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HIGH G PYROTECHNIC SHOCK SIMULATION USING METAL-TO-METAL IMPACT

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This report presents a technique for simulating high g level pyrotechnic shocks, and the results of applying the technique to obtain the MIL-STD-1540A shock spectrum with a maximum acceleration of 18,000 g at 2000 Hz.

Designing the resonant beam and plate on which the test unit is mounted, and generating a proper impulsive load on them, were the essentials of the technique. One dimensional stress wave and Euler equations were employed in the design. A metal pendulum hammer was used to generate the impulsive load.

INTRODUCTION

A given pyrotechnic shock spectrum can be obtained in an infinite number of ways, since there is no uniqueness between the shock transient and its shock spectrum. Drop table machines are often used to produce a given shock spectrum by generating a classical pulse such as a half sine. The distinct characteristics of the shock spectrum generated by this technique are a constant slope of 6 dB/octave (most of the slopes of pyrotechnic shock spectra are between 9 and 12 dB/octave) and a significant difference between the positive and negative spectra. The shock synthesis method, using an electromagnetic shaker controlled by a digital computer, can produce a shock spectrum of any shape. However, the amplitude of the spectrum is limited by the capacity of the shaker. A metal-to-metal impact technique can produce a very high g shock relatively easily. However, controllability and repeatability of the test are known to be rather poor. Without using an explosive, this technique seems to be the most promising approach in obtaining a high g shock spectrum such as that specified in MIL-STD-1540A.

In order to control the shock response spectrum, understanding the response characteristics of single-degree-of-freedom spring mass systems was a fundamental step, since the shock response spectrum is defined as the absolute maximum dynamic response of many single-degree-of-freedom spring mass systems with damping. An ideal shock transient can be modeled for a given shock spectrum. The next step was to design a beam or plate which could produce such a transient using one-dimensional wave propagation theory of the Euler equation. The final step was to develop an impulsive loading technique.

To produce the MIL-STD-1540A shock spectrum, the ideal transient should have a fundamental frequency of 2,000 Hz and highest energy at that frequency in its shock spectrum. Amplitudes of the frequencies higher than the fundamental frequency in the Fourier spectrum should be lower. To excite the fixture so that the dominant frequency matches the fundamental frequency, the duration of the impulsive loading should be approximately equal to half the duration of the fundamental frequency. Because of mathematical difficulties encountered in trying to theoretically predict the dynamic response of the beam or plated under a metal impact, the emphasis in this study was initially experimental.

DESIGN OF THE RESONANT FIXTURE

To perform the required shock tests in the three orthogonal directions, a 48 x 6 x 1-in. aluminum beam and a 17 x 10 x 3-in. aluminum plate were designed for the resonant fixtures on which the test unit was mounted and excited. A 13-pound steel block pendulum hammer was arranged to generate an impulsive load on the fixture beam or plate. Schematic setups of the two fixtures and the pendulum are shown in Figs. 1 and 2.

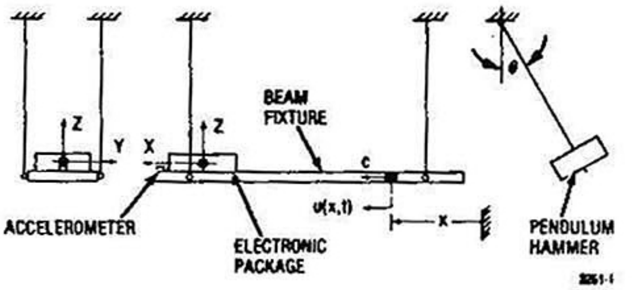

Fig. 1 – Diagrammatic Arrangement of Beam Fixture and Pendulum Hammer for Test in the X Direction

The length of the resonant beam, L, was determined from the equation.

$$L = \frac{c}{2 f_1} \tag{1}$$

where c is the speed of the dilatational wave and f_1 is the fundamental frequency. The harmonic frequencies can be calculated from the general form of Eq. (1).

$$f_n = \frac{nc}{2L}, \quad n = 1, 2, 3, \ldots \tag{2}$$

This equation is derived from the one-dimensional wave equation,

$$\frac{\partial^2 u(x,t)}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 u(x,t)}{\partial t^2} \tag{3}$$

with proper boundary conditions. The beam fixture can be used to perform in the X and Y directions by rotating the unit 90° along the Z axis.

