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Transducers for Structural Dynamics and Solid Mechanics

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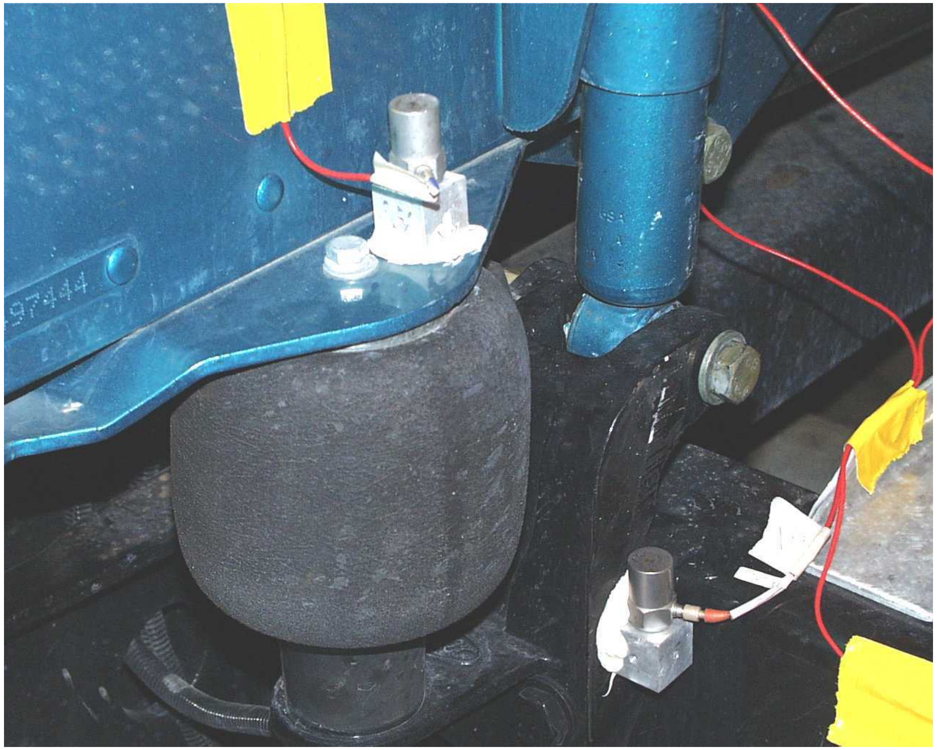
Topics

- Introduction
- Strain Gages
- Accelerometers
- Force Transducers
- Displacement Transducers



Introduction

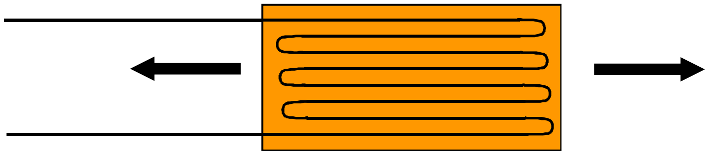
- Many different quantities to be measured
  - Strain
  - Acceleration
  - Force
  - Displacement
  - Velocity (to be covered in a later lecture)
- Different gages for different response levels/environments
  - Important to choose proper gage for application
- Mounting of gage important
  - Ease of mounting vs integrity of mount
  - Mounts can affect response

Strain Gages

- Used to measure strain
- Available in
  - Uniaxial: one axis of strain
  - Biaxial: two orthogonal axis of strain (principal strains when orientation is known)
  - Three element Rosettes: complete 2-D state of strain
  - Shear: direct measure of shear strain

How does a Strain Gage work

Δresistivity = Δresistivity due to Δgeometry
+ Δresistivity due to piezoresistive effect



- Gage consists of loops of wire
- Stretching of gage produces a change in resistance in the wire
- Resistance drop is measured by a voltage change in a Bridge
- Measured strain is an average over the length of gage

