HIGH SURVIVABILITY ACCELEROMETER FOR FUZE APPLICATIONS

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Outline

- Introduction and background
- Discussion topics will include:
  - Gas damping and mechanical stops
  - Survivability and zero shift after shock
    - Results from Hopkinson bar and simulated environment testing
  - Linearity
  - Frequency Response
  - Warm up
- Summary
- Questions

Introduction

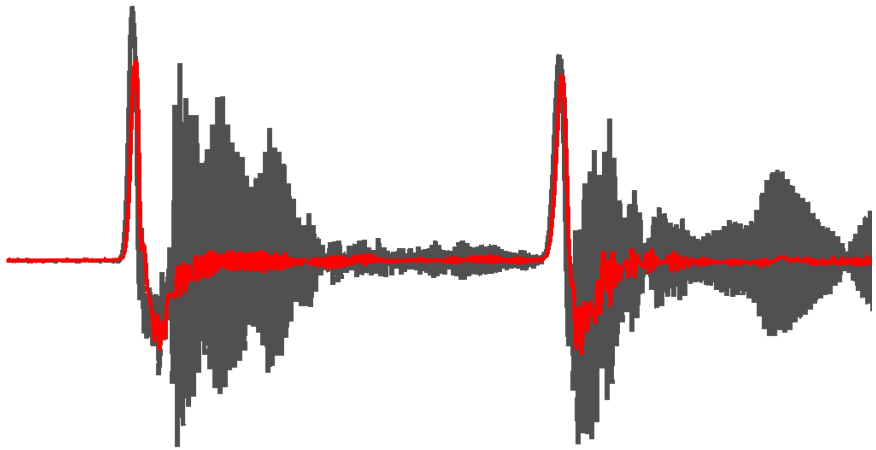
- Endevco® damped high-g shock accelerometers with extreme survivability and overrange capability
- Package configurations:
  - Surface mountable leadless chip carrier (LCC) [72]
  - Bolt mount [7280A]
  - Integral stud mount [7280AM4]
- Ranges:
  - 20,000 g & 60,000 g

Background

- Early results on the 20,000 g ranged damped accelerometer were presented at the 54th Annual Fuze Conference [1]
- Key take aways include:
  - High shock survivability of 4X full range
  - Minimum zero shift after shock
  - Light gas damping between 2 and 10 percent
  - Linearity through full range
  - Mechanical stops between 2 and 3 three times full range
  - Frequency response flat to 10 kHz
- This presentation will provide updates on topics above as well as present new test results

[1] R. Martin, G. Pender, J. Letterneau, T. Kwa, "Results from Preliminary Testing of a New Generation of High-Shock Accelerometers with Extreme Survivability Performance," Proc. 54th NDIA Fuze Conference, Kansas City, MO, May 13, 2010

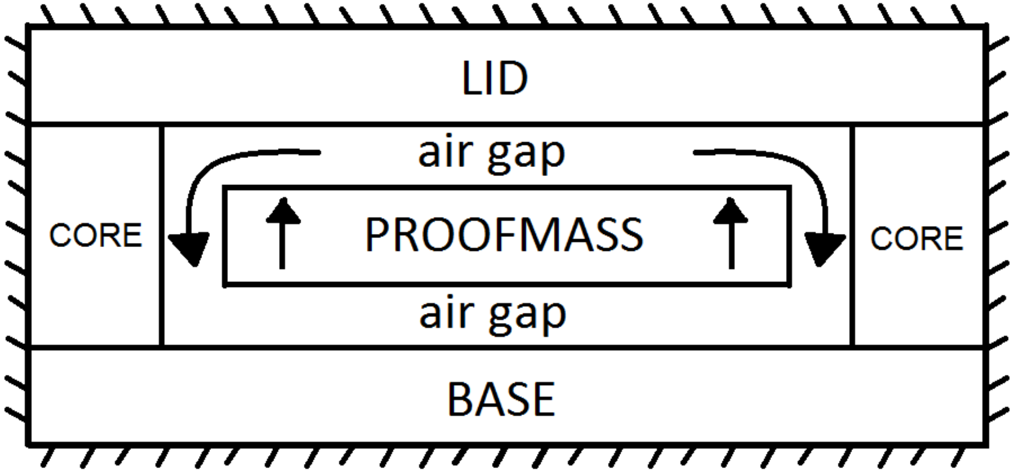
Light gas damping



- Certain high frequency environments will cause the undamped 7270A-type accelerometer to resonate
- The amplification factor at resonance can result in damage to the undamped accelerometer, especially when no stops are present
- Introducing even a small amount of damping (~5%) reduces the amplification at resonance by a factor of 10

Light gas damping continued

- Squeeze film damping is the squeezing and displacing of gas as one plate (the proof mass) approaches a second fixed plate (the lid or cover)

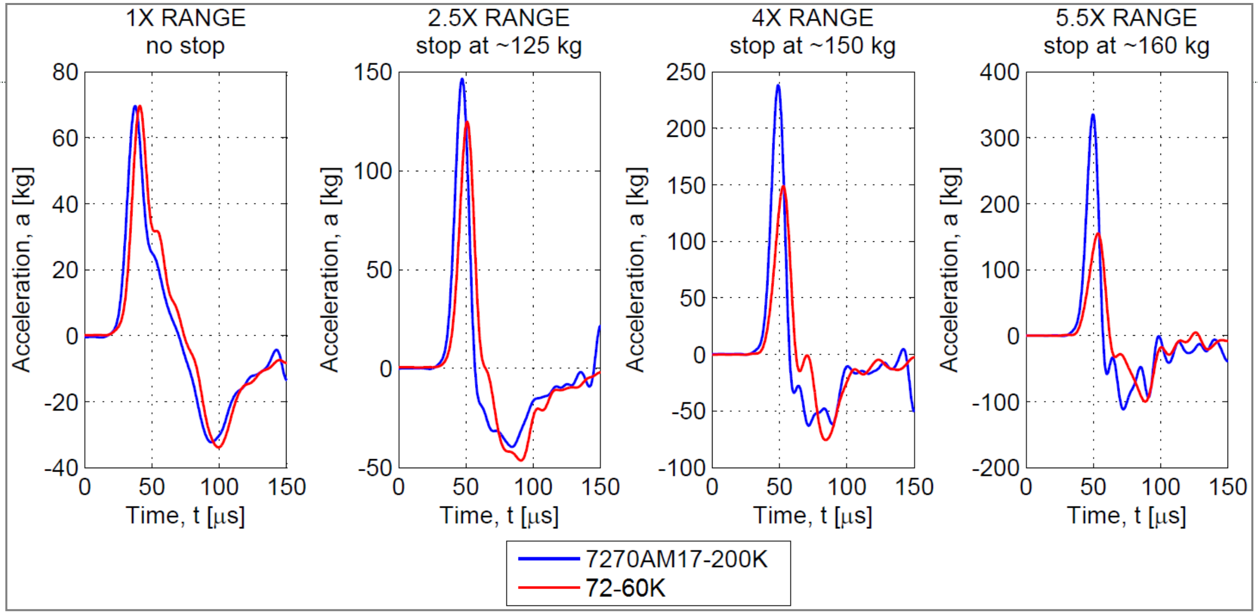


- Squeeze film damping is only effective with adequate displacement of the proof mass, requiring a softer suspension system (lower resonant frequency)
- A lower resonant frequency has implications on frequency response.

