



***STRUCTURAL HEALTH MONITORING
AND COLD –WORKING VALIDATION
USING DMI OPTICAL SR-2
TECHNOLOGY***

***W.F. RANSON, R.I. VACHON, G.L. HOVIS
DIRECT MEASUREMENTS, INC.***





- **DMI Technology**
- **Tests to detect crack initiation and growth**
- **Tests validating cold-working in rivet holes**
- **Technology as an inspection tool**





- 1. Technology: Gages, Software, Sensor**

- 2. Testing Results**
 - Northrop-Grumman (DARPA/SIPS Program)**
 - Testing with Fasteners**
 - NAVAIR/FTI/DMI Testing Initiative**



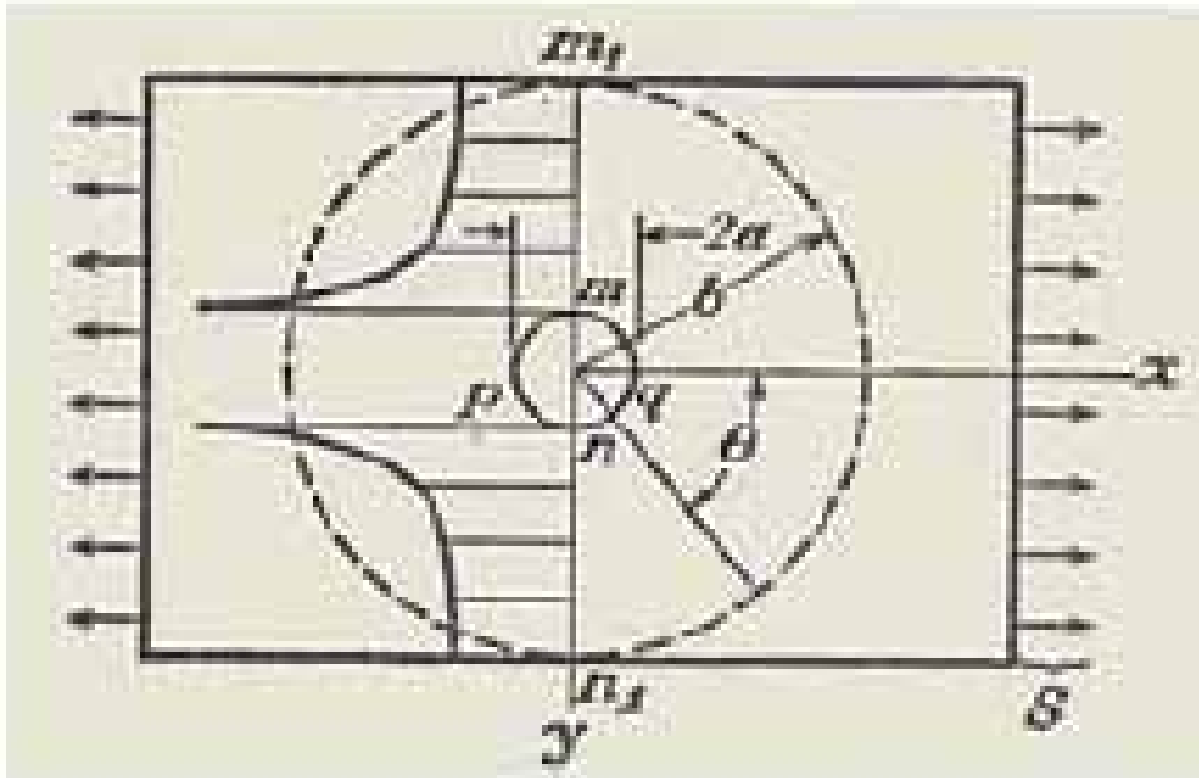


Figure 1. Stress distribution near a hole in a plate

Measures Total Strain



US & Int'l Pat. Pend.