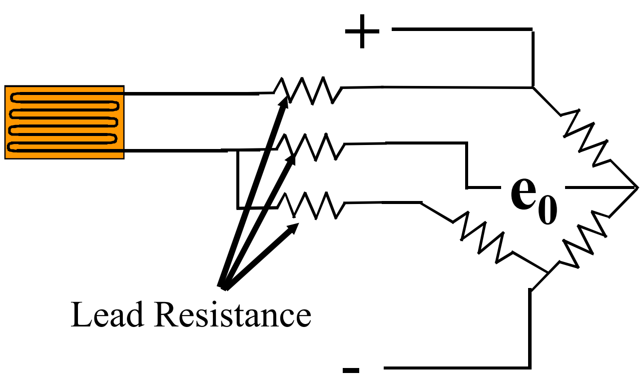
Applications

- Monitoring for yield in materials
- Model validation
- Failure Analysis
- Load Characterization

Implementation Details

- Typically mounted using high strength glue
  - Abnormal environments require advanced bonding
- Requires amplifiers to complete bridge circuit
- Temperature Compensation
- Noise Attenuation
  - Strain gages look and act like antennas

Basic Setup
(3 wire)



Calibration and Sensitivity

- Sensitivity specified in Gage Factor
  - Gage Factor (%Δresistivity/strain)
- Gage Factor provided by manufacturer based upon “lot” that gage is a member of
- Sensitivity (strain/voltage) is based upon gage factor
- Sensitivity varies based upon expected range to be measured
  - Resistivity change in wire is slightly non-linear

What to look for in a Strain Gage

- Range of strains expected
- Mounting Surface
- Material being strained
  - Softer material requires softer strain gage
  - Most strain gages designed for steel/aluminum like stiffness
  - Orthotropic
- Operating environment
  - Temperature
  - Electric Fields
  - Flying Debris

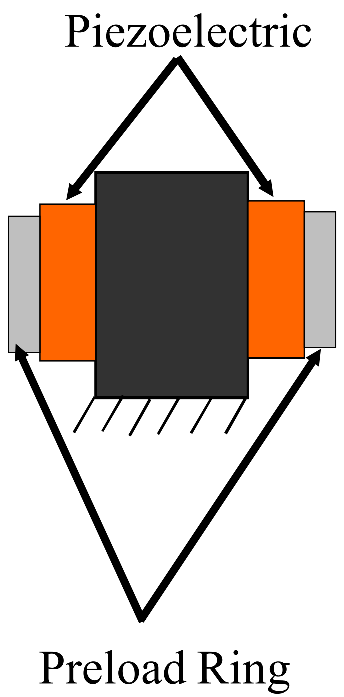
Piezoelectric Strain Gages

- Self contained like an accelerometer
- Conditioned like an accelerometer
- Mounts like an accelerometer
- Only measures dynamic strain
  - PE gages are not sensitive to static loads

Accelerometers

- Used to measure acceleration
- Most common measurement in structural dynamics/solid mechanics
- Two major types of accelerometers
  - Piezoelectric
  - Piezoresistive
- Available in
  - Uniaxial: Measures single direction
  - Biaxial: Measures two orthogonal axes
  - Triaxial: Measures three orthogonal axes

Piezoelectric Accelerometers



Shear Mode Accelerometer

- Used to measure low accelerations
  - Modal levels
  - Shaker Environments
  - Non-shock Environments
- Measure the charge in a deformed quartz crystal to estimate acceleration
- Not sensitive to DC

