A STRAIN GAGE BASED PROJECTILE HEALTH MONITOR AND SALVAGE INDICATING CIRCUIT FOR KINETIC ENERGY PENETRATING PROJECTILES

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An Employee-Owned Company

■ Program Overview

- ***Develop a Means & Method to:***
  - ***Detect and Monitor Stresses Caused by:***
    - ***Weapon Case Axial Loads***
    - ***Weapon Case Lateral Loads***
  - ***Distinguish Between Normal and Deleterious Stress Conditions and Detect Excessive Kinematic Behavior***
- ***Verify the Method Against Real World Events***
- ***Design the Damage Signaling Circuitry`***

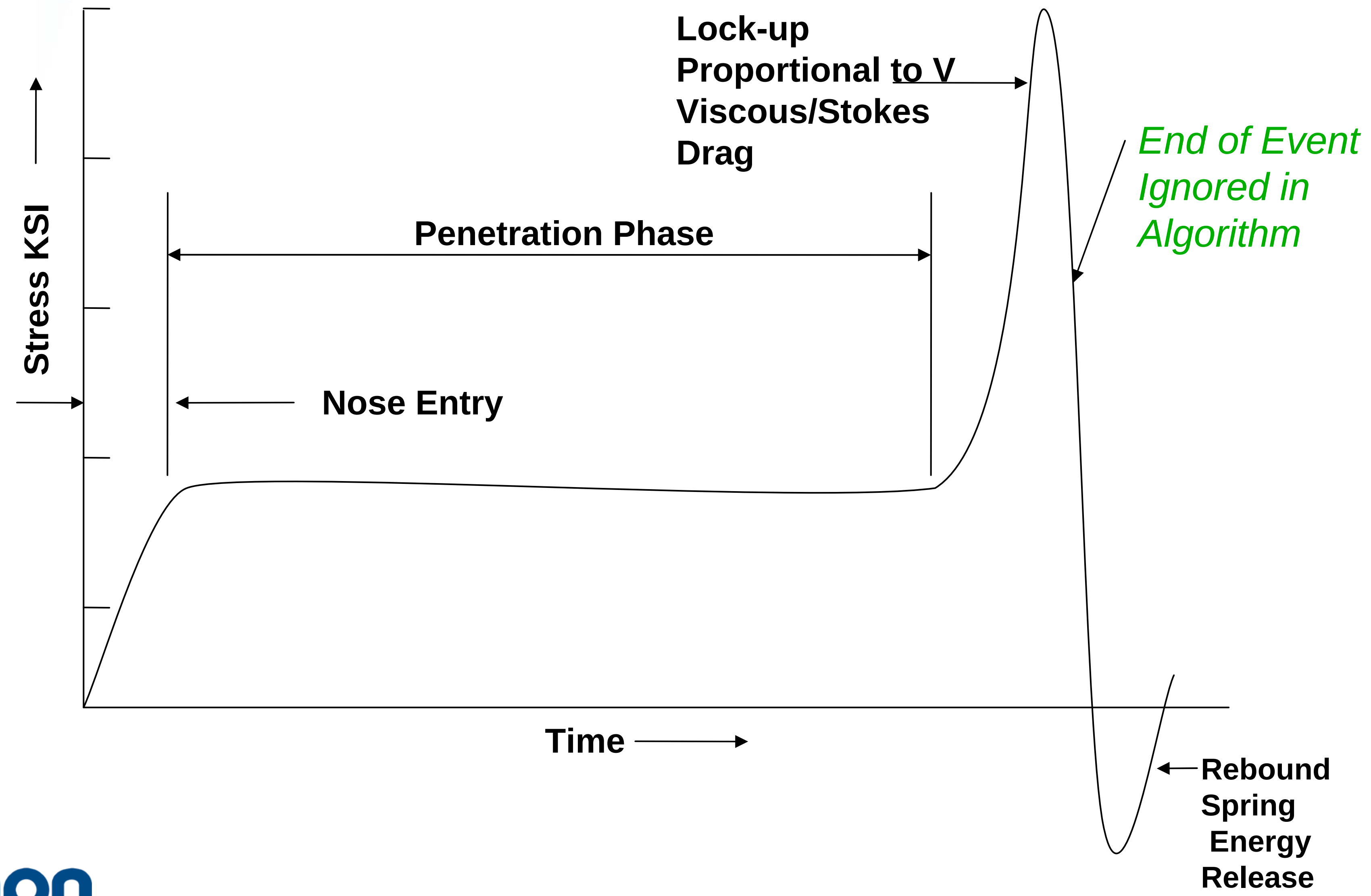
Program Goals

- Set-up the Detection Algorithm in a Simulator
- Verify the Algorithm (method) against Real World Events (actual tests)
- Design the Circuitry and Select the Transducer
- Select the Hardware Interface for DSP Chip