Mechanical over-travel stops

- The lid and base required for SFD also act as the mechanical over-travel stops
- Stops limit the displacement of the proof mass to safe levels in extreme shock environments
- Damping begins to affect linearity above 1.5X full range
- With a sufficiently high shock level the proof mass will eventually approach the hard physical stop as the air is displaced from the air gap
- The physical stop is set between 2X and 3X full range

Mechanical over-travel stops continued



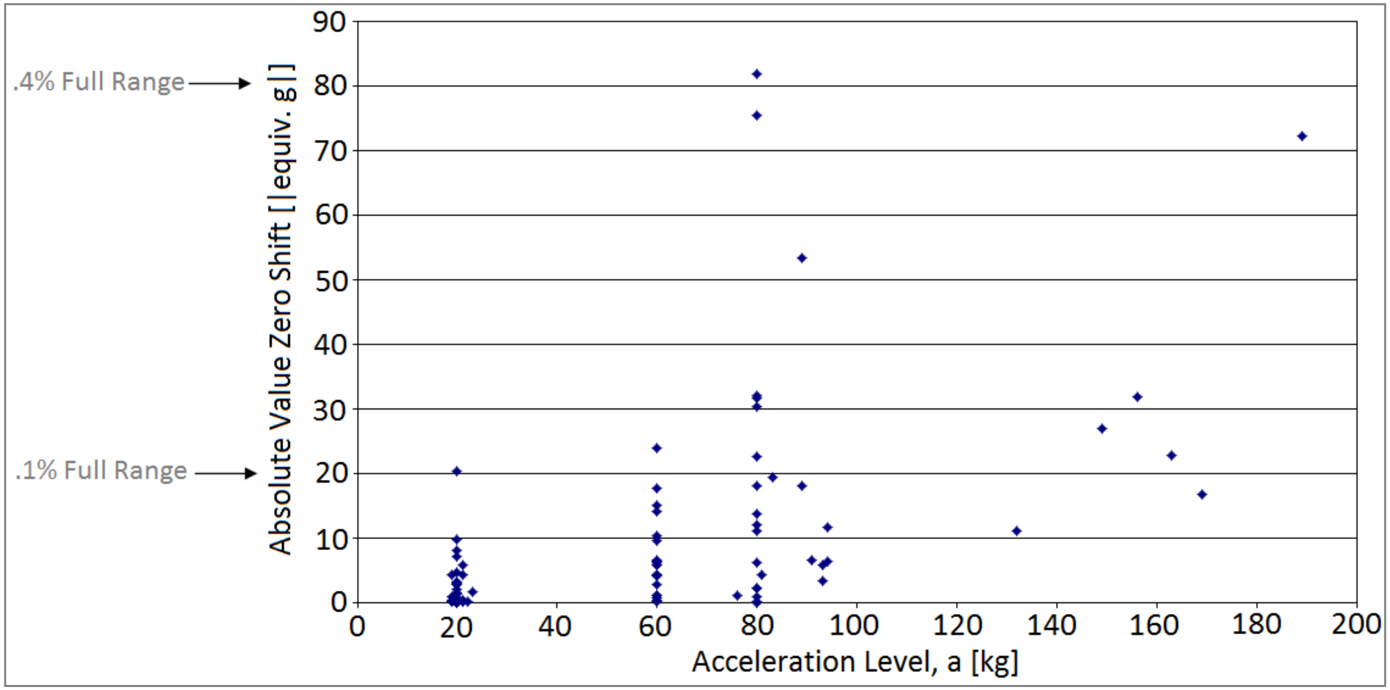
» "How will I know when the stops are engaged?"

- First, define the upper limit of the linear range of the damped accelerometer as 1.5X full range
- It is always safe to assume the damping is attenuating the signal to some degree if the recorded level is above 1.5X full range (the linear range)
- The level of signal attenuation depends on shock amplitude and duration
- The influence of the attenuation is short-lived and the accelerometer will respond very quickly once the amplitude drops into the linear range

Survivability and zero shift after shock

Hopkinson bar testing: 20,000 g range

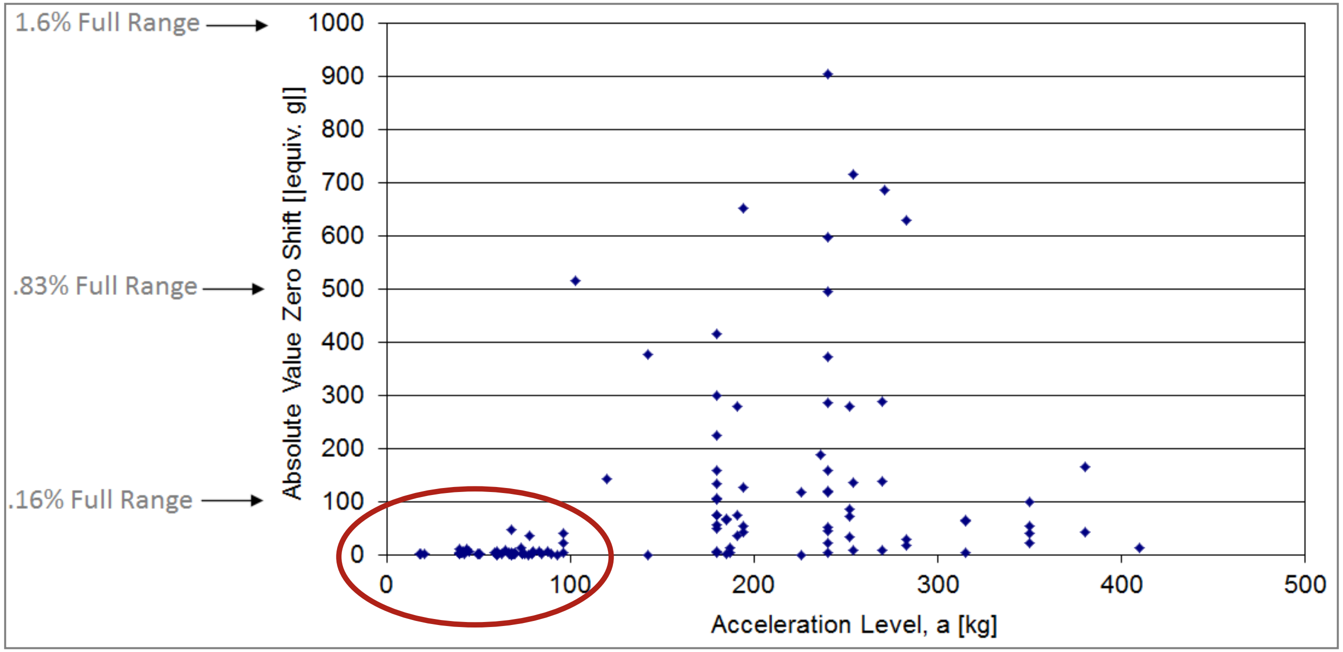
- Hopkinson bar testing at Meggitt's shock laboratory on 34 units
- Zero shifts at full range less than 0.1% full scale output (FSO)
- Zero shifts at levels up to 9X range less than 0.4% FSO
  - Granted pulse durations at these levels are very short