Signal Conditioning

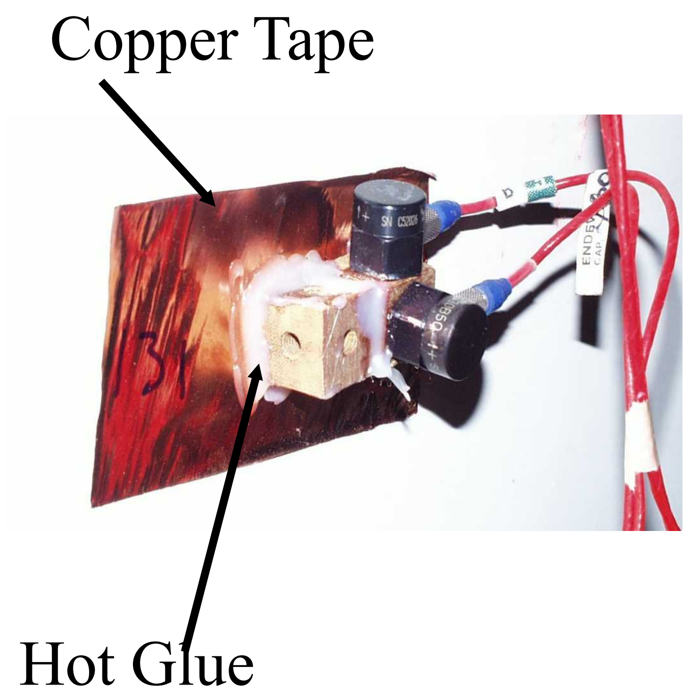
- Three types of Piezoelectric Accelerometers
  - Integrated Circuit (IEPE, ICP, etc)
    - Most common
    - Requires a small current (4-10 milliamps) power
    - Outputs a voltage proportional to (force) acceleration
    - Circuits internal to accelerometer convert charge to voltage
  - Charge Mode
    - Requires external conditioning to convert charge to voltage
  - TEDS (Transducer Electronic Data Sheet)
    - Has internal permanent (ROM) and programmable (EEPROM) memory
    - Has serial number, manufacturer, sensitivity, cal date, etc stored internally
    - Can access serial number, etc through conditioning system
    - Has small amount of internal memory to store other information such as location

Environment Sensitivity

- Base Strain
  - Strain at the base of the accelerometer appears as a measured acceleration
  - Gage needs to be isolated through the use of a mounting block
- Thermal loads
  - Temperature variations cause the sensitivity of the gage to vary
  - May need to insulate gages to protect from thermal variations
- Acoustics
  - Sound waves around test article can induce measured response on accelerometer (non-structural)
  - Test when lab is quite or isolate gage

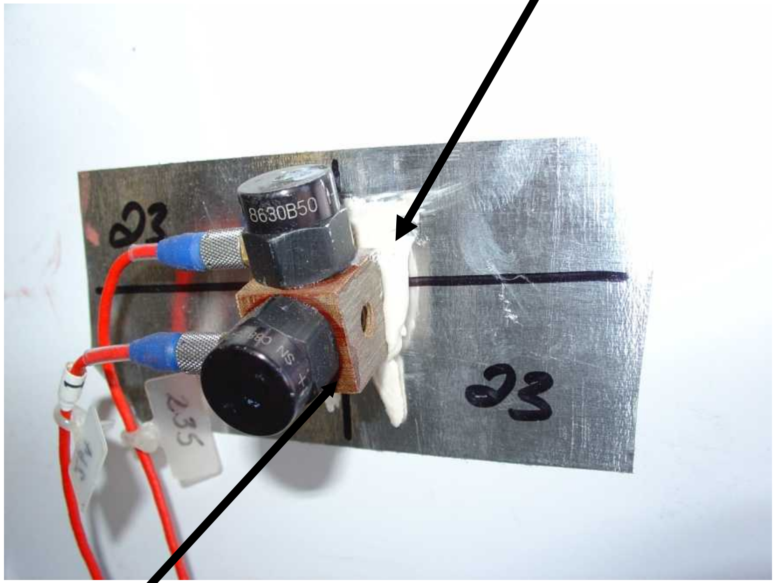
Mounting Techniques

- Wax
  - Low frequency/Amplitude applications
  - Quick
  - Not permanent or reliable
    - Not for internal gages
- Hot Glue
  - Quick
  - Very common mounting technique
  - Can debond adhesive on mounting surface (copper tape)



Mounting Techniques (con't)