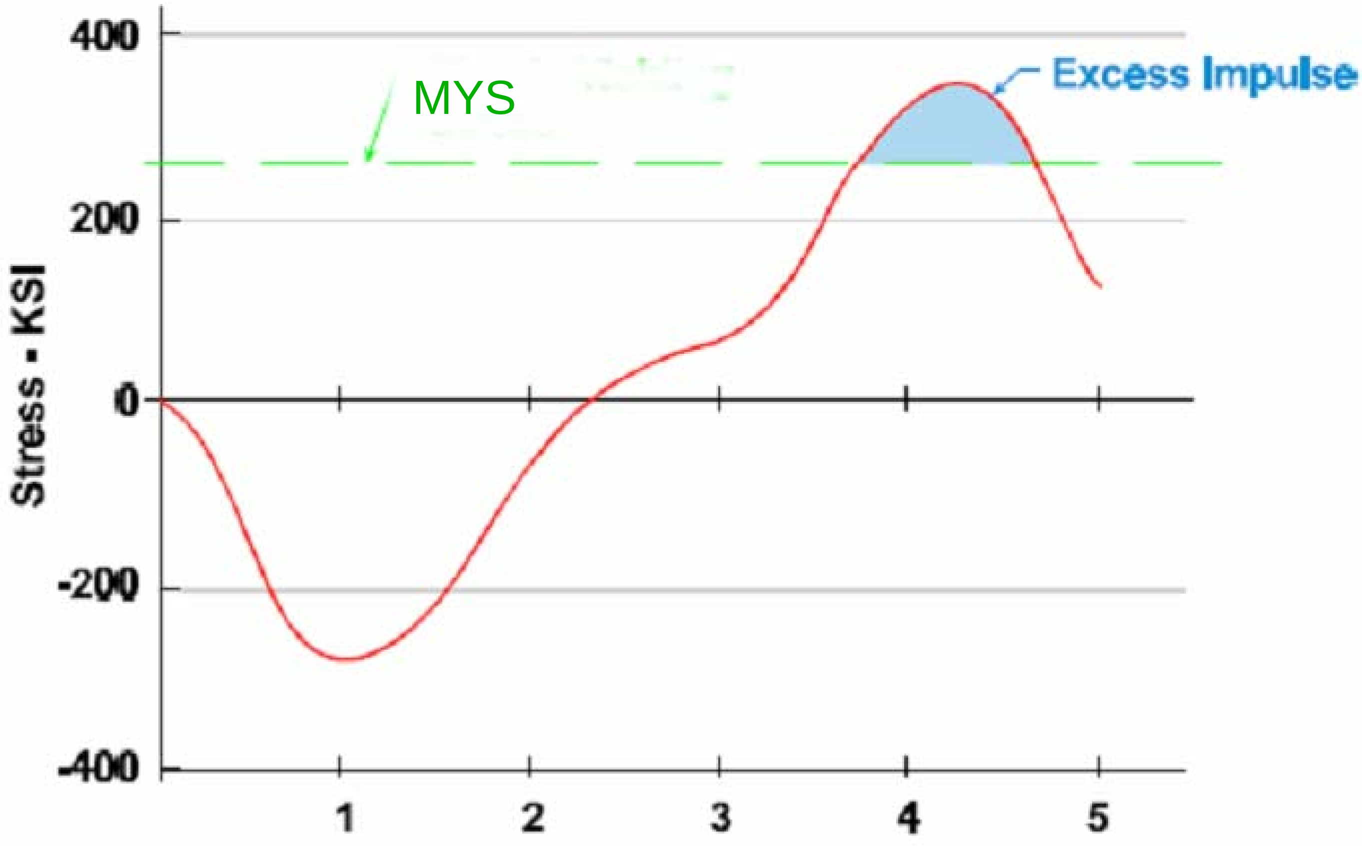
The Stress Measurement

- Rigid Body (RB) Movements (Axial tape measure but lateral micrometer) form basis of the Algorithm
  - Body encountering a resisting target with a force of opposite sense as velocity and proportional to V^2
  - Rise time equal to crater depth (Nose Length)
  - Axial RB Stress Waveform a non-structured trapezoid (= low frequency <100 Hz)
  - Lateral RB Stress Waveform a low frequency sinusoid (<500Hz)
  - Total (Heterodyned) Stress RB Waveform a non-structured Sinusoid (= low frequency extraction ~300 Hz)

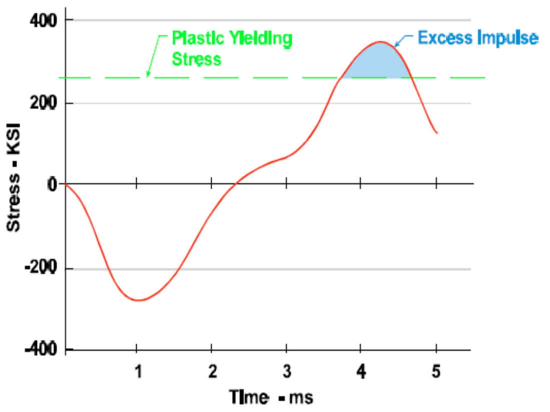
Axial Characteristics of RB Signal



Heterodyned Axial & Lateral Characteristics of RB Signal



Heterodyned Signal is the Running 'beat' of Axial and Lateral Case Stresses which forms a Low Frequency Sinusoid



- A plastic yielding stress is defined; it is:
  - A Modified Yield Strength (MYS) which
    - Takes into account strain rate effects and
    - Is approximately 20% higher than yield
- When the Heterodyned Signal exceeds the MYS
  - The area (Integral above MYS) is defined as an excess impulse (EI)
  - The maximum allowable excess impulse (MAEI) is defined as the "Failure Criteria" (point)
  - And thus a singular value (empirically determined) annunciates failure