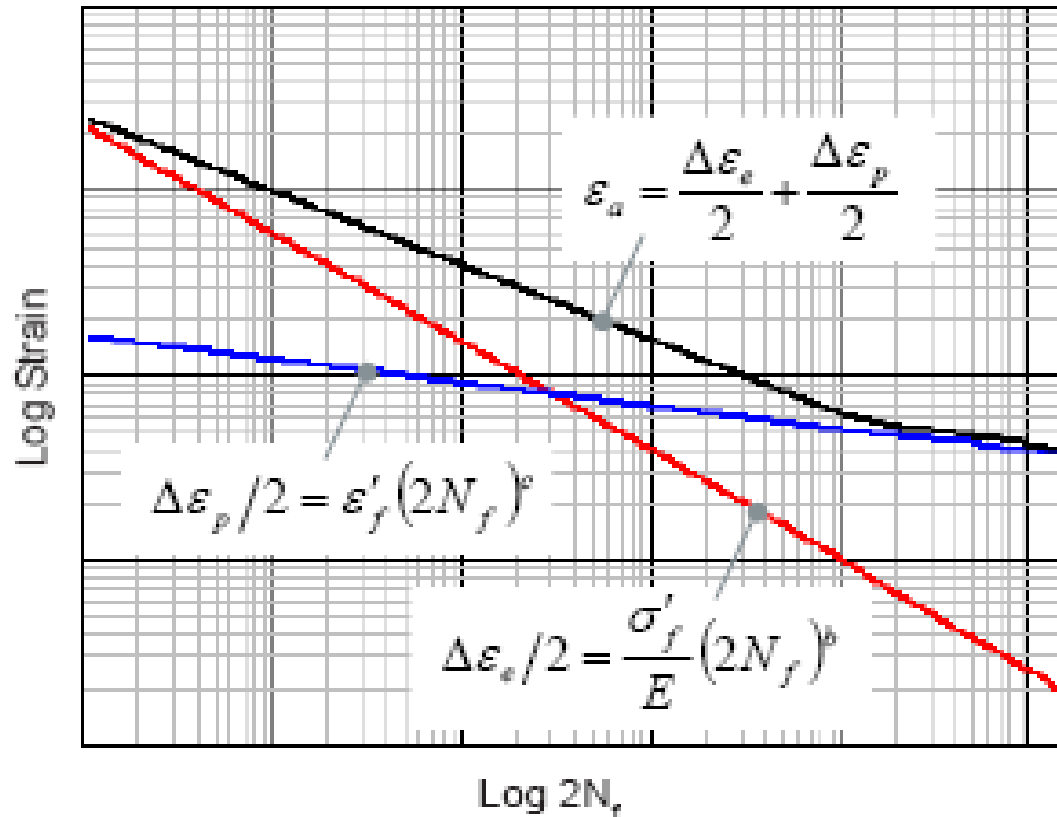


Figure 2. Total Strain and Elastic and Plastic Strain



Uniform Distortion of an Element



US & Int'l Pat. Pend.

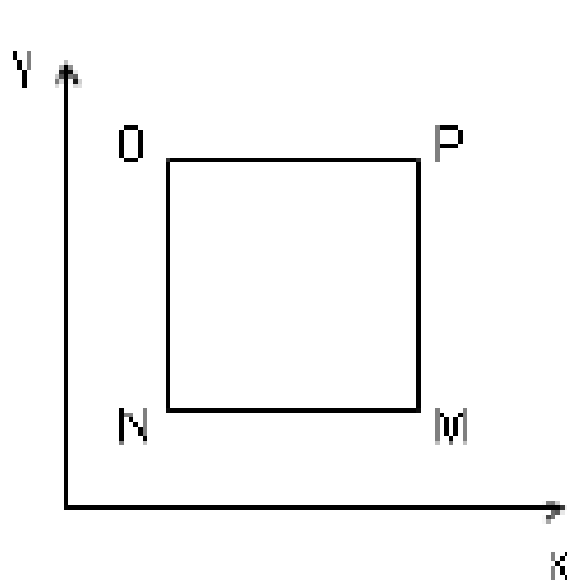


Figure 3a. Element before deformation

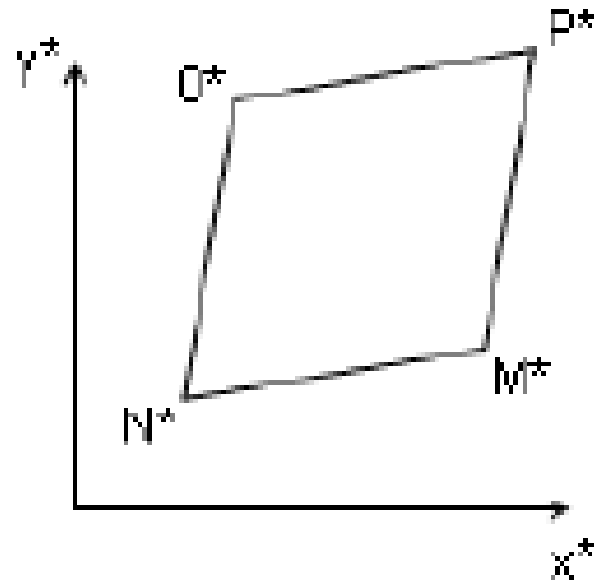


Figure 3b. Element after uniform deformation

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Non-uniform Distortion of an Element



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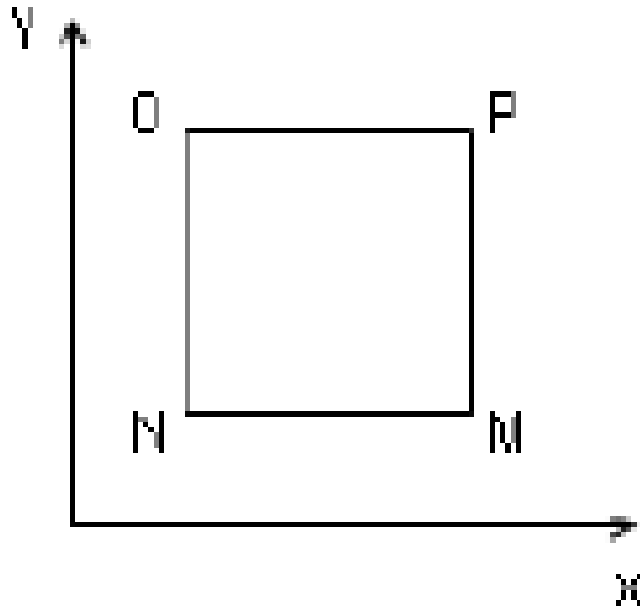


Figure 4a. Element before deformation

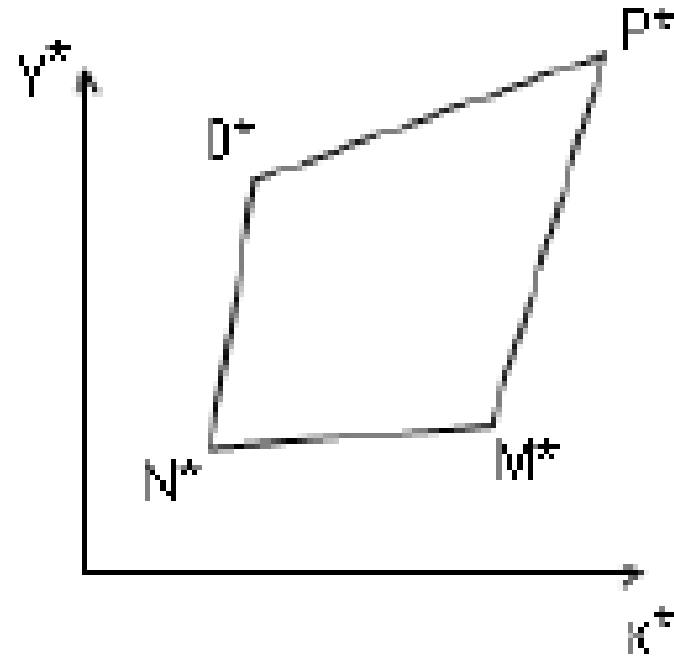


Figure 4b. Element after non-uniform deformation

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Theory Translated into Application



US & Int'l Pat. Pend.

