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CONF-9010172--4

EVALUATION OF UNIAXIAL AND TRIAXIAL SHOCK ISOLATION TECHNIQUES FOR A PIEZORESISTIVE ACCELEROMETER

SAND--90-1579C

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ABSTRACT

Development of both uniaxial and triaxial shock isolation techniques for pyroshock and impact tests has continued this year. The uniaxial shock isolation technique has demonstrated acceptable characteristics for a temperature range of -50°F to +186°F and a frequency bandwidth of DC to 10 kHz. The triaxial shock isolation technique has demonstrated acceptable results for a temperature range of -50°F to 70°F and a frequency bandwidth of DC to 10 kHz.

INTRODUCTION

Sandia National Laboratories (SNL) conduct impact testing for a variety of structures. Examples of these tests are presented in our previous paper on shock isolation techniques [1] and in another paper for this conference [2]. During an impact test, metal to metal contact may occur within the structure and produce high frequency, high amplitude shock inputs. The high frequency portion of this transient vibration has been observed to excite an accelerometer into resonance even though this resonance exceeds 350 kHz. An accelerometer may fail in this situation. Even if the accelerometer does not fail, the amplitude of the resonating accelerometer response can be so large that the data are clipped and rendered useless. If the data are not clipped, a digital filter must be applied to eliminate undesirable accelerometer resonant response. In anticipation of accelerometers' resonating during a test, the data channels may be set to accomodate the large amplitude of the accelerometer resonance. The result is usually an unacceptably small signal to noise ratio. If possible, it is more desirable to prevent excitation of the accelerometer resonance. This may be accomplished by mechanically isolating the accelerometer from the high frequency excitation without degrading the transducer response in the bandwidth of interest, which is 10 kHz in this study. The bandwidth of 10 kHz is needed for many applications because more sophisticated analyses are being performed with the field data [2].

The uniaxial and triaxial isolation techniques were designed and evaluated for the desired bandwidth of 10 kHz. These techniques are used with a piezoresistive accelerometer which is frequently used for field tests of various high reliability structures which must withstand severe shock environments. Piezoresistive accelerometers are used because they have several desirable characteristics: DC response, low power requirements, minimal zero shift, and high resonant frequency. One undesirable characteristic is that the piezoresisitive accelerometer is undamped. A high frequency input may cause it to resonate, and the resulting large amplitude may exceed the measuring capability of the instrumetation system. A commerical piezoelectric accelerometer with integral electronics and mechanical isolation is available but cannot be used in our application because of signal conditioning requirements.

The uniaxial isolation technique developed at SNL has proven to have superior performance over techniques used in the past to isolate accelerometers from high frequency input [1]. The uniaxial technique has been fielded in a variety of applications this year, some of which require usage at extreme temperatures of -50°F and +186°F. The uniaxial technique has been qualified at these extreme temperatures. Additional requests have been made for triaxial measurements in high shock applications. A 0.6 in. cube has been developed to meet these requirements. Results in both the time domain and the frequency domain will be presented for the two isolation techniques.

HOPKINSON BAR CONFIGURATIONS FOR CHARACTERIZATION OF SHOCK ISOLATION TECHNIQUES

Accelerometers for this study were calibrated in the SNL Calibration Laboratory using three methods: 1) shaker calibration; 2) centrifuge calibration; and 3) dropball calibration. The three methods are traceable to the National Institute of Standards and Technology, NIST, formerly NBS and are described in our previous paper on shock isolation techniques. The uniaxial isolation technique has demonstrated acceptable performance for all three calibration techniques at ambient temperature [1]. Calibrations at temperatures other than ambient can only be conducted with the shaker due to limitations of existing equipment. For shock accelerometers, it is desirable to calibrate with the dropball or with another shock producing technique such as the Hopkinson bar. The Hopkinson bar easily lends itself to temperature conditioning because the end of the bar is simply inserted into a temperature chamber. For this reason, shock calibrations for the shock isolation techniques at the temperature extremes of -50°F and +186°F were conducted with a Hopkinson bar located in the SNL Shock Laboratory. The configuration for a normal input is shown in Figure 1. Normal input in this configuration is an input that is normal to the mounting surface and is also parallel to the integral mounting stud. Both the uniaxial technique and one axis of the triaxial isolation technique are tested with the normal input. The other two axes of the triax are characterized with a transverse input created by the Hopkinson bar configuration in Figure 2. A transverse input is perpendicular to the mounting stud or parallel to the mounting surface. An in-axis response is the response of an accelerometer whose sensitive axis is in the direction of the shock. An out-of-axis response is the response of an accelerometer whose sensitive axis is <u>not</u> in the direction of the shock. The uniaxial isolation technique and one axis of the triaxial isolation technique have in-axis response for a normal input. Each of the two other orthogonal axes of the triaxial isolation technique can have in-axis response for a transverse input.