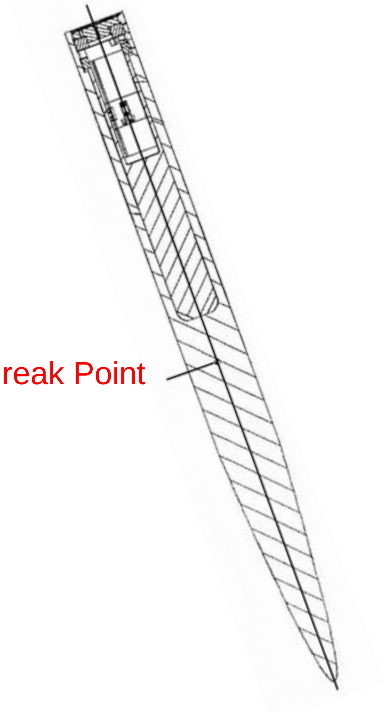
Testing the Robustness of the EI Algorithm

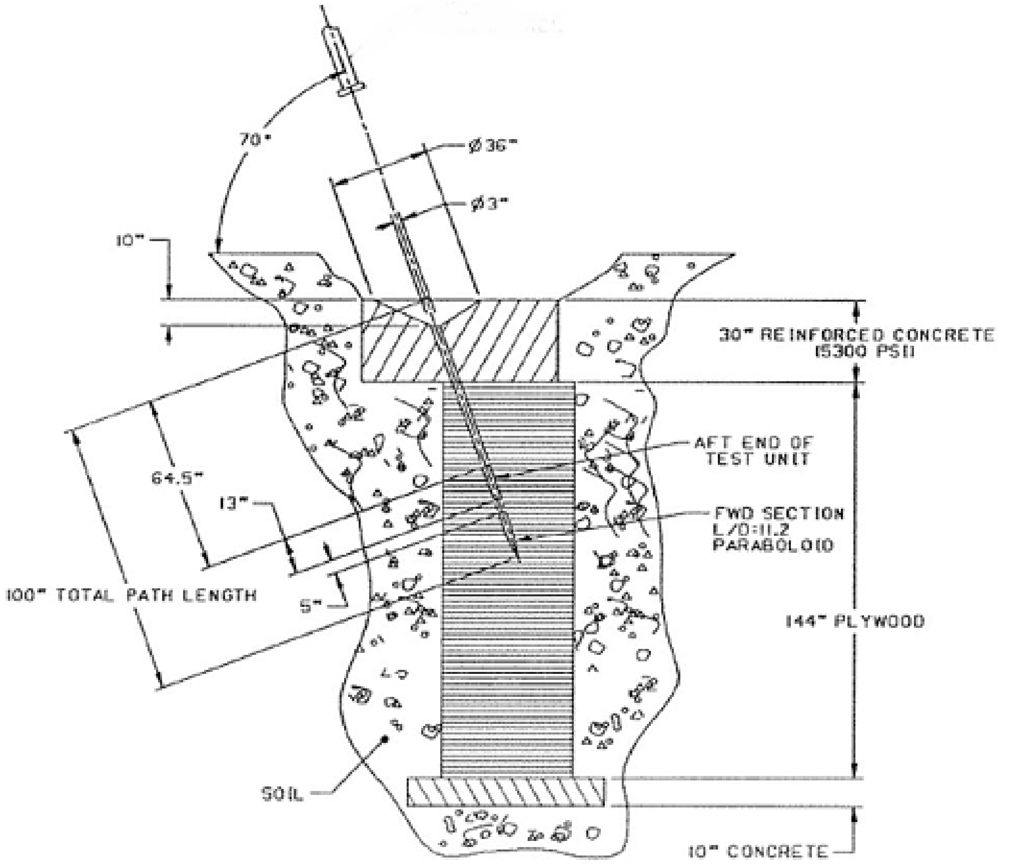
- First the MYS value is selected for the Device Under Test
  - While Scaled from Empirically based knowledge and Somewhat Arbitrary it:
    - Is selected in the plastic regime of the material stress strain curve
      - Since area within the linear elastic region (LER) is not of concern and
      - Short excursion into the plastic regime are not of concern and
      - Selection in the LER would desensitize the MAEI
- Second the initial conditions for the DUT are calculated to exceed the failure criteria
- The Device is tested, under these conditions, to failure and the EI algorithm failure criteria exactly determined
- By scaling, the EI value for the entire family of weapon enclosure failure points is determined
- Low cost scaled family testing is utilized to empirically determine the critical point as:
  - Signal Strength is not effected by scale leaving electrical and calculation systems unaffected
  - The selected scales maintain constant strain rate effects for the rest of the family