Dental Cement



Super Glue

- Super Glue
  - Cyanoacrylate
  - Quick, very common
  - Good for small accelerometers
  - Strong bond
  - No filling capabilities
  - Weak in shear
- Dental Cement
  - Strong, Stiff
  - Can act as filler
  - Good for large accelerometers
- Torr Seal
  - Vacuum bonding agent
  - Very strong bond
  - Not used much with PE

Mounting Techniques (con't)

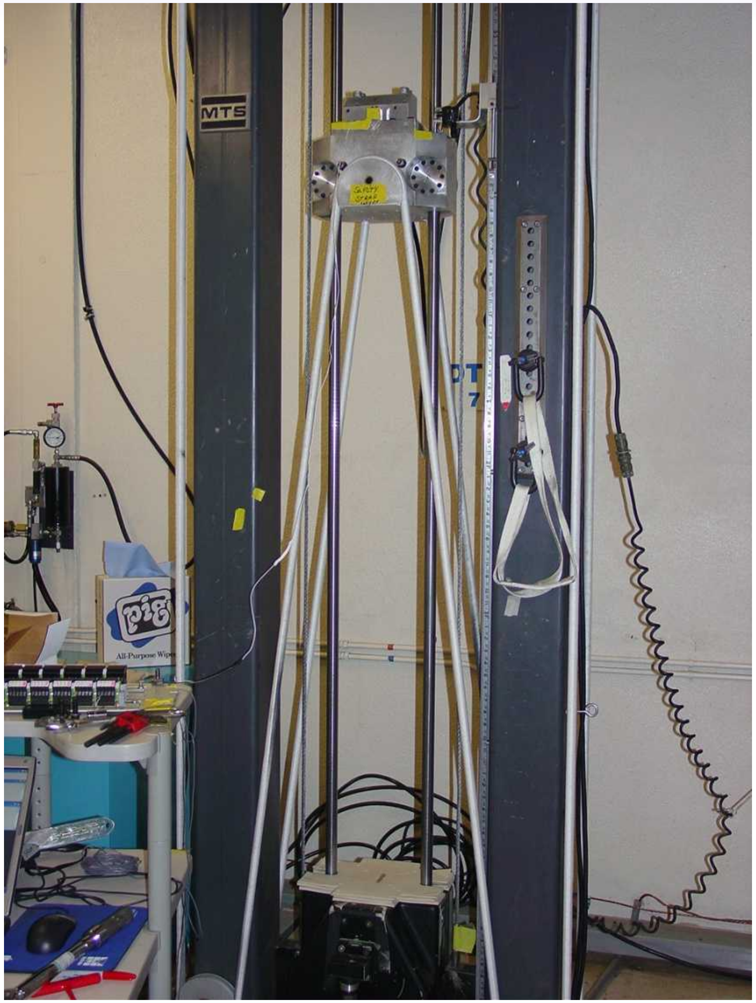
- Stud Mounting
  - Extremely Strong
  - Used for permanent mounting
  - Sometimes used in combination with a bond
  - Failure requires mounting screw to break

