An Alternative to Pyrotechnic Testing For Shock Identification

J. J. Titulaer B. R. Allen J. R. Maly
CSA Engineering, Inc.
2565 Leghorn Street
Mountain View, CA 94043

ABSTRACT

The ability to produce a repeatable shock spectrum is needed for many applications in industry. Flight components and structural systems often require qualification testing consisting of subjecting the payload to a specified shock response spectrum (SRS). Testing is used to qualify sensitive packages for flight, ensuring that the unit will survive and continue to function normally during and after being subjected to the anticipated environment. Traditional pyroshock testing is expensive, the excitation can over test flight components and it is often not repeatable within desired limits. Furthermore, development of shock isolation systems to reduce environments for flight payloads requires similar testing capability.

A compressed-air shock test system has been developed using a pneumatic gun to deliver repeatable and controlled transient loads, simulating high-shock flight conditions. This “shock gun” delivers a captive projectile through a barrel to provide the desired structural response. Measured accelerations are used to quantify the shock performance, typically using the SRS technique. Shock isolation systems have been developed and refined with this system, directed at attenuating high-level, high-frequency loads associated with typical conditions such as launch vehicle fairing and stage separation events. The performance of the present system will be reviewed, and possible extensions of this test method, including ultimate limitations in frequency and amplitude, will be discussed in the paper.

1 Introduction

Traditional methods of qualifying sensitive payloads for flight normally involve shock testing using pyrotechnic or drop testing methods. Pyrotechnic shock methods typically are slow and not very repeatable which add cost to testing as well as damage potential to the payload. Acoustic excitation, particularly with pyrotechnic simulation methods, is quite often ineffective at replicating loads seen in applications.

A simple yet uncommon method has been utilized which provides several advantages to pyrotechnic shock testing as well as drop testing. The method uses a pneumatic gun to fire a captive projectile which impacts a mounting block. A picture of the system is shown in Figure 1. Mounting blocks are designed to provide a Shock Response Spectrum (SRS) which is representative of a particular specification. Specifications normally are derived from acceleration response measurements at or near the location of the payload. Mounting blocks may be tuned using damping design techniques to more closely match a specification. The blocks provide a known shock environment for future testing of additional or different components. This method produces a highly repeatable and tunable shock input. The time between sequential shock events can be as little as a few minutes. Qualification in three axes can take less than half a day to complete. This method also provides a practical way to design and test mitigating structural elements such as shock isolators and whole spacecraft isolation systems.

Figure 1 Shock Test System.

2 Pneumatic Shock System

The pneumatic shock test system developed consists of three main parts, the pneumatic gun, the mounting block and the test stand. Each part plays a significant role in the resulting SRS generated using the system.

The pneumatic gun consists of an air tank, two air valves, and a captive projectile in the barrel. An input valve controls the amount of compressed air allowed to enter the air tank. The pressure is monitored with a standard pressure gauge. An output valve releases the compressed air from the tank into the barrel. This applies a near constant force on the bullet and propels it down the length of the barrel. The bullet is captive in the barrel. The bullet’s tip extends from the end of the barrel and strikes the mounting block.

The mounting block is designed such that the modal dynamics predominantly shape the SRS. A target material is placed between the mounting block and the bullet which controls the pulse width or frequency content of the input. The payload is normally bolted onto the back of the mounting block. Accelerometers located near the payload measure the resulting shock event. Temperature control can be used to qualify articles which experience shock levels at other than ambient conditions. Temperatures below freezing can be accommodated.

The test stand provides the boundary conditions for the test. In most cases, the boundary condition is free-free, meaning that the block is supported by a cable and is allowed to rotate about the cable as well as translate in the horizontal plane, but not the vertical plane.

3 Shaping the SRS

The SRS is a common standard for shock specifications in industry. Unlike the Fourier Transform an SRS is not unique to a single time history and the process is not reversible. This section discusses the SRS function and presents some examples of shaping.