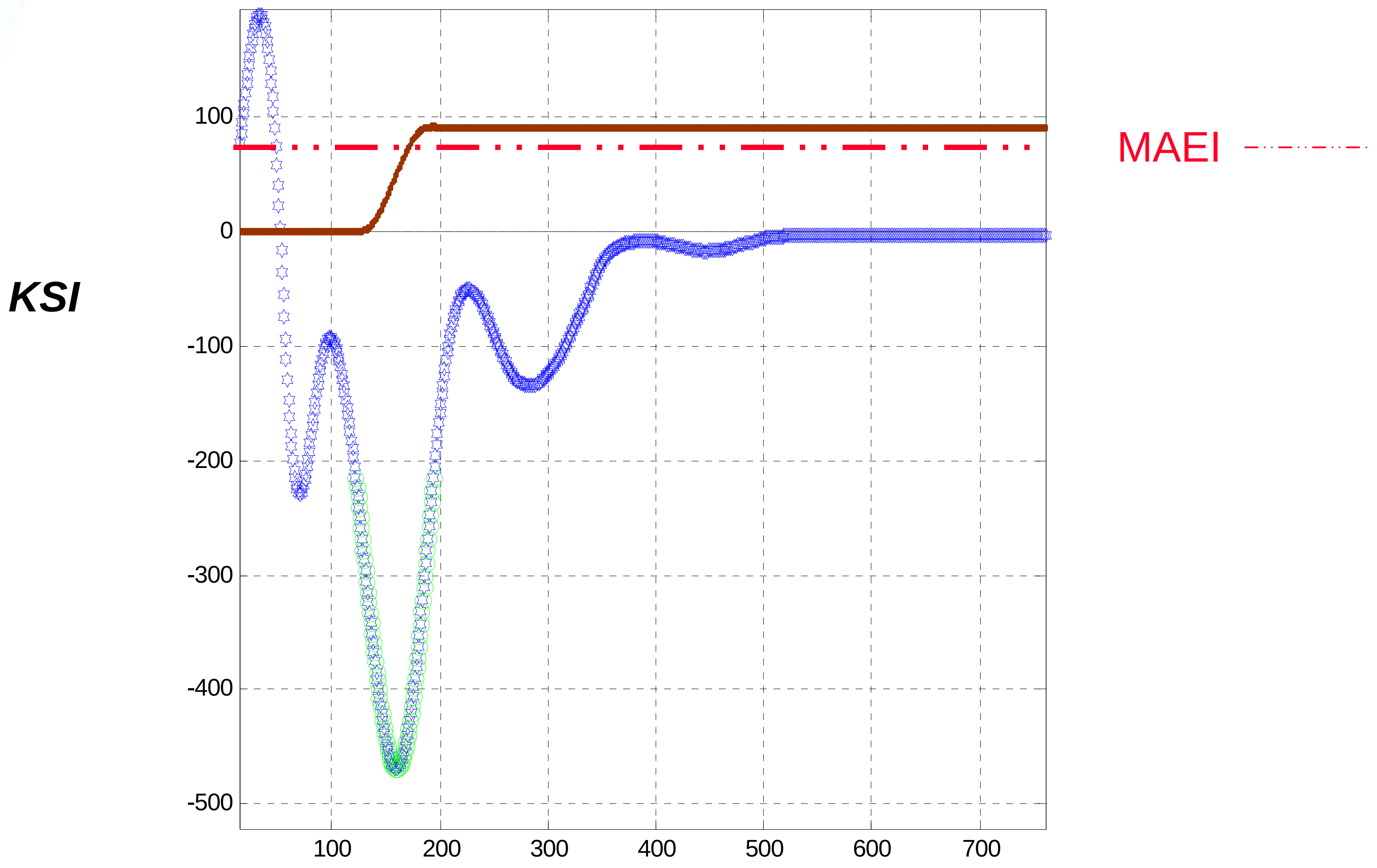
Verification Test No. 1 – OD 2.7" – L/D 11.2 – W 38# - 2 Degrees Nose Up

