SUB '86

The Controlled Response of Resonating Fixtures Used to Simulate Pyroshock Environments

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ABSTRACT

This paper describes the test techniques used at Sandia National Laboratories for simulating pyrotechnic shock on components. It is a "Resonating Fixture" approach, sometimes known as a hammer test. This paper brings together information that is available separately in the literature, and adds details, not previously published, which should enable the reader to reproduce these techniques for their own use.

When working with some pyrotechnic device, or some other impulsive stimuli on a real structure, (Fig. 1), experience indicates that somewhere near that pyrotechnic device, very high g levels; perhaps greater than 100,000 g's, and very high frequencies, perhaps greater than 50-100 kHz, exist. In this region (Region I, Fig. 1), the shock is best described in terms of stress wave propagation as opposed to structural response. I describe this region as the "material response to the stimuli." In most structures, somewhere remote to the pyrotechnic device, g levels tend to be lower, typically less than 20,000 g's, and dominant frequencies are also lower. Those dominant frequencies are on the order of 1,000-10,000 Hz. The response of the structure in this region (Region II, Figure 1) is dominated by the structural response of the entire structure. Most of the pyrotechnic shock environments encountered at Sandia are of the Region II type. This Region II environment can be adequately simulated with mechanical impact test techniques; a number of these mechanical impact techniques are described in the literature.

Figure 2 shows design philosophies for some of these impact test techniques. In Figure 2a, the test component is attached to the actual structure it will be used in. The test structure is struck in a trial and error fashion until a response which satisfies the test requirement is obtained.

Another test technique (Figure 2b) also uses a trial and error method of determining the response at the test item. Instead of using the actual structure which may be very complex, a test fixture of a simpler geometry, such as a plate fixture, is used.

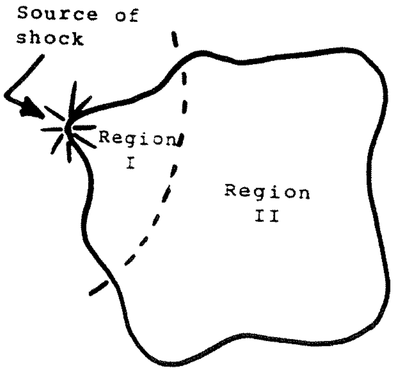

Figure 1. Two distinct regions of pyrotechnic shock.

Sandia has many different test items with various shock spectrum requirements, as opposed to a production agency that might have only a few test items with the same requirement. We must have a test technique where we can easily develop a variety of shock spectra without an elaborate effort to design a very specific test apparatus. Figure 2c shows how this is done. We have a test fixture to which we mount the test item. That test fixture is struck with either a pendulum hammer or an airgun-fired projectile. That test fixture is analytically designed so the response of the test fixture and the test item are know prior to performing the actual test.

The fixture response is some function of the test item material and geometry, the test fixture material and geometry, the impact forcing function, and its location and direction. This could be a very complex analysis, but fortunately the analysis can be simplified in several ways. First, a simple test fixture, e.g., a beam, thick plate, or bar fixture whose modes are simple and a known function of geometry can be selected. Second, the fixture can be made relatively stiff and massive so its response is essentially independent of the test item to which it is mounted. Thus, the test item can be neglected and the solution to the analysis decoupled. Experience indicates we can assume that the impact is approximately a half sine pulse with variable amplitude and duration.

The two fixtures selected for this purpose are a bending plate fixture and a longitudinally resonant bar fixture, hereafter referred to as a Hopkinson bar. The bending plate fixture is a square plate whose dimensions are L by L by thickness T (Fig. 3). It is struck on the center of one side, and the component is mounted on the opposite face in the center of the plate. The first bending mode of the plate is the one which we attempt to use. This is approximately given by equation 1.[2] For this case, the component, as shown in Figure 3, is located at an anti-node for the first bending mode. The response we excite is perpendicular to the base of the component for this configuration.

The Hopkinson bar, (Fig. 4), is utilized in a similar manner, but impact occurs on one of its ends, thus exciting that fixture into its longitudinal modes of vibration. Those modes are calculated from the one-dimensional wave equation. The result is given by equation 2.[3] In the configuration illustrated, the input to the test item would be tranverse to the base.