Survivability and zero shift after shock

Hopkinson bar testing: 60,000 g range

- Based on Hopkinson bar testing of 24 units:
  - Zero shifts at full range less than 0.1% full scale output (FSO)
  - Zero shifts at levels up to 6X range less than 1.6% FSO

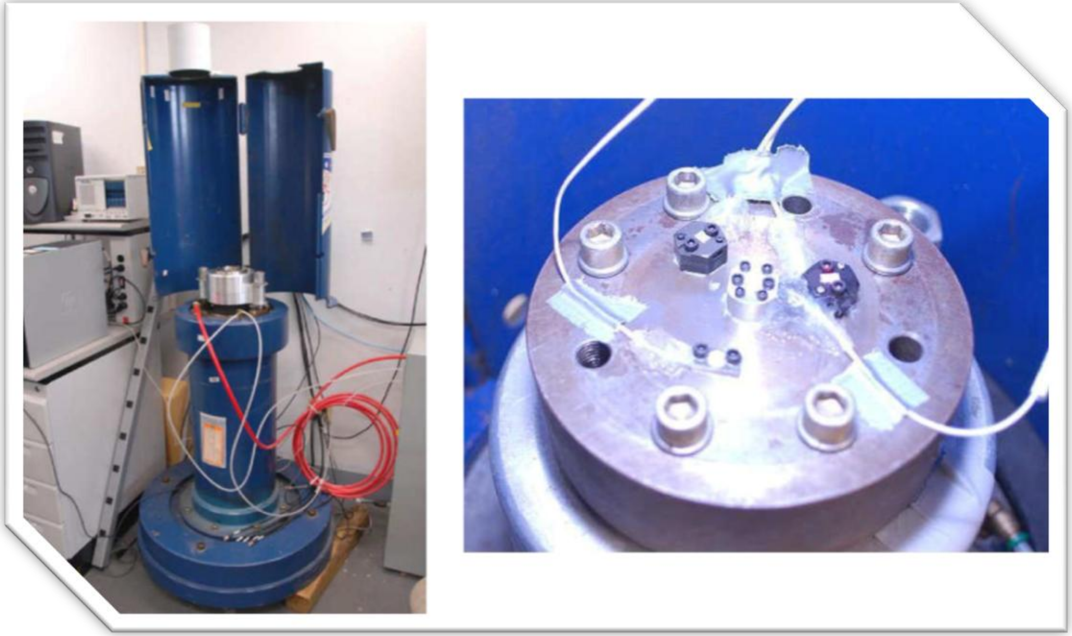


- Testing on three units (not shown here) suggests that zero shifts are much smaller for shocks in the transverse axis.

Survivability

Simulated environment: Very High G (VHG)

- The next step to increase the Technology Readiness Level (TRL) for the damped accelerometer is the first simulated environment, the Very High G (VHG) shock machine
- Performed as part of a Cooperative Research and Development Agreement (CRADA) with Eglin Air Force Base (AFB)



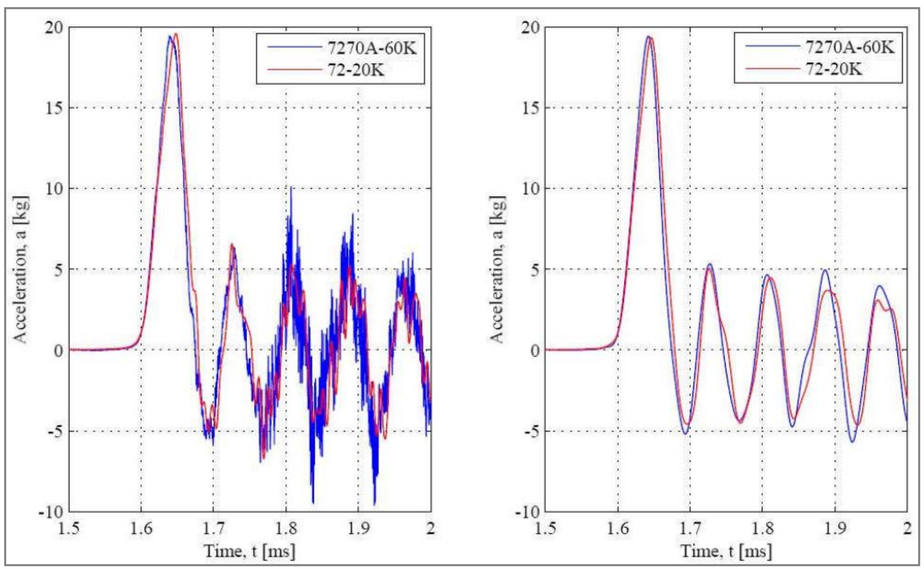
Survivability

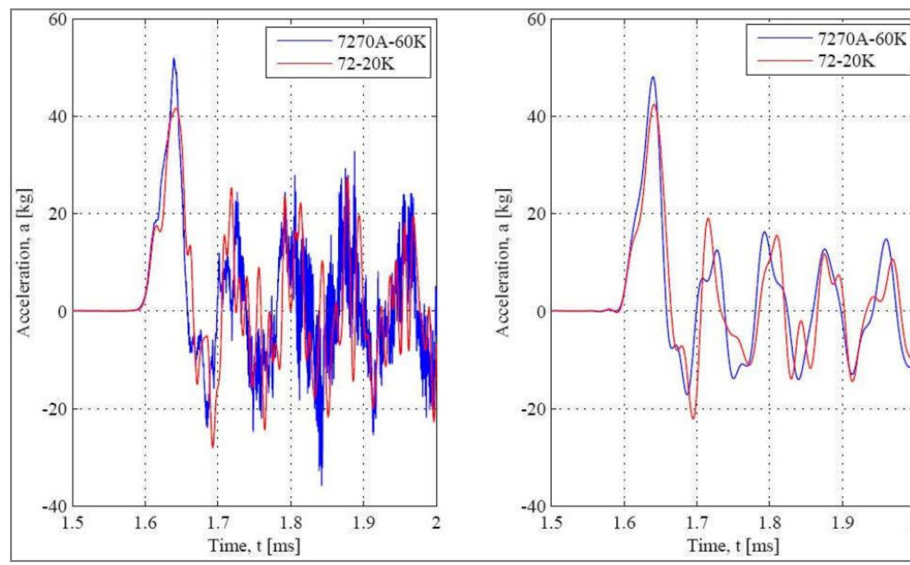
Simulated environment: Very High G (VHG) cont.

