Strain Measurement

- **Basic definition:**
  
  \[
  \varepsilon = \frac{\text{change in length}}{\text{length}} = \frac{dL}{L} \\
  \approx \frac{\text{change in length}}{\text{initial length}} = \frac{L - L_0}{L_0} = \frac{\Delta L}{L_0}
  \]

  Must measure a \( \Delta L \) as well as a base length, \( L_0 \).

- **Full-field methods**
  - Optical interference (Moire)
  - Holographic
  - Interferometric
  - brittle coatings
  - grids and rulings
  - photoelastic methods

- **Point measurement**
  - bonded electrical resistance strain gages
  - extensiometers (clip gages)
  - others...

Larger \( L_0 \) means larger \( \Delta L \) for same strain but averages strain over larger length.

Smaller \( L_0 \) provides better spatial resolution but results in smaller \( \Delta L \).
Full Field Measurements

- Useful to see macroscopic effects before looking into details
  - *where will stress be greatest?*
  - *how extensive a region must be studied?*
- Some methods are suitable for large deformations
  - *post-yield and strain to failure*
  - *finite deformations associated with manufacturing*
  - *forming, drawing, extrusion, forging*
- Optical methods are VERY sensitive and generally require a lab environment to function to maximum limits
- Photoelastic methods have been popular over the past 100 years but require tedious casting, machining and “freezing” operations.
  - *3D is complex and tedious.*
  - *Responds to differences in principal stresses*
Polarized Light and the Polariscope
Photoelasticity Basics

- Light transmitted at different velocities along axes aligned with principal strains.
- Index of refraction = speed of light divided by light speed in material.
- Relative retardation, $\delta$, depends on difference in velocities and hence difference in index of refraction on propagation axes.

Brewster’s Law: retardation is proportional to difference in principal strains
- Polarisocopes measure retardation (difference in principal strains) and principal strain directions
- Transmission vs reflection designs
Analysis of Fringes

- **Isoclinics**: black fringes that define lines of constant principal strain directions
- **Isochromatics**: watery colored lines denoting lines of constant differences in principal strains

![Isoclinics and Isochromatics Diagram]
Analysis of Fringes - cont’d

- Can trace lines perpendicular to isoclinics to define isostatics (lines along principal stress directions)
- Determining principal strains is more difficult and requires use of “compensators” to count fringe differences.

See: http://www.measurementsgroup.com
Basic Strain Measurement

• From the definition, we must measure a change in length over some specified base or gage length.
  – fundamentally a displacement measurement
  – must define the gage length

• Strain is computed over gage length
  – smaller gage lengths give better geometric precision
  – larger gage lengths increase sensitivity by allowing larger displacements for the same strain.
Extensiometers

- Simple designs
  - limited sensitivity but can be made quite rugged
  - easily attached and removed (reusable)
Lord Kelvin had the first ideas about resistance and resistivity

First practical (patented) gage appeared in 1938 (Simmons) and Ruge developed it independently
- bonded wire gage
- called SR-4 gages for many years
- bonded with nitrocellulose cement

Metal foil gages
- die cut
- lithographic
- wide variety and form

Other types:
- unbonded wires
- welded
- ...
Rosette Gages

- By making simultaneous measurements of strain in different directions at a point, it is possible to determine the state of strain: $\varepsilon_1$, $\varepsilon_2$, and $\phi$.
- From 3 independent (different) extensional strain readings, one can develop 3 equations to solve for $\varepsilon_1$, $\varepsilon_2$, and $\phi$ and from this to determine strains, $\varepsilon_x$, $\varepsilon_y$ and $\gamma_{xy}$ in any direction.
- Other configurations (2 gages) can also be used.
- See Gere & Timoshenko, Mechanics of Materials
**Gage Materials**

- Wide variety of metals...
  - *strain sensitivity*
  - *fatigue*
  - *max extension*
  - *temperature*
- Semiconductors
  - *HIGH sensitivity*
  - *variable properties!*