The method of using the first modes of a plate fixture or a Hopkinson bar to simulate pyrotechnic shock was first proposed by Bai and Thatcher.[1] In their paper, they selected a pair of fixtures, a bending plate fixture and a Hopkinson bar fixture, which have the same first modes. They tested the component perpendicular to its mounting direction on the bending plate fixture and the two transverse directions on the Hopkinson bar fixture.

These fixtures are designed in a simple way, so that their structural mode(s) match the frequency content of a given test specification (i.e., shock spetrum). Figure 5 shows a normalized log-log shock spectrum of a single degree-of-freedom, damped linear oscillator; while not exactly drawn, the character is shown. If the first mode of one of these fixtures is excited, the resultant shock spectrum would resemble that in Figure 5, and the time history would resemble the inset drawing.

A shock spectrum from an actual pyrotechnic shock is shown in Figure 6. The shock spectrum from a single degree-of-freedom oscillator can be overlayed in such a manner as engineering judgment

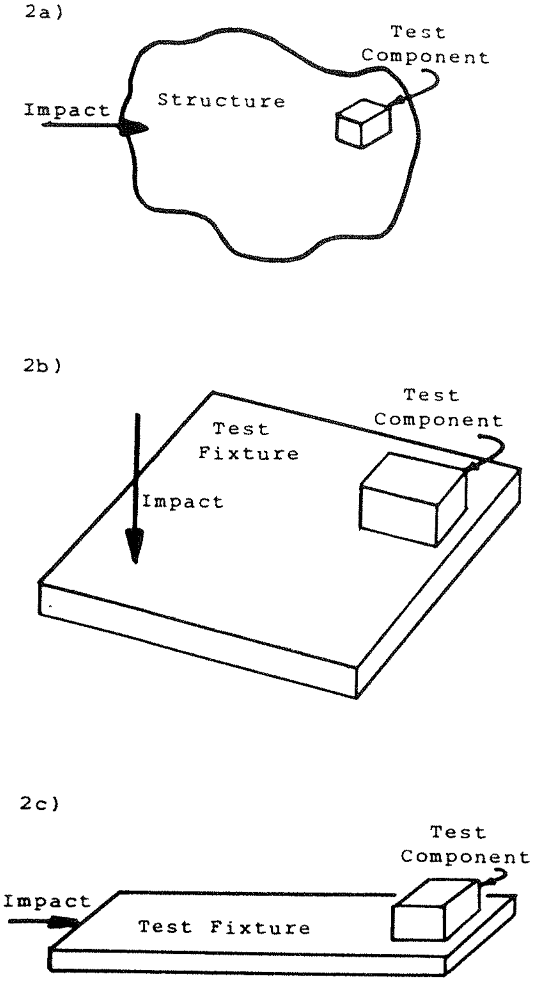

Figure 2. Test design philosophies.

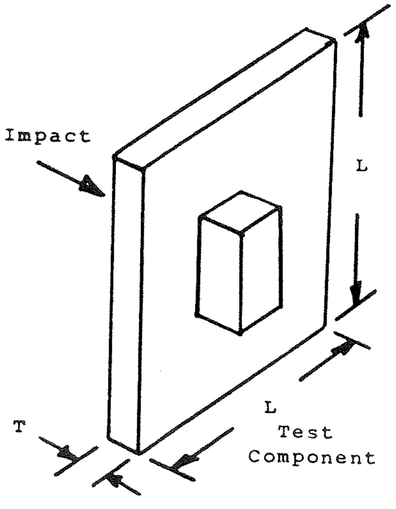

Figure 3. Bending plate fixture.

would dictate to be the best envelope. Figure 7 illustrates this envelope. It turns out that a fixture resonance of about 2,000 Hz with a peak acceleration of about 2000 g's is needed to simulate this particular environment.

$$f_1 \simeq 22.4\sqrt{\frac{ET^2}{12L^4\rho}}$$

where E = modulus of Elasticity

ρ = density

T = plate thickness

L = plate length and width

Equation 1

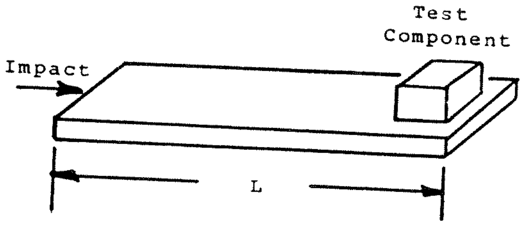

Figure 4. Hopkinson bar fixture.

