Mechanically Isolated & Electrically Filtered ICP pyroshock Accelerometers

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Agenda

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- Pyroshock
- Mechanically isolated shock sensor design
- MIL-STD-810G, Change Notice 1 calibration criteria
- Hopkinson bar testing & Calibration data

Accelerometer Summary

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- Piezoelectric accelerometers offer 2-wire ease of use for shock measurements
  - Out of band energy may lead to zero-shift in ceramic crystalline materials
  - They require use of mechanical isolation
- Damped MEMS accelerometers avoid high-Q factor and zero-shift
  - At the expense of signal to noise ratio
  - In this presentation we will only cover Mechanical Isolated shock sensors
- A challenging question
  - Which type of measurement sensor to select?

Models 3501A12/1360KG
MEMS High-G Shock
Accelerometers

Model 350D02
High Shock
ICP® Accelerometer

Pyroshock

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- Pyroshock events come from
  - Explosive bolts
  - Stage separation testing
  - High shock metal-to-metal impact

Pyroshock Purpose

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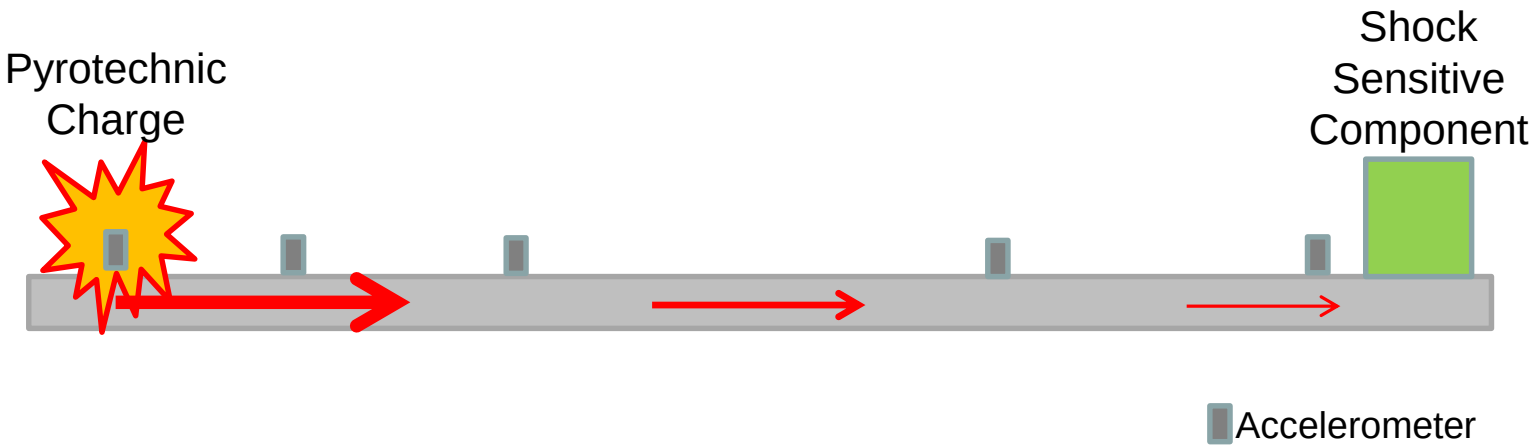
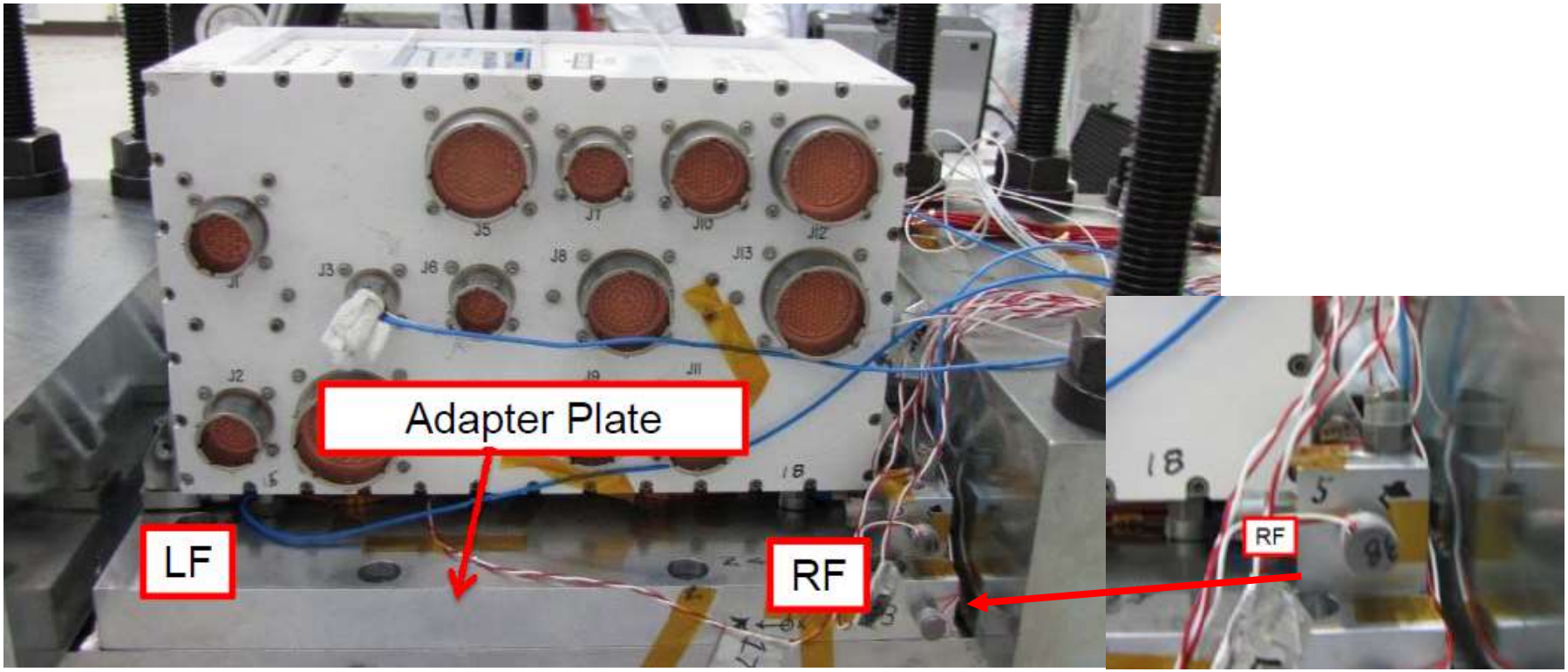
- Measure pyrotechnic “source shock” as closely as possible
- Markets and Applications where you find Pyroshock Events
  - **Explosive bolts**
    - Such as used on rockets to separate external fuel tanks or launch satellites
  - **Stage separation**
    - Such as used on rockets to jettison lower stages of launch vehicles
  - **High shock metal-to-metal impact**
    - Experienced in defense applications of military vehicles hit by an IED
    - Navy ships hit by a mine or torpedo