- Compared to the Hopkinson bar, the VHG produces shock inputs that are much less controlled with a wider band of frequencies
- 12 tests of varying amplitudes performed on 72-20K
- Left and right plots filtered at 204.5 kHz and 40 kHz, respectively

- At ~20,000 g results agree nicely with 7270A reference

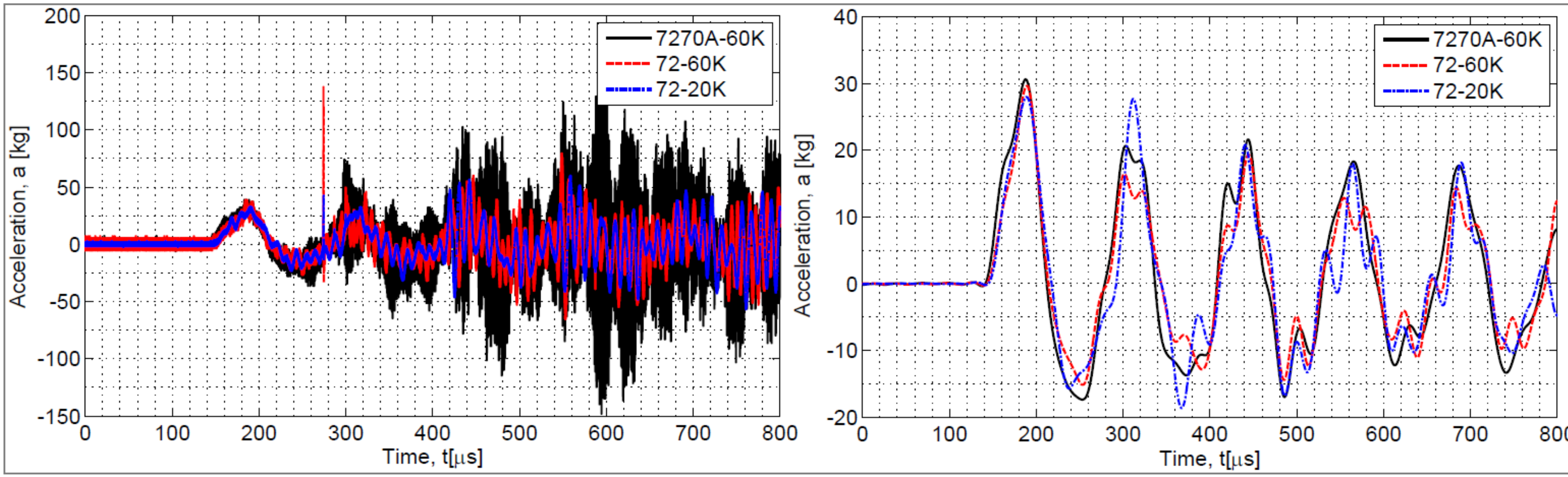
- At ~50,000 g signal attenuation from mechanical stop is visible

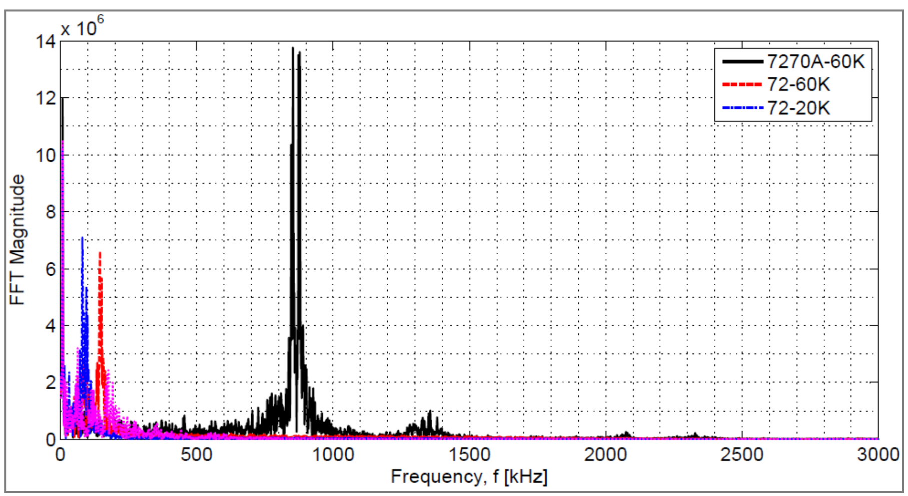




Survivability

Simulated environment: Very High G (VHG) cont.