<table>
<thead>
<tr>
<th>Material</th>
<th>Composition</th>
<th>Use</th>
<th>GF</th>
<th>Resistivity (Ohm/mil-ft)</th>
<th>Temp. Coef. of Resistance (ppm/F)</th>
<th>Temp. Coef. of Expansion (ppm/F)</th>
<th>Max Operating Temp. (F)</th>
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</thead>
<tbody>
<tr>
<td>Constantan</td>
<td>45% Ni, 55% Cu</td>
<td>Strain Gage</td>
<td>2.0</td>
<td>290</td>
<td>6</td>
<td>8</td>
<td>900</td>
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<tr>
<td>Isoelastic</td>
<td>36% Ni, 8% Cr, 0.5% Mo, 55.5% Fe</td>
<td>Strain gage (dynamic)</td>
<td>3.5</td>
<td>680</td>
<td>260</td>
<td></td>
<td>800</td>
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<tr>
<td>Manganin</td>
<td>84% Cu, 12% Mn, 4% Ni</td>
<td>Strain gage (shock)</td>
<td>0.5</td>
<td>260</td>
<td>6</td>
<td></td>
<td></td>
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<tr>
<td>Nichrome</td>
<td>80% Ni, 20% Cu</td>
<td>Thermometer</td>
<td>2.0</td>
<td>640</td>
<td>220</td>
<td>5</td>
<td>2000</td>
</tr>
<tr>
<td>Iridium-Platinum</td>
<td>95% Pt, 5% Ir</td>
<td>Thermometer</td>
<td>5.1</td>
<td>135</td>
<td>700</td>
<td>5</td>
<td>2000</td>
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<tr>
<td>Monel</td>
<td>67% Ni, 33% Cu</td>
<td></td>
<td>1.9</td>
<td>240</td>
<td>1100</td>
<td></td>
<td></td>
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<tr>
<td>Nickel</td>
<td>-12</td>
<td></td>
<td>-12</td>
<td>45</td>
<td>2400</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Karma</td>
<td>74% Ni, 20% Cr, 3% Al, 3% Fe</td>
<td>Strain Gage (hi temp)</td>
<td>2.4</td>
<td>800</td>
<td>10</td>
<td></td>
<td>1500</td>
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Gage Backing Materials

- “Systems” are provided by gage manufacturers
- Other methods...

<table>
<thead>
<tr>
<th>Grid and Backing Material</th>
<th>Recommended Adhesive</th>
<th>Temperature Range (C)</th>
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<tbody>
<tr>
<td>Foil on epoxy</td>
<td>Cyanoacrylate</td>
<td>-75 to 95</td>
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<tr>
<td>Foil on phenol-impregnated fiberglass</td>
<td>phenolic</td>
<td>-240 to 200</td>
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<tr>
<td>Strippable foil or wire</td>
<td>ceramic</td>
<td>-240 to 400</td>
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<tr>
<td></td>
<td></td>
<td>(to 1000 for short tests)</td>
</tr>
<tr>
<td>Unbonded (free) element</td>
<td>ceramic</td>
<td>-240 to 650</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(to 1200 for short tests)</td>
</tr>
</tbody>
</table>
Gage Application - Surface Preparation

- Method depends on adhesive and gage backing material
- MM M-Bond 200 (cyanoacrylate)

Abrade Surface (400 grit)
Surface Conditioning
Neturalize Surface for Adhesive

Keep Surface Clean and Free of Grease
Gage Application - Gluing to Surface

- M-Bond 200

1. Lay Out Gage & Tabs and Pick Up with Tape

2. Transfer Gage & Tabs to Location

3. Peel Back Gage & Tabs for Adhesive

4. Optional: Apply Accelerator to Back of Gage and let dry completely
Apply SMALL Amount of Adhesive at Crease in Tape

Smoothly Lay Down Tape and Wipe Across to Squeeze out Adhesive

Hold Finger on Tape for 60 Sec.

Carefully Peel Back Tape Exposing Gage & Tabs

DO NOT GLUE YOUR FINGERS
Gage Application - Lead Attachment

- Makes electrical attachment to gage.
- Provides strain relief to protect delicate strain gage from mechanical loads from leadwires.

**Soldering Steps**

- solder jumper wire to gage tab first
- bend jumper & trim until it rests on gage element tab
- solder to gage element tab
- trim & tin leadwires
- solder leadwires to gage tab
- remove any residual flux
- apply gage coating
Gage Application - Soldering Technique

1. Mask Gage and Tabs
2. Solder Strain Relief Jumpers to Tab FIRST
3. Next Solder Jumpers to Gage
4. Solder Leadwires to Tab

Soldering Tips:
- Keep tip of iron “wet” and clean
- Heat junction, THEN apply solder so it melts on junction
- Move quickly to avoid burning gage

Coat Gage with Waterproofing