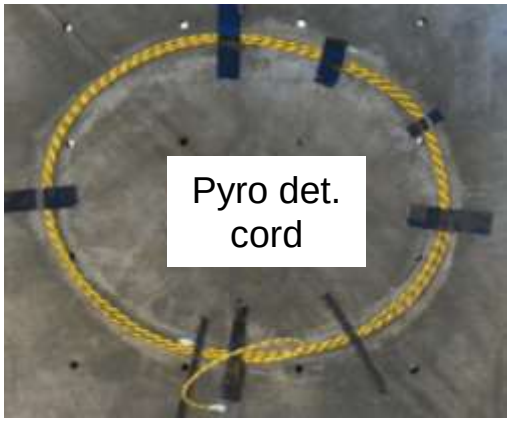
Pyroshock

- Typical test lab pyroshock simulation



Pyroshock

- Typical live explosive pyroshock simulation



On back side of plate

Pyroshock Video

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Data examples

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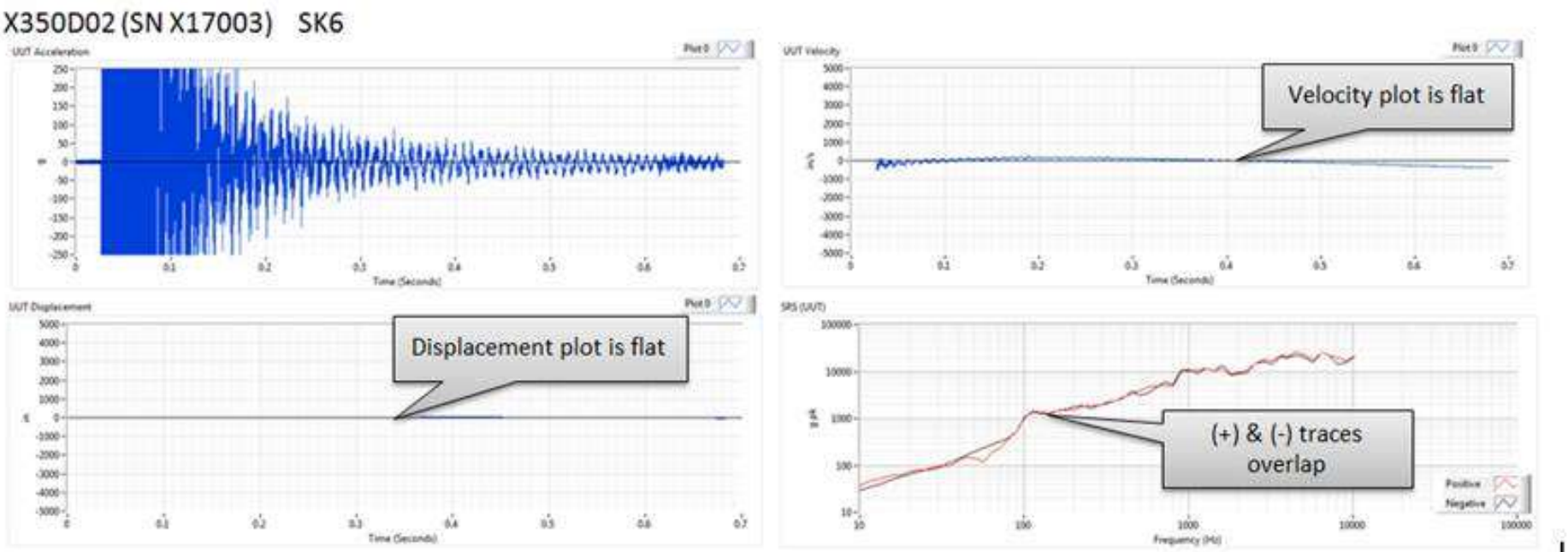
- Good data