These two Hopkinson bar configurations are used to characterize the response of the isolation techniques in both the time domain as a sensitivity calculation and in the frequency domain as frequency response functions. The sensitivity calculation is described below. The sensitivity calculation is not a true calibration because our methods are not strictly NIST traceable, however the ambient results from the

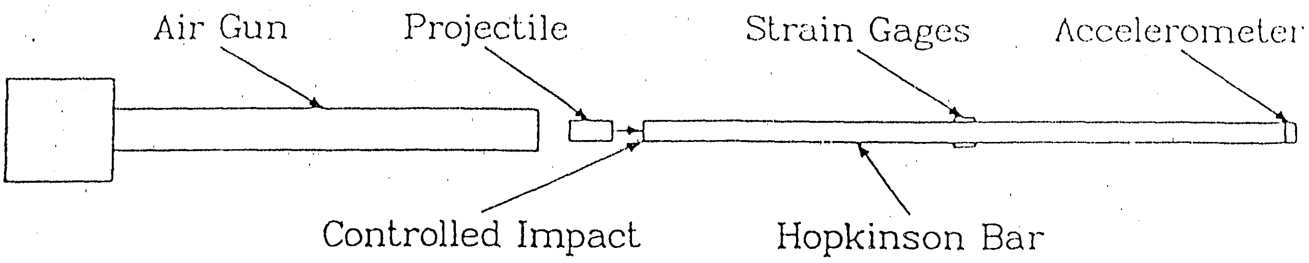


Figure 1: Hopkinson Bar Configuration for Normal Input.

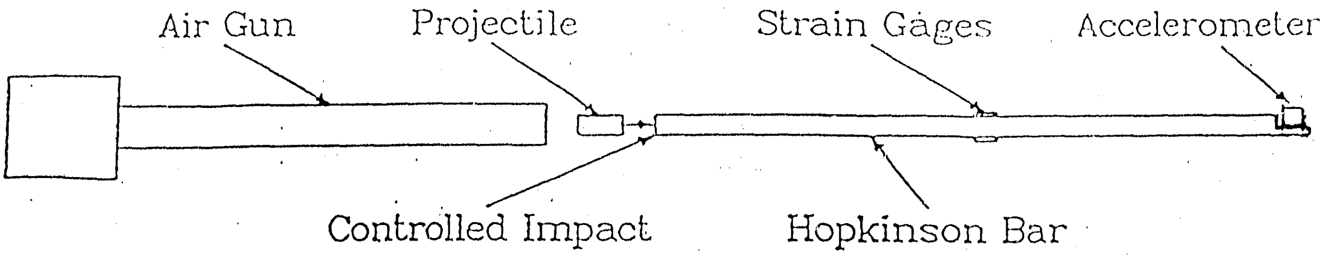


Figure 2: Hopkinson Bar Configuration for Transverse Input.

Hopkinson bar agree well with results from the Calibration Laboratory. The frequency response functions are calculated in the same manner as reported previously [1] except that an accelerometer mounted on the end of the bar is used as the reference acceleration for transverse inputs.

The theory of stress wave propagation in a Hopkinson bar is well documented in the literature [3,4]. The results of this theory are summarized as follows:

> A Hopkinson bar is defined as a perfectly elastic, homogeneous bar of constant cross-section.
>
> A stress wave will propagate in a Hopkinson bar as a one-dimensional elastic wave without attenuation or distortion if the wavelength is large relative to the diameter.
>
> For a one-dimensional wave propagating in a Hopkinson bar, the motion of a free end of the bar as a result of this wave is:

$$v = 2c\varepsilon$$

$$\text{or,} \quad a = 2c\left[\frac{d\varepsilon}{dt}\right] \tag{1}$$

where v and a are the velocity and acceleration, respectively, of the end of the bar, $c = \sqrt{E/\rho}$ is the wave propagation speed in the bar, and ε is the strain measured in the bar at a location that is not affected by reflections during the measurement interval.