Shaping an SRS to match a particular specification can be very involved. Variables which affect accurate narrowband SRS level include block mass, shape, and material type as well as material type at the striker plate interface. In cases where another mass is isolated off of the primary mounting block, mounting frequencies and mass ratios between isolated and base masses play an important role in shaping the response. Fortunately, mounting blocks can be designed with the aid of finite element analysis. Finite element analysis is also cost effective for tuning the damping treatment of an individual block.

3.1 SRS Background

The SRS is a function of frequency where the frequency bins are the peak amplitude levels from a time history which results from convolving a tuned single degree-of-freedom (DOF) oscillator with the input shock history. For example, when the oscillator frequency is set to 100 Hz, the resulting output is the 100 Hz bin in the SRS. The convolution process is repeated at many frequencies to generate an SRS. The equation form of the oscillator is unitless, and is the same form as the single DOF transmissibility function seen in vibration texts.

Because excitations are commonly in the form of a half-sine pulse, understanding the appearance of this function in the form of an SRS is important. Figure 2 shows time histories of two half-sine pulses and their corresponding SRS functions.

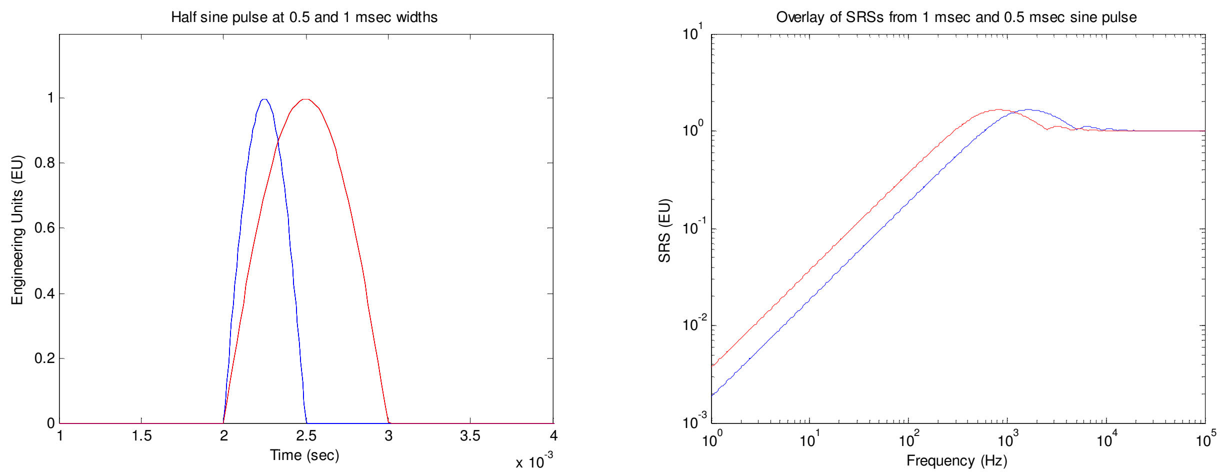

Figure 2 - Half sine pulses and their corresponding SRSs

SRSs of rigid masses that are freely supported in space appear as shown in Figure 2. In practice, structures have many modes that are inside the spectral bandwidth.

3.2 Block Design

Mounting blocks are designed for individual SRS specifications. Typically, a launch vehicle manufacturer or satellite manufacturer has a test article that must be qualified for flight by subjecting it to a flight-like shock environment. SRS specifications are commonly developed from the shock events recorded during previous flights. Mounting blocks are designed to simulate this shock environment. Designers work to reconstruct specified SRS levels by selectively placing resonant frequencies of the mounting block to reconstruct the SRS shape. With upward sloping specifications as seen in Figure 3, resonant frequencies of the mounting block are typically placed at frequencies above the specification.

