Arguments for wider bandwidth data are given in section 4.5. Data acquisition systems (DAS) with 1-MHz bandwidths and 16-bit (or more) digital-to-analog converters are recommended for near-field and mid-field pyroshock because of high-frequency content in the data that may be accelerometer resonance, the measured environment, or the electromagnetic pulse created by pyrotechnic detonation. The DAS should be evaluated prior to purchase or use to determine that it meets the manufacturer's specifications⁹ (see IEST-RD-DTE012). The evaluation is especially important for near-field and mid-field pyroshock measurements because the high-frequency content may overwhelm the DAS analog front-end as discussed. This problem will evidence itself as a slew rate problem: a low-frequency modulation of the lower frequencies in the DAS bandwidth or an offset as discussed in section 4.5 of this RP (see IEST-RD-DTE012). For pyroshock measurements, it is imperative that the DAS not alias the data.¹⁰ Figure 2 shows a typical near-field pyroshock time-history and the resulting acceleration SRS up to 10 kHz. Every SRS has a knee at some frequency, and other SRS are plotted showing the knee frequencies above 10 kHz in this document. In all cases, the acceleration-based SRS should be calculated according to ISO 18431-4.

The use of pseudo-velocity SRS should be considered for two reasons: (1) velocity is proportional to stress and strain, and (2) velocity is a better indicator of damage potential than acceleration.^{11,12} Both the pseudo-velocity and the static-equivalent acceleration are defined in terms of δ_m , the maximum relative displacement for a single-degree-of-freedom system, as $2\pi f_n \delta_m$ and $((2\pi f_n)^2 \delta_m)$, respectively, where f_n is the natural frequency used in the SRS calculation.¹³ These quantities may be more useful than the acceleration-based SRS for predicting equipment failure. A good approximation of the pseudo-velocity SRS may be obtained by multiplying the acceleration SRS by $2\pi f_n$ and converting g units to in./sec or ft/sec.¹² The pseudo-velocity SRS is plotted on a four-coordinate graph.

The acceleration data should be analyzed using the same technique used to analyze the time-history data from which the test specification was derived. Test margin and tolerance bands are applied to the data analysis. For instance, if the SRS is being used, a



a) Acceleration time-history.



b) Velocity time-history (integral of 4a acceleration time-history).

Figure 4—Near-field pyroshock data with erroneous accelerometer offset. (Continued on next page.)