350 bad data example

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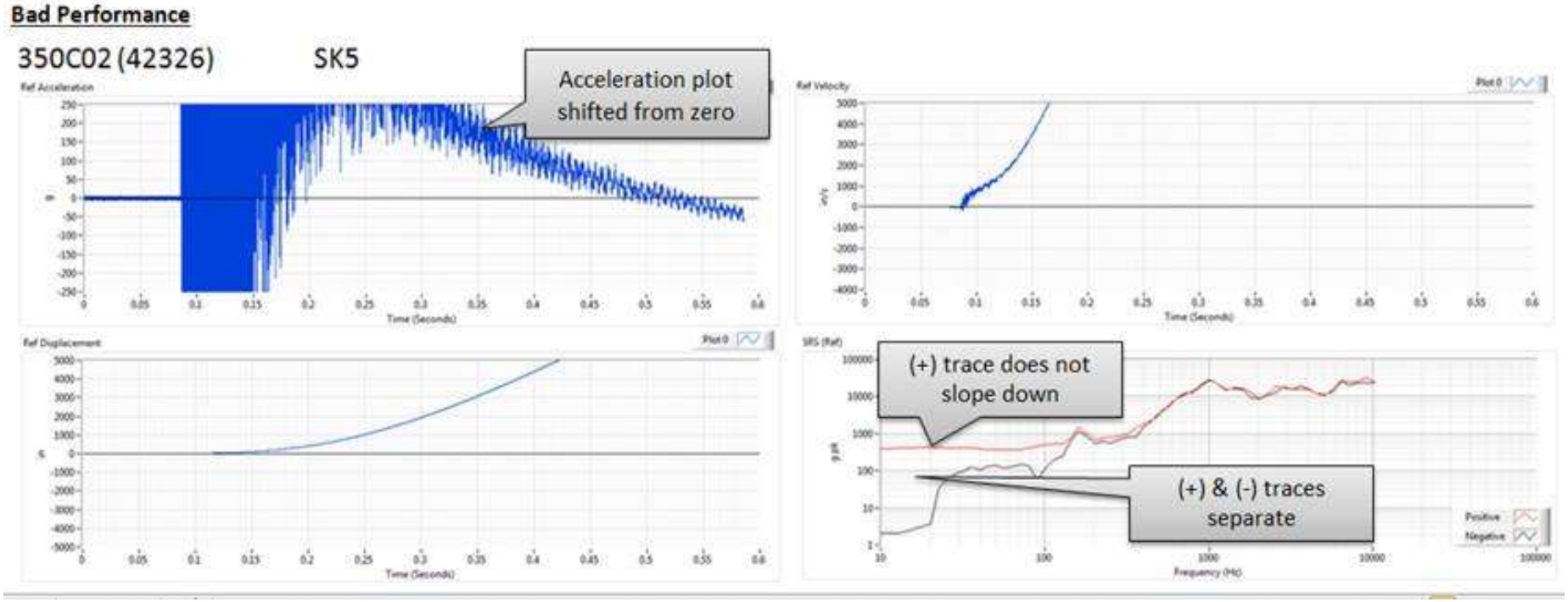
- Poor data



Zero Shift Sources

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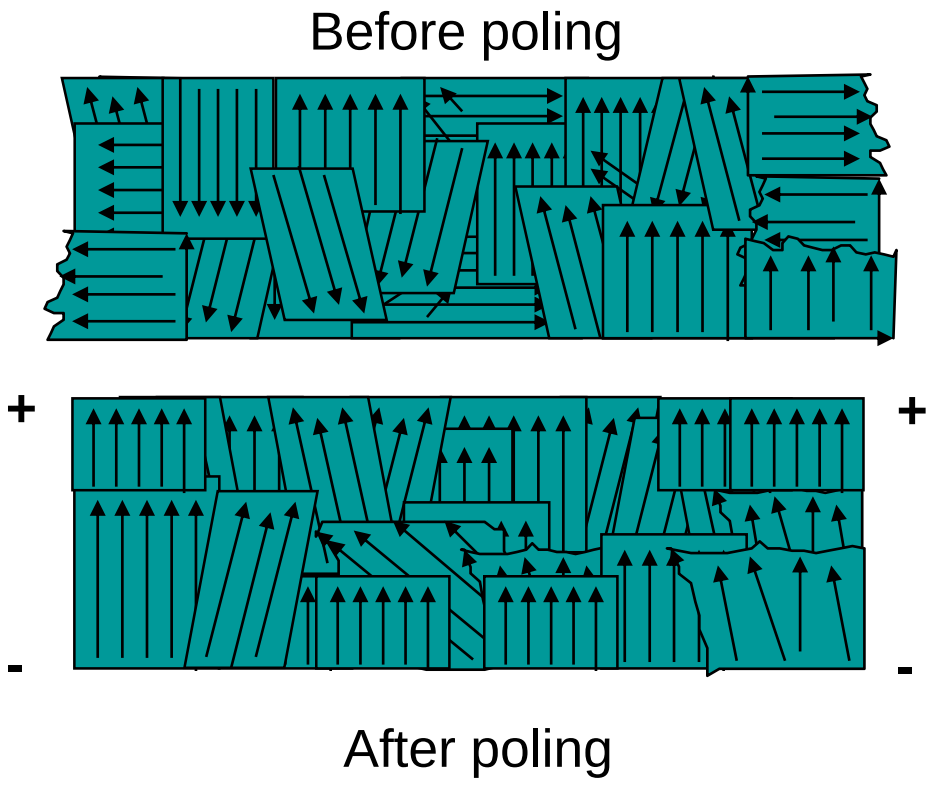
- Ceramics used in piezoelectric accelerometers
- Dipoling during shock