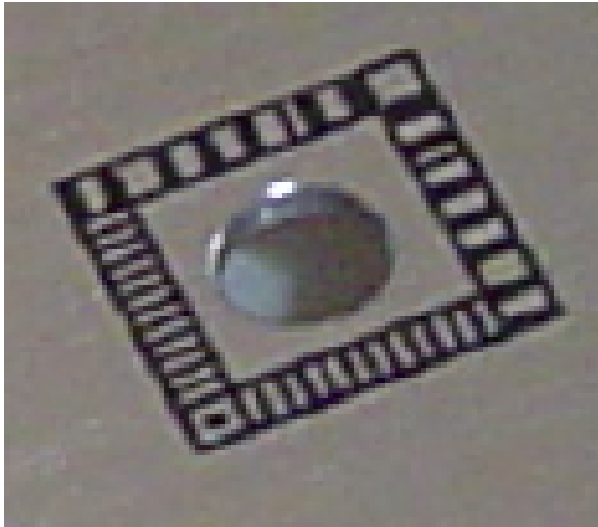


Figure 5a. DMI proprietary gage centered on open hole

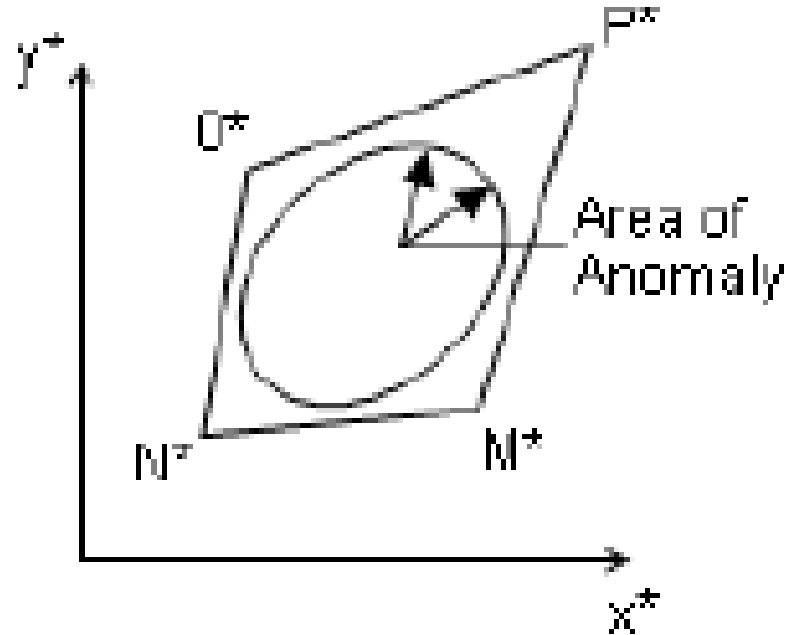


Figure 5b. Sides of gage deformed non-uniformly and DMI Technology detects the difference in strain on opposing sides