The motion of an accelerometer mounted on the end of the bar will be governed by (1) if the mechanical impedance of the accelerometer is much less than that of the bar or if the thickness of the accelerometer is much less than the wavelength.

The Hopkinson bar is made of 6 Al, 4 V titanium alloy, and is 72 inches long with a 0.76 inch diameter. The bar is supported in a way that allows it to move freely in the axial direction. A low pressure air gun is used to fire a 2 inch long hardened tool steel projectile at the end of the bar. This impact creates a repeatable stress pulse which propagates toward the opposite end of the Hopkinson bar. The amplitude of the pulse is controlled by regulating the air gun pressure, which determines the impact speed. The shape (approximately a half sine) and duration of the pulse are controlled by placing various thicknesses of paper (3x5 index cards) on the impact surface. The two strain gages are located 22 inches from the impact end and are mounted at diametrically opposite positions on the bar. These gages are connected in opposite arms of a Wheatstone bridge in order to measure the net axial strain. The reference acceleration is derived from the strain gages on the bar and is unaffected by the temperature change at the end of the bar.

The selected calibration technique, using the acceleration derived from the Hopkinson bar strain measurements, can be used only to estimate the change in sensitivity due to temperature because of the uncertainties associated with the measurements. Most of the errors are deterministic and will be cancelled when the percentage sensitivity change due to the -50°F temperature is calculated in the equation [5]:

$$C = \left[\frac{A_{Ac-50}}{A_{Ac-A}} \cdot \frac{A_{Hop-A}}{A_{Hop-50}} - 1\right] \times 100 \tag{2}$$

where: C = Percentage sensitivity change at -50°F as compared to ambient,

A_{Ac-50} = Shock amplitude measured by 7270A at -50°F,

A_{Ac-A} = Shock amplitude measured by 7270A at ambient,

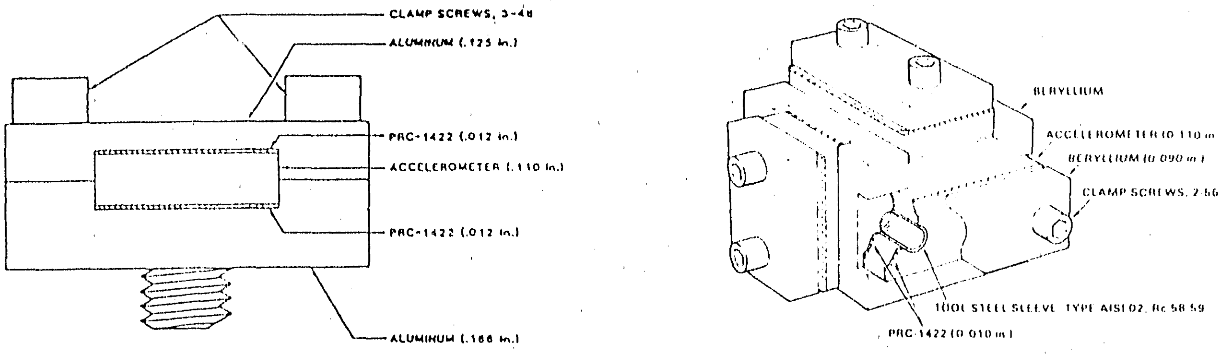
A_{Hop-A} = Shock amplitude derived from strain gages for ambient test, and

A_{Hop-50} = Shock amplitude derived from strain gages for -50°F test.

A similar equation is used for the sensitivity change at +186°F.

UNIAXIAL AND TRIAXIAL ISOLATION DESIGNS

The uniaxial and triaxial isolation techniques are shown in Figure 3. The uniaxial technique consists of an aluminum disk that has a slot for the accelerometer. The disk is divided into two halves that are held together by two screws. A layer of polysulfide rubber is positioned on each side of the accelerometer in the slot. Brass locator pins (not shown) hold the polysulfide rubber and accelerometer layers in place in the slot. A brass stud on the bottom of the disk is used to attach the disk assembly to the test structure. Shrink tubing is used on the brass pins in the disk technique to prevent metal to metal contact during lateral shocks.



a) Uniaxial Isolation Technique

b) Triaxial Isolation Technique

Figure 3: Uniaxial and Triaxial Isolation Techniques for a Piezoresistive Accelerometer.

