Strainstall
Sensing the needs of industry

Advanced Strain Gauge Applications
BSSM
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Residual Stress Measurement Techniques

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Residual Stress Measurement Techniques

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Residual Stress Measurement Techniques

Why measure residual stress?

- What live stress a component/structure is capable of
- How effective a surface treatment has been
- Reason for failure

Residual Stress Measurement Techniques

Different Methods of Residual Stress Determination

- **Non strain measurement**

  X Ray, neutron diffraction, DIC, interferometry, laser ultrasound, deep hole methods

- **Strain measurement**

  centre hole, layer removal, material removal

❖ **Only strain gauge based techniques will be discussed in this short presentation**

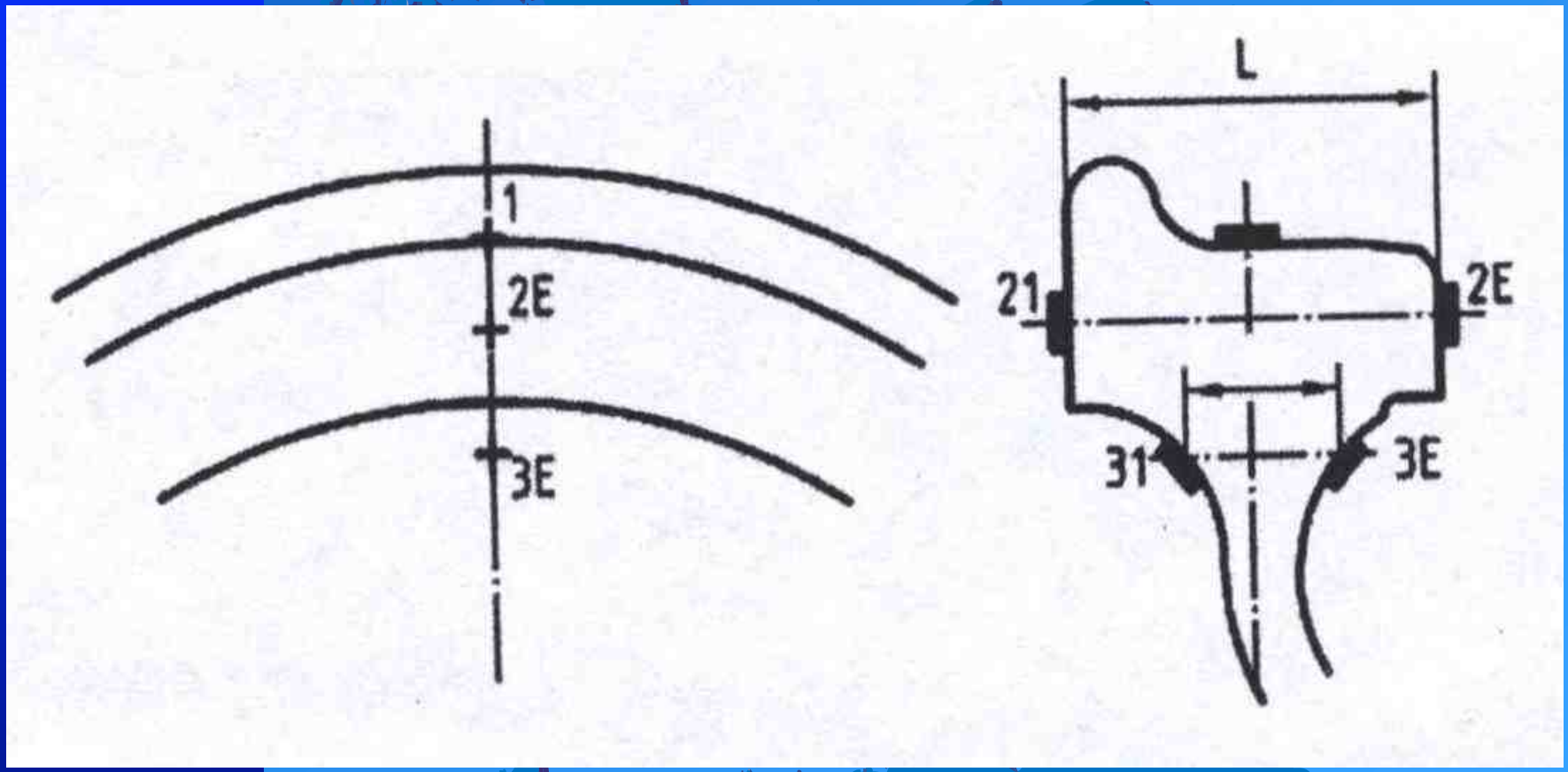
Residual Stress Measurement Techniques

Material Removal

- Destructive technique
- Install a strain gauge and then remove the material until only a small piece of material remains containing the gauge