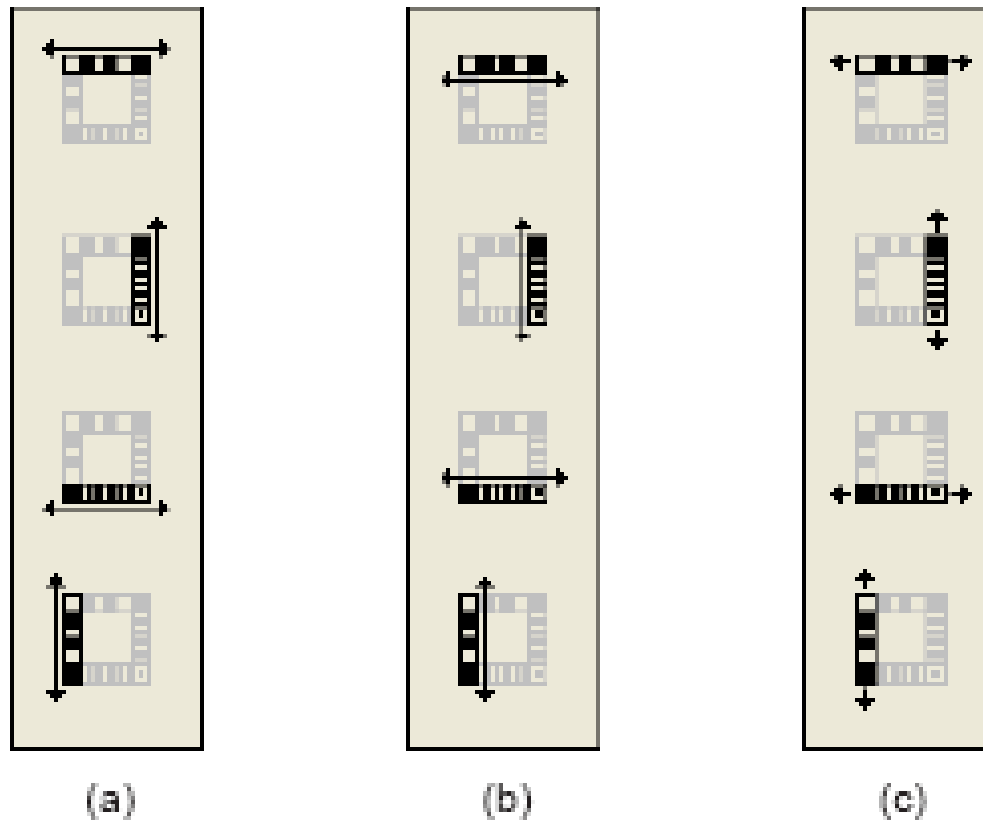


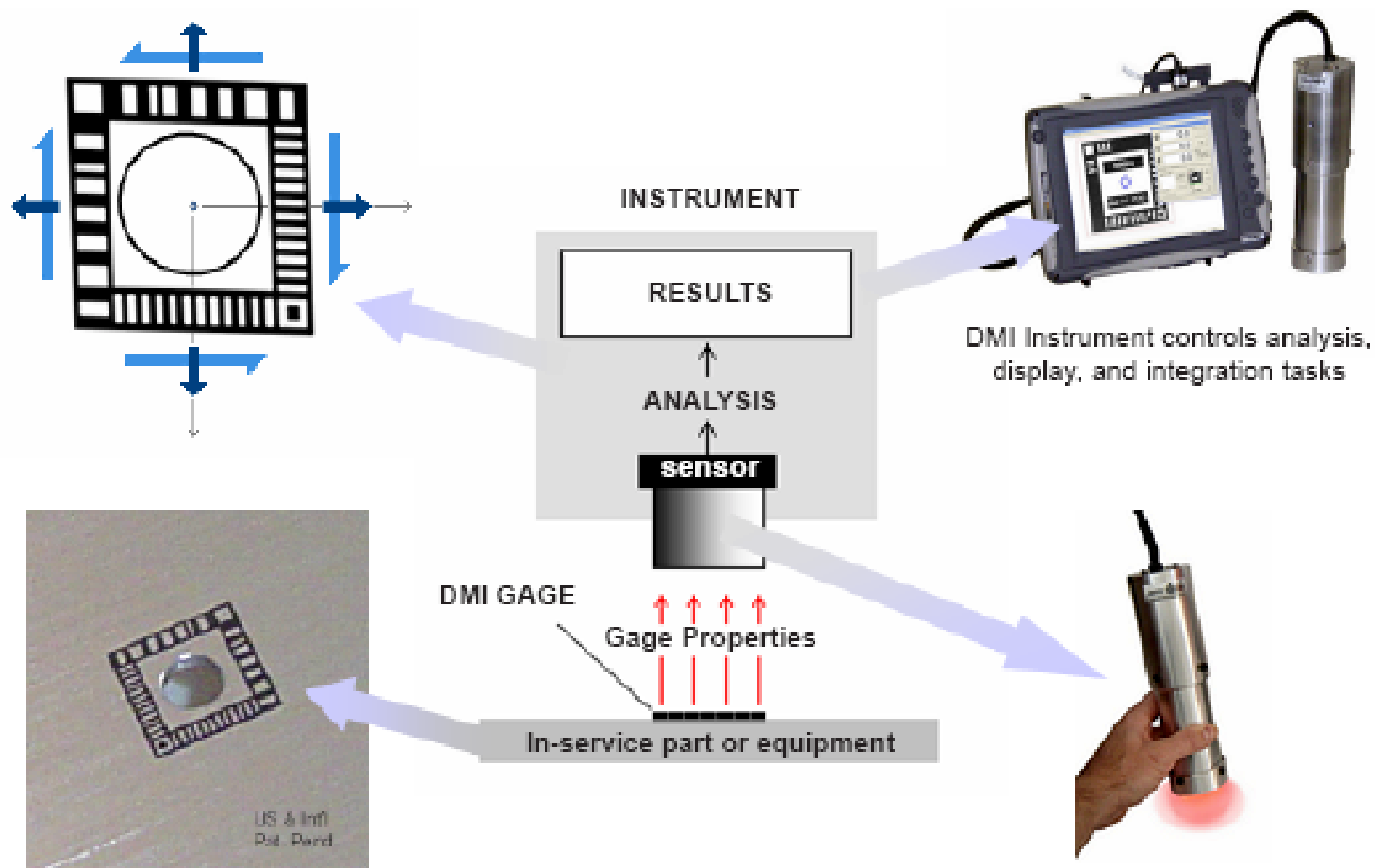
Figure 24. Boundary element strain sensors in the DMI strain gage