The triaxial isolation technique, also shown in Figure 3, consists of a 0.6 in. cube of either 7075 aluminum or beryllium that has been machined with a slot on each of three orthogonal faces. The piezoresistive accelerometers are mounted in the slots with a layer of PRC-1422 on either side in the same manner as the uniaxial isolation technique. Hardened steel sleeves are covered with shrink tubing to prevent metal-to-metal contact and are pressed into the mounting holes in the accelerometer. The sleeves are 0.125 in. long and provide correct spacing between the top plate and the bottom of the slot so that a consistent compression is maintained on the elastic material, PRC-1422. The plate, accelerometer, and layers of PRC-1422 are held in place with 2-56 screws that are torqued to 60 in-oz. A mounting torque of 40 in-lbs is used for the triaxial isolation technique.

UNIAXIAL ISOLATION TECHNIQUE PERFORMANCE AT EXTREME TEMPERATURES

Twelve piezoresistive accelerometers mounted in the uniaxial isolation technique were used to assess the performance of the technique at -50°F and +186°F. Each accelerometer was subjected to five 5000 g pulses with a duration of 100 μs at each of five temperatures: ambient (70°F), -50°F, ambient, +185°F, and ambient. The accelerometers were tested at ambient after each test at a temperature extreme because the temperatures of -50°F and +186°F are beyond the manufacturer's limits for the piezoresistive accelerometer's operational range, -30°F to +150°F, so the last ambient test ensures the accelerometer is still operational after exposure to the extreme temperature environment.

The uniaxial isolation technique was characterized in the time domain with equation (2). The data from both the strain gages and the accelerometers were digitally filtered at 17 kHz prior to the sensitivity calculation. The average sensitivity change at -50°F was 6.0% or -0.05%/°F. The average sensitivity change at +185°F was -4.3% or -0.04%/°F. These results are lower than the -0.06%/°F quoted in the manufacturer's specifications.

An acceleration-to-acceleration frequency response function was calculated for the uniaxial isolation technique at the two temperature extremes and compared to the frequency response function at ambient temperature. The calculations were made in the same manner as those published previously [1], and the frequency resolution for these calculations is 244 Hz. The magnitudes of the frequency response functions are shown in Figure 4 which shows that the magnitudes at 10 kHz deviate less than 10 percent from the magnitude at low frequency for all three temperature conditions. The frequency response function phase (not shown) varies in an approximately linear manner up to 10 kHz for all three temperature conditions. The deviation in the frequency response function magnitude above 20 kHz can be explained by the coherence functions (not shown) because the coherence between the input and the output accelerations is less than one above 20 kHz. The lack of coherence creates a computational anomaly that appears as a resonance above 20 kHz but is not a mechanical resonance in the uniaxial isolation technique.

TRIAXIAL ISOLATION TECHNIQUE PERFORMANCE

The triaxial isolation technique, made with beryllium, has been characterized at both ambient and at -50°F. Two beryllium triaxes were characterized at two levels: 2500 g and 5000 g, but only the results for the 5000 g input are shown here because of space limitations. The 2500 g results are similar. Each accelerometer in each triax was subjected to five 2500 g, 70 μs pulses and to five 5000 g, 70 μs pulses at the two temperatures: ambient (70°F) and -50°F. The data from both the strain gages and the accelerometers were digitally filtered at 25 kHz prior to the calculations. Sensitivity changes were calculated for the ten pulses applied to each accelerometer and averaged. The sensitivities in the table range from -0.05 %/°F to -0.11 %/°F and are generally higher than the -0.06%/°F quoted in the Endevco specifications. At this point, the calculated sensitivity is applied to each individual accelerometer until more data can be accumulated for an average sensitivity calculation.

Frequency response function magnitudes for the triax at ambient are shown in Figure 5 for both the normal input and the transverse input. Frequency response functions for the triax at -50°F are shown in Figure 6 for both the normal input and the transverse input. Phase and coherence functions were also calculated but are not shown because of space limitations. The phase is approximately linear over the 10 kHz bandwidth, and the coherence is one until about 20 kHz which causes the large deviations in the magnitudes shown in Figures 5-6. The phase changes more for the transverse input than for the normal input over the 10 kHz bandwidth.