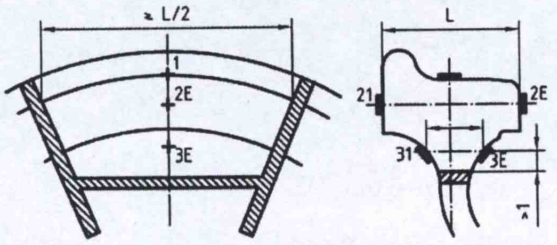
Residual Stress Measurement Techniques

Material Removal – Railway wheel # 1

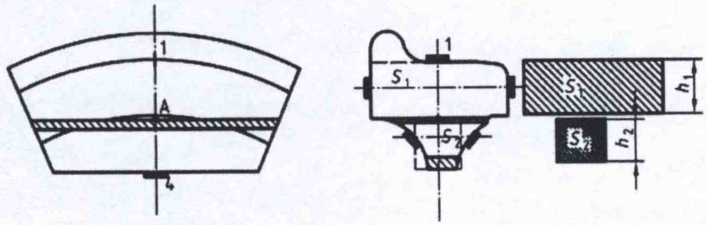


Residual Stress Measurement Techniques

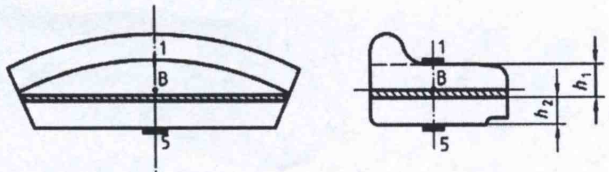
Material Removal – Railway wheel # 2



Cutting operation 1



Cutting operation 2



Cutting operation 3

Residual Stress Measurement Techniques

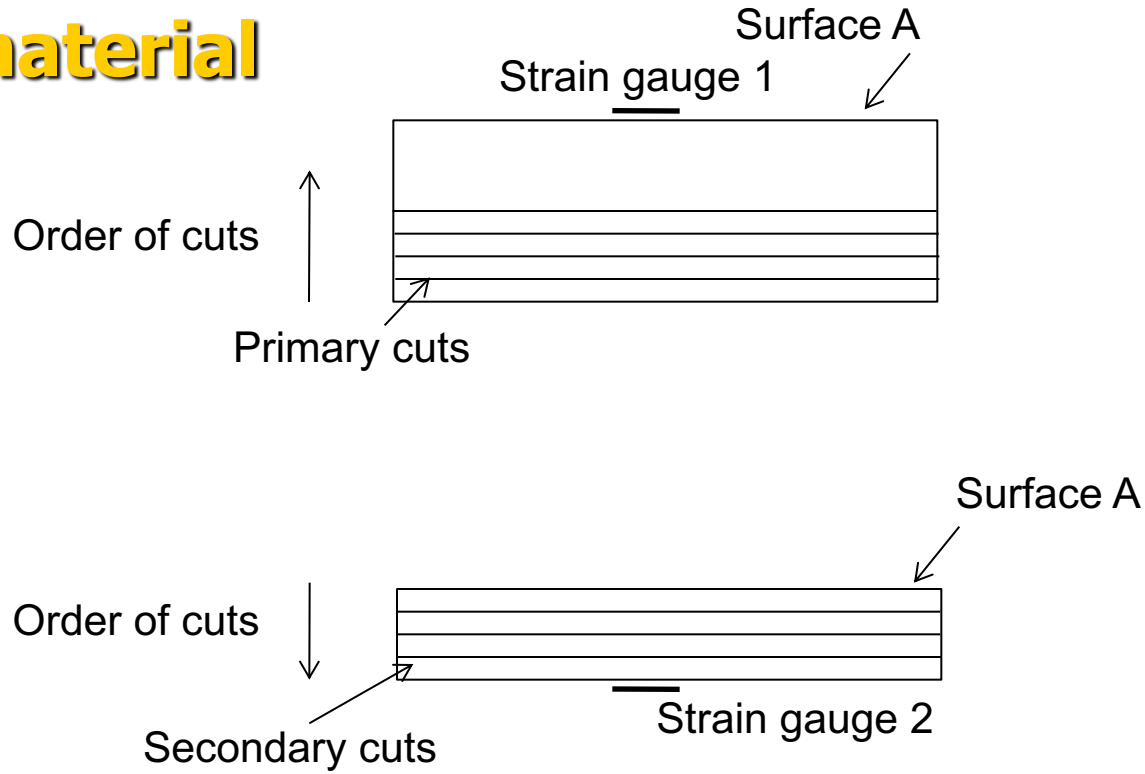
Layer removal

- Destructive technique
- Generally carried out on a coupon of material and a through thickness technique
- Install strain gauge on one surface
- Remove material from opposite surface and record strain change
- Use equations of equilibrium to determine residual stress in layer removed

Residual Stress Measurement Techniques

Layer removal

Flat material



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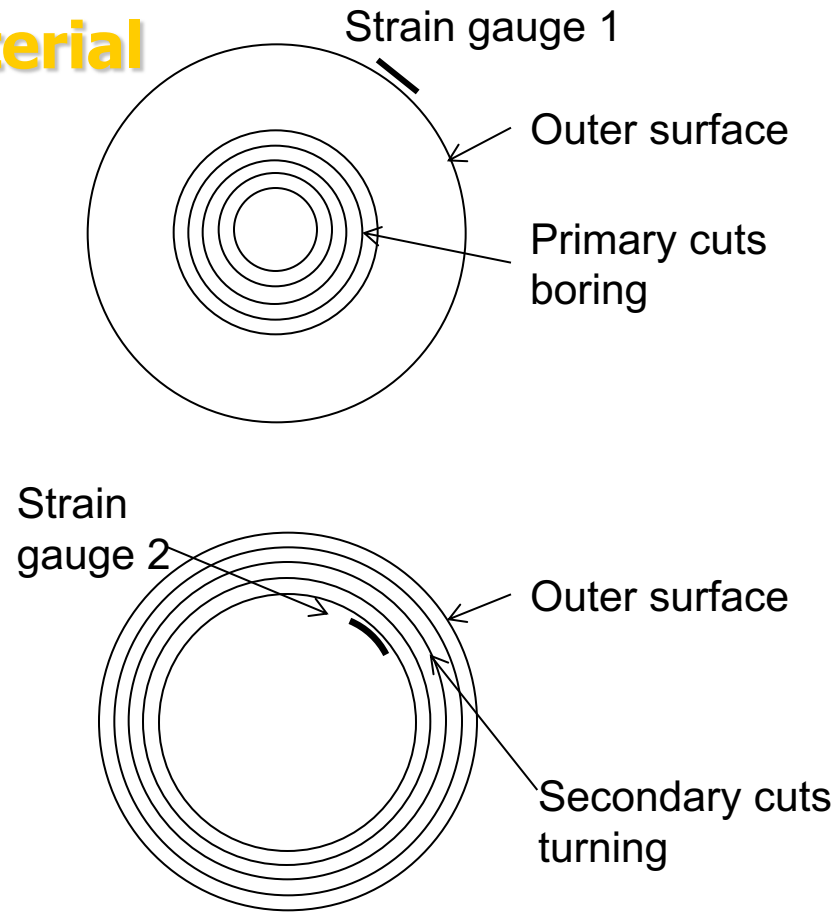
Layer removal

Cylindrical material



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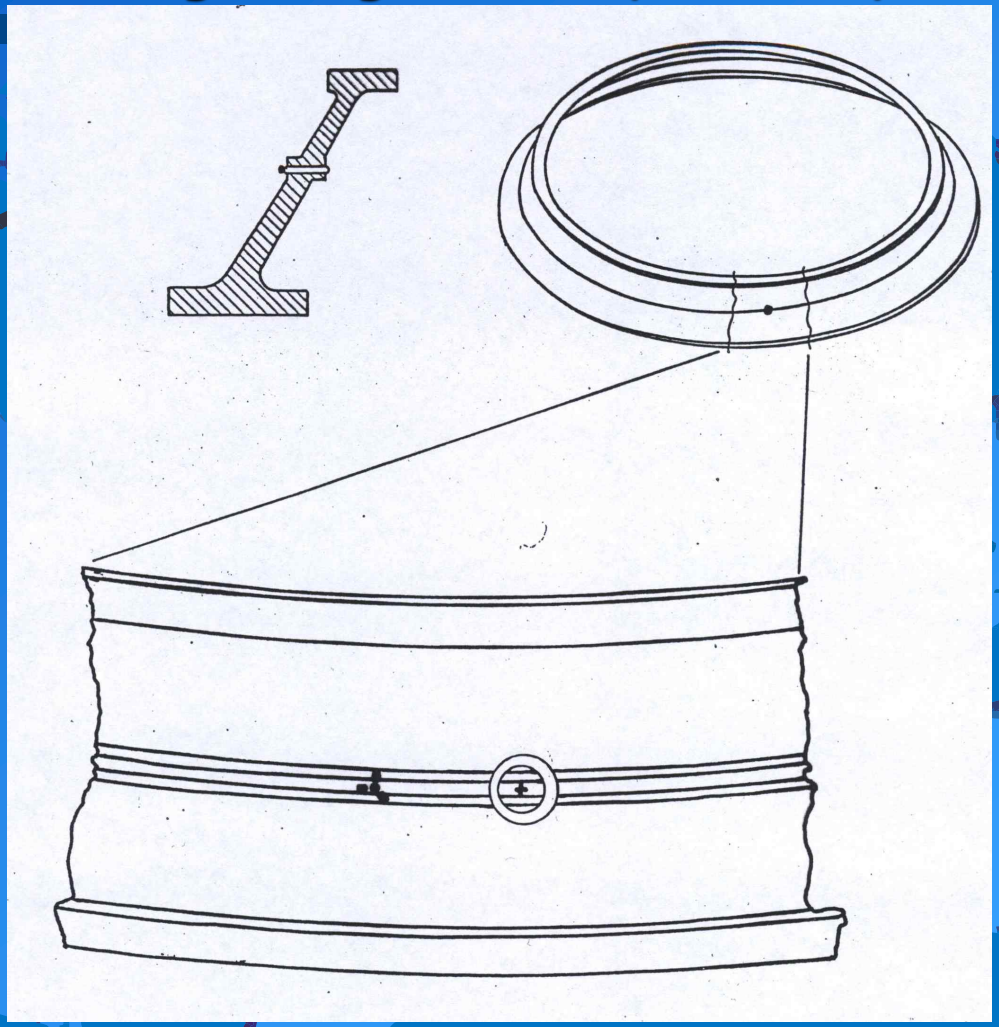
Layer Removal - Ring to ring butt weld, Titanium, Aero engine # 1