Piezoelectric Accelerometer Summary

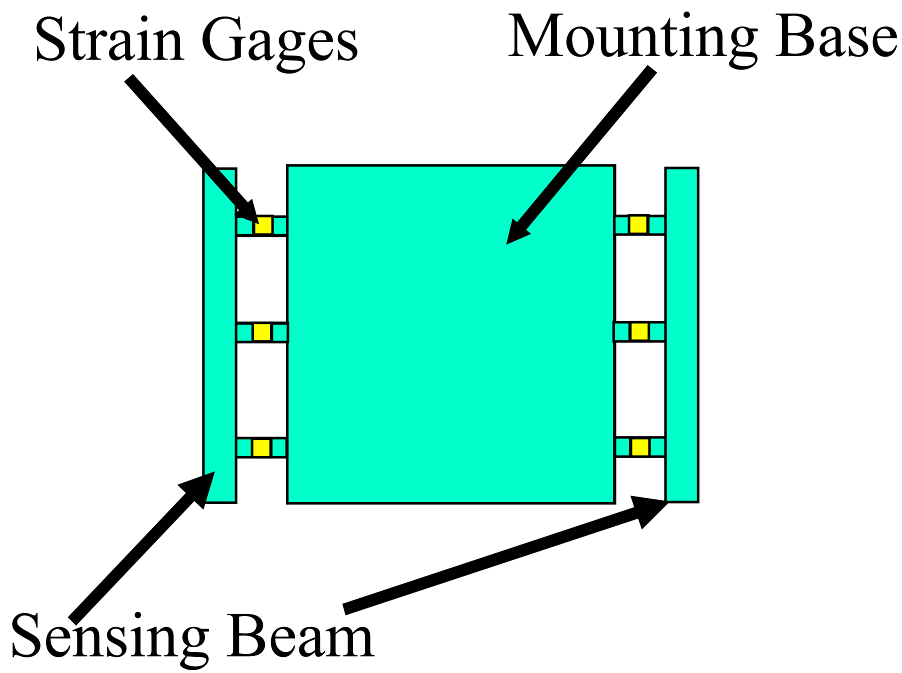
- Good for low amplitude, non-shock responses
  - Modal measurements
  - Shaker Environments
- Measures response of crystal to estimate acceleration
- Requires a small current to drive
- Can measure environment as well as acceleration
  - Need to minimize environment sensitivity
  - Acts as an unknown bias (epistemic uncertainty) on the gage
- Mounting dependent on application

Piezoresistive Accelerometers

- Used to measure shock events
  - Hopkinson Bar
  - Drop table
  - Drop/pull-down tests
  - LIHE/Mag-flyer Impulse tests
  - Sled Track
  - Explosive tests



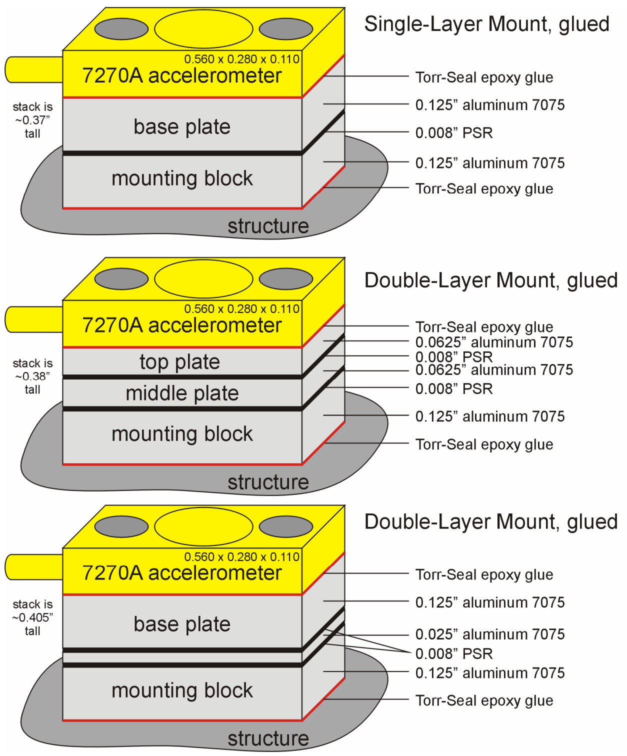
How does a PR Gage work?



- Piezoresistive gages measure the strain developed in a beam during loading
- The strain is linearly related to acceleration (to a point)
- Calibration is used to relate strain to acceleration
- Gage contains three legs of the Bridge
- Conditioning amplifier completes the bridge

Mounting Techniques

- Base Strain Sensitive
  - Mount on a Block
  - Endevco 7270 has mounting requirements called out
- Short duration/High Frequency responses can "ring" the gage
  - Ringing is defined as exciting the natural resonance of the accelerometer
  - Typically for these environments, the gage is mechanically isolated (filtered) to minimize ringing
  - Isolation affects frequency response
    - Can attenuate frequencies of interest
    - Characterize the isolation
- Sensitive to high electric fields
  - Need to isolate/ground properly



Which PR gage do I use?