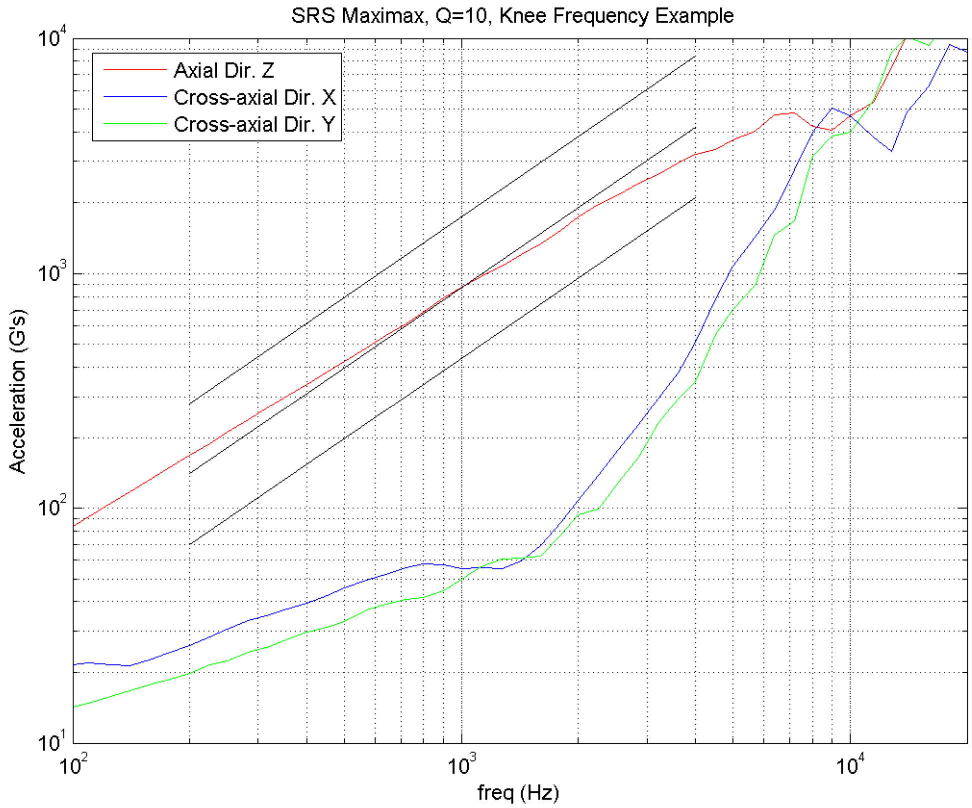

Figure 3 – Example of an Up-sloping SRS Function

Payloads are normally mounted at or near the center of the mounting block. The distance between payload mounting locations needs to be small relative to the wavelength of any modes of the mounting block. This assures the payload sees a consistent acceleration level at each of its mounts, and that the accelerometer accurately reflects levels seen by the test article [Ref. 1].

Acceleration readings can also be affected by forces from the test article depending on its mass relative to the mounting block. It is typical to limit payload mass of the test article to 1/20th of the mounting block mass to avoid distortion of response levels.

Damping treatments can be applied to a mounting block to reduce ringing at flexural frequencies. This can be accomplished by targeting the desired mode with viscoelastic materials and constraining layers. The constraining layer shears the viscoelastic material and absorbs energy thus reducing ringing and lowering the SRS levels at frequencies near the damped resonance. Figure 4 below shows excellent SRS specification matching using a simple constraining layer damping treatment. The mode at 5 kHz has enough damping to meet the specification.

Mounting block mass can limit the overall input acceleration levels. The required acceleration level ultimately limits the size of the test article. Shock levels in excess of 10,000 G's have been demonstrated with excellent repeatability.