For the test in the Z direction, the 17 x 10 x 3-in. aluminum plate was used, the design of which was based on the Euler equation.

$$\frac{\partial^2 u(x,t)}{\partial t^2} = \frac{EIg}{\gamma}\frac{\partial^4 u(x,t)}{\partial x^4} \tag{4}$$

with completely free boundary condition.

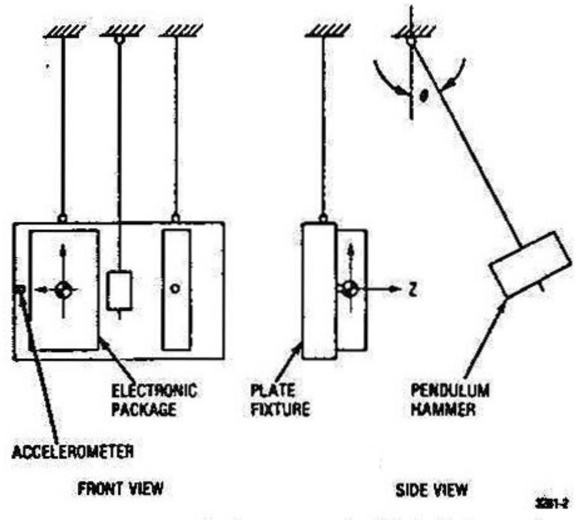

Fig. 2 – Diagrammatic Arrangement of Plate Fixture and Pendulum Hammer for Test in Z Direction

TESTS AND ANALYSIS

Shock transients were measure by the shock accelerometer, Endevco model 2292, with the shock amplifier, Endevco model 2740B, and analyzed with a Time/Data Digital Computer. A diagrammatic arrangement of the instrumentation is shown in Fig. 3. Three tests in each axis were conducted after calibrating the setup with a mockup unit.

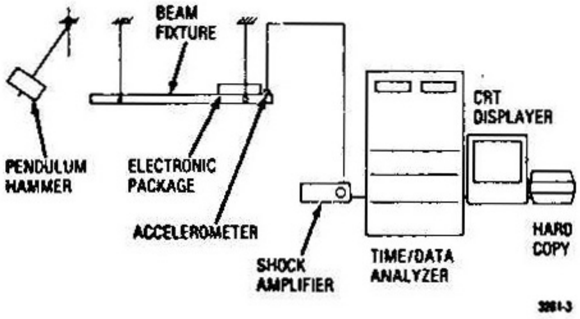

Fig. 3 – Diagrammatic Arrangement of Instrumentation

A typical acceleration measurement in the X direction and its shock and Fourier spectra are shown in Figs. 4, 5, and 6. The fundamental frequency of 2017 Hz with is harmonic frequencies of 4065, 6050, and 8010 Hz were measured in Fig. 5. These frequencies, which were predicted with Eq. (2) to be 2068, 4136, 6025 and 6272 Hz, are important characteristics of the beam that can only be changed by altering its length.

