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ACCELEROMETER ISOLATOR

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ACCELEROMETER ISOLATOR*

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ABSTRACT

A mechanical clipper for isolating accelerometers from unwanted high-frequency, high-amplitude inputs in effects tests at the Nevada Test Site has been successfully designed and tested. The clipper, which behaves as an elastic, plastic acceleration input limiter, is mounted between the accelerometer and the surface whose acceleration is to be measured. The clipper is designed to allow predetermination of the maximum acceleration amplitude to which the accelerometers will respond. In addition, it significantly reduces ringing of the accelerometers.

INTRODUCTION

Tests to verify experimentally predicted responses of various weapon components to impulsive loading produced by x-ray deposition are performed during effects shots at the Nevada Test Site and by simulation techniques. We desire to use accelerometers for measuring such responses, although many previous attempts have been unsuccessful.

Impulsive loadings produce low-amplitude, high-frequency pressure pulses. Although the magnitude of the displacements resulting from the pressure pulses may be relatively small, the change in displacement rate of rise can be extremely high and can induce large accelerations. During high rates of rise, accelerometer behavior is characterized by ringing at amplitudes that often exceed the recording bandwidth, thus making data retrieval difficult. Some accelerometers have been permanently damaged during testing. In a shock environment it is difficult to determine whether ringing is caused by acceleration or by accelerometer response as a vibrometer.

Accelerations of interest for the design discussed here are on the order of 300 g with a frequency of approximately 300 Hz. This is a relatively low-frequency, low-amplitude excitation when compared to 10-kHz (or greater) natural frequency and 3,000-g (or greater) amplitude capability of the accelerometers used. A small mass accelerometer with high response was chosen to minimize transducer effects on structural response.

With the accelerometer shock isolator, we are able to

- Define the maximum recording amplitude
- Protect the transducer from mechanical damage
- Reduce accelerometer ringing

In this report we describe a shock isolator that behaves as a mechanical clipper and that enables us to record meaningful acceleration in effects and simulation tests.

Recent simulation tests indicate that some applications for the isolator may involve multiple pulse excitation. The design of the device is based on a single excitation pulse and was tested for this mode of operation. Clearly, for closely spaced (in time) multiple pulses the clipper could be continually driven to its clipping level and thereby invalidate the data. For the remainder of this report, however, we assume that only a single pulse is involved.

ISOLATOR DESIGN

A mechanical clipper for limiting accelerations experienced by an accelerometer requires a mechanical element that limits force. The idealized characteristics of such an element are shown in Fig. 1.

Fig. 1. Rigid, perfectly plastic ideal force-displacement characteristics for isolator.

different from the natural frequency of the accelerometer. The new (or isolator) natural frequency can theoretically be designed to be either above or below the natural frequency of the accelerometer. However, it should be several times the frequency to be measured so that effective digital filtering of the data may be applied later in order to remove the natural frequency introduced by the isolator.

Because the isolator introduces its own natural frequency, isolation of the accelerometer may be considered to be partly a result of a frequency filter formed by the elastic response. Even though this probably does account for a small part of the effectiveness of the isolator, amplitude clipping is the major effect involved.

Because a rigid, perfectly plastic system does not exist, we had to use the imperfect, elastic, perfectly plastic model shown in Fig. 2. By placing the mechanical element (Fig. 3), with force limiting characteristics between the accelerometer and the surface whose acceleration is to be measured, the maximum acceleration transmitted is determined by dividing the force (Fig. 2) by the mass of the mounted accelerometer.

The spring constant, represented by the elastic portion of the force limiting characteristic (Fig. 2), and the mass of the accelerometer, including its mounting atop the isolator, introduce a new natural frequency,

Fig. 2. Force-displacement characteristic for isolator.

Fig. 3. Accelerometer and isolator assembly.

An inverted tube energy absorber¹ was designed to serve as the isolator element. Since in many cases, the high-frequency excitation is in the form of wave motion, an additional reason for choosing the inverted tube is that it provides a long and rather tortuous path for waves attempting to enter the accelerometer. Significant dissipation would be expected both because of the path length and because of two-dimensional effects. The absorber is basically an element, which, in deforming, transmits a constant axial force (once sufficient force is achieved to begin the deformation). The absorber and its mounting structure are shown in Fig. 3. Although the tube is designed for deformation in either direction, its behavior is more predictable when the gap between the base and the accelerometer mount is closed. Normally, accelerometers can be located so that the maximum shock pulse that reaches the isolator (and causes deflection) will cause the gap to close.

The tube design parameters were selected to limit accelerations to approximately 1,000 g. The dominant vibration mode in the isolator design is in bending, with a natural frequency of approximately 3 kHz.

We selected 1100-0 aluminum because of its low yield strength and reasonably high modulus so that the cross section of the tube could be maximized, thus making the elastic spring constant as high as possible and permitting ease of fabrication. The tubes were made in a spinning operation and then annealed.

TESTING

The performance of the design was examined using three tests. One test consisted of mounting the isolator-accelerometer assembly on the end of a cantilever beam (Fig. 4) and exciting the beam by dropping a hardened steel ball on the beam opposite the isolator. The second test consisted of a frequency sweep, from 20 Hz to 10 kHz, on a shaker. Finally, an acceleration pulse test was applied by using a ball drop with a pulse shaper between the ball and the specimen. A reference accelerometer was used to compare the pulse shape and amplitude reproduction. The pulse used (≈ 3 msec) was long enough so as not to produce overshoot in the elastic response of the isolator.