Technology at a Glance – Gages/Software/Sensors



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Gage –each gage a unique ID



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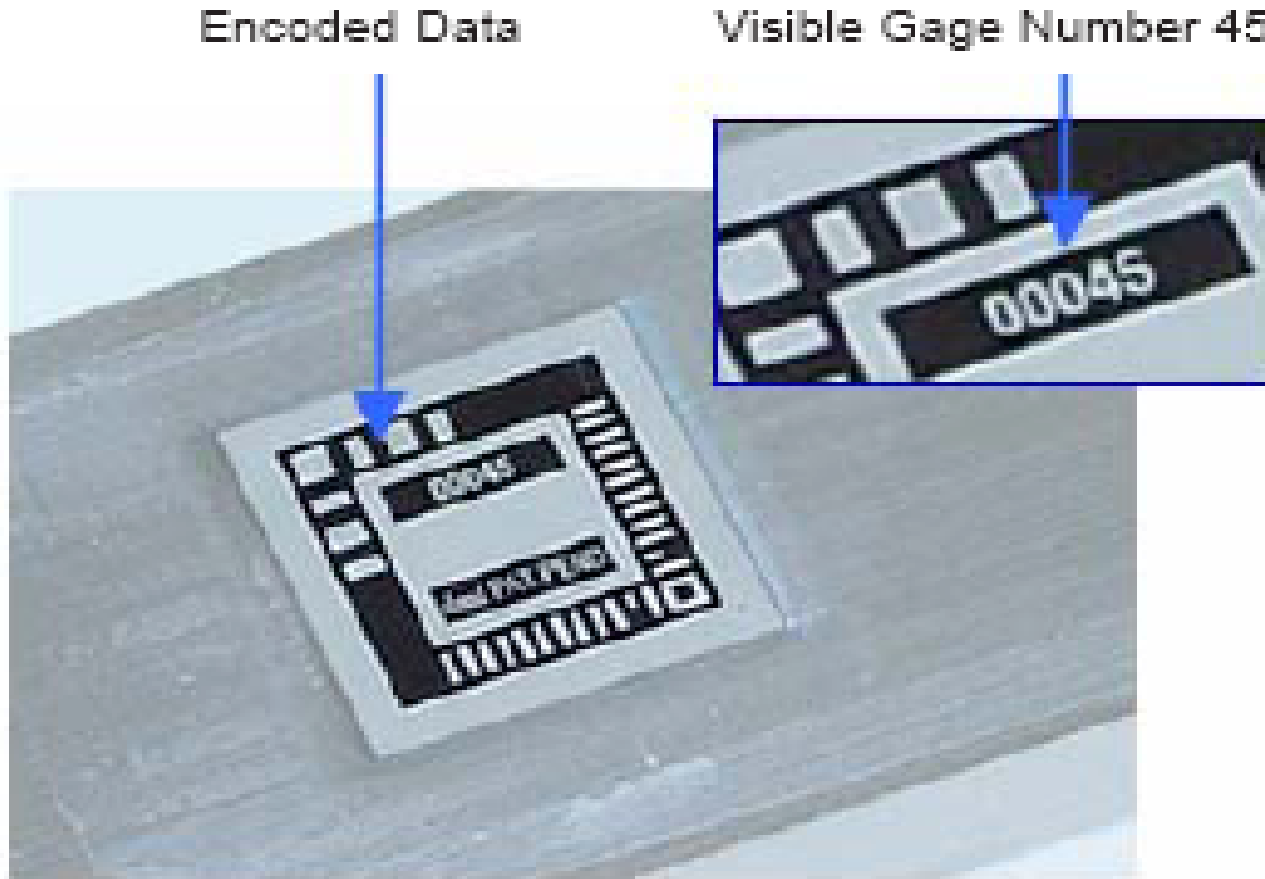


Figure 7. DML gage encoded information



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Technology

- **Self-contained strain measurement system – two orthogonal and shear strains**
- **Uniform AND non-uniform strains across the gage/sensor**
- **Wire free for lab or field applications**
- **Detects crack initiation**
- **Monitors crack growth**
- **Validates cold-working**
- **Real-time measurement**



DMI Gage Utility



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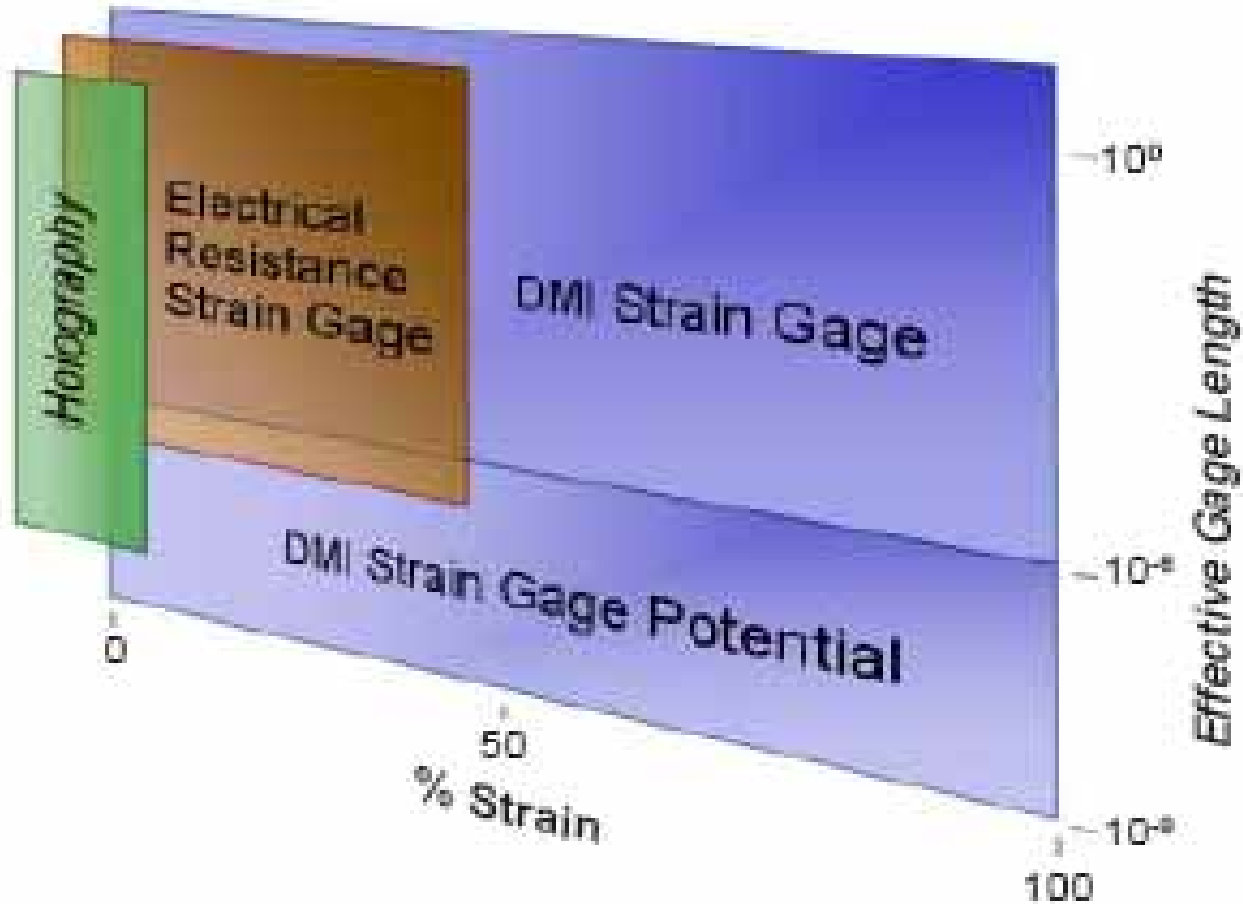