$$f_n = \frac{nc}{2L}$$

where $n = 1, 2, 3...$

c = wave speed in bar

L = bar length

Equation 2

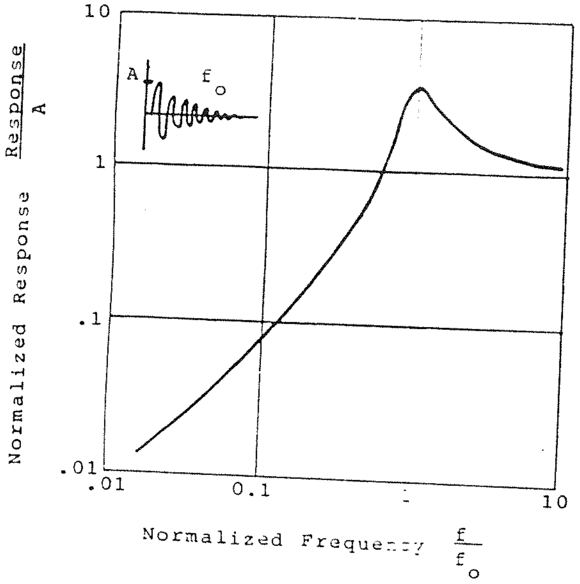

Figure 5. Normalized shock spectrum of a damped linear oscillator.

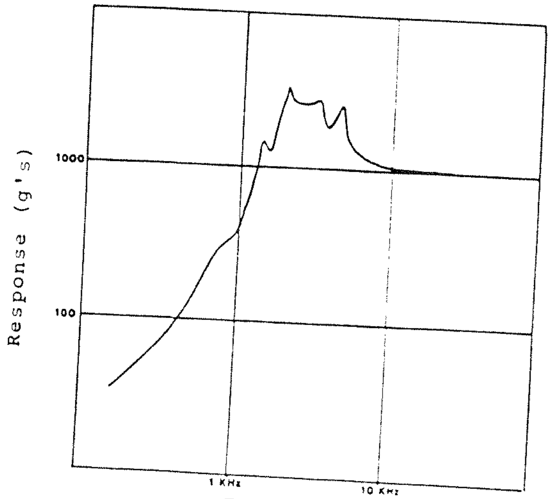

Figure 6. Shock spectrum of actual pyrotechnic shock.

The first modes of these fixtures are used since the response shock spectrum is approximately known. The dimensions of these fixtures are designed so their first modes correspond with the peak on the shock spectrum. This method applies to a somewhat limited class of pyrotechnic shock environments that have a shape similar to that one-dimensional decayed oscillator. Most actual environments seen at Sandia Laboratories fit that shape very well. Once the fixture geometries are selected and their sizes determined, their modes of vibration are fixed. We then impact the fixture in order to excite the first mode. This is done by controlling the amplitude and duration of the input pulse which is applied by a hammer or projectile. For example, a beam with a first mode of 1,000 hz, requires an input pulse duration of about one millisecond. The amplitude of

that pulse is simply varied by increasing or decreasing the impact velocity; the duration is controlled by various shock programmers. Sometimes an elastic programmer (Figure 8) is used, which consists of a piece of Delrin plastic and a piece of felt. This is typically for plates with a low natural frequency (<1000 Hz). For higher frequencies, a metal-to-metal impact is used. In these cases, the programming material is usually a piece of aluminum. The aluminum is indented with a projectile or hammer which has either a spherical or conical nose. The duration is varied by changing the spherical radius or cone angle. For example, if the cone is made sharper, the impact duration would be longer. With only minimal trial and error, the impact duration can be lengthened or shortened so that the first mode of the plate or a beam fixture is excited.

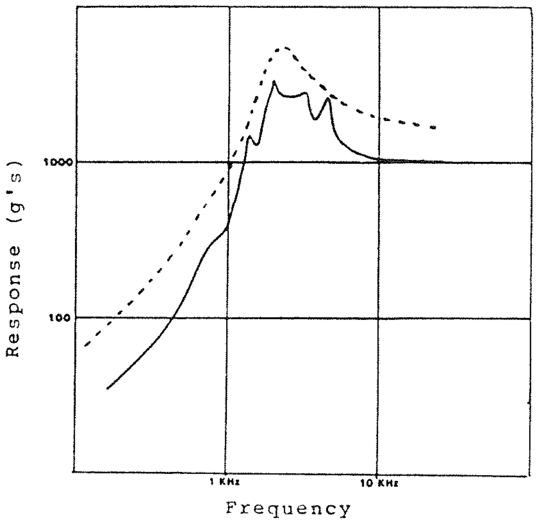

Figure 7. Previous shock spectrum showing envelope.