Excitation of the cantilever beam was also accomplished (in place of the ball) using a pulsed ruby laser.² The pulsed laser, while potentially introducing higher frequencies than the ball drop on the cantilever beam, did not produce the amplitude that was achieved with the ball drop and did not seem to constitute a more severe environment. For these reasons, and because of difficulty in obtaining a repeatable response, we decided to use the ball drop exclusively for exciting the cantilever beam.

To verify that the dominant isolation effect was amplitude clipping and not frequency filtering, the isolator design was duplicated, except that 6061-T6 aluminum was used for the inverted tube instead of 1100-0. Because the inversion force, i.e., isolation level, is theoretically directly proportional to the yield strength of the material, it would be expected that the isolation level might be 3 to 8 times higher in the 6061 than in the 1100 aluminum.

Fig. 4. Ball impact test.

The range of 3 to 8 was selected because a single yield strength does not apply around the whole inversion, since the material tends to work harden during the inversion process, and because of strain-rate effects. Clearly, if no change in isolation level were observed between the two tubes, the behavior of the isolator could be characterized as a frequency filter only and the unit could be replaced with a simple elastic spring.

RESULTS AND DISCUSSION

Initial comparisons between hard mounting and isolation mounting were made with the ball drop on a cantilever beam. The isolator natural frequency was approximately 3 kHz and the accelerometer natural frequency was approximately 25 kHz. A direct comparison of the accelerometer amplitude is shown in Fig. 5 for two equivalent ball drops. Note that there is nearly a 1:10 reduction in accelerometer amplitude as a result of the application of the isolator. Although ringing is still present, its amplitude is nowhere near the amplitude encountered before the isolator was applied, and the duration of violent ringing is reduced. Figure 6 is essentially the same as Fig. 5, except that the time window is larger to allow assessment of the

(a) Without isolator: 2,500 g/cm,
100 μ sec/cm

(b) With isolator: 250 g/cm,
100 μ sec/cm

Fig. 5. Accelerometer amplitude response.

(a) Without isolator

(b) With isolator

Fig. 6. Accelerometer amplitude response: 250 g/cm, 2 msec/cm.

effect of the isolator on the 250-Hz data (the low-frequency, low-amplitude data similar to that which will be measured in actual application). Note the considerable period of time that data for the hard mounted accelerometer is outside of the recording band.

After the prototype isolator was built and tested, several production models were manufactured for use in a nuclear event. Production testing consisted of (1) an initial 2-g input frequency sweep from 20 Hz to 10 kHz, (2) two acceleration pulses (produced with a ball drop calibrator and appropriate

attenuators), one nominally 80 g and the other nominally 250 g, each with a 2 to 3 ms duration, using a reference accelerometer for comparison, (3) a ball drop on cantilever beam test to determine isolation level, and (4) a final frequency sweep identical to the initial frequency sweep.

Several interesting results were discovered in this testing. Even though the design and prototype isolation levels were approximately 1,000 g, variations in manufacture caused the value to vary between 1,000 and 2,500 g, with most of the units falling between 1,400 and 2,000 g. Comparisons between the initial and final frequency sweeps for a given unit indicated some changes of the natural frequency of the isolator. These changes can be explained in two ways: (1) excess bonding material used in manufacture (Fig. 3) might cause the isolator to appear stiff until exercised, and (2) during the spinning operation, variations in thickness around the inversion could account for stiffening. To eliminate stiffening resulting from excess bonding material, extra care in the bonding process must be exercised. Assuming that the wall thickness of the inverted tube can be held to tolerance more easily than the inversion area during the spinning process, the tube can be manufactured longer than necessary then preloaded and deformed to the design height to minimize stiffness variations resulting from different wall thicknesses in the spun inversion region. In any case, the units appeared to be stabilized with respect to natural frequency after production testing.

The results of the shaped pulse tests, comparing a reference accelerometer with the isolated accelerometer, indicate that the clipping process begins at between 20 and 30% of the full clipping value. Thus, there is a nonlinear region between approximately 350 g and the nominal clipping level (1,400 g to 2,000 g) in which the measured pulse is distorted compared to the input pulse. In the application for which the isolator was designed accelerations are expected to be 300 g or less, therefore all measurements of interest can be made in the linear region. Because it is desirable to have the data of interest fall within the linear response (elastic) regime of the isolator, expected data acceleration amplitudes should be fairly well predicted for specification of a clipper design.

Upon testing the 6061 isolator and comparing it to the previous results of the 1100 isolators, the isolation level of the 6061 isolator was 2 to 5 times higher than that of the 1100. This indicates that the predominant behavior of the isolator is that of an amplitude clipper. This test does not preclude the possibility that a minor part of the isolator's effectiveness can be attributed to its effect as a frequency filter.

FOOTNOTES

*This work was performed under the auspices of the U. S. Atomic Energy Commission.

1. Alcone, J. M., "Analysis of the Inverting Tube Energy Absorber," The Shock and Vibration Bulletin, December 1970.
2. Our thanks to Arthur L. Hull of Sandia Laboratories, Livermore, for his assistance and the use of his laser equipment.