Velocity = 1200'/sec

Break Point





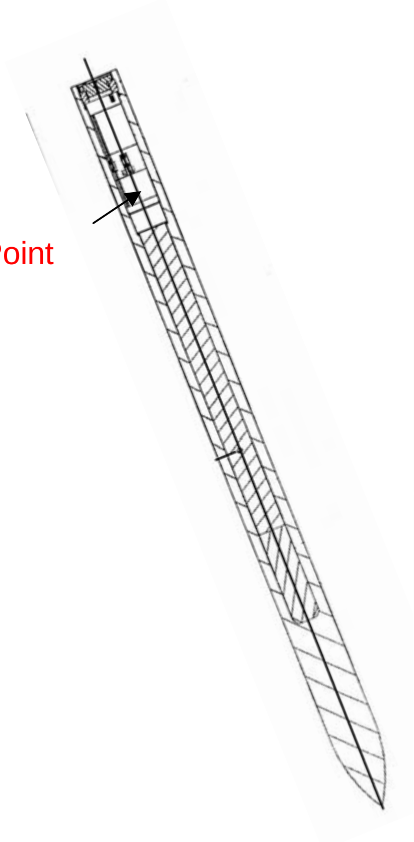


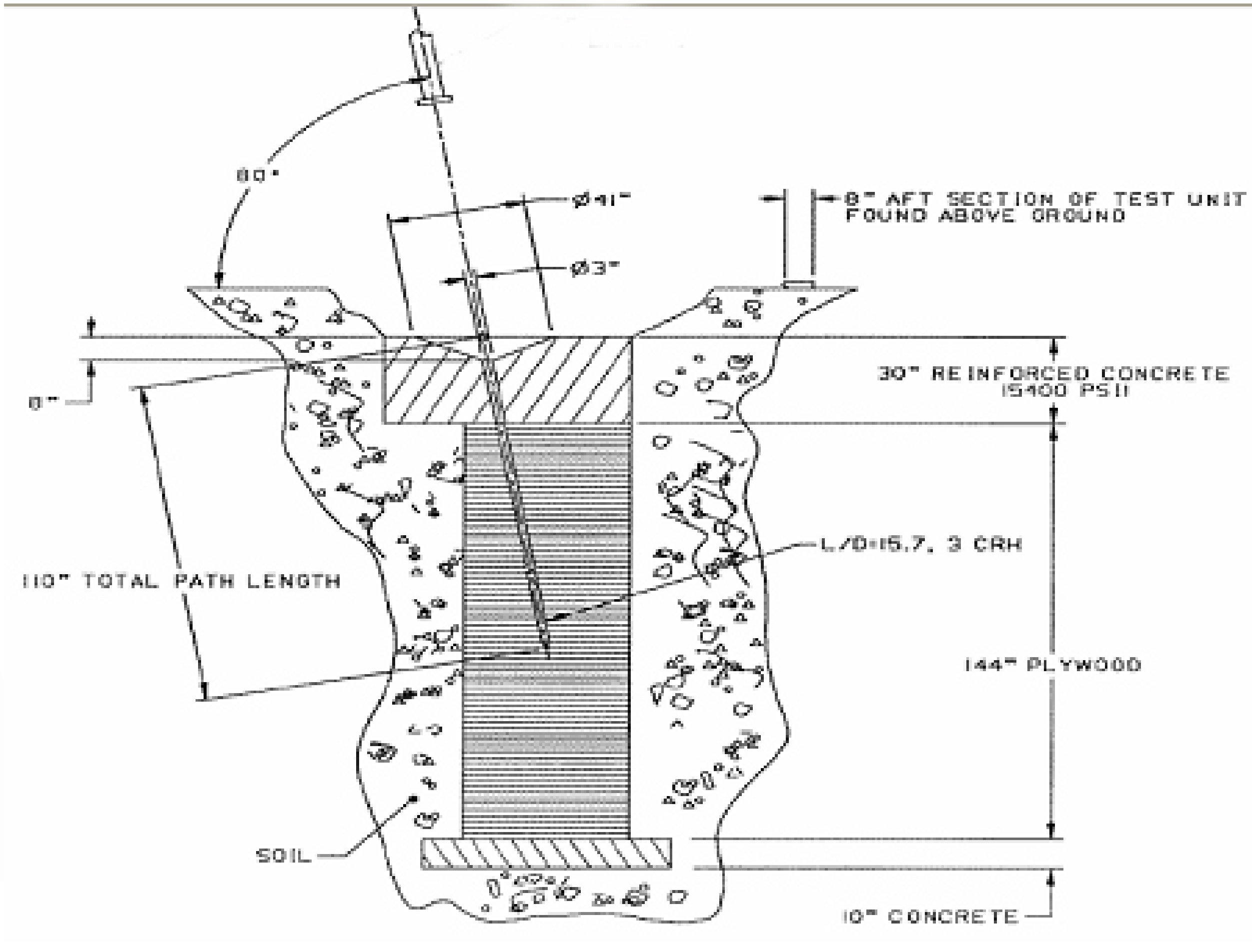
Heterodyned Stress Signal, **Excess Impulse Integral**, and Integration Area