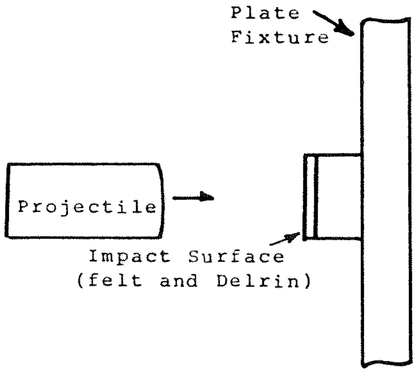

Figure 8. Detail of typcial impact surface.

Fixture damping is another parameter which needs control. These structures are fairly uniform, continuous media, hence they have very little damping of themselves. A component mounted to that structure increases the mechanical damping, however, these fixtures still resonate for hundreds of milliseconds. This is not desirable because the actual pyrotechnic shock environment typically lasts less than 20 milliseconds. These fixtures can be mechanically dampened by clamping various bar or plate materials to the fixture itself. These bars tend to lower the first mode of the fixture by not more than 20%, which is usually acceptable. This simplifies the analysis since the damping clamps do not have to be accounted for when calculating the first mode frequency of the fixture. For example, a damping arrangement on the bending plate fixture as shown in Figure 9 is a square aluminum bar clamped to two edges of the plate with C-clamps or bolts. The same thing can be done for the Hopkinson bar by clamping a small plate stock on its impact end (Figure 10). The small x's indicate the presence of either a bolt or a C-clamp attachment point. The damping may be increased (or decreased) by using more (or fewer) clamps. The maximum number of clamps needed does not greatly affect the calculated first mode of the structure.

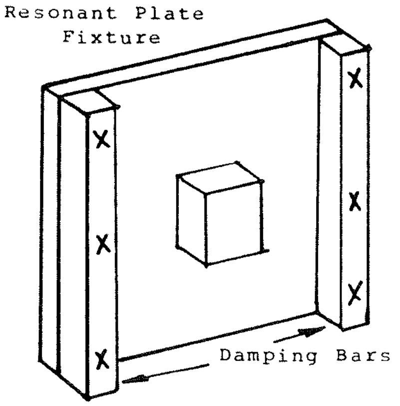

Figure 9. Damping bars added to bending plate fixture.

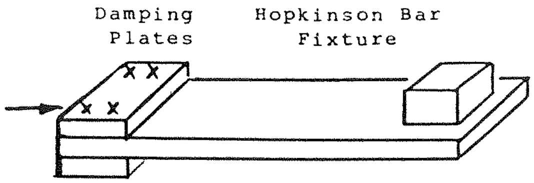

Figure 10. Damping plates added to Hopkinson bar fixture.

Controlling the response of the Hopkinson bar fixture with these damping clamps is the subject of a paper presented by the author at the 1985 IES Annual Technical Meeting.[4] The basic result of that paper states "Masses clamped at the nodes of the ith mode cause the response to be dominated by that ith mode." For example, the nodes for the second mode of the Hopkinson bar occur at L/4 from each end. Figure 11 shows a pair of masses (plates) clamped at the nodes of mode 2 for a Hopkinson bar. If that plate is impacted longitudinally with the appropriate duration pulse, the fixture can be excited into its second mode response. The Hopkinson bar used consisted of a two-inch by ten-inch by eight-foot long aluminum bar which was the basic test fixture. Figure 12 illustrates the shock spectrum of such an arrangement. The first mode of that fixture is 1,000 Hz. Note that the 2,000 Hz second mode is dominant and the first mode is suppressed and shifted to about 800 Hz. With this method, the 1st, 2nd, or 3rd mode of this Hopkinson bar can be selectively excited. At higher modes the nodal spacing becomes closer and there is a tendency to overlap different nodes with the clamps placed on the bar.