Figure 8. Comparison of strain sensors



Easy to Use – No Age Discrimination



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Figure 12. Fatigue test coupon with DMI gages

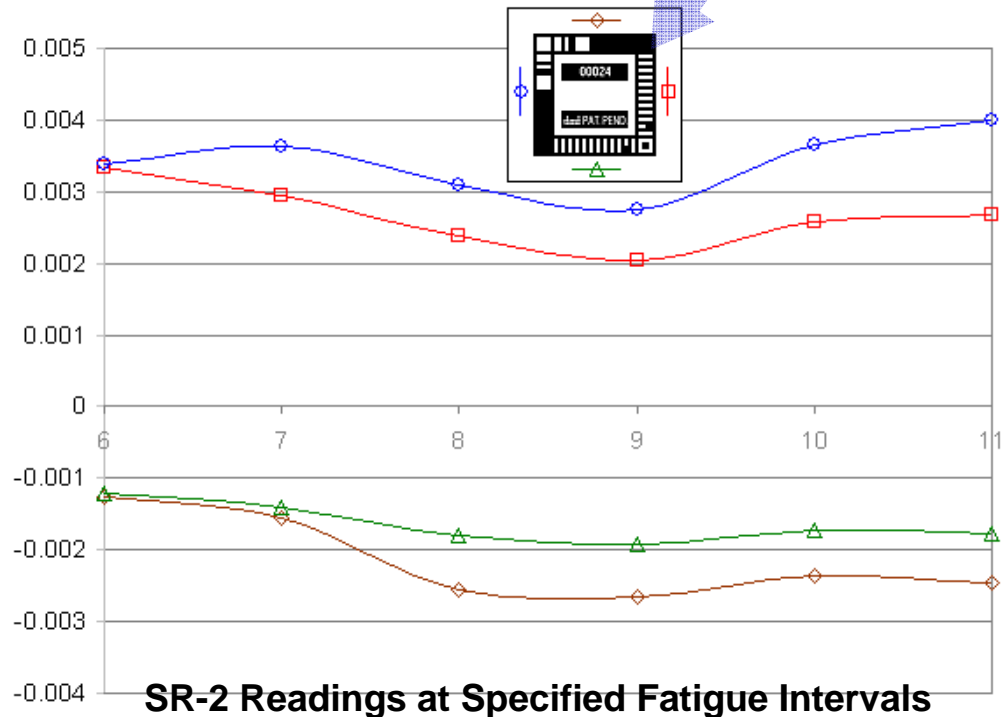


Thin AL plate (0.060 in.) fatigue load 0-3353 lbs. tension

- Readings at specified fatigue-cycle counts
- Four simultaneous strain-element readings taken by SR-2 at each 'hold point'
- Anomaly detected left side – crack eventually formed in that location



Visible Fatigue Crack



SR-2 Readings at Specified Fatigue Intervals

Zero Load Measurement

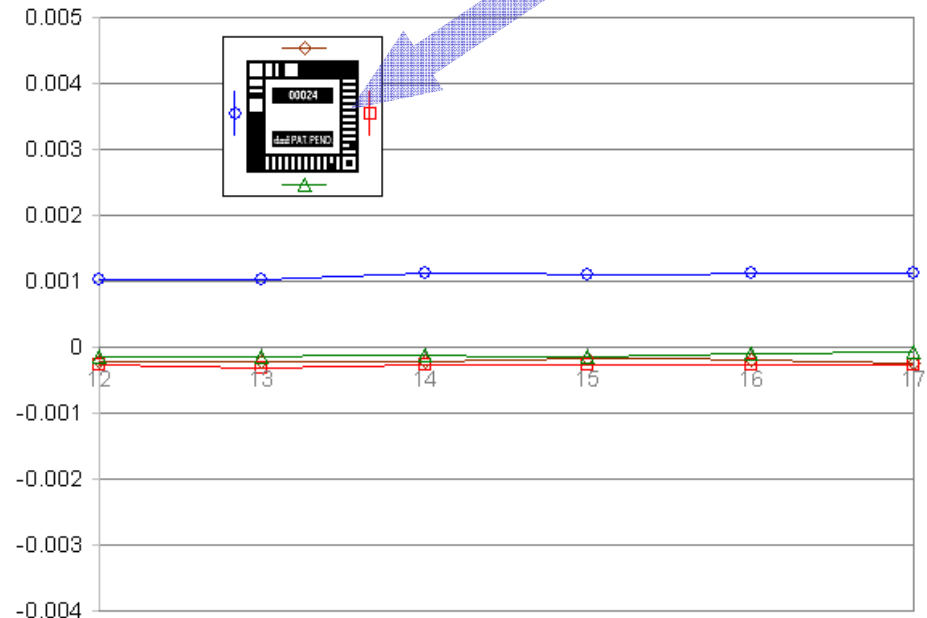


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- Readings taken zero load
- Top, right, and bottom returned to near-zero strain
- Left side (crack location) shows large-magnitude fixed strain