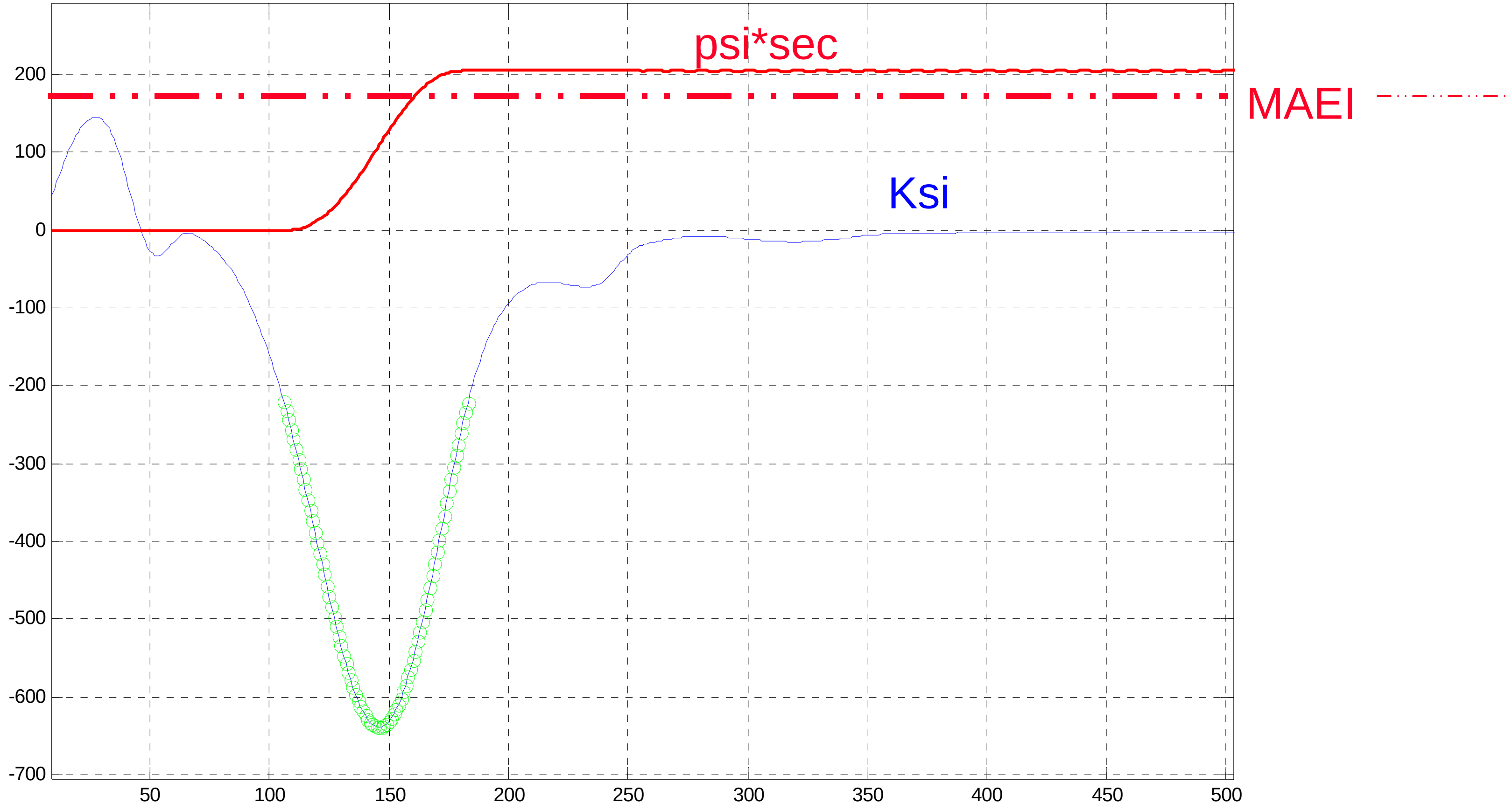
Test No. 2 – OD 2.25" – L/D 15.7 – W 38# - 2 Degrees Nose Up