The triaxial isolation technique, made with 7075 aluminum, has also been tested but generally has acceptable performance over a more limited frequency bandwidth, about 4 kHz, than the beryllium. Additionally, the screws in the aluminum blocks loosen more easily, and there is more out-of-axis response for the aluminum triax. The out-of-axis response is increased in the aluminum block because it has a resonance at about the same frequency as the resonance of the 20,000 g piezoresistive

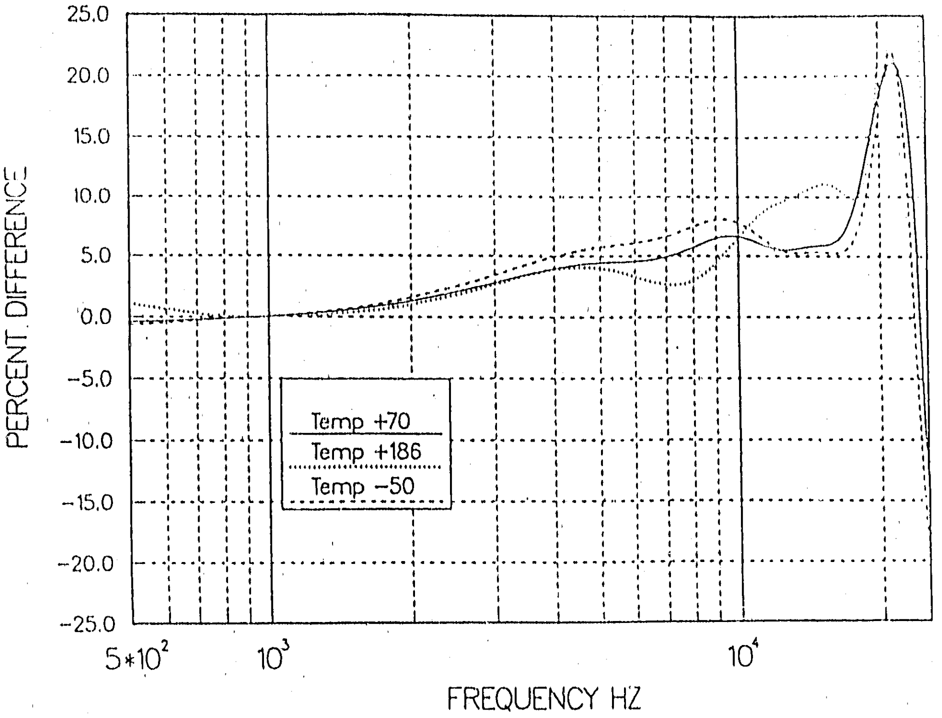
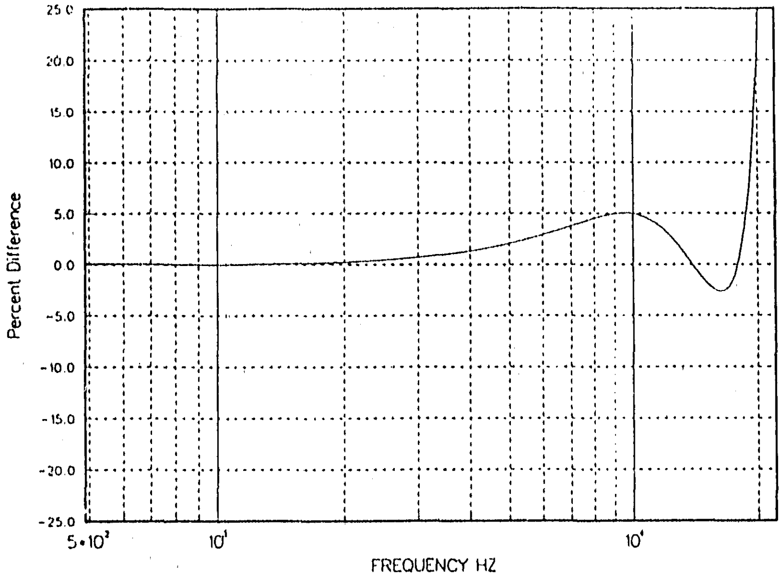


Figure 4: Frequency Response Function Magnitude for the Uniaxial Isolation Technique at -50°F, Ambient (70°F), and +185°F with a 5000 g, 100 μs Input Pulse.