Mechanical Isolation

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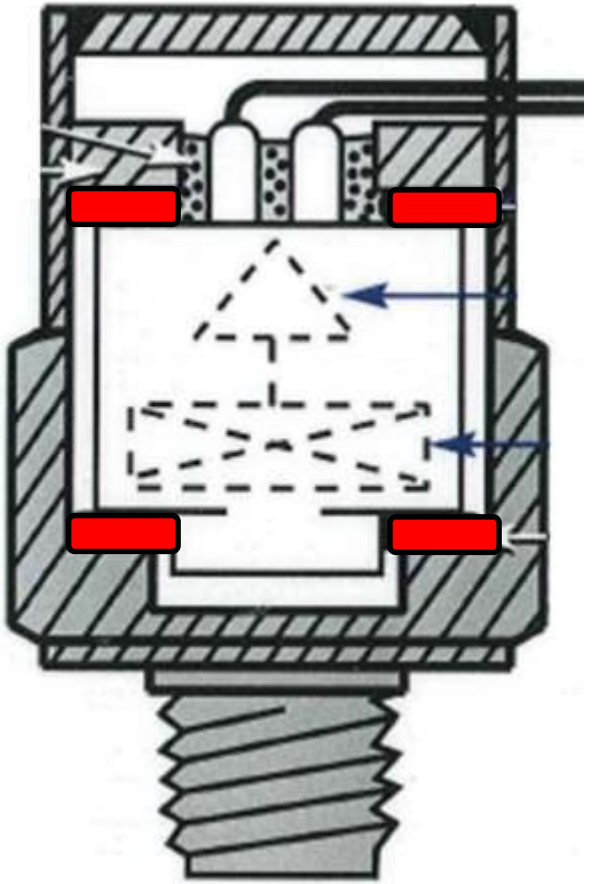
- Mechanical isolation is common in accelerometers designed for extreme shock
  - Moves sensing element from strain
  - Better measurement accuracy
  - Less prone to zero shift
  - Lowers transverse sensitivity
  - More durable
- Functions as low pass filter
  - Decouples element from housing
  - Isolates & protects element
    - Undesirable & out-of-bandwidth
    - High frequencies and energy



Mechanical Isolation

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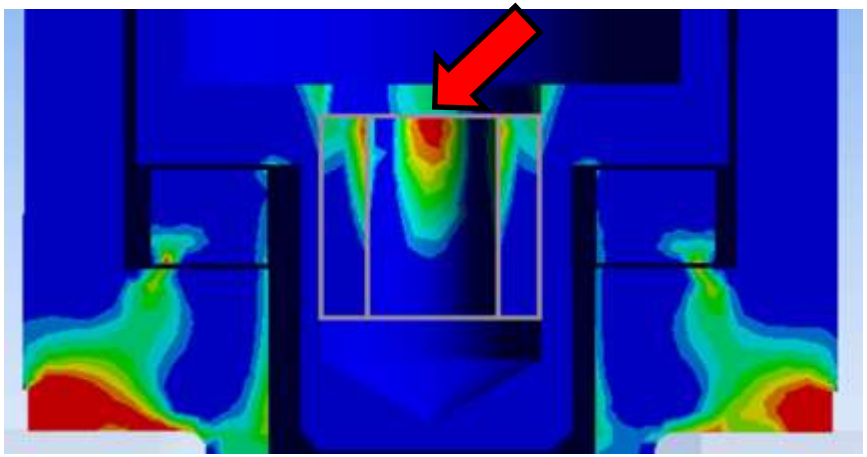
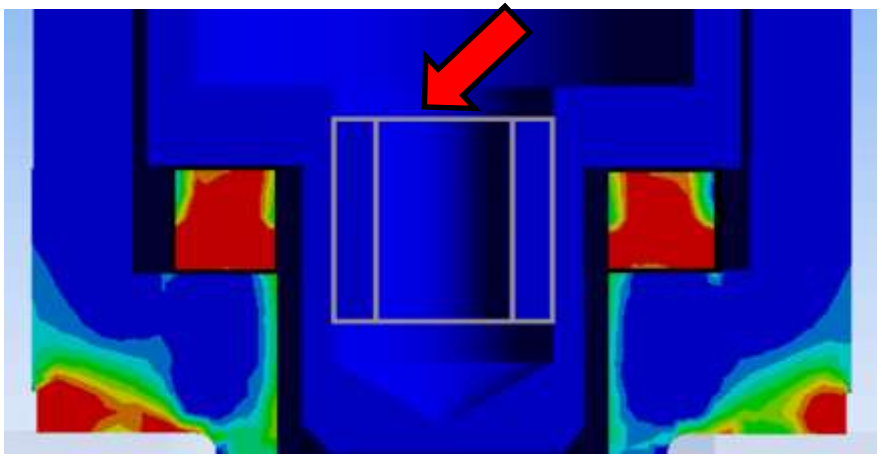
- Reduces base strain transmitted to sensing element
  - Base strain is any undesired output caused by deformation
  - Often the root cause of measurement inaccuracies
    - Non-linearity
    - Zero shift
    - Transverse sensitivity
  - Base strain increases with shock amplitude
    - Additional output will also increase
    - Causes higher sensitivity at full scale
    - Causes non-linearity