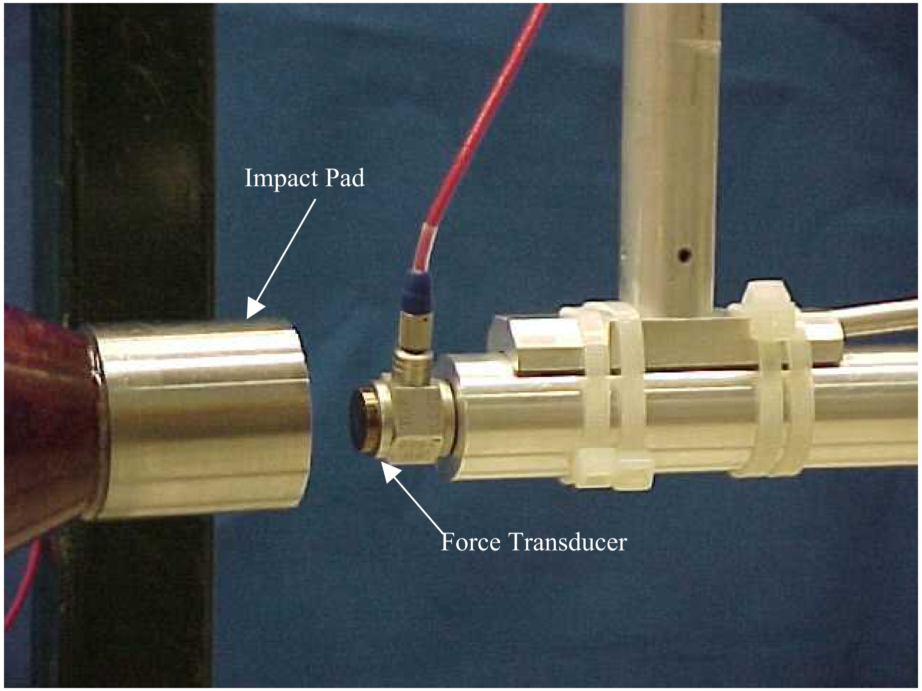
- Expected range of Accelerations
  - 2 kG, 6 kG, 20 kG, 60 kG, 200 kG
  - Size high for application to insure gage doesn’t over-range
  - Gage is linear (good) to about 2 (3) times the rated range of gage – except for 200 kG gage
- Mounting Technique
  - If low frequency, hard mount accelerometer to structure
  - If high frequency
    - Choose appropriate isolation
    - Choose gage resonance to be out of bandwidth of interest, if possible

Summary of Accelerometers

- Piezoelectric
  - Low acceleration, low frequency environments
  - Very common in modal applications
- Piezoresistive
  - Shock environments
  - High accelerations, high frequency events
  - May need mechanical isolation (mechanical filtering)

Force Transducers

- Used to measure force
- Available for static and dynamic applications
  - Static works like a strain gage
  - Dynamic operates similar to a piezoelectric accelerometer
    - Down to 0.0003 Hertz for some
    - Based upon charge leakage from crystal
- Available with a built in accelerometer (Impedance head)
- Instrumented bolts are also available to measure preload/fixture loads
- Pressure transducers are similar