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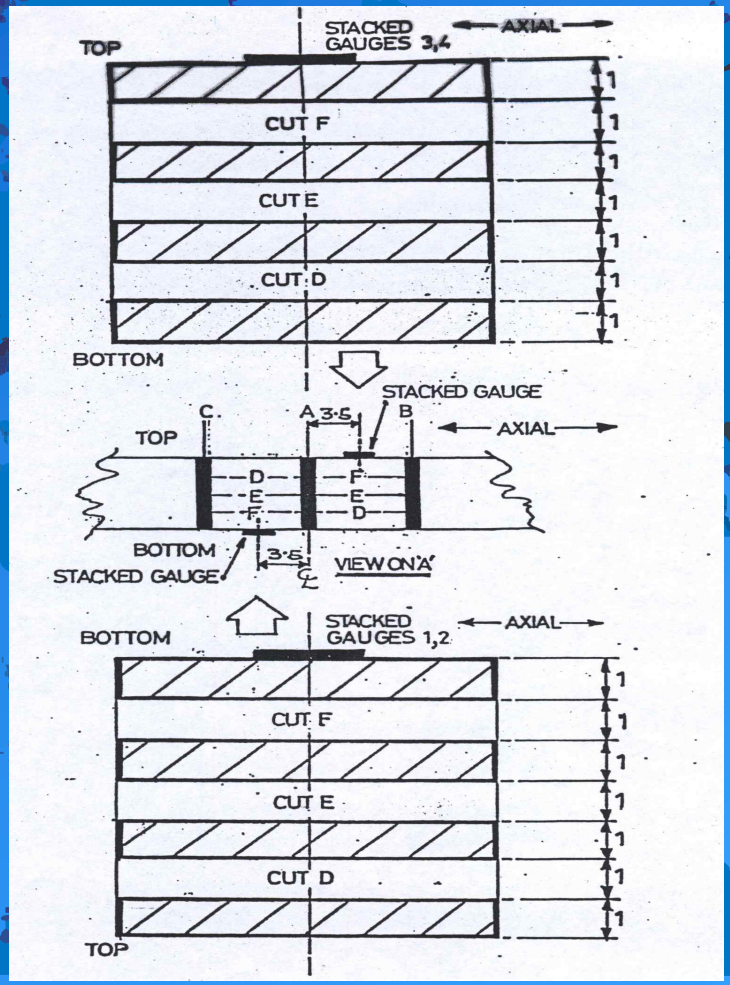
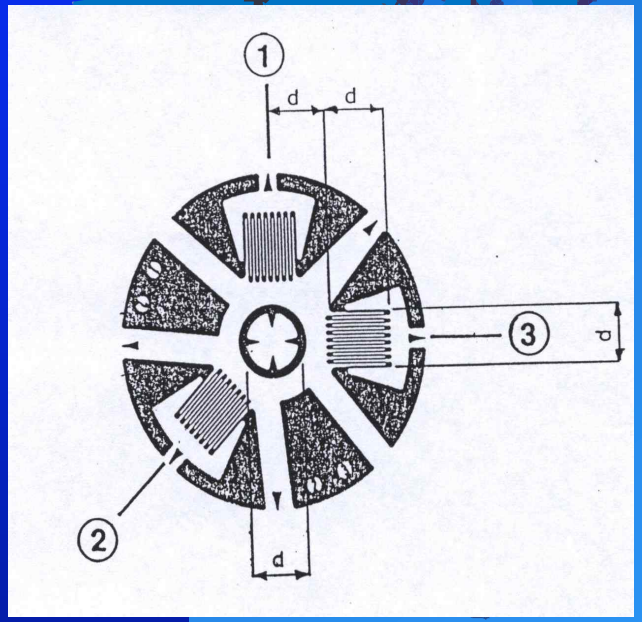
Layer Removal - Ring to ring butt weld, Titanium, Aero engine # 2

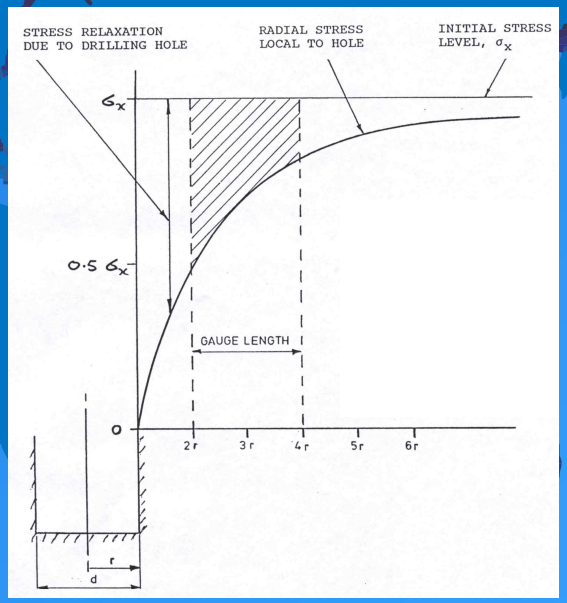


Residual Stress Measurement Techniques

Centre hole or blind hole technique

- Semi destructive technique





- Hole diameter typically equals hole depth

Residual Stress Measurement Techniques

Centre hole or blind hole technique

- **Standard rosettes for hole diameters 0.8mm to 5mm**
- **Non standard rosettes can be used for quite large hole diameters**

Residual Stress Measurement Techniques

Method of machining #1

- Must be done with minimal effort
- Do not want to induce stresses due to machining
- Closer the strain gauge to the machining then effect is more critical
- Depends on hardness of material
- For material removal and layer removal use ECM, EDM or very light milling cuts with coolant

Residual Stress Measurement Techniques

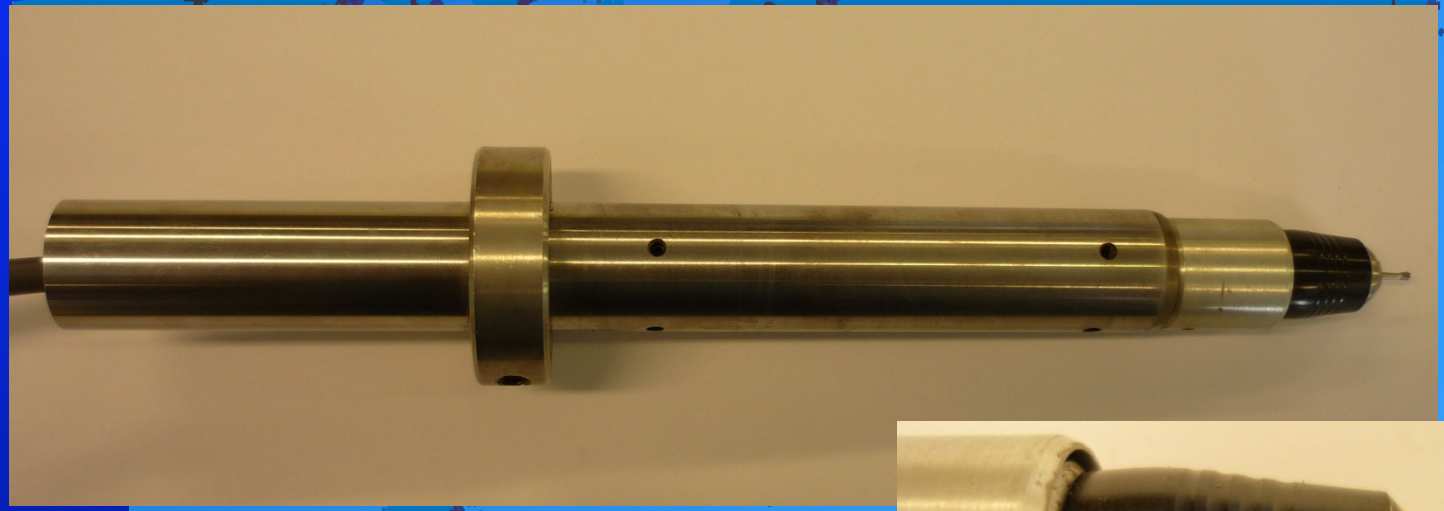
Method of machining #2

- For centre hole technique and hole diameters 0.8 to 5mm more critical as strain gauge very close to hole edge