Unisolated



Mechanical isolation

Mechanical Isolation

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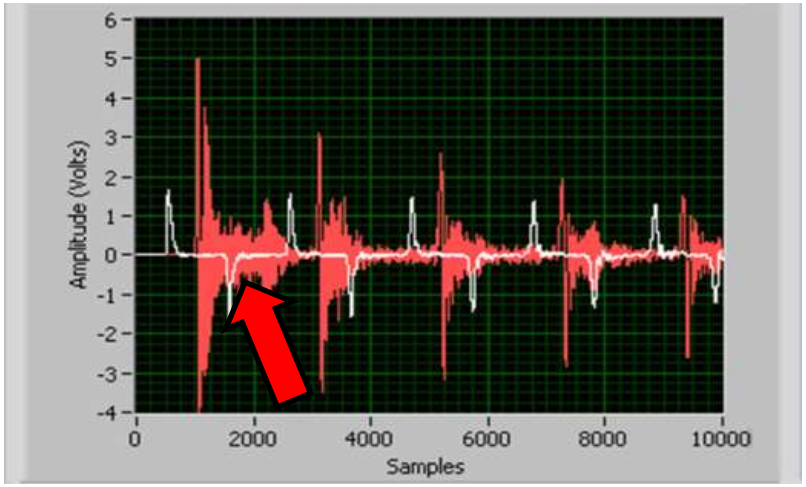
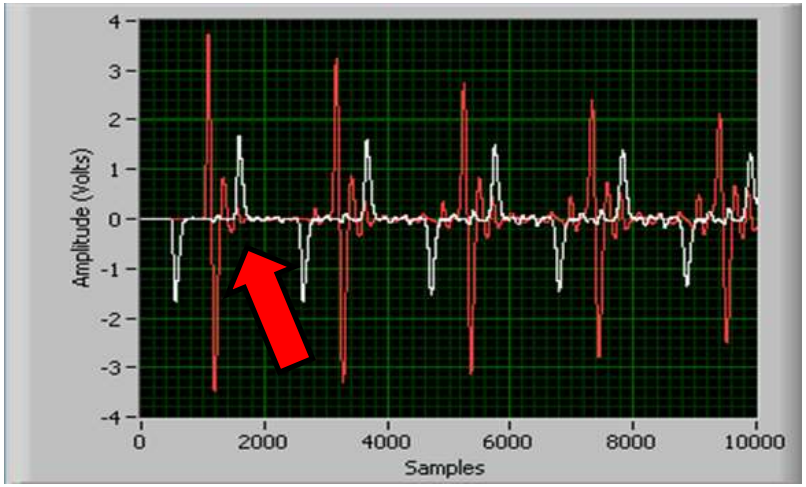
- Compare Unisolated vs Mechanically Isolated
  - Metal to metal impact
  - Mechanically Isolated
    - No high frequency
  - Unisolated
    - High frequency ringing
    - Potential measurement errors from sensor and/or conditioning



Unisolated



Mechanical isolated

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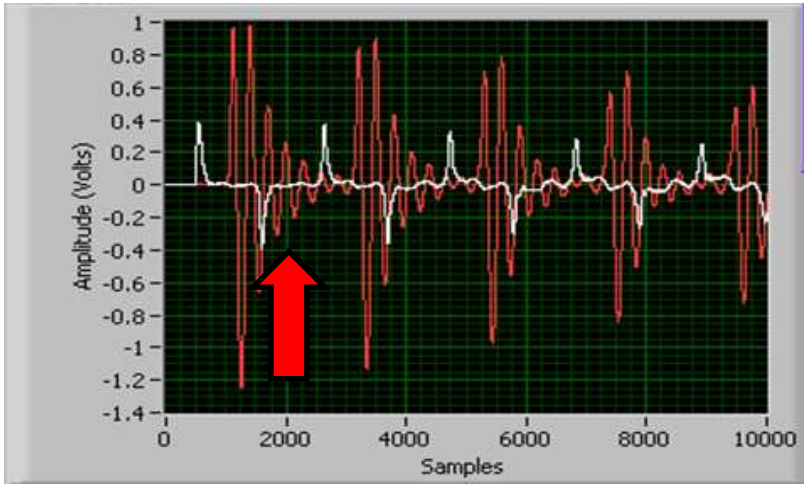
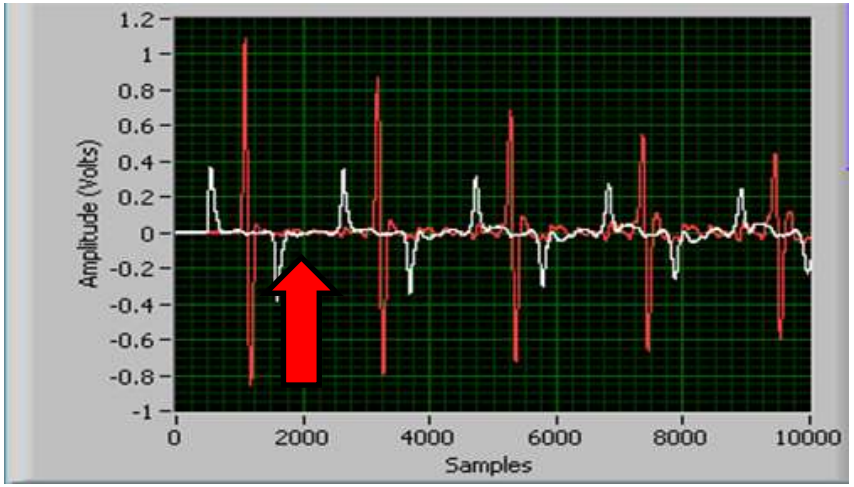
- **Cutoff frequency of isolator**
  - Much lower than the accelerometer resonance
  - Assure adequate high-frequency attenuation
  - Q factor
    - Relationship between stored energy and energy dissipation
    - Optimally damped is desired
    - Maximize frequency response
    - High Q factor (under damped) will oscillate