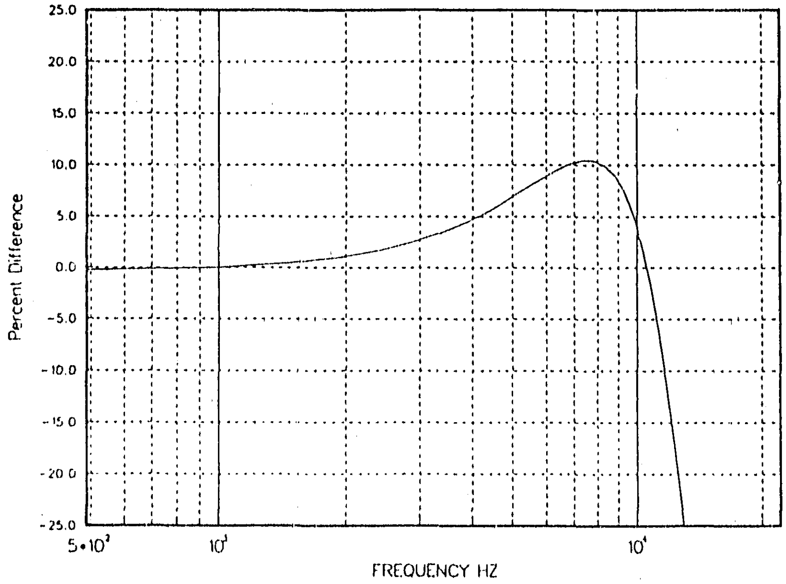
accelerometers mounted in the triax, 350 kHz. The beryllium is stiffer and less dense, so its first resonance is in excess of 400 kHz and does not excite the accelerometer's resonance.

The attachment of the triax to the bar was critical with the Hopkinson bar configuration for a transverse input. The triax was bolted to the Hopkinson bar at the lower acceleration levels, but at input acceleration levels of about 4000 g and above, the triax had to be bolted and glued to the bar. With the bolt and the glue, the triax was prevented from moving with respect to the Hopkinson bar surface during the application of the input acceleration pulse. Additionally, there was a difference in the response of the out-of-axis transverse accelerometers that seems to be dependent upon their orientation. As can be seen in Figure 3, the two transverse accelerometers are not oriented the same way; they are oriented at 90° to each other. The out-of-axis response was generally about 10% if the shock passed across the long dimension of the accelerometer. If the shock passed across the short dimension of the accelerometer, the out-of-axis response was somewhat larger (about 50%) and appeared to contain more excitation of the accelerometer's resonance.

Finally, a comparison of the Fourier transforms for a hard mounted accelerometer and one axis of the triaxial isolation technique is shown in Figure 7 for a 5000 g, 70 μs input pulse on the Hopkinson bar. Figure 7 shows that the triaxial isolation technique has attenuated the accelerometer resonance by a factor of three and, therefore, has successfully isolated the accelerometer from high frequency input.