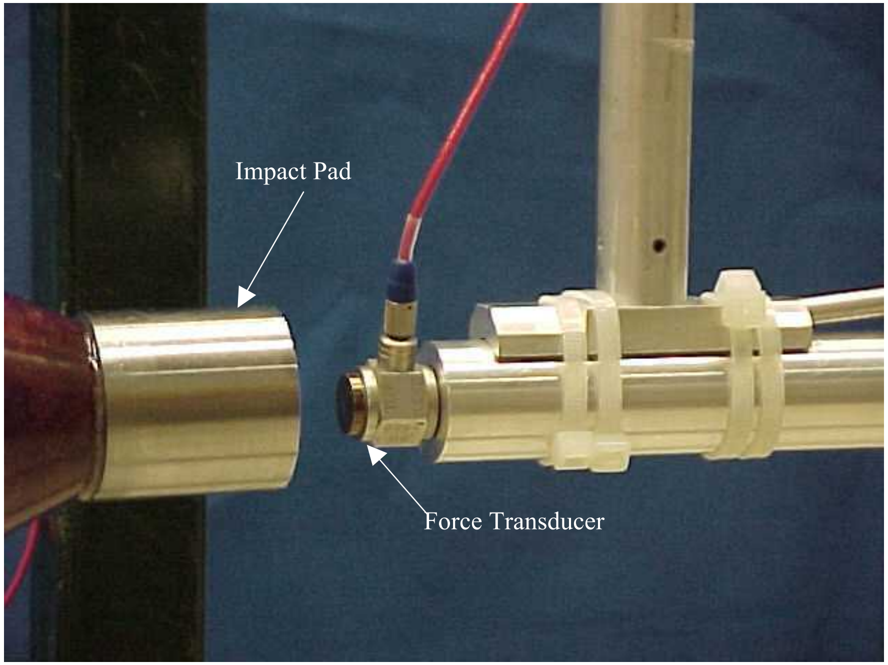


Signal Conditioning

- Static Force Gages require bridge completion like strain gages
- Dynamic Force Gages are conditioned with amplifiers used for piezoelectric accelerometers
  - Require a small (4-20 milliamp) current source
  - Output a voltage

Mounting Techniques

- Typically stud mounted or bolted to structure
- Can be part of testing machine (MTS)
- Calibration performed using reference load cell
- Alignment critical to insure accurate measurement (no moments)



Which Force Gage do I use?

- Static vs Dynamic
- Load range expected
  - Appropriately sized gage will be more accurate in range of interest
- Operating environment
  - Explosive
  - Corrosive
  - High Temperature
- Gage size for application
- Impact of inserting gage into system
  - Typically gage will soften the original system

Displacement Transducers

- Used to measure displacement
- Many different types
  - Linear variable differential transformer (LVDT)
  - String potentiometers
  - LASER based
  - Extensometers (Strain based)
- Frequency response of displacement gages vary greatly

LVDT

- Linear variable differential transformer
- The gage generates a voltage dependent on the location of the center rod
- Has an internal transformer
- Very little applied force
- Very common gage