Under damped response



Optimally damped response

Mechanical Isolation

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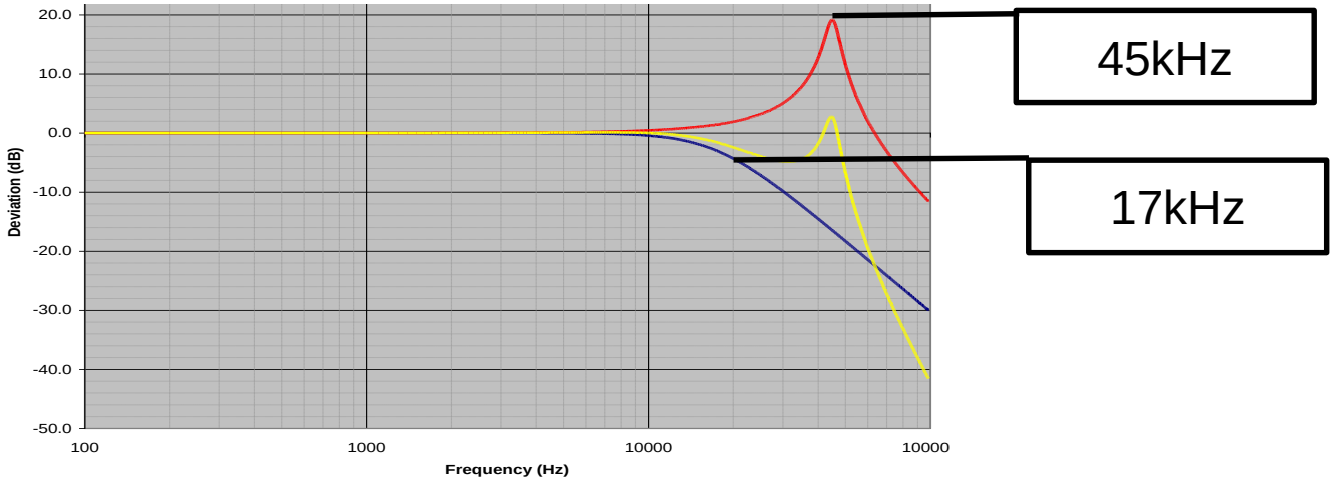
- Low pass electrical filtering
  - Helps attain optimal damping
    - Cannot be with elastomeric material alone
  - Attenuates resonant peak from isolator
  - Further eliminates high frequencies
  - Prevents overloading of signal conditioning
  - Tailored to the mechanical isolator's resonant frequency
  - Result: Flat frequency response to > 10 kHz



Amplitude vs. Frequency

MIL-STD-810G

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- To help ensure that a shock accelerometer meets the needs of a pyroshock environment, MIL-STD-810G Change 1 method 517.2 (pp 517.2 22,23) describes
  - Qualifying Hopkinson bar tests
  - Some accelerometer product specifications

- Although shakers can provide the most accurate calibrations…
  - Vibration calibration can be over wide frequency range, up to 20kHz
  - Cannot achieve high g levels, only ~10 g rms
  - Can use resonant fixtures, up to 1500 g rms at a particular frequency

- We need to calibrate to full scale
  - Use of a Hopkinson Bar Test System conforms to these MIL-STD-810G, CN 1 requirements

- And the results of shock and vibration must agree within 10%

Hopkinson Bar Testing

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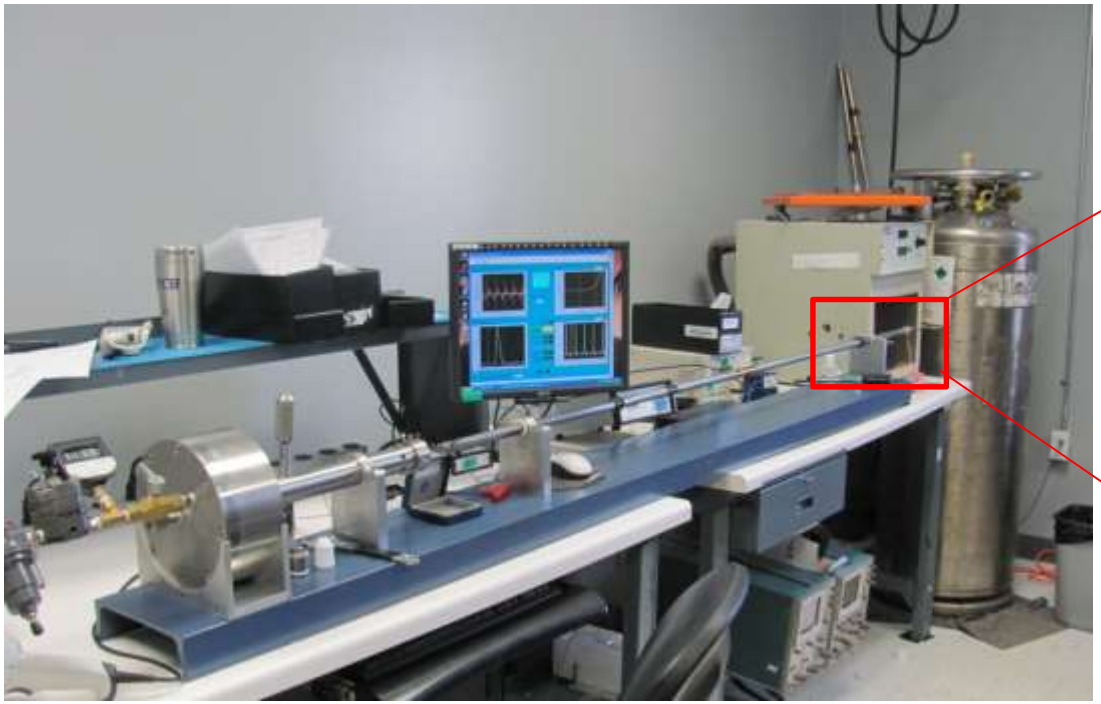
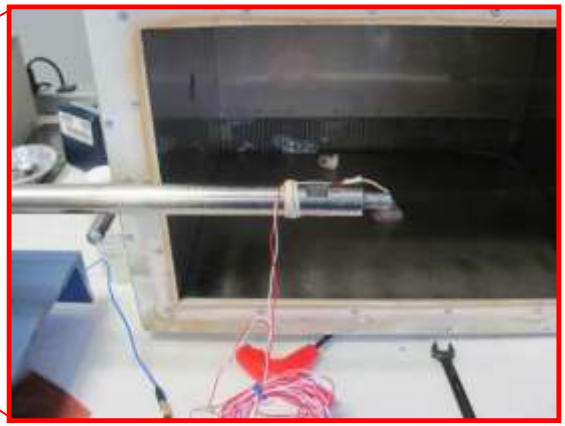
- Strain gage reference (velocity)
- Strain gage velocity calibrated with laser vibrometer