Velocity = 1170'/sec

Break Point

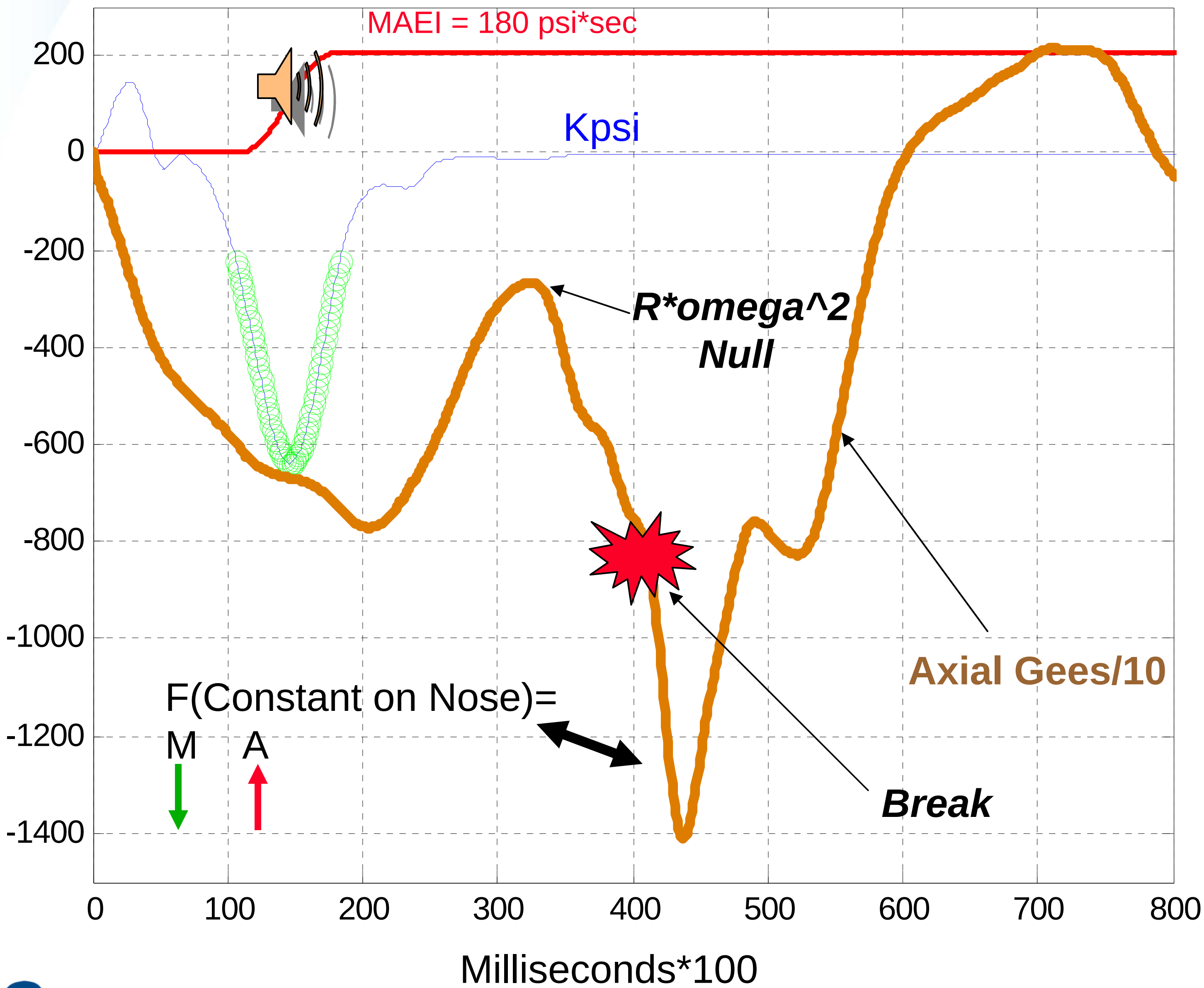






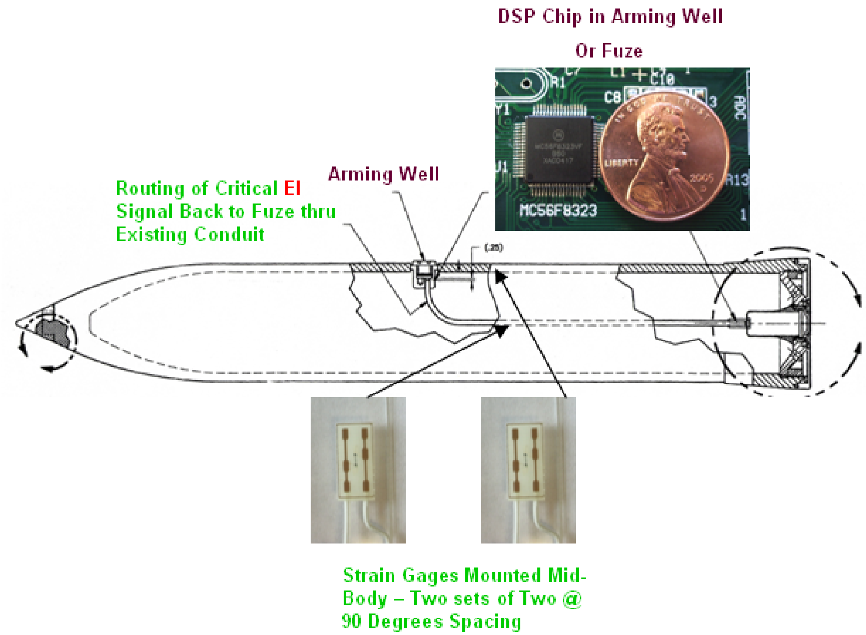
Heterodyned Stress Signal, Excess Impulse Integral, and Integration Area

Do We Signal in Time? YES



An Example

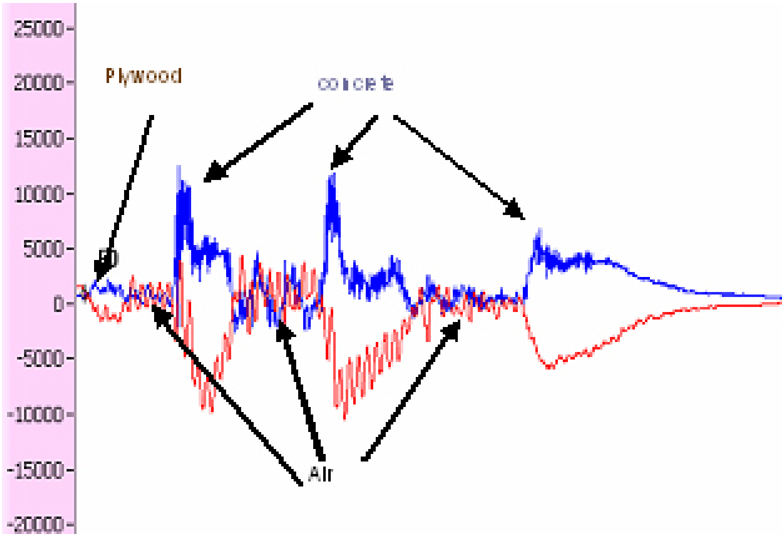
- Axial & Lateral low cost Semi-conductor strain gages are placed near CG
- Set duplicated at a point 90 degrees rotated from the first
- First set is on nose to tail axis
- Thin wires routed underneath aspaltic primer to fuze where bridge power is picked up or fzu power used and fire signal impressed on existing wires then demodulated at fuze
- Gages produce ~1 volt signal and case acts as anti- alias filter
- Heterodyned Signal directly connected to chip A/D. No amplifier, no filter. Chip extracts the low frequency component (filter) or digital beating is used
- ***This DSP microcontroller chip with GPIO makes the integration, interprets the result, outputs command to fire when critical EI value is reached***