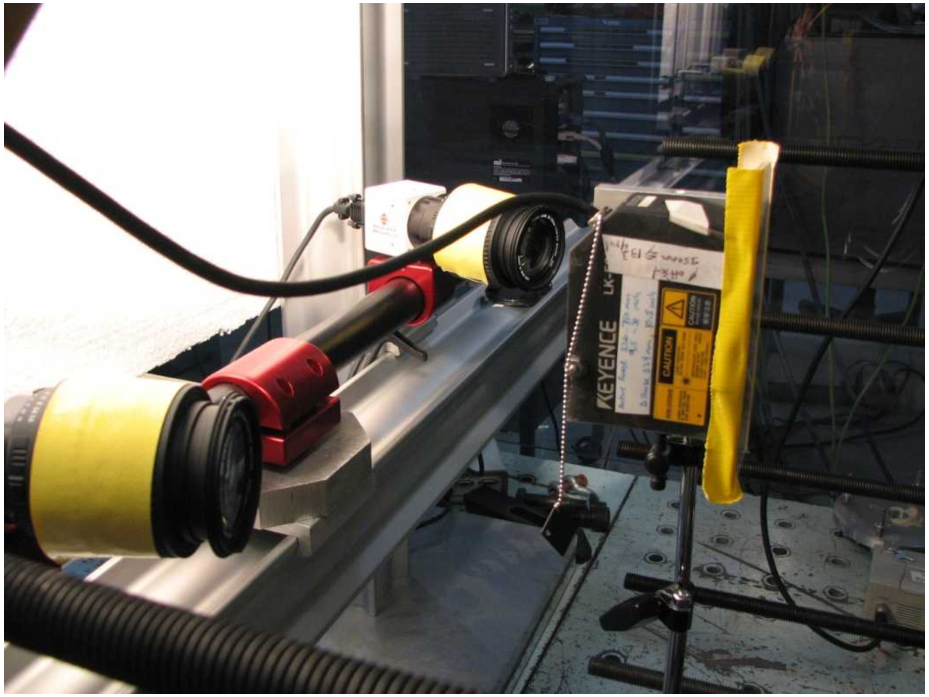
String Potentiometer

String Potentiometer

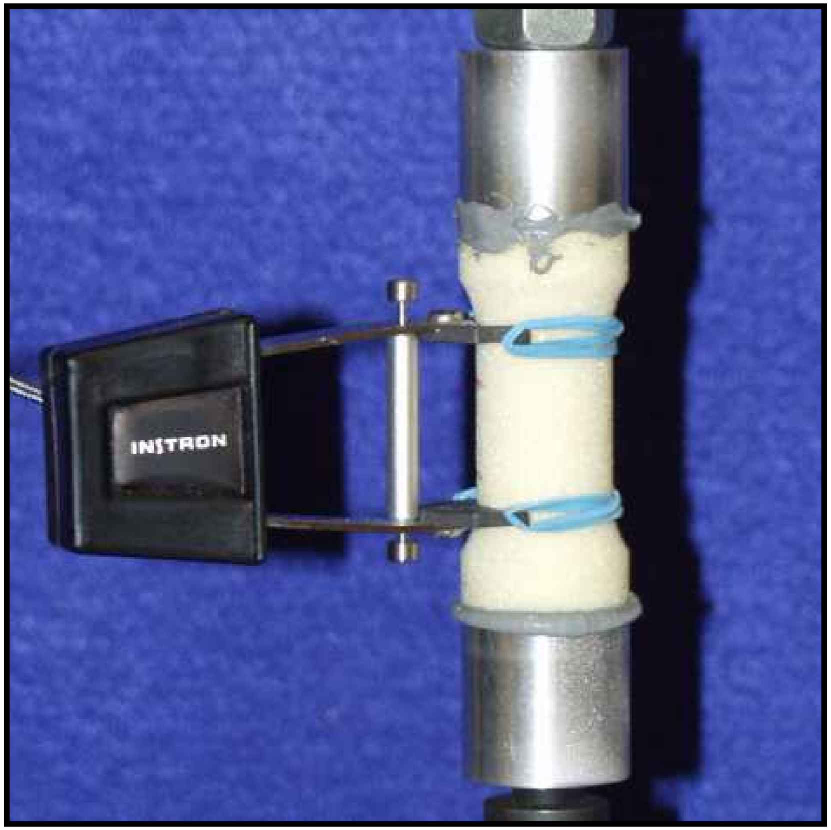
- Very simple in principle
- A string is wrapped around a potentiometer.
- As string is pulled out, the resistance across the pot changes
- Very low frequency response
- Low displacement resolution
- Exhibits drag on string
- Good for measuring very large displacements (inches to feet)

LASER Displacement Gages

- Requires accurate alignment
- Non-contacting (no applied force)
- Large mass



Extensometers



- Operates like a strain gage
- Measures very small displacements
- Produces a force in parallel with test region
- Very robust

Which Displacement Gage to Use?

- Estimate displacement range expected
- Is the force over the test region important?
  - If so than non-contacting or low force gages are important
  - If not than more common options are available
- Operating environment (any special concerns)
- Is the mass of the gage important
  - A displacement gage in a drop test with many accelerometers would need to be smaller than a test to yield of a material

Summary

- Many different quantities to be measured
  - Strain
  - Acceleration
  - Force
  - Displacement
  - Velocity (to be covered in a later lecture)
- Different gages for different response levels/environments
  - Important to choose proper gage for application
- Mounting of gage important
  - Ease of mounting vs integrity of mount
  - Mounts can affect response

Thanks for the Help!

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