Visible Fatigue Crack



SR-2 Readings at ZERO LOAD

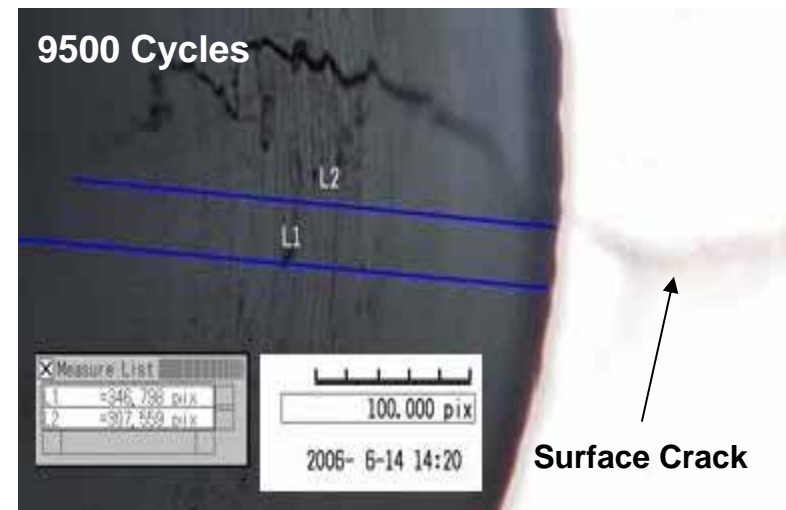
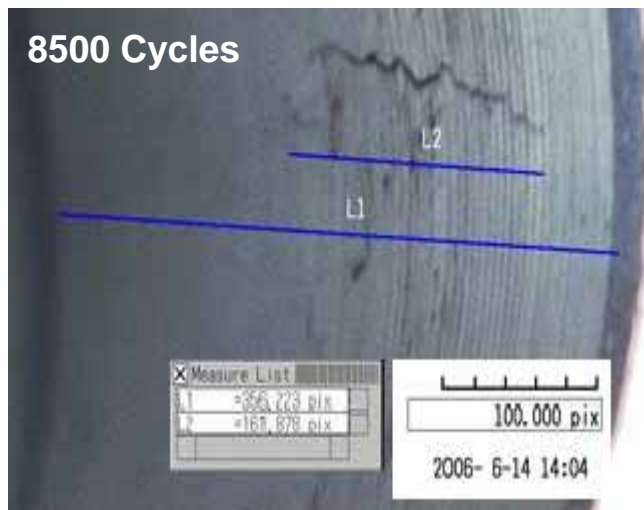
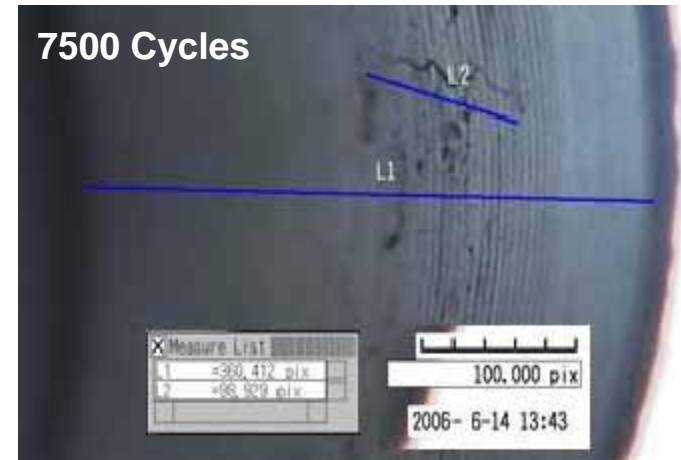
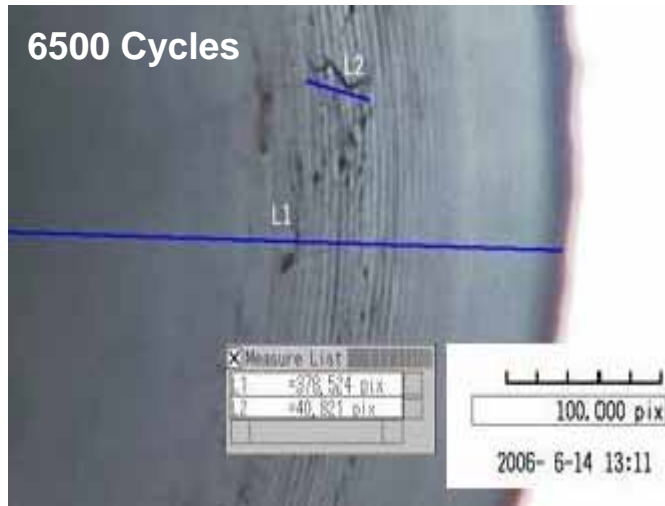
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Hirox confirms DMI SR-2 readings