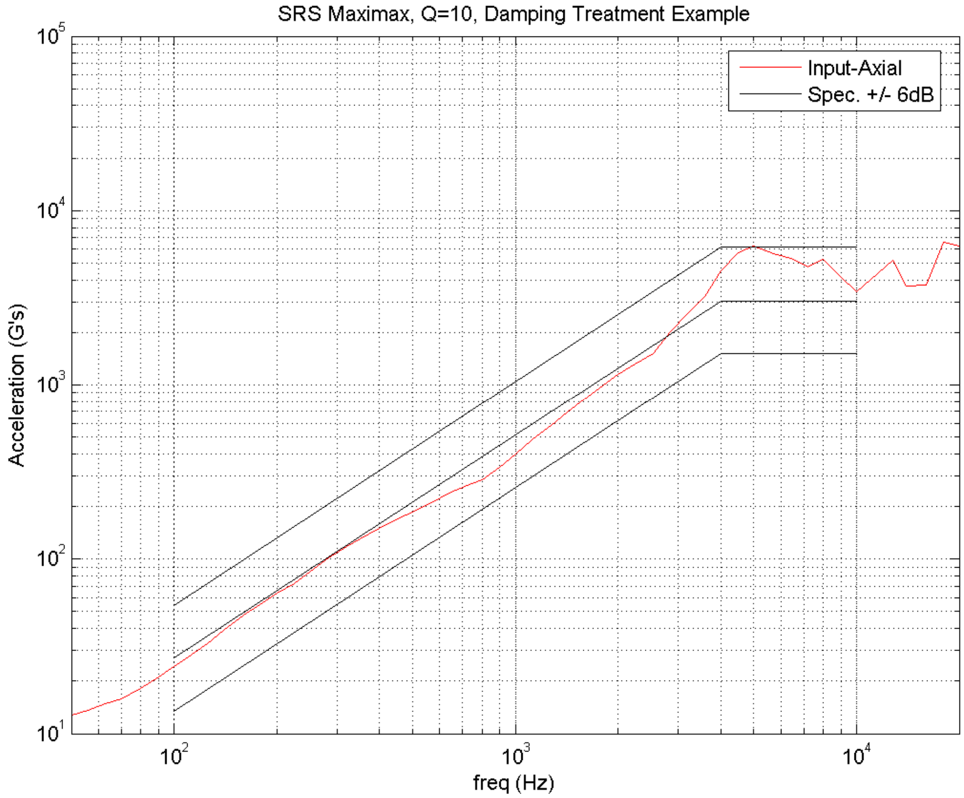

Figure 4 Mounting Block Damping Treatment Example.

3.3 Pulse Width Control

Coarse and fine tuning of a SRS can be accomplished with differing target materials. Target materials are sacrificial pieces which are placed between the bullet and the mounting block and aid in shaping the input pulse to the mounting block. Hard materials create a shorter pulse width which inputs higher frequency content into the block. Softer materials create a longer pulse width which inputs lower frequency content into the block. Coarse tuning can be accomplished with this technique as shown below in Figure 5. Maximum shock levels can be limited when using softer materials due to the energy absorbed by the target during impact.