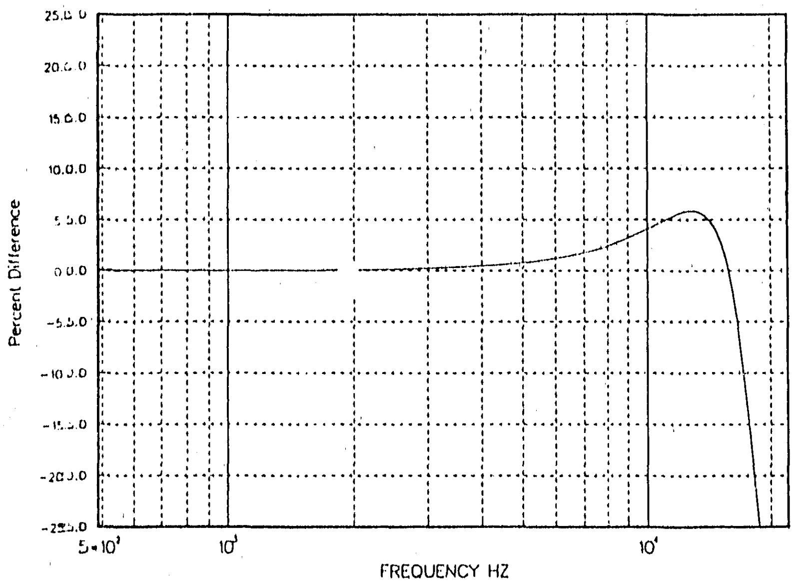


a) Normal Input

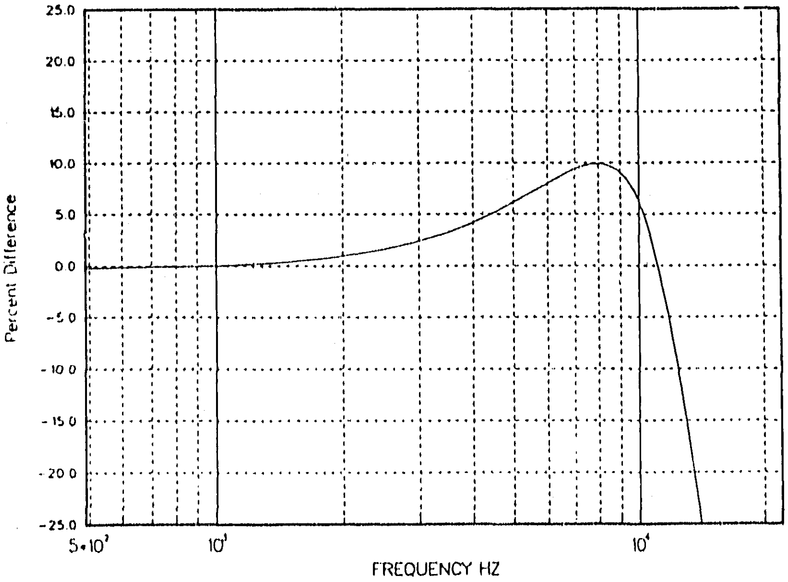


b) Transverse Input

Figure 5: Frequency Response Function Magnitude for the Triaxial Isolation Technique at Ambient (70°F) with a 5000 g, 70 μs Input Pulse.



a) Normal Input



b) Transverse Input

Figure 6: Frequency Response Function Magnitude for the Triaxial Isolation Technique at -50°F with a 5000 g, 70 μs Input Pulse.

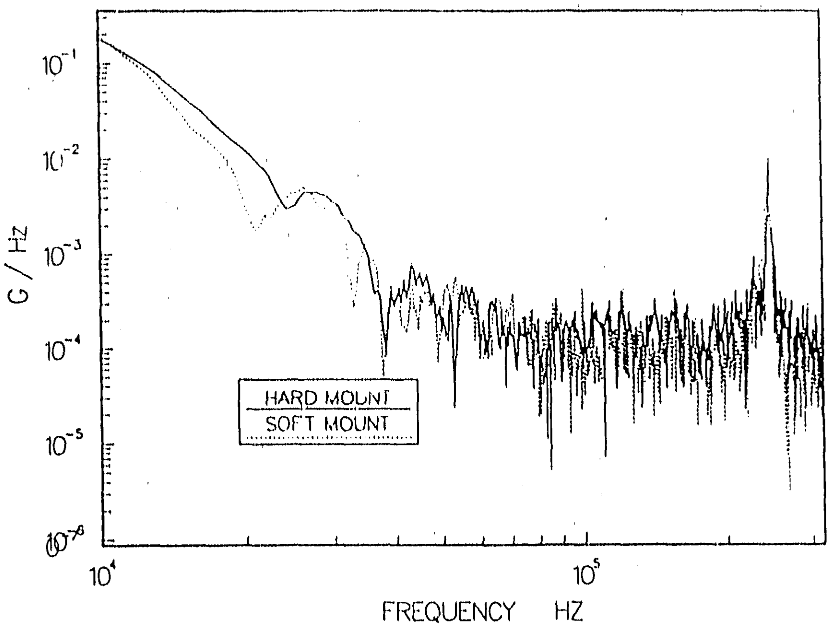


Figure 7: Comparison of Fourier Transforms for a Hard Mounted Accelerometer and One Axis of the Triaxial Isolation Technique with a 5000 g, 70 μs Pulse Input.

CONCLUSIONS AND FUTURE WORK

The uniaxial isolation technique has shown acceptable performance over a bandwidth of 10 kHz and a temperature range of -50°F to +186°F. The beryllium triax isolation technique has shown acceptable performance over a bandwidth of 10 kHz and a temperature range of -50°F to 70°F. Work on the triaxial isolation technique will continue to extend the operational temperature range. Both isolation techniques will be characterized for a higher acceleration input of 10,000 g.

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