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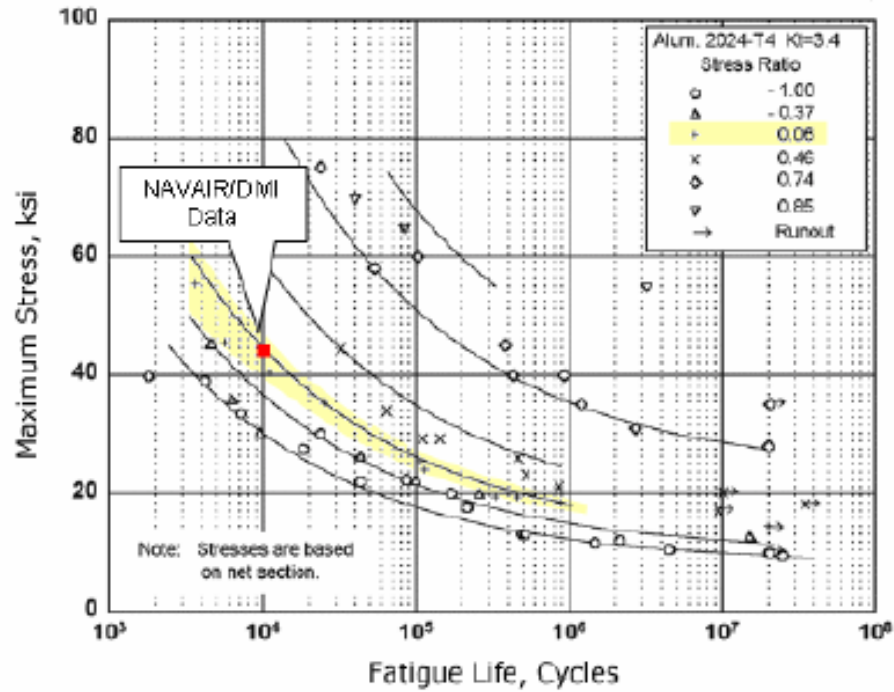
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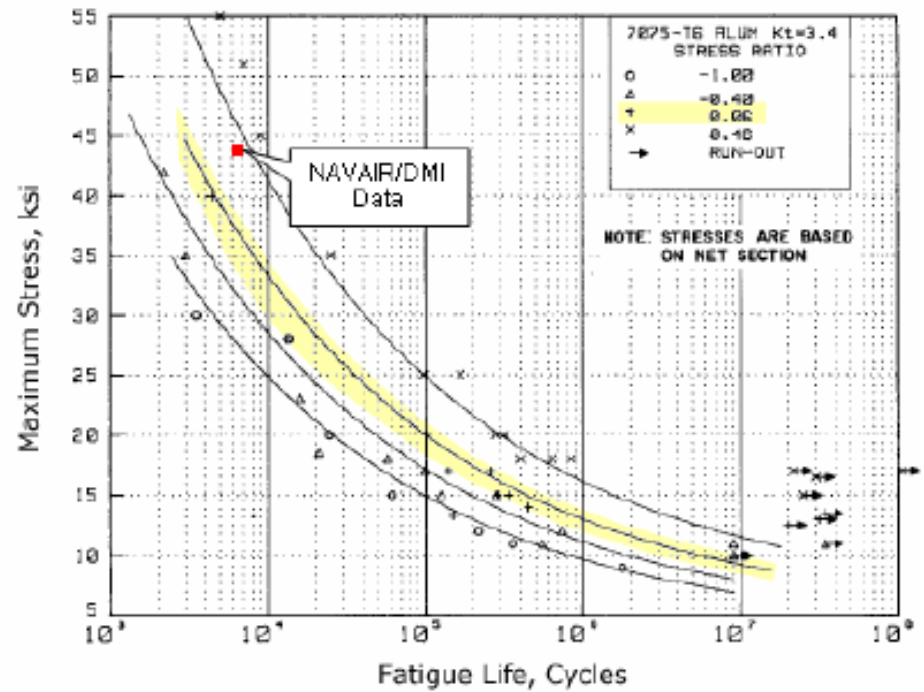
MIL-HDBK-5J Stress Life Chart



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DMI fatigue data for 2024-T3 aluminum



DMI fatigue data for 7075 aluminum



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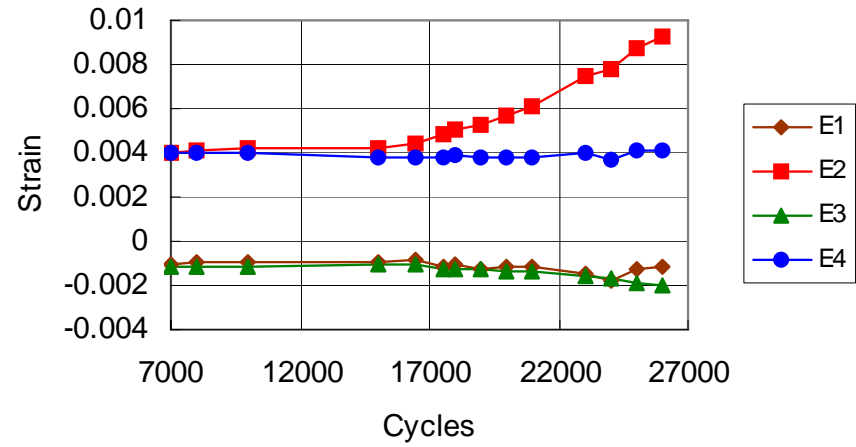
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Fatigue Results of a Plate with a Central Hole

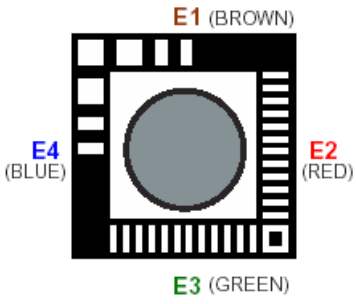