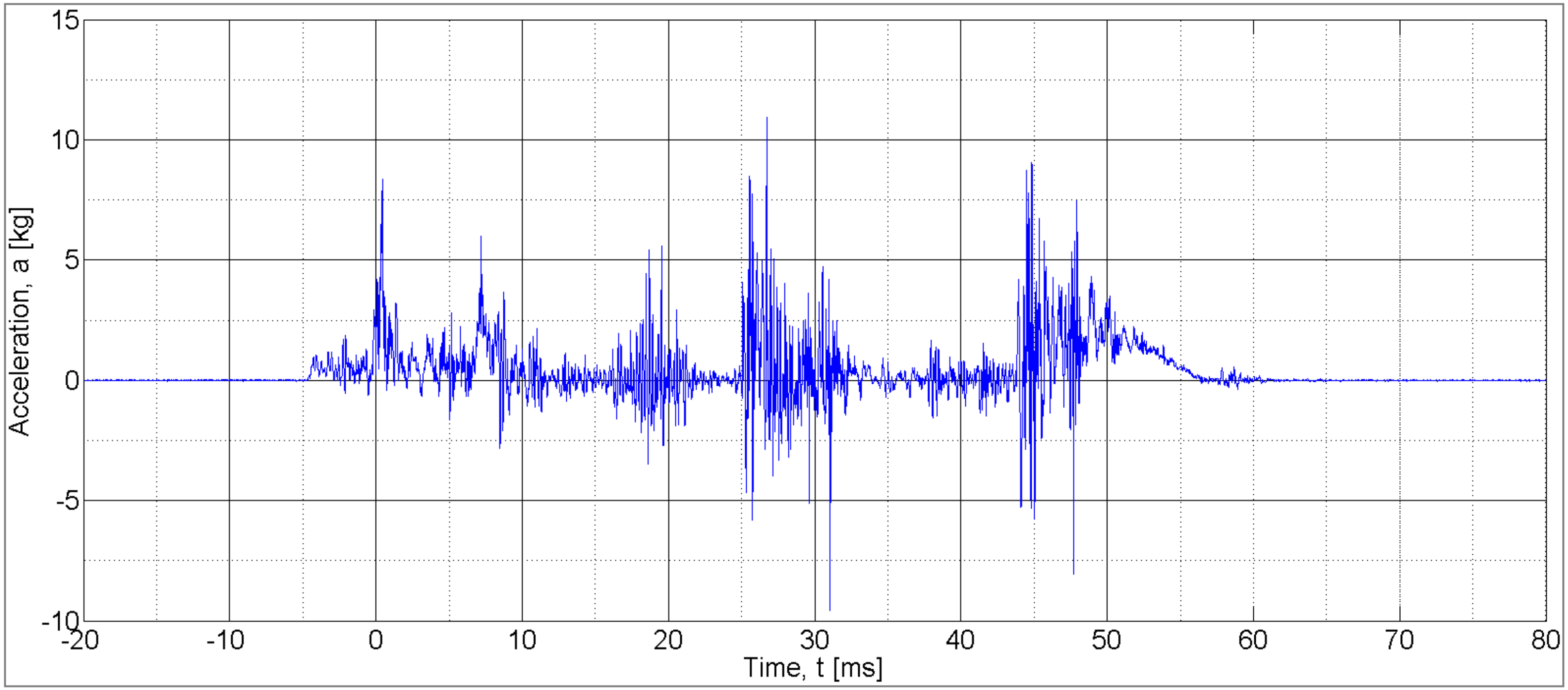


- Performed under a Proprietary Information Exchange Agreement with Alliant Techsystems (ATK)
- 17 shocks at amplitudes up to 50,000 g performed on 72-20K and 72-60K
- Undamped and 40 kHz filtered data shown for a VHG test near 30,000 g

Survivability and zero shift after shock

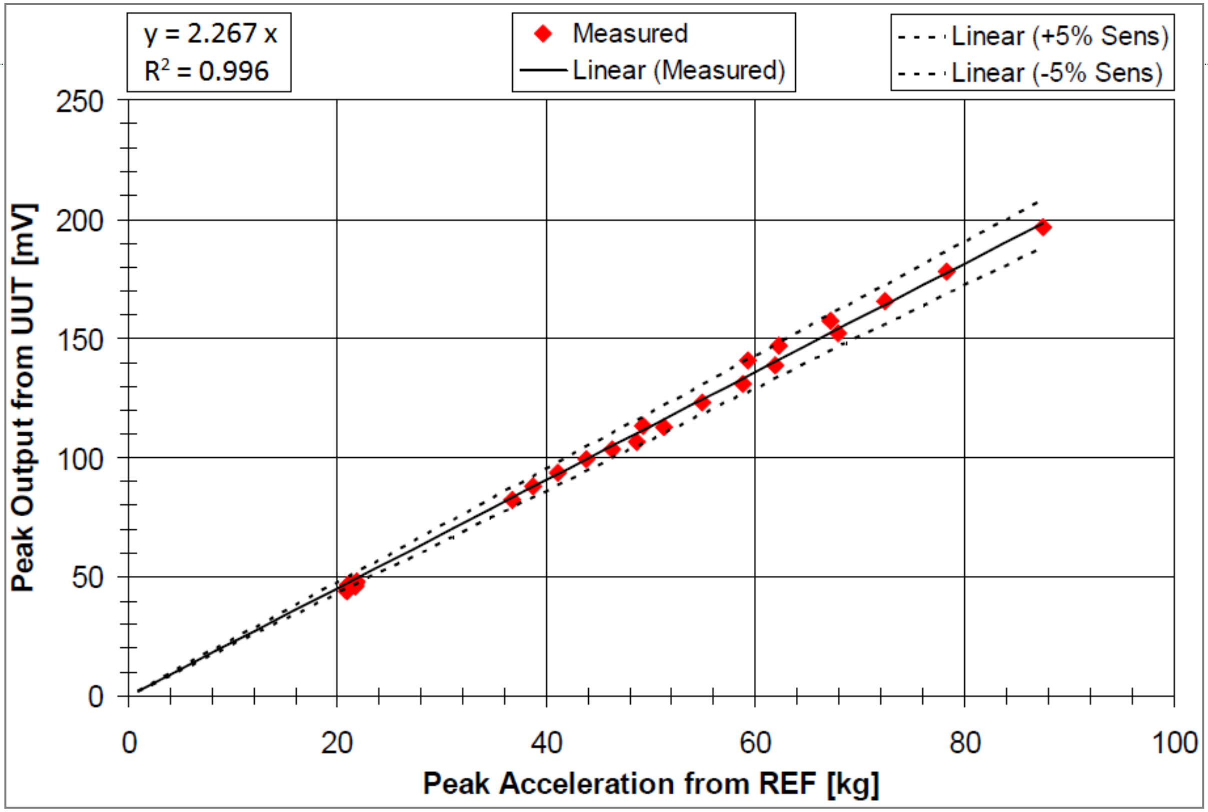
Simulated environment: penetration event

- The next step is exposing the damped accelerometer to an actual penetration event through a complex target



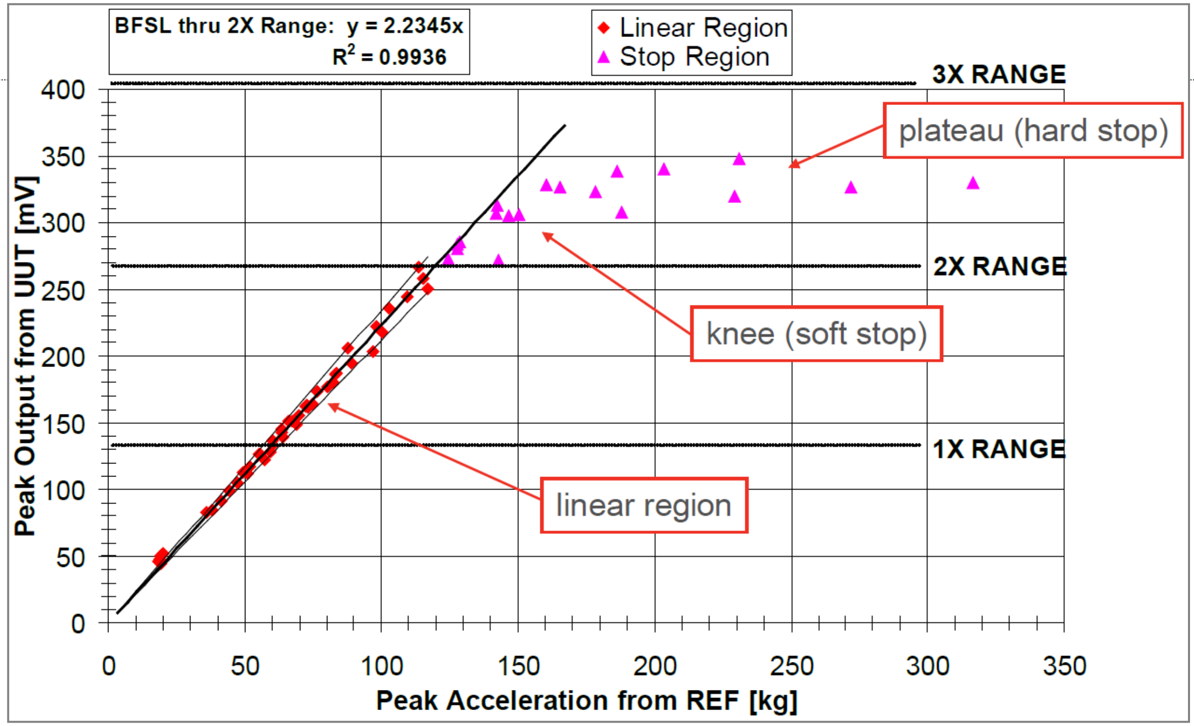
- 72-20K survived with a zero shift of approximately 6 equivalent g (or 0.03% full scale output)