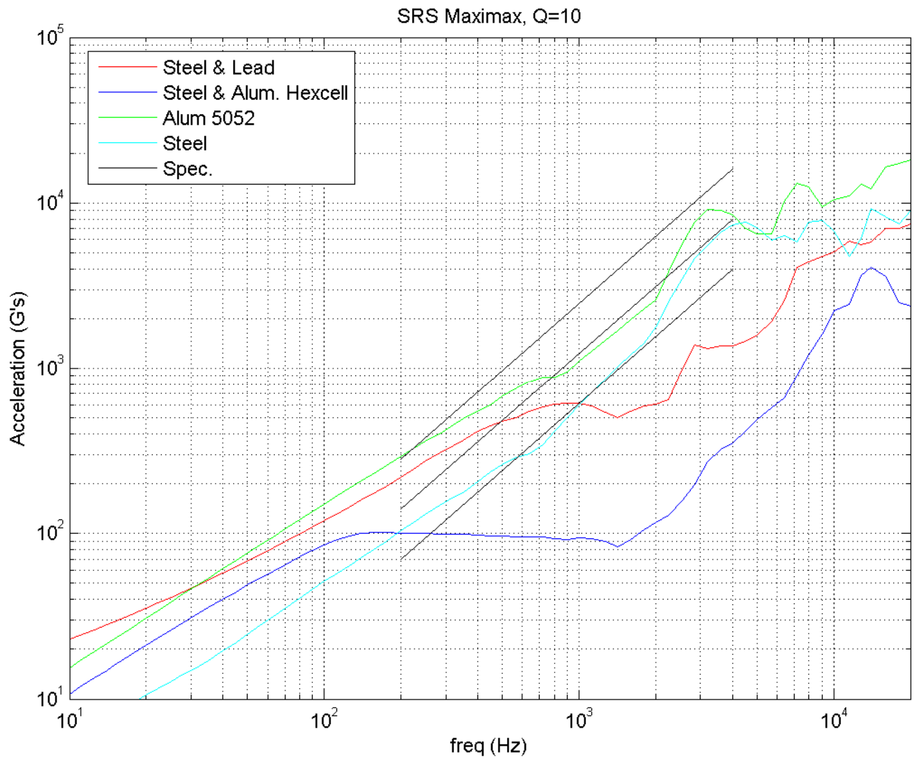

Figure 5 SRS Tuning example

Results

3.4 **Structural Element Proof Testing**

The shock test system described above was developed particularly to proof test shock isolation systems. An example of a mounting block designed to proof test an isolation system is shown in Figure 6. The impact block in front simulates the mounting location for a satellite. The block on the rear simulates the satellite. Sandwiched between the two large octagon blocks is a "ShockRing". ShockRings were developed by CSA (US patent 6,202,691) to isolate small satellites on launch vehicles from pyrotechnic events commonly seen during launch. Deployment devices have been used in conjunction with ShockRings and qualified for flight. Figure 7 shows typical reduction of SRS levels using a ShockRing and Figure 8 shows a close-up of the acceleration time histories. A reduction of greater than 1 decade is commonly seen across the majority of the frequency range for ShockRings.