Hopkinson Bar Testing

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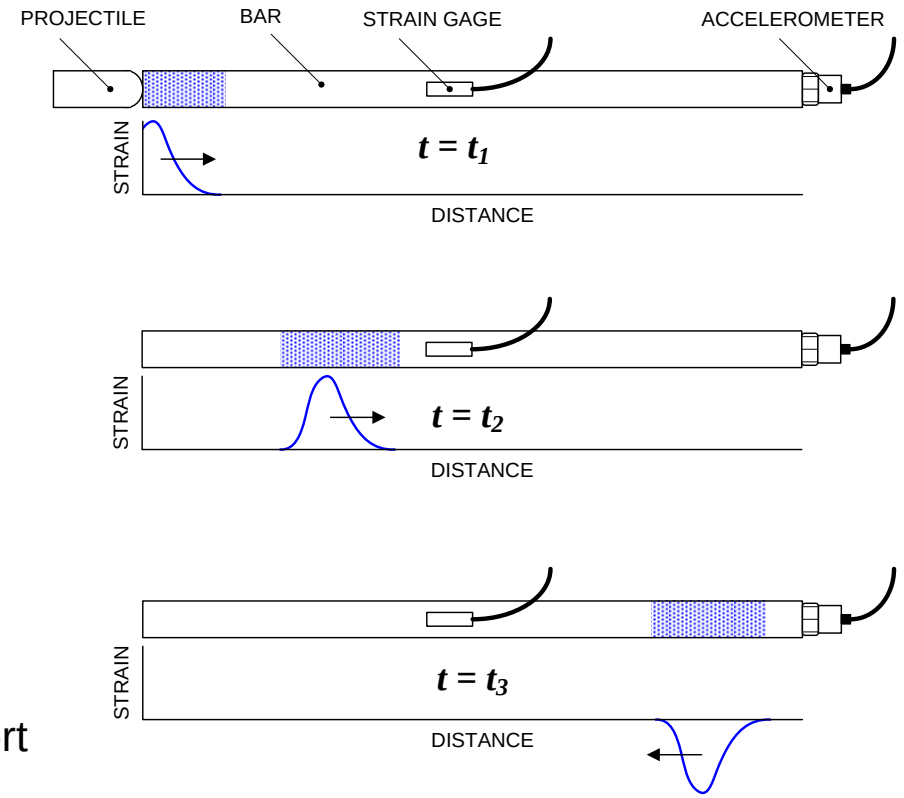
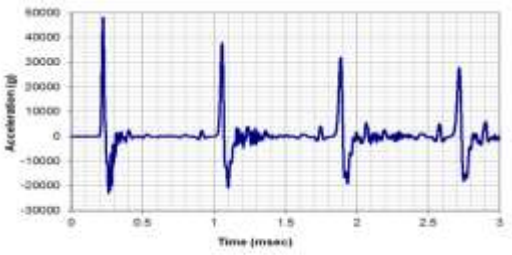
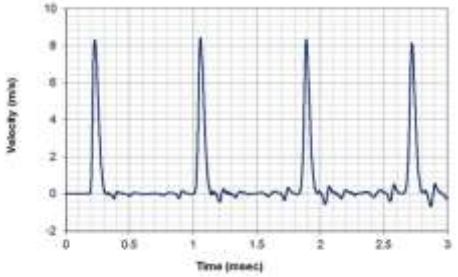
- Application
  - Sensitivity
  - Over-range survivability
  - Linearity
  - Zero-shift
- Strain reference
  - Strain proportional to velocity
  - Calibrated by laser vibrometer
- Assumptions
  - Perfect reflection at end
    - Accelerometer lightweight and short
  - Dispersion and attenuation small for frequency of interest
    - Wavelength > diameter
  - Linear elastic stress-strain