Linearity



- 72-60K tested on Hopkinson bar to 1.5X full range
  - Amplitude response is linear to 1.5X full range minimum
  - Within linear region the slope of best-fit-straight-line is the experimental sensitivity

Beyond the linear region



» 72-60K tested on Hopkinson bar to 5X full range

- Knee region: beyond the linear region the damping begins to attenuate the signal as air is squeezed and displaced from the gap, limiting the displacement of the proof mass
- Plateau region: shock amplitude and duration is sufficient to allow the proof mass to approach the hard, physical stop

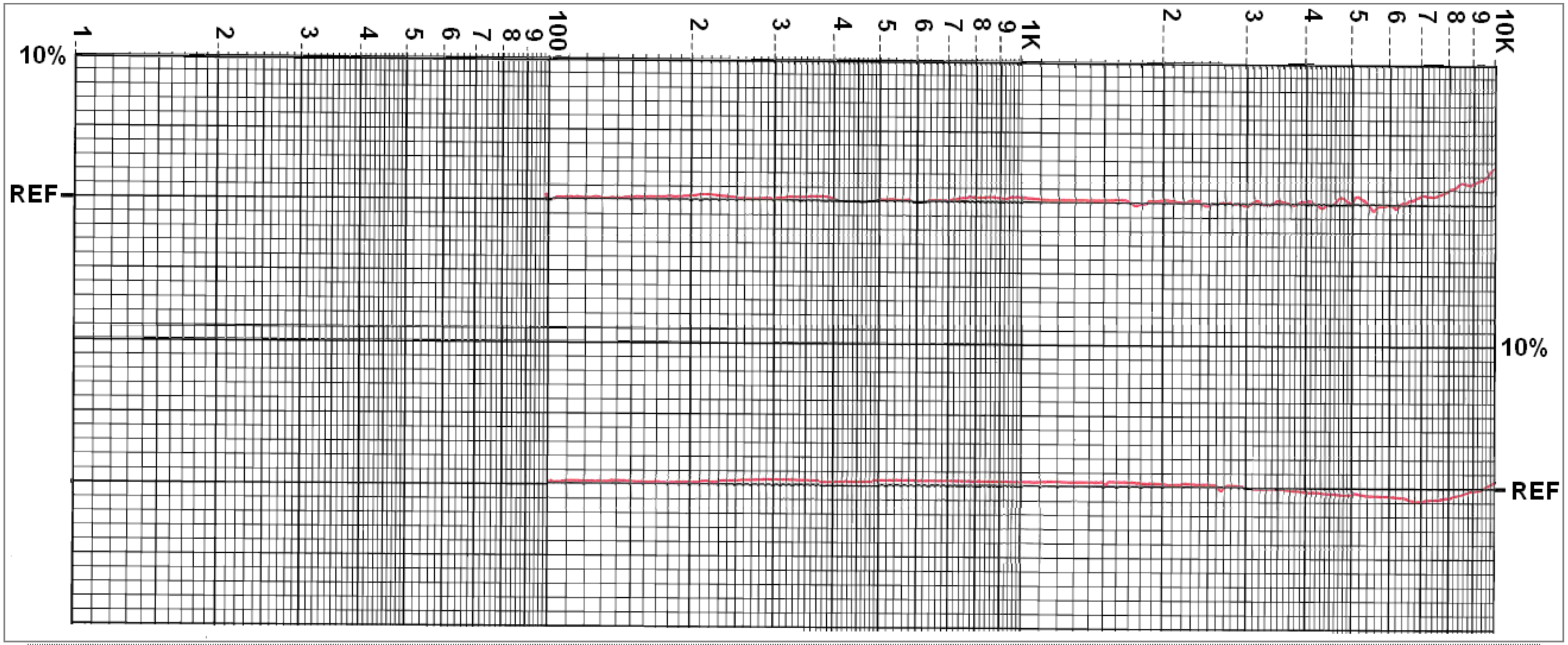
Frequency response

- Signal-to-noise ratios limit the capability to measure frequency response of high-g shock accelerometers by conventional methods
  - The Endevco® Automated Accelerometer Calibration System (AACS) 2901 shaker performs sine sweeps at ≤10 peak g up to 50 kHz.
  - Unholtz-Dickie (UD) shakers perform sine sweeps at ≤50 peak g up to 10 kHz.
  - 10 peak g is only 0.05% full scale output for a 20,000 g device
  - Frequency limitation cannot capture the high resonant frequencies
- One alternate method involves capturing multiple data sets from repeatable Hopkinson bar tests to performing analysis in the frequency domain
  - Such results have been previously reported [1] and are not discussed here