Residual Stress Measurement Techniques

Method of machining #3

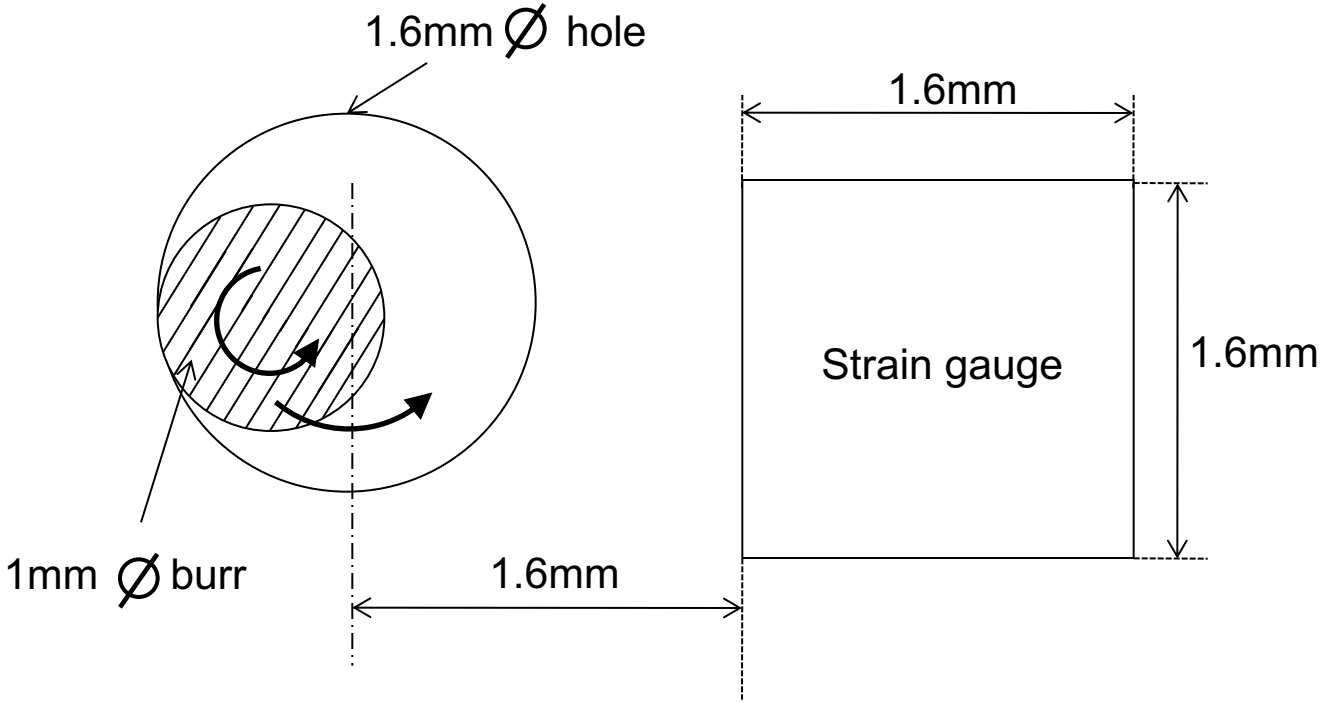
- High speed air turbine



Residual Stress Measurement Techniques

Method of machining #4

- Hole is trepanned



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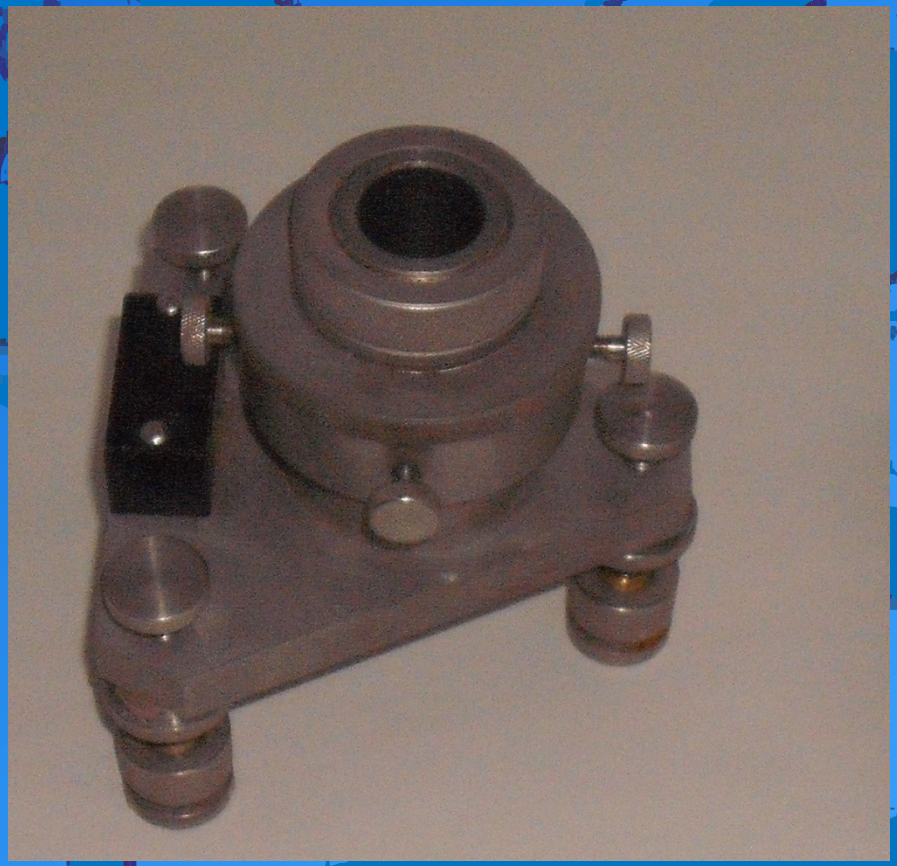
Method of machining #5

- Most materials use carbide burrs
- Stainless steel and high tensile steel use diamond burrs

Residual Stress Measurement Techniques

Drilling guide # 1



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Drilling guide # 2

- Microscope used for alignment

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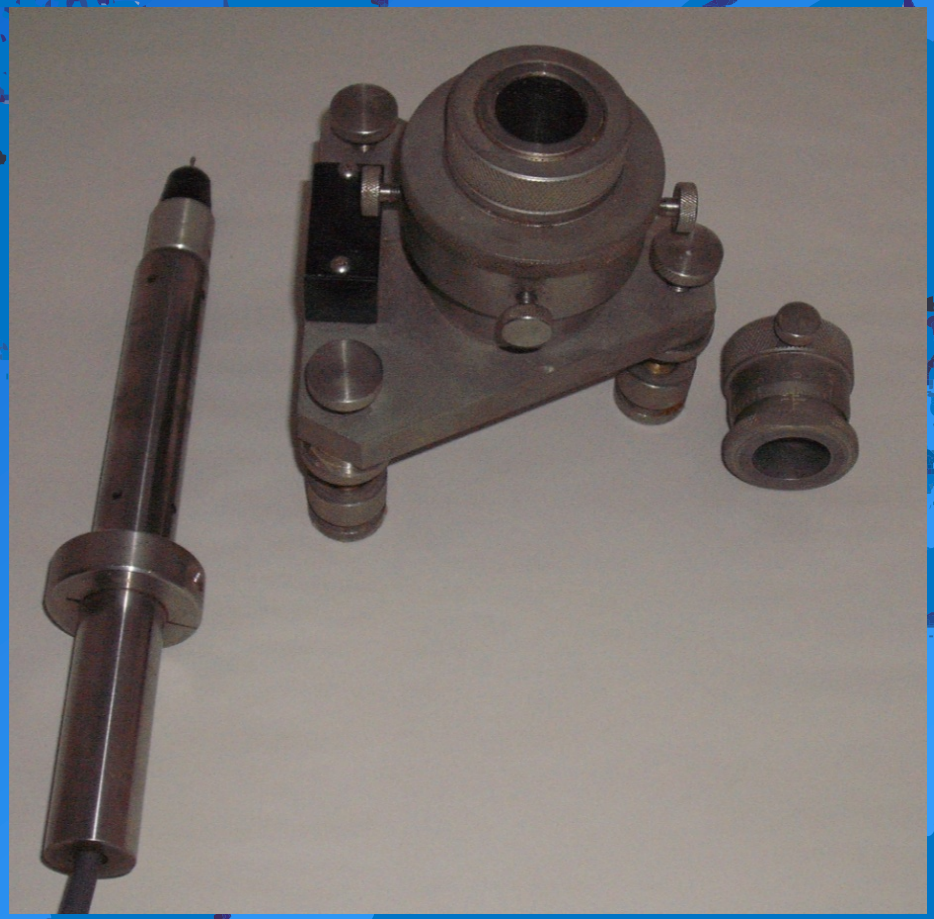
Drilling guide # 3