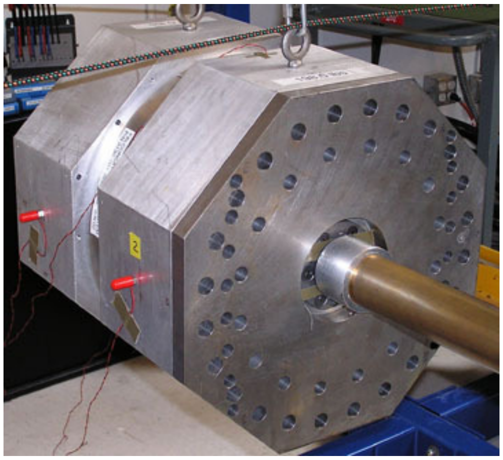

Figure 6 Structural Isolator Test Setup

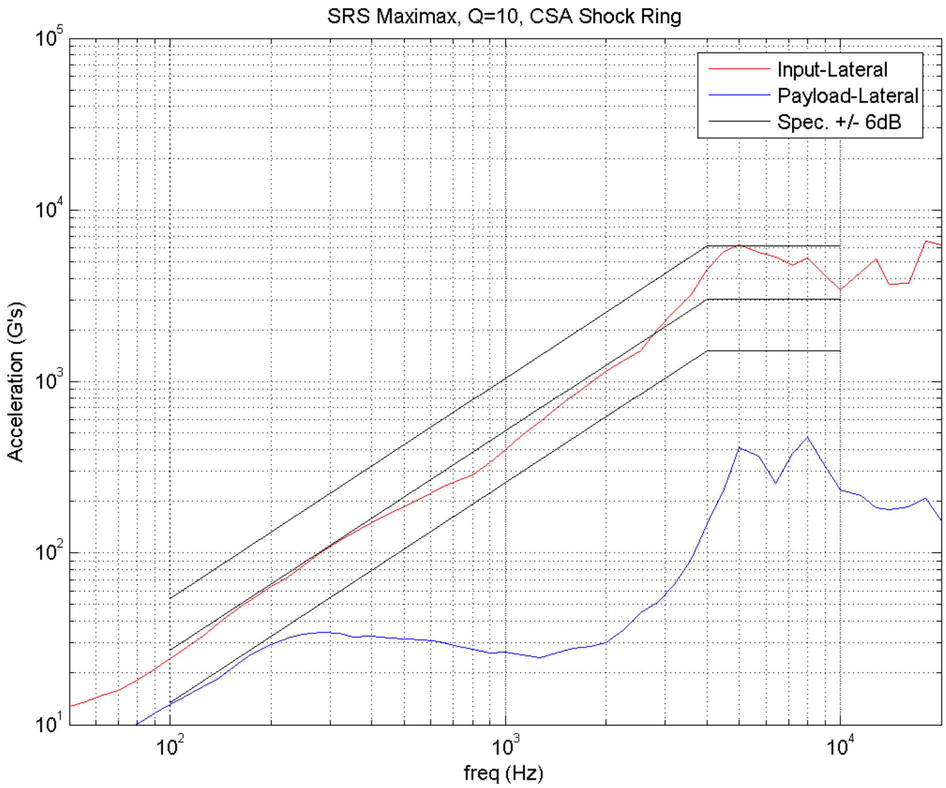

Figure 7 Resulting SRS for ShockRing

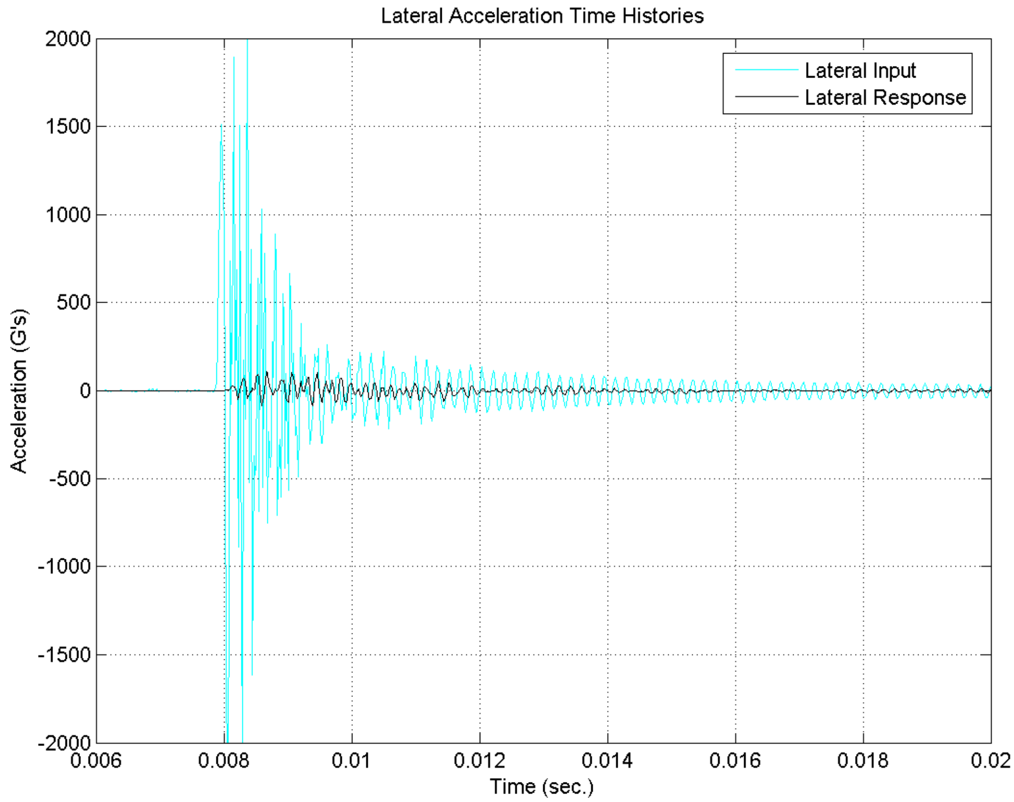

Figure 8 Resulting Time Histories for ShockRing

Figure 9 shows an SRS plot of an avionics package mounted on custom thermally conductive viscoelastic isolators shown in Figure 10. Shock levels are significantly reduced above 100Hz. The isolation frequency is clearly visible just below 100Hz.