Frequency response

Best attempt measurement on the UD shaker

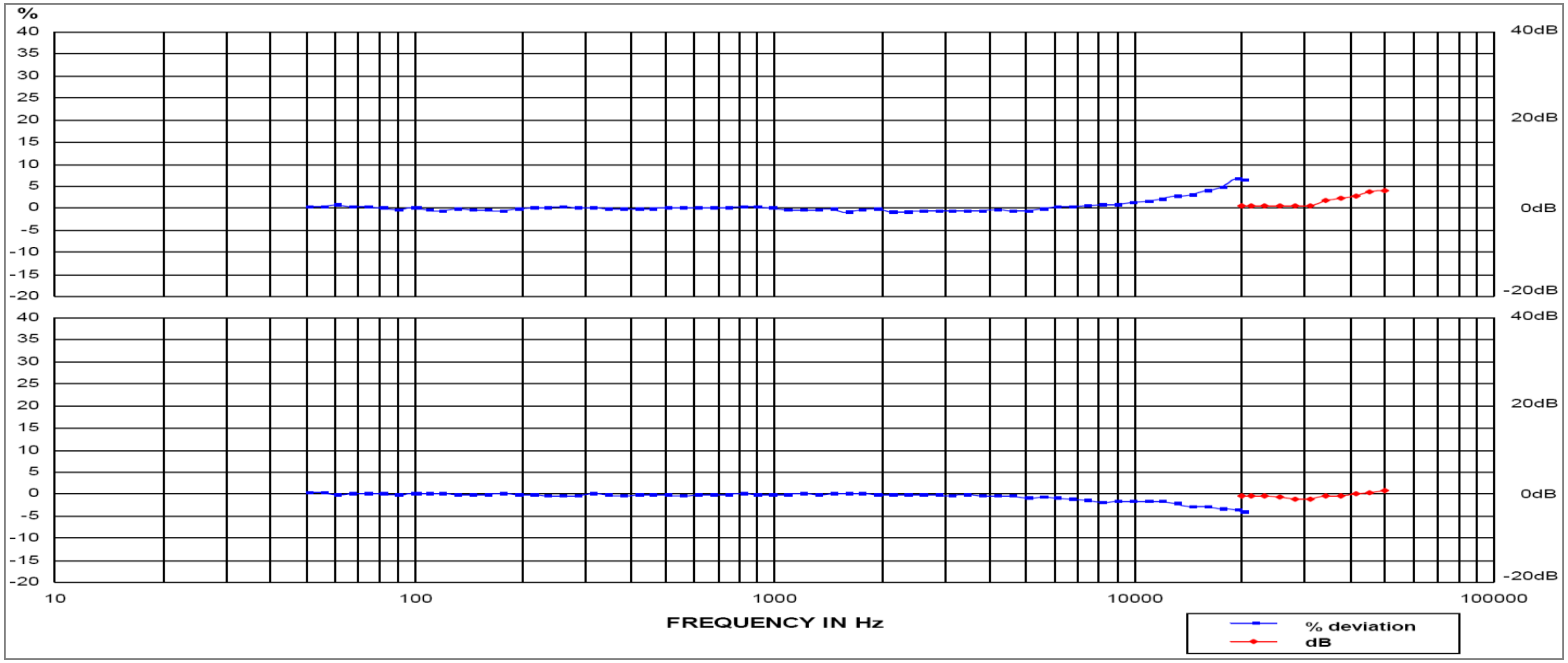
- » Top curve is damped 7280A-20K unit showing ~3% rise at 10 kHz
- » Bottom curve is undamped 7270A-20K unit showing near flat response through
  - – Any deviations are assume to be a result of poor signal-to-noise ratio



Frequency response continued

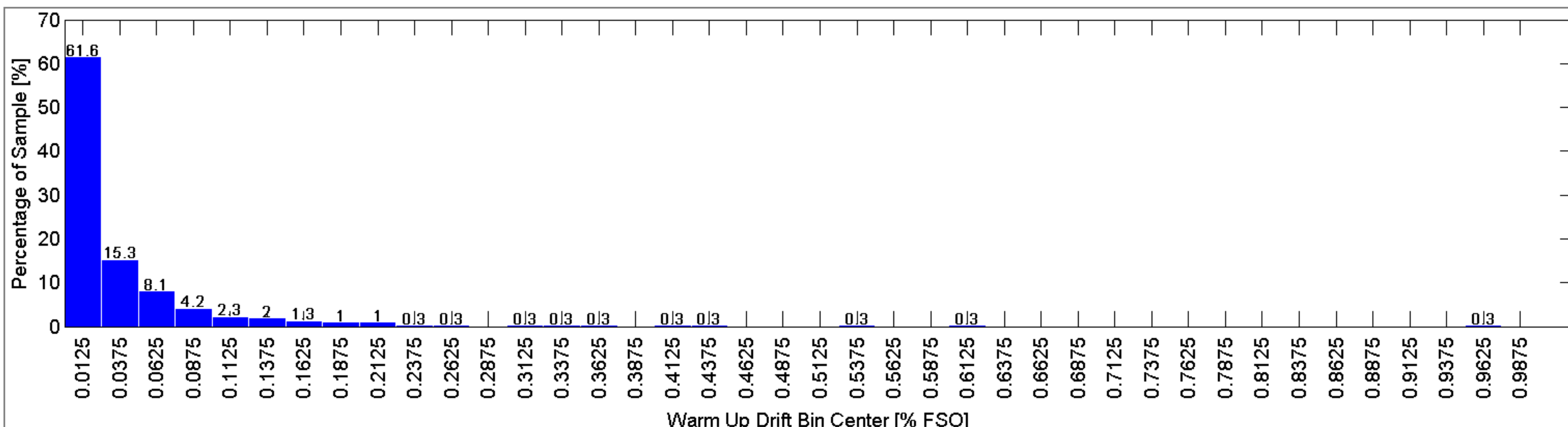
Best attempt measurement on the AACS shaker

- Top curve is damped 7280A-20K unit showing ~2% rise at 10 kHz
- Bottom curve is 7270A-20K unit showing slight roll off near 10 kHz
  - The roll-off is likely an artifact of the poor signal-to-noise ratio and is not assumed to be real (assumption based on testing of 7270A-2K)



Warm up drift

- Distribution of warm up performance
  - 307 tests on 101 different damped units
  - Tested from 1 second to 5 minutes from power on
  - Tests run at ambient temperature, in addition to hot and cold temperature extremes
  - Results show 90% of units will drift by less than 0.10% full scale output at any temperature.



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Summary

- The Endevco® lightly damped, high-g shock accelerometer is available in:
  - Surface mountable leadless chip carrier (LCC) package [72]
  - Traditional bolt mount package [7280A]
  - Integral stud mount package [7280AM4]
  - And coming soon, a triaxial bolt mount package [7284]
- Contributing factors to survivability are damping and mechanical stops
- Amplitude response is linear to a minimum of 1.5X full range
- Beyond the linear region the damping begins to attenuate the signal.
  - It is always safest to assume that the damping is attenuating the signal to some degree if the recorded shock level is greater than 1.5X full scale range
- Test results, including data from a penetration event, were presented.
- Frequency response measurements show +3% at 10 kHz.
- Warm up data shows 90% of units drift less than 0.10% FSO from 1 second to 5 minutes from power on at any temperature.

Acknowledgments

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Questions?

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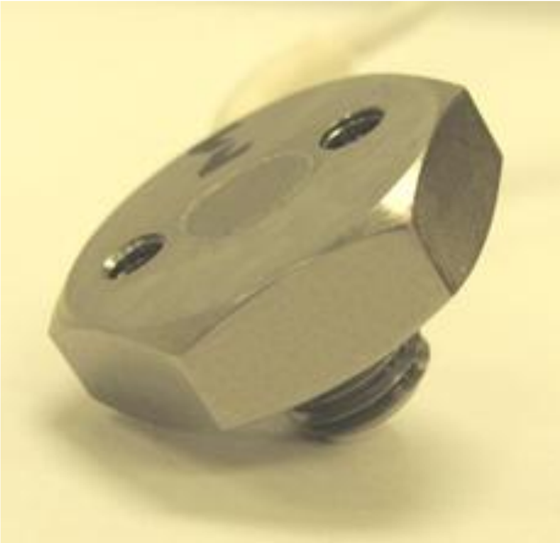
Back up slide number one

Meggitt shock lab Hopkinson bar test configuration

- Size of Hopkinson bar prevent from testing “side-by-side”
- A 7270A-type reference accelerometer is used to perform tested in a “back-to-back” configuration.