Residual Stress Measurement Techniques

Drilling guide # 4

Residual Stress Measurement Techniques

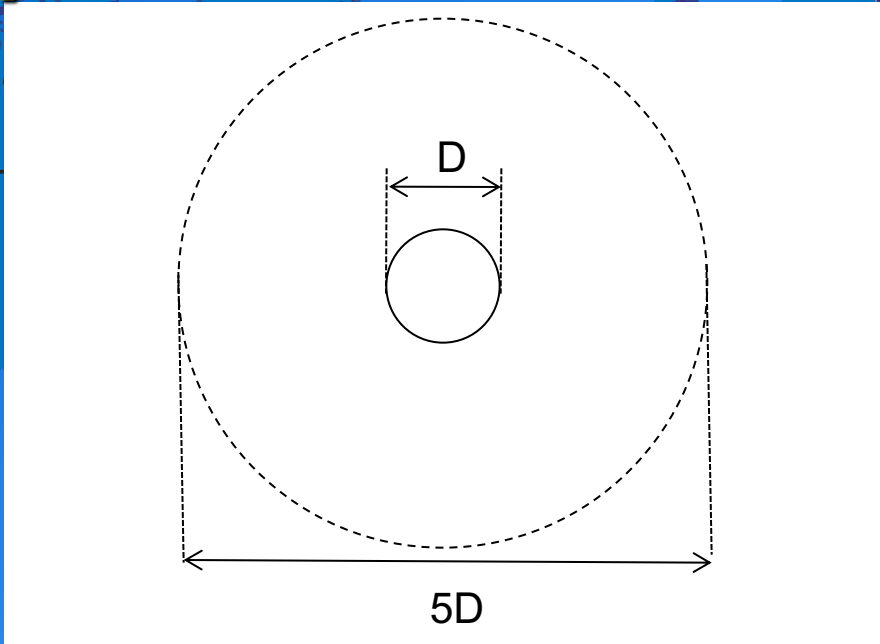
Drilling guide # 5

- Sensitivity affected by hole size so diameter important

Residual Stress Measurement Techniques

Zones of influence # 1

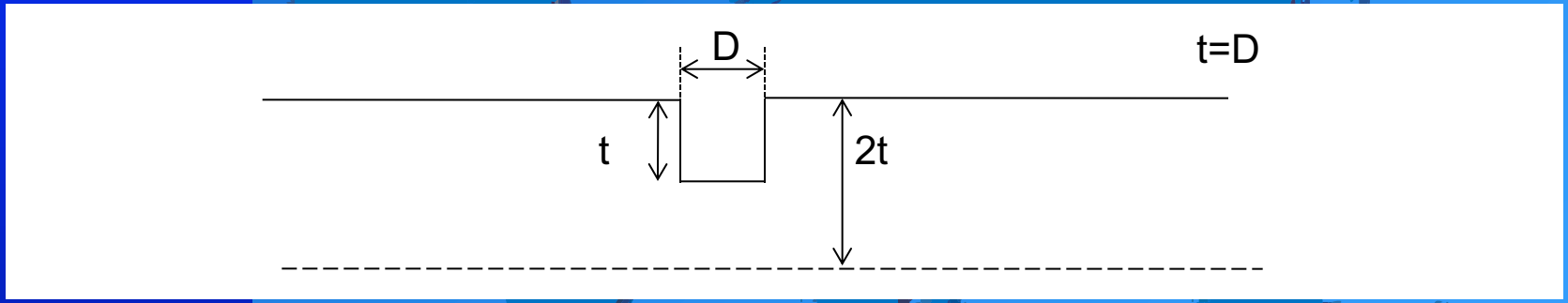
- The theory assumes a semi infinite plate



In practice means that there must be no discontinuity with 5 diameters

Residual Stress Measurement Techniques

Zones of influence # 2



Also the section thickness must be greater than 2 diameters (with diameter = depth)

Residual Stress Measurement Techniques

Data analysis #1

- Incremental analysis must be used for accuracy
- Allows incremental analysis of stress with depth to a depth of 0.5 diameter
- Analysis is based on finite element analaysis

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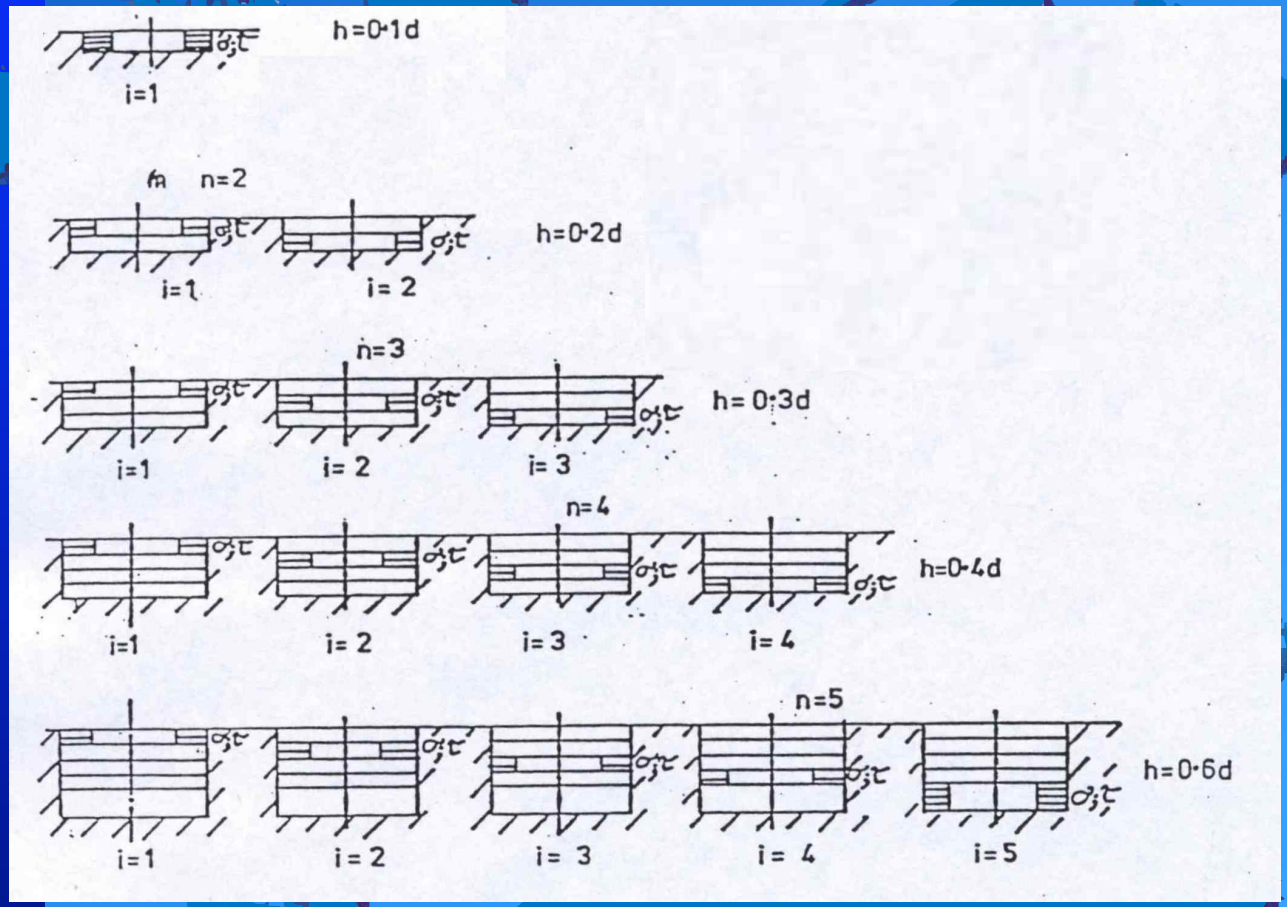
Data analysis # 2