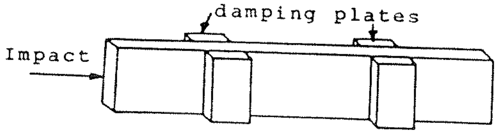

Figure 11. Damping plates positioned on a Hopkinson bar, so that the second mode is dominant.

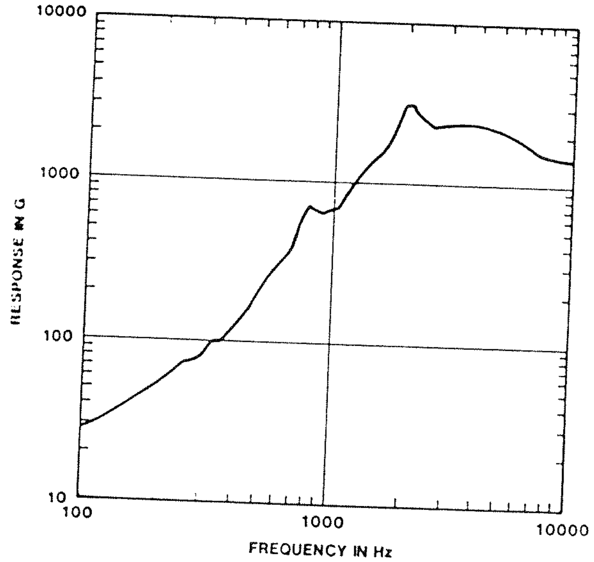

Figure 12. Shock spectrum showing a dominant mode 2 response.

The techniques described provide a very practical means of simulating pyrotechnic shock of the structural response type (Region II of Fig. 1). These techniques eliminate most of the trial and error required by other test methods.

REFERENCES

1. Bai, Monty, and Thatcher, Wesley, "High G Pyrotechnic Shock Simulation Using Metal-To-Metal Impact," Shock and Vibration Bulletin No. 49, Part I, S.V.I.C., September, 1979.

2. Thompson, William, "Theory of Vibration with Applications," Prentice Hall Inc., Englewood, NJ, 1972.

3. Kolsky, H., "Stress Waves in Solids," Dover Publications Inc., 1963.

4. Davie, Neil T., "Pyrotechnic Shock Simulation Using the Controlled Response of a Resonating Bar Fixture," 1985 Proceedings of the Institute of Environmental Sciences 31st Annual Technical Meeting, 1985.

APPENDIX

Transcript of discussion following presentation of this paper at the 56th Shock and Vibration Symposium.

Mr. Safford (Agabian Associates): About 1971 or 1972, Pat O'Neil and Chuck Tierman or TRW did some hammer-type impact tests on long bars where they hung weights that were gasketed with an elasto-plastic material. They were looking to attenuate the shock front. They did a lot of very nice work. It might be applicable. It is published material and easily accessibile. It is a nice little article; it might help you.

Mr. Galef (TRW): It looks like you are hitting that free-free plate with a rather good sized mass going at a rather good speed. You are also exciting the rigid body mode in addition the the first mode that you want to excite. I believe you are applying a test which is quite unrealistic in comparison to pyrotechnic shocks. You will have much more energy than you want at the low frequencies unless you somehow restrain that plate.

Mr. Davie: It turns out that the velocity change of the plate, which is very massive, is very small. The hammer may be large by what your experience indicates, but the velocity change of the plate due to the impulse is fairly small. You can see that by looking at the shock spectrum that we have generated from these techniques. The velocity change is usually well under ten feet per second, perhaps even less. It is true the velocity change might be higher than what you would see in an actual pyrotechnic shock environment; however, as far as the shock spectrm is concerned, if you had an undesirably high velocity change, that would be indicated in the shock spectrum, and that is not the case.

Mr. Powers: I really appreciate Neil's idea of defining two distinctive areas. I think many people do not realize that there really are two distinctive areas in pyrotechnic shock. When you are very near the source, we make comments like, "The shock response spectrum in all three axes is approximately equal." We also have to realize about the comment about three accelerometers that what we are looking at are all mounted on a little one-inch block. However, as you travel further away from this Zone 1, the basic structure is no longer excited primarily due to the speed of sound, or through the longitudinal modes of the structure. It is excited more in the classical modes of vibration and dynamics. As I said earlier today, if you go away from a source, I don't really think it would make much difference what you hit the aft end with. By the time you are far from the source, if you monitor on a telemetry rack, it will resonate at its own natural frequency.