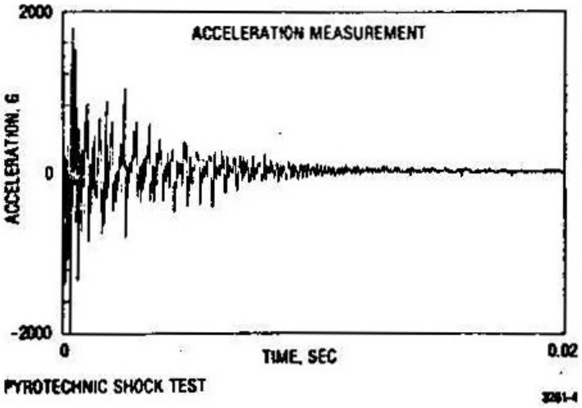

Fig. 4 – Shock Transient Measured in X Direction

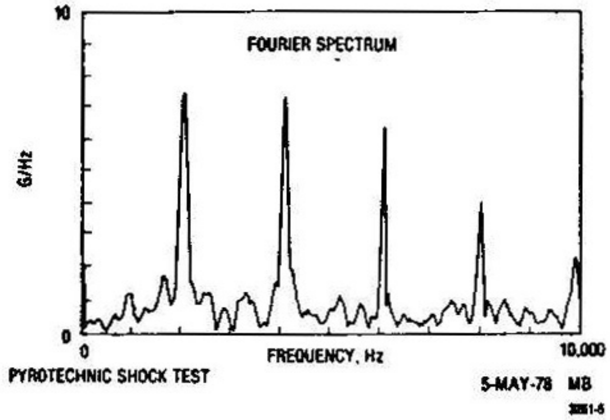

Fig. 5 – Fourier Amplitude Spectrum of Shock Transient Measured in X Direction

The shape of the shock spectrum can be predicted from the Fourier spectrum of the shock transient. The relative amplitudes of the frequencies in the Fourier spectrum can be effectively adjusted by placing a small aluminum block at the impact area, thus changing the impact loading duration. Wideband noise in the shock transients was generated by the test unit, especially during tests in the Z direction. The level of noise was considerably reduced by increasing the thickness of the fixture plate.

Test results in the X, Y and Z directions are shown in Figs. 7, 8 and 9. Seventy-two percent of the data points were in the tolerance bands of +6dB from 100 to 5000 Hz, +9 dB from 5,000 to 10,000 Hz, and –3 dB from 100 to 10,000 Hz. These results shown more over-tolerance points than under-tolerance points, as was intended, although it was not planned to over-test that much, especially in the low frequency range (83% of the data points were within the tolerance bands with the mockup unit). It is believed that the differences in the two units caused the variation in the results.