Residual Stress Measurement Techniques

Data analysis # 3

$$\sigma_{1hn} = \frac{(\varepsilon'_n - \sum_{i=1}^{n-1} \varepsilon'_{in})[A_{nn} - B_{nn}\cos 2(\alpha_n + \phi)] - (\varepsilon''_n - \sum_{i=1}^{n-1} \varepsilon''_{in})[A_{nn} - B_{nn}\cos 2\alpha_n]}{2A_{nn}B_{nn}[\cos 2\alpha_n - \cos 2(\alpha_n + \phi)]\Delta h_n}$$

$$\sigma_{2hn} = \frac{(\varepsilon''_n - \sum_{i=1}^{n-1} \varepsilon''_{in})[A_{nn} + B_{nn}\cos 2\alpha_n] - (\varepsilon'_n - \sum_{i=1}^{n-1} \varepsilon'_{in})[A_{nn} + B_{nn}\cos 2(\alpha_n + \phi)]}{2A_{nn}B_{nn}[\cos 2\alpha_n - \cos 2(\alpha_n + \phi)]\Delta h_n} \qquad (11)$$

$$\alpha_n = \frac{1}{2}\,\mathrm{arctg}\left\{ \frac{\begin{array}{l}(\varepsilon''_n - \sum_{i=1}^{n-1} \varepsilon''_n) - (\varepsilon'''_n - \sum_{i=1}^{n-1} \varepsilon'''_{in}) + \cos 2\psi[(\varepsilon'_n - \sum_{i=1}^{n-1} \varepsilon'_{in}) - (\varepsilon''_n - \sum_{i=1}^{n-i} \varepsilon''_{in})] + \\ + \cos 2\phi[(\varepsilon'''_n - \sum_{i=1}^{n-1} \varepsilon'''_{in}) - (\varepsilon'_n - \sum_{i=1}^{n-1} \varepsilon'_{in})]\end{array}}{\left[(\varepsilon'_n - \sum_{i=1}^{n-1} \varepsilon'_{in}) - (\varepsilon''_n - \sum_{i=1}^{n-1} \varepsilon''_{in})\right]\sin 2\psi + \left[(\varepsilon'''_n - \sum_{i=1}^{n-1} \varepsilon'''_{in}) - (\varepsilon'_n - \sum_{i=1}^{n-1} \varepsilon'_{in})\right]\sin 2\phi} \right\}$$

Residual Stress Measurement Techniques

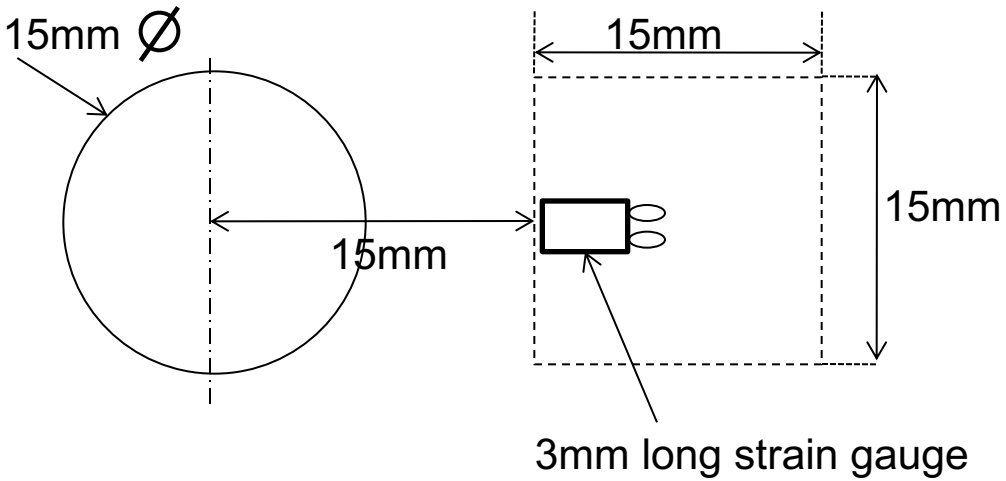
Typical hole sizes # 1

0.8, 1.6 & 3.2mm	Vishay standard	High speed drilling
5mm	HBM standard	High speed drilling
10 to 12mm	Non standard	Strainstall equipment
15 to 100mm	Non standard	Rotabroach

Residual Stress Measurement Techniques

Typical hole sizes # 2

- Vishay gauge and equivalent non standard hole/gauge geometrics



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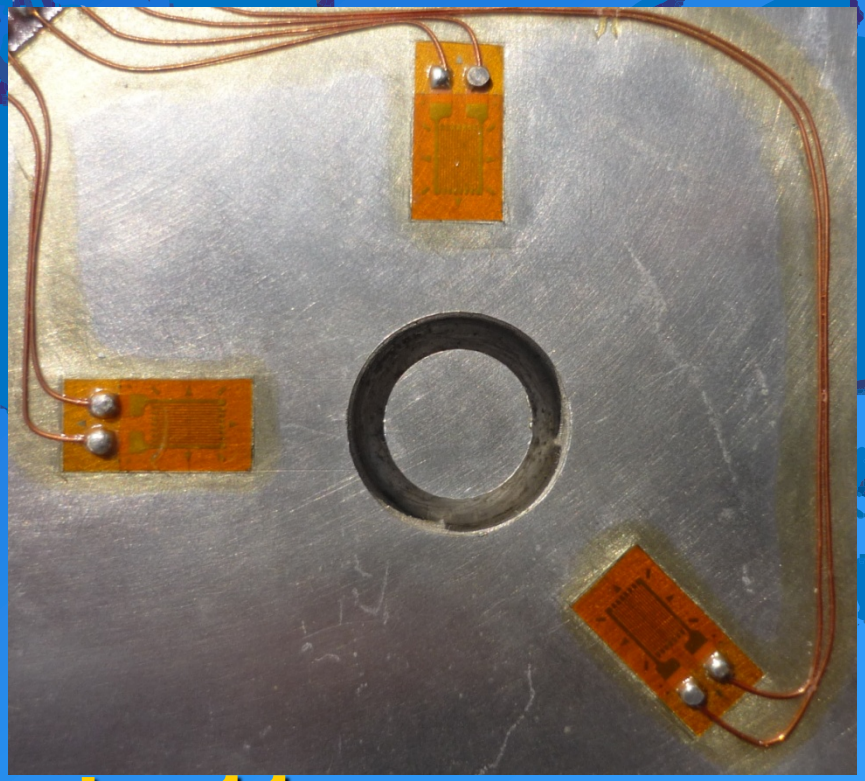
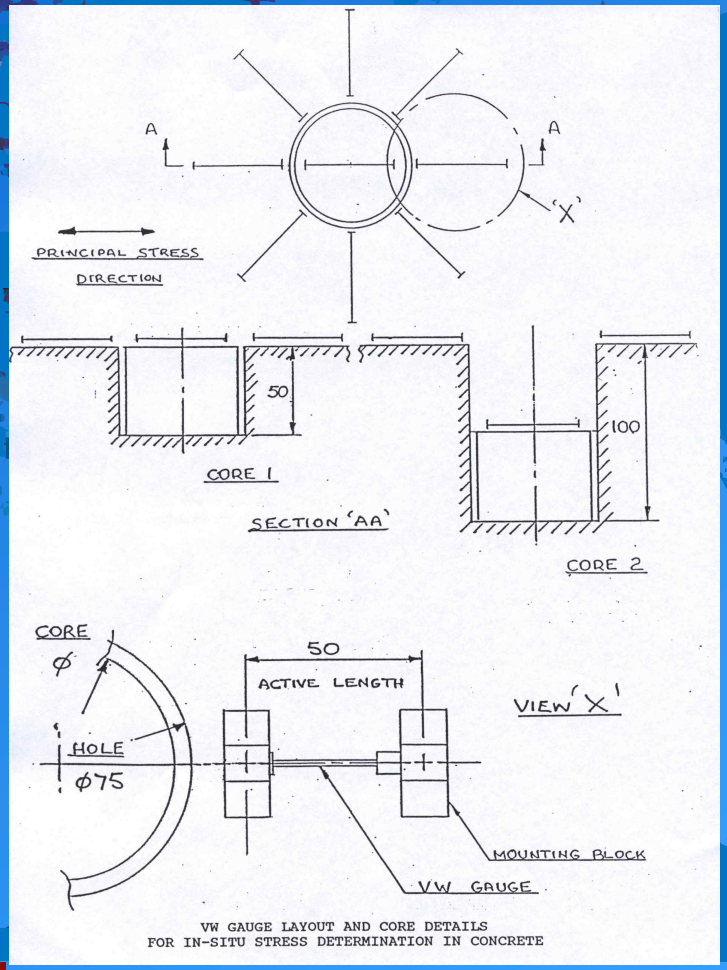
Typical non standard rosette