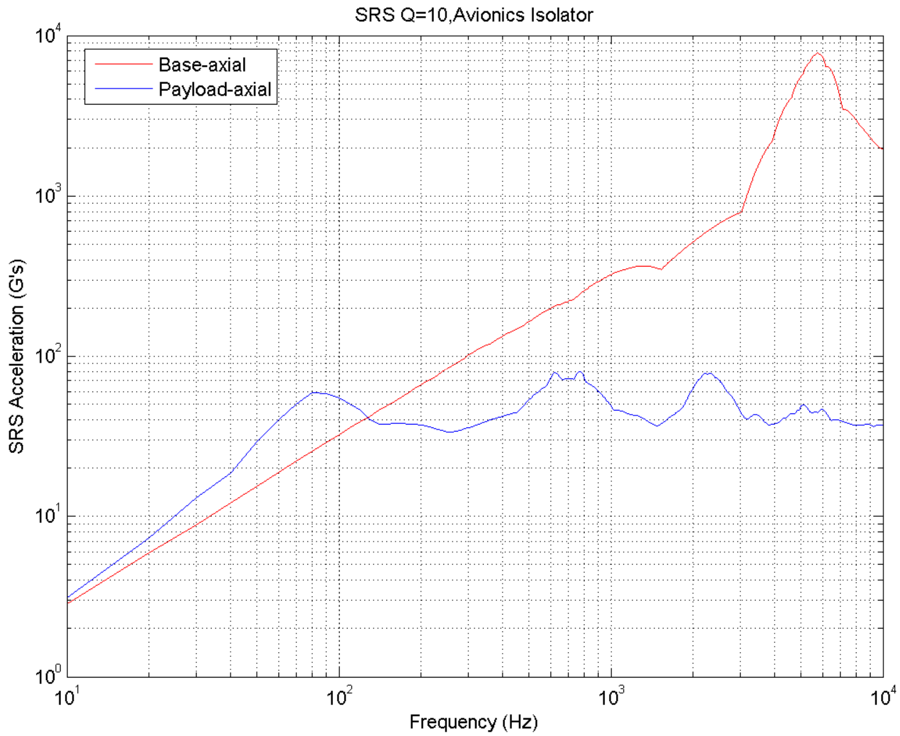

Figure 9 SRS of Custom Thermally Conductive Isolators

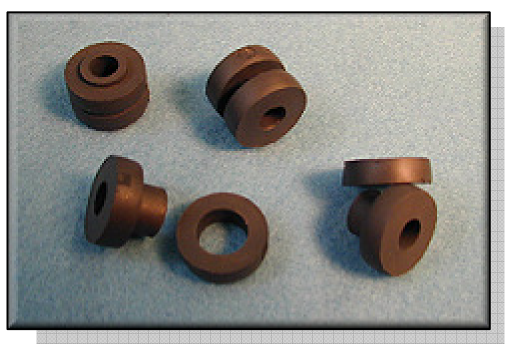

Figure 10 Thermally Conductive Isolators

ShockRings have been developed which combine the thermally conductive material of the isolators above with the ShockRing shape. Results are shown in Figure 11. Reductions of 1-2 orders of magnitude can be realized in certain frequency ranges. The shock test system is an extremely effective tool to rapidly test and verify custom isolation systems.