Shock Accelerometer Calibration

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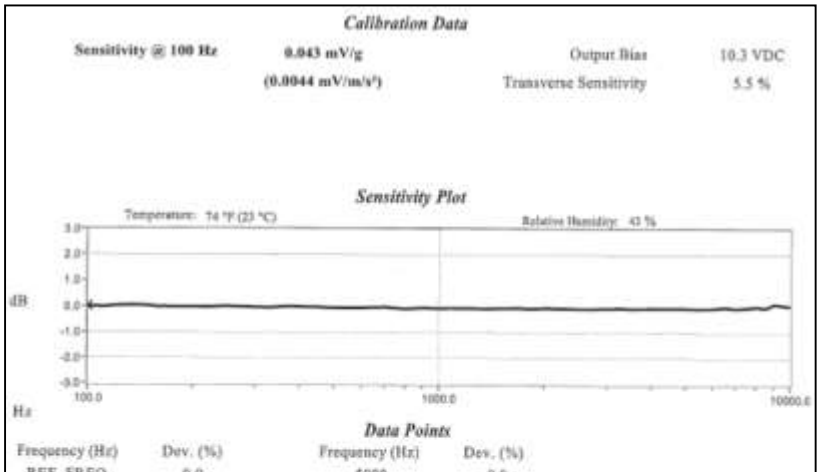
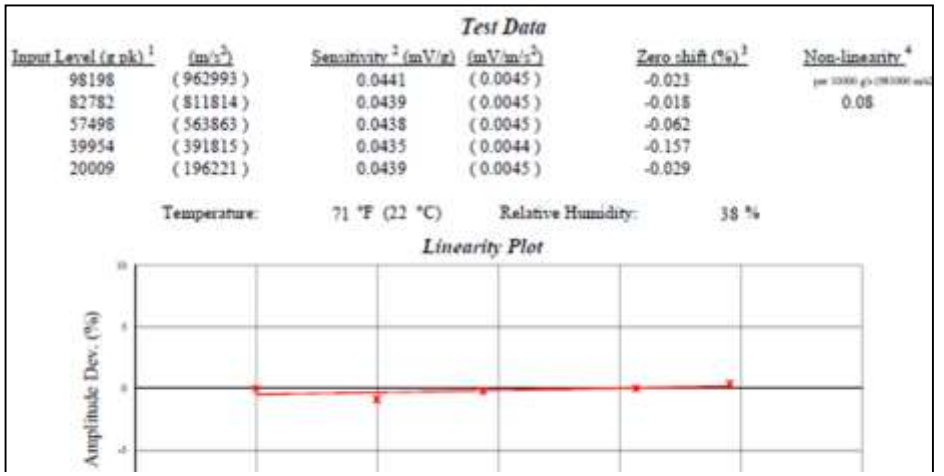
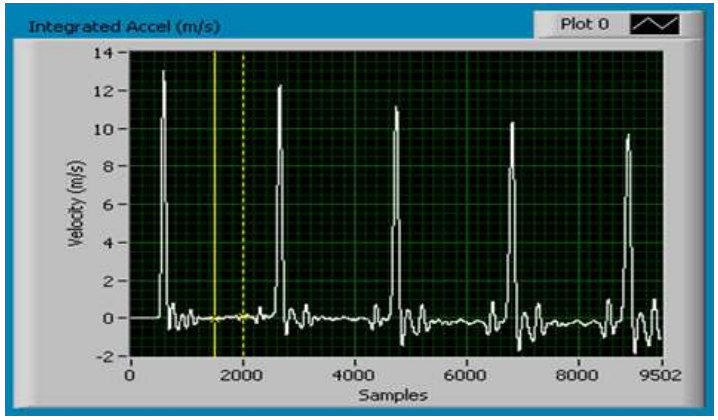
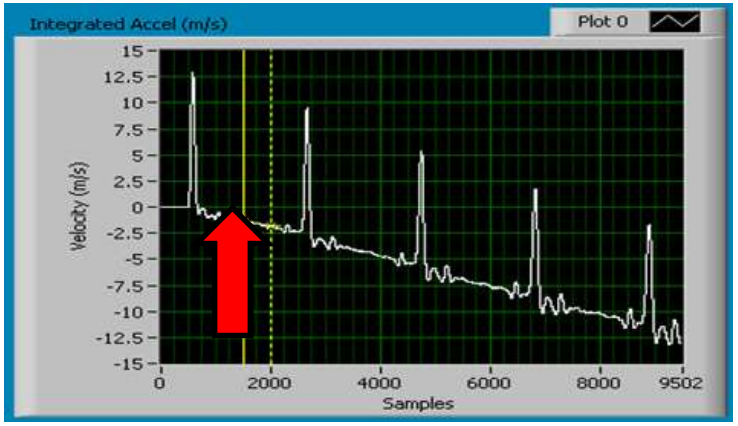




- Zero shift
  - Undesirable even in small fractions of a percent
  - Easily detected when integrating accelerometer output to get velocity



Low Zero shift



High Zero Shift (~300G equivalent)
(0.3% of 100kG)

New 350B01

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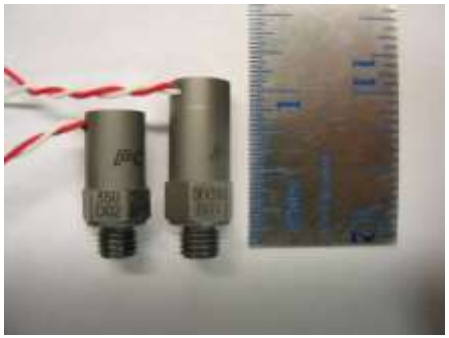
- 350B01 is a Replacement for MODEL 350B21
- ICP® accelerometer, 0.05 mV/g, 100 kg
- 350B21was not mechanically isolated or electrically filtered & caused measurement errors
  - Clipping
  - Ringing
  - Zero-shift
- 0.17 inch (4.3 mm) taller



Summary

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- Mechanically isolated & electrically filtered designed for Pyroshock
  - Avoids ringing
  - Avoids amplifier saturation and signal clipping
  - Minimizes zero shift
  - Case isolated
- Titanium, hermetically sealed element for dirty environments
- Provided with calibration in accordance with MIL-STD-810G, Method 517, Change Notice 1
  - Amplitude response from 100 Hz to upper 1 dB frequency, max 15 kHz (ISO 17025)
  - High-G verification using Hopkinson bar to max g range, NIST traceable