- **Hole diameter 11mm**

Residual Stress Measurement Techniques

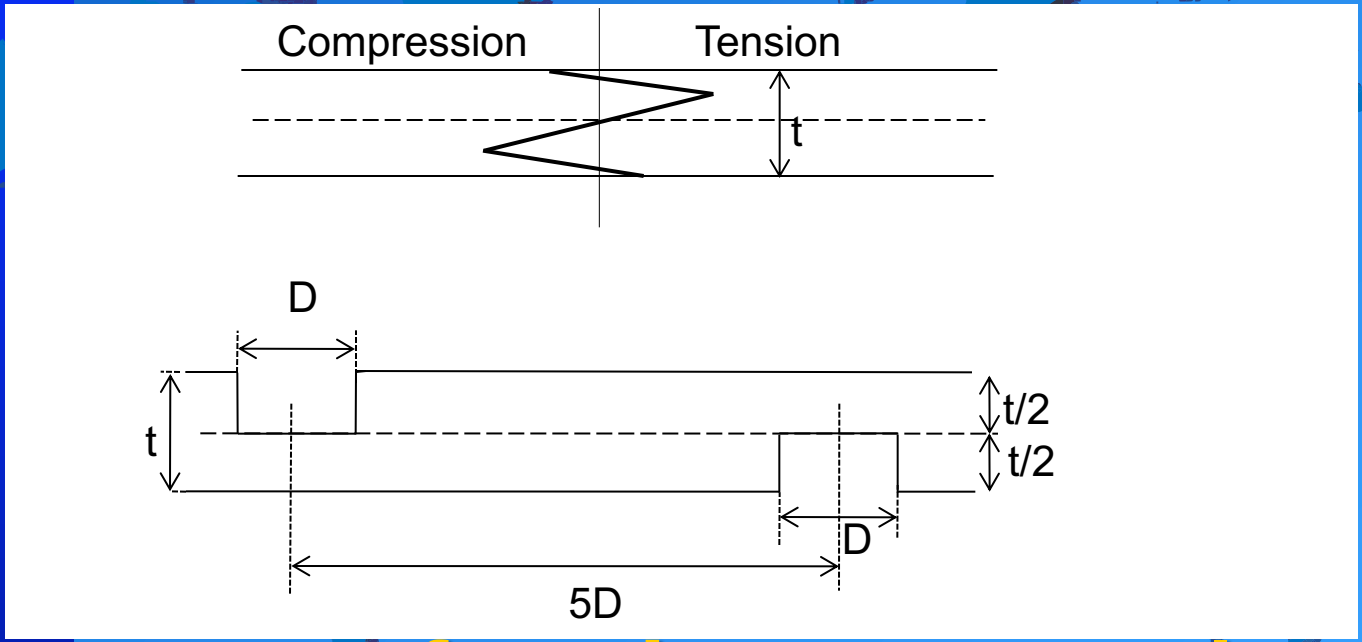
Centre hole method for concrete



VW GAUGE LAYOUT AND CORE DETAILS
FOR IN-SITU STRESS DETERMINATION IN CONCRETE

Residual Stress Measurement Techniques

Example #1 Through thickness steel plate



- Average manufacturing stress equals zero
- Average stress equals dead load stress