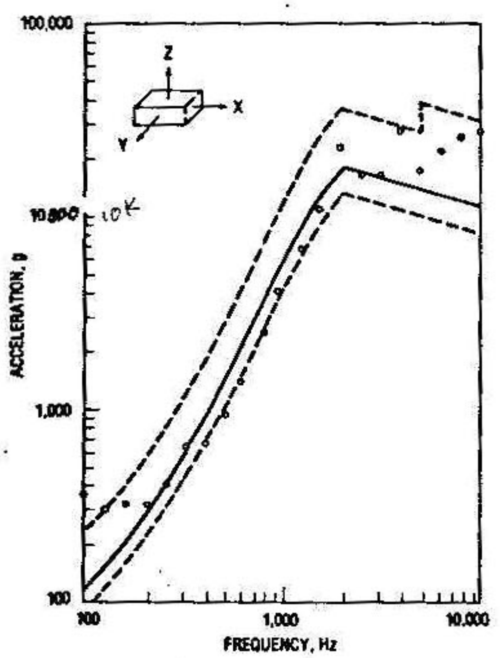

Fig. 6 - Shock Response Spectrum of Shock Transient Measured in X Direction

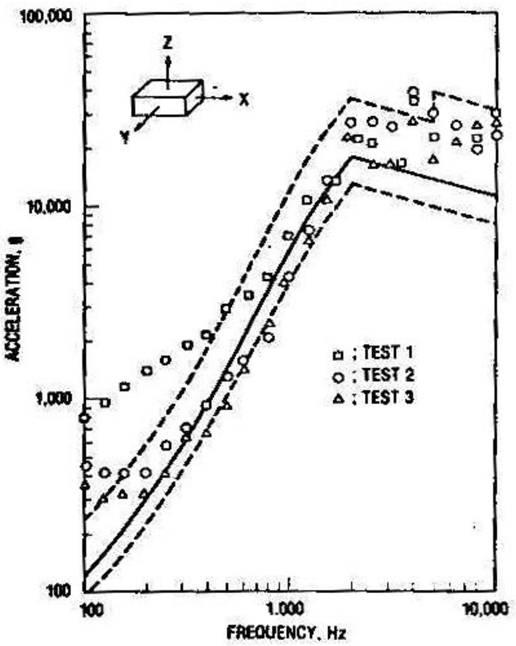

Fig. 7 - Shock Response Spectra of Tests in X Direction

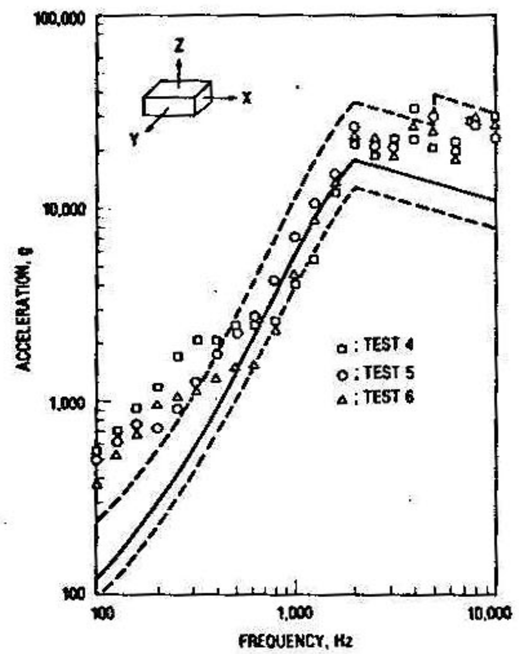

Fig. 8 - Shock Response Spectra of Tests in Y Direction

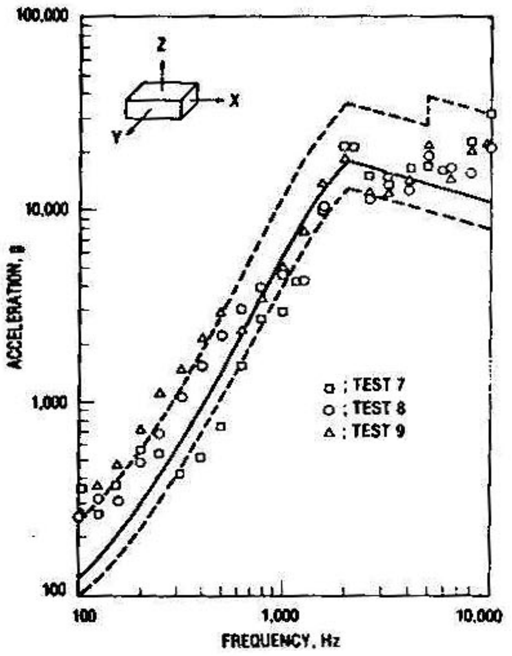

Fig. 9 - Shock Response Spectra of Tests in Z Direction

DISCUSSION AND RECOMMENDATIONS

The capability for high g pyrotechnic shock simulation tests was demonstrated using the metal-to-metal impact technique and a Time/Data Analyzer. This was done by performing the required pyrotechnic shock tests on a real unit according to MIL-STD-1540A, with a maximum acceleration of 18,000 g at 2,000 Hz. Designing the resonant fixtures and generating an optimum impulsive load on them were the essentials of the technique. It was relatively easy to obtain high g's of around 20,000 g in the shock spectrum. However, it was difficult to improve controllability and repeatability of the tests because of the nature of the metal impact and wideband noise generated by the test unit.

Seventy-two percent of the data points were within tolerance bands while 7% of the data points were shown to be under the tolerance bands. These results form the real unit were considerably different from the shock spectrum obtained with a mockup unit (83% of the data points were within the bands). It is believed that the cables and connectors attached to the actual unit, but not to the mockup unit, as well as elongation of the mounting holes on the mockup unit, were the main parameters contributing to the difference in the results from the two units.

Wideband noise in the shock transients was generated by the test unit, especially during tests in the Z direction. In this experimental study, a low level of noise appeared to help bring the spectrum level up about 2,000 Hz. This undesirable noise was minimized by increasing the thickness of the fixture plate and decreasing the contact area of the unit on the fixture. It is generally true that reducing the contact area reduces the shock level transmitted to the unit. Further improvement of the setup for generating an optimum impulsive load should be made. The pendulum hammer can be replaced by an air gun. A proper arrangement of the air gun, with an accurate pressure gage and a device detecting the projectile impact velocity, will eliminate alignment problems and improve the test repeatability.

A dynamic strain gage can be used to find the impulsive load. Therefore, the air gun arrangement and dynamic strain gage instrumentation are highly recommended for systematic and effective operation of pyrotechnic shock simulation tests.