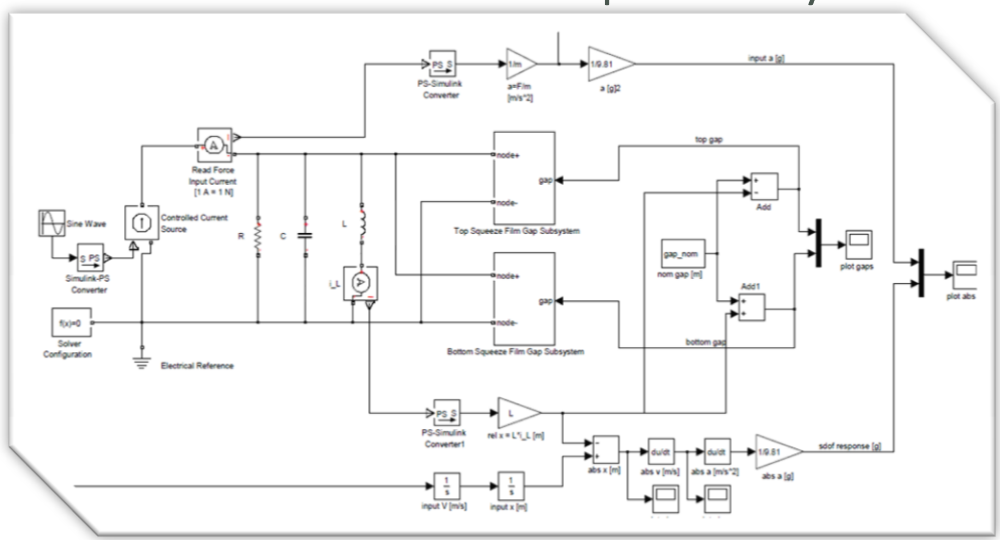


- Earlier testing shows “back-to-back” configuration introduces no measurable phase shift (or time delay).

Back up slide number two

Squeeze film damping model

- » A theoretical model was derived in Simulink to simulate the frequency response of the damped accelerometer
  - – The model doesn't properly represent the large displacement response as the proofmass approaches the stops
  - – The small displacement response seems reasonable
  - – Because the model is a work in progress there has not been any formal publication; additional details can be requested by contacting the factory.



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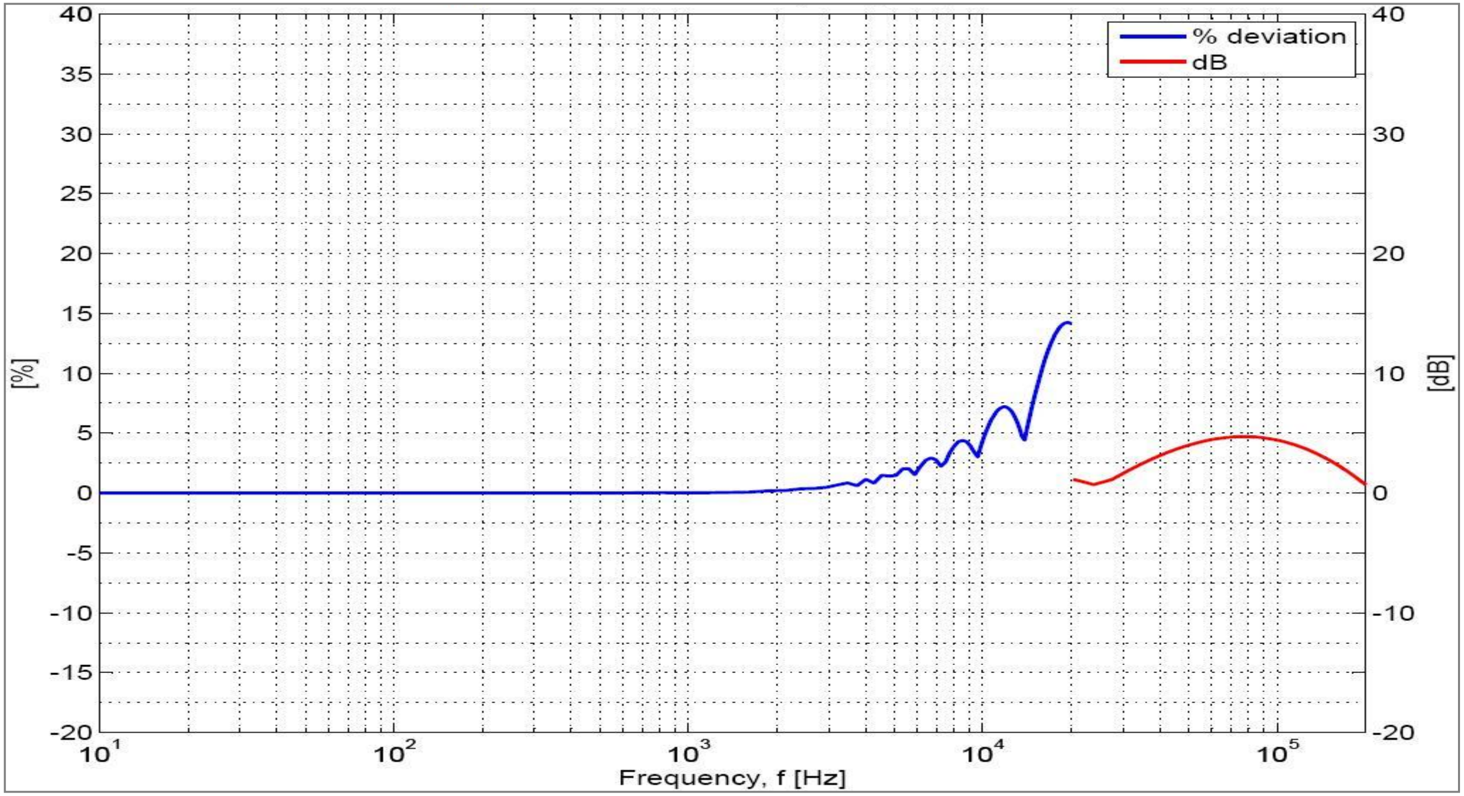
Back up slide number three

Squeeze film damping model prediction

- » A simulated frequency response of the 60,000 g damped accelerometer using small displacements is shown
  - – Approximate rise of 4 % at 10 kHz is not far from measured response



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