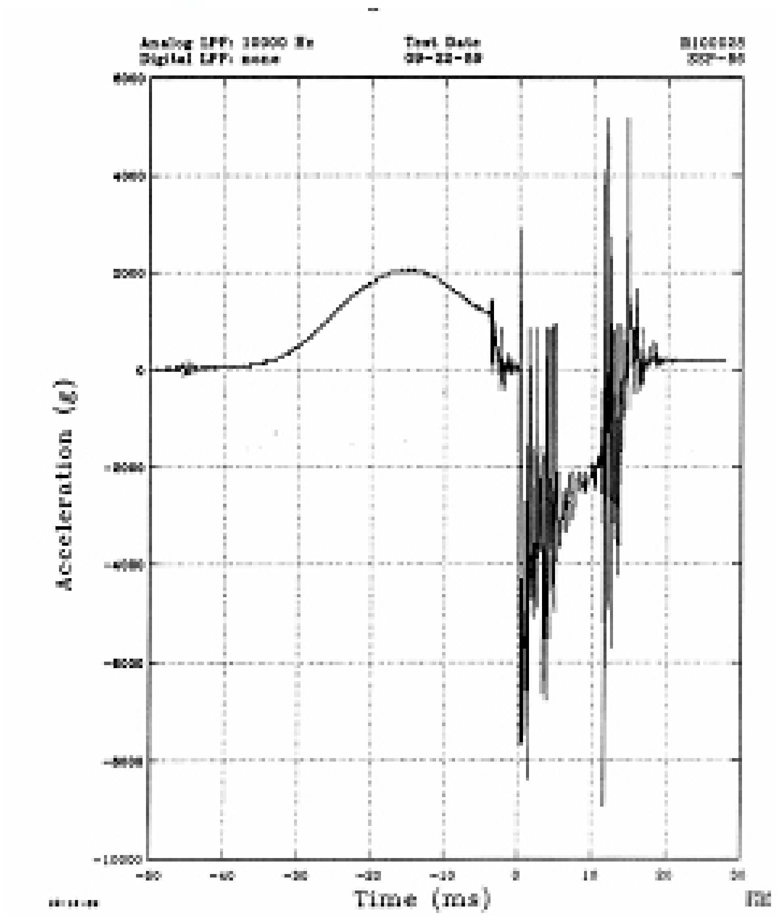
This example can be applied to any weapon case of any geometry

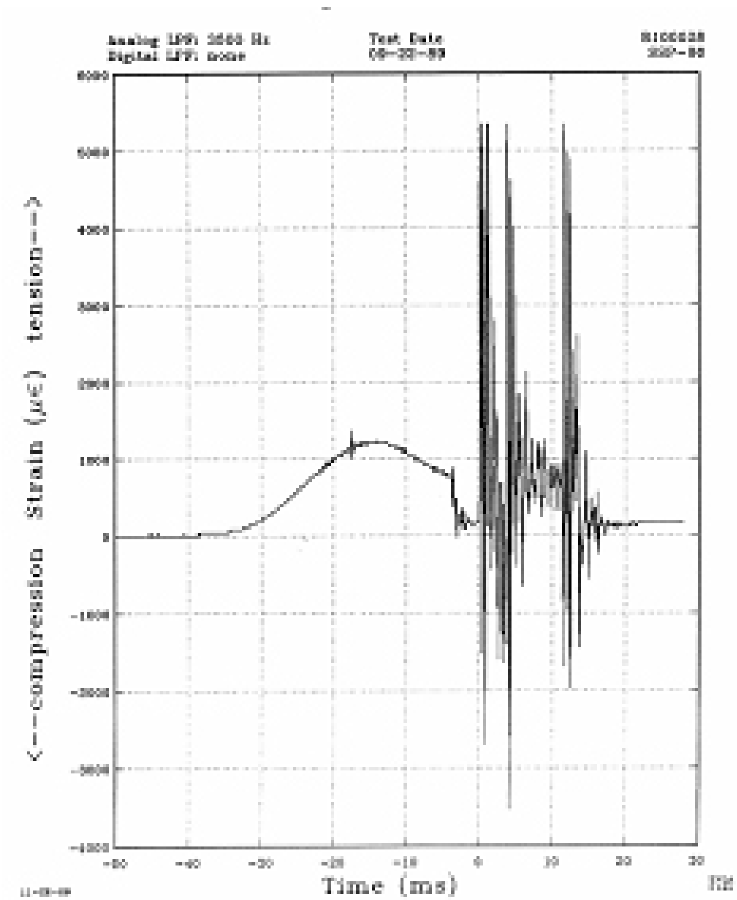
An Additional Use of the Strain Sensor

- The axial sensing gages in previous example will reproduce rigid body deceleration.
- The case mass above the gages provide enough impetus to preserve a robust SNR
- To the right results from an Edisonion Effort to:
  - Compare 7270 to Strain Gage
  - 100 # projectile @ 2500'/sec
  - Multilayer Target consisting of:
    - Concrete
    - Plywood
    - Air
- As shown the agreement is good and in this case preserves area.
- Thus, the sensor can act as a layer detector at 1/1000 of the cost. The controller need only be re-programmed with a detection algorithm



Another Comparison
1400’/sec 800 # Accel vs Strain





Program Accomplishments

- ***A Means & Method to:***
  - ***Detect and Monitor Stresses Caused by:***
    - ***Weapon Case Axial Loads***
    - ***Weapon Case Lateral Loads and***
  - ***Distinguish Between Normal and Deleterious Stress Conditions***

  Was developed
- ***The Method was Verified Against Real World Events***
- ***Detection algorithm was developed***
- ***A preliminary Design of the Damage Signaling Circuitry was completed***
- ***Alternative smart uses of strain gages verified thru Edisonion methods***