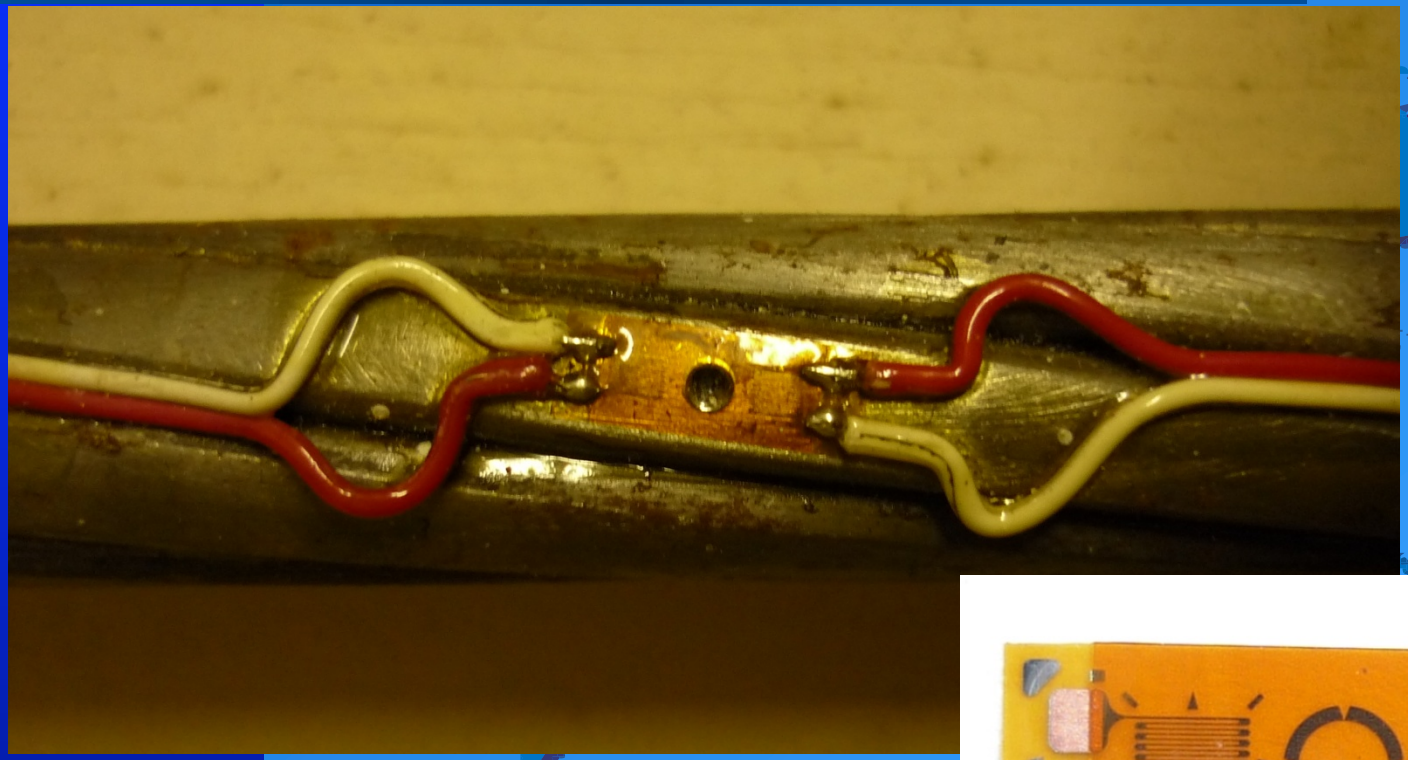
Residual Stress Measurement Techniques

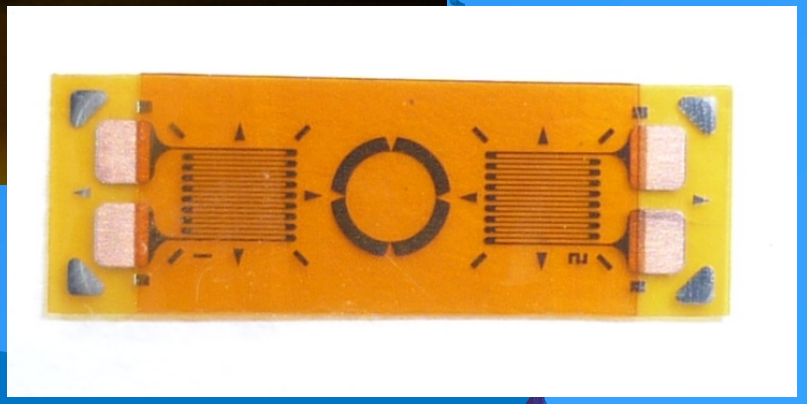
Example #2 Post tensioning wire

- To determine dead load …affected by load loss, temperature, corrosion

Residual Stress Measurement Techniques

Example #2 Post tensioning wire

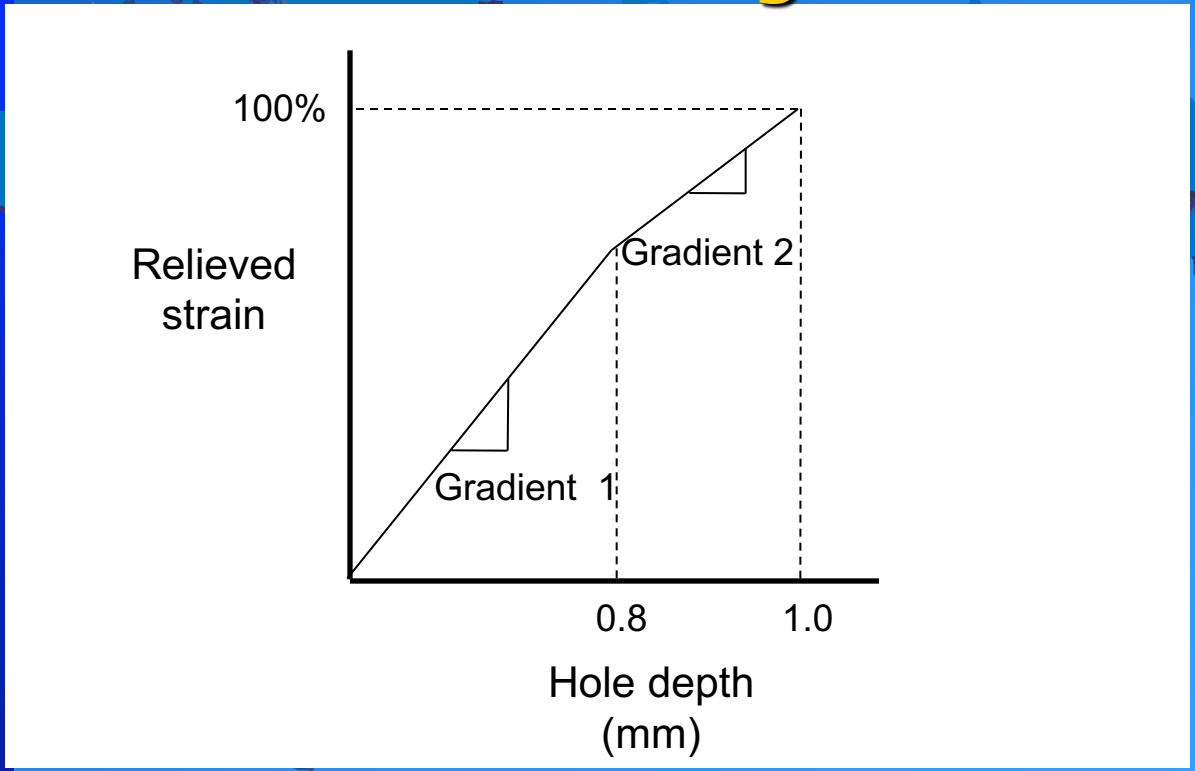




- Hole depth 1.0mm
- Hole diameter 1.6mm

Residual Stress Measurement Techniques

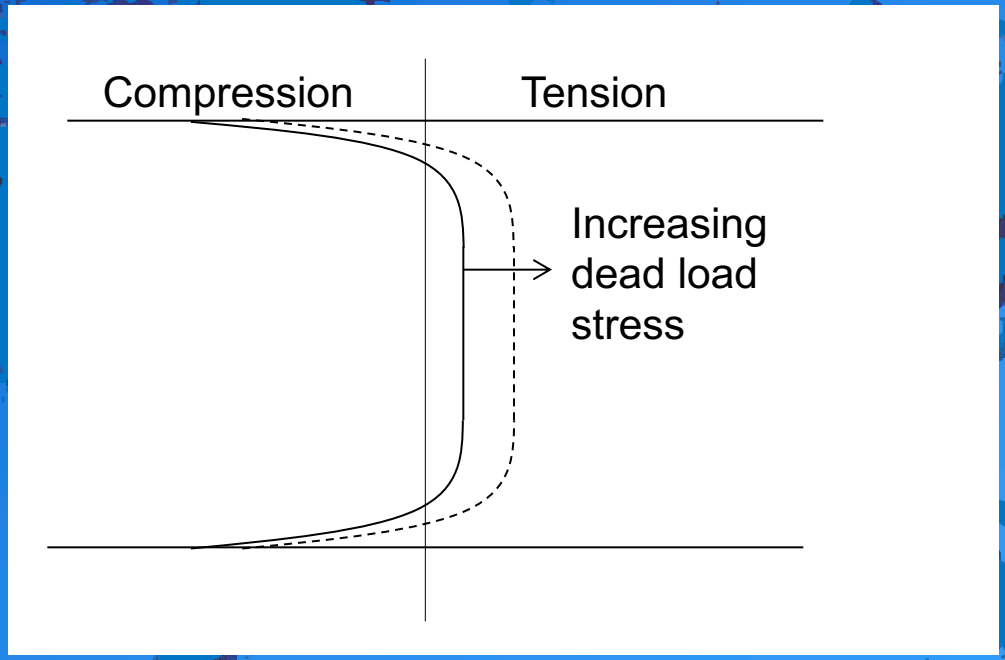
Example #2 Post tensioning wire



- Typical applied stress 1300MPa
- Manufacturing stress 30MPa

Residual Stress Measurement Techniques

Example #3 Surface treated material



- To determine depth of surface treatment
- Quenched and peened and cast components have compressive surface stresses

Residual Stress Measurement Techniques

Example #4 Rolled Steel Joist (RSJ)

- **Understanding residual stress distribution to determine where to measure dead load stress**