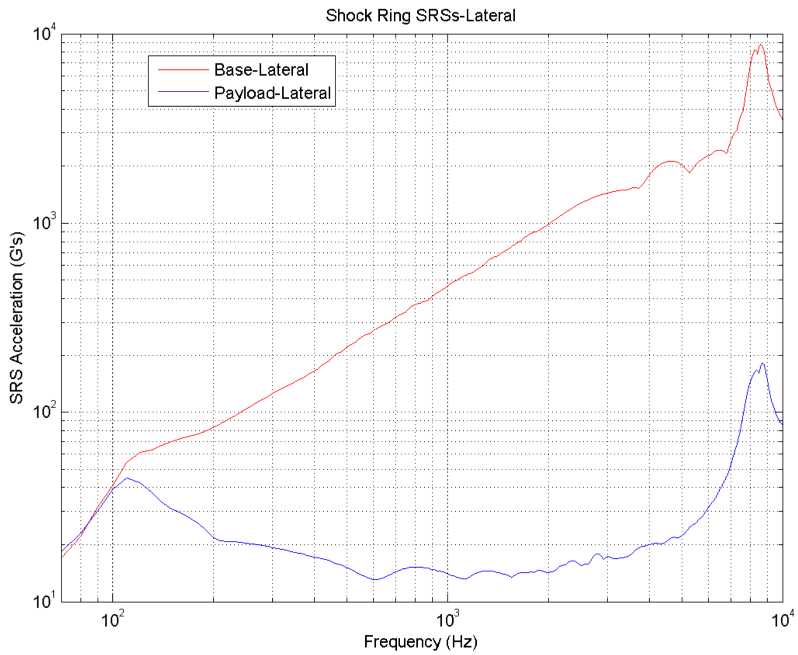

Figure 11 Hybrid ShockRing SRS.

3.5 **Repeatability of SRS Spectra**

One common problem with pyrotechnic shock testing is repeatability of shock levels between tests. Over testing is common and can cause damage itself. Shock testing with a pneumatic gun provides excellent repeatability. Figure 12 displays the characteristic repeatability of three subsequent shocks as seen with the pneumatic shock test system described above. Typically, levels overlay each other from impact to impact up to 10 kHz.

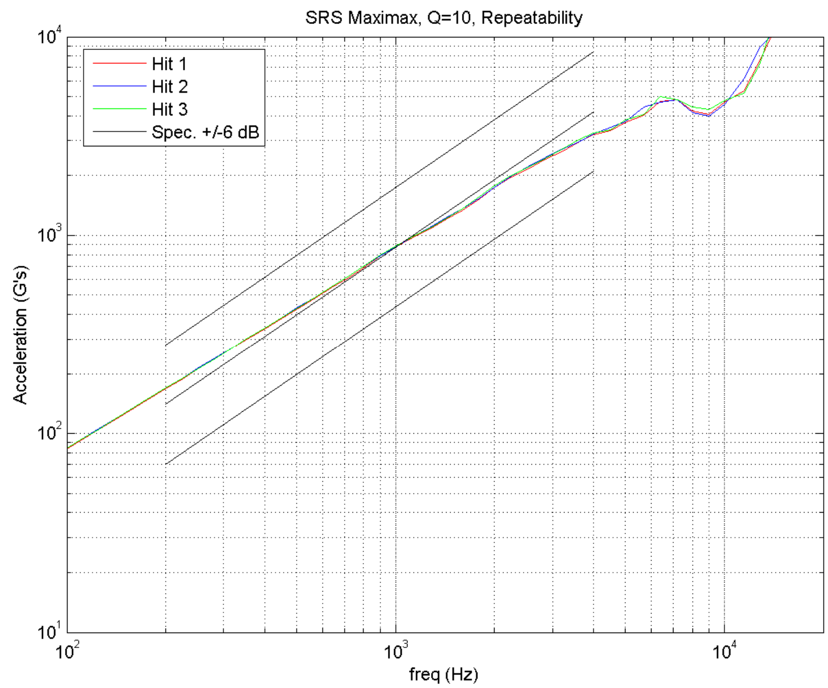

Figure 12 Example of SRS Spectra Repeatability

5 Conclusions

The pneumatic shock test system has been developed to deliver repeatable and controlled transient loads, simulating high-shock conditions to provide an effective tool for industrial shock qualification testing. Application of the system for flight qualifying spacecraft payloads has been demonstrated, with the capability to produce a repeatable SRS. The approach is cost effective, especially when compared to pyrotechnic testing, and achievable levels are much higher than traditional drop testing techniques. Testing time is reduced due to rapid turn around time between shock events. Mounting blocks provide spacecraft integrators, or other users, with a standard SRS platform for payload testing. Shock isolation systems have been developed and refined with this system, directed at attenuating high-level, high-frequency loads associated with typical conditions such as launch vehicle fairing and stage separation events.

ACKNOWLEDGEMENTS

Thanks to Jim Goodding for his design efforts with development of the shock gun.

REFERENCES

[1] Davie Neil T., Bateman Vesta I., *Chapter 26 Shock Testing Machines and Pyroshock Testing, Harris' Shock and Vibration Handbook, Fifth Edition. McGraw-Hill, [26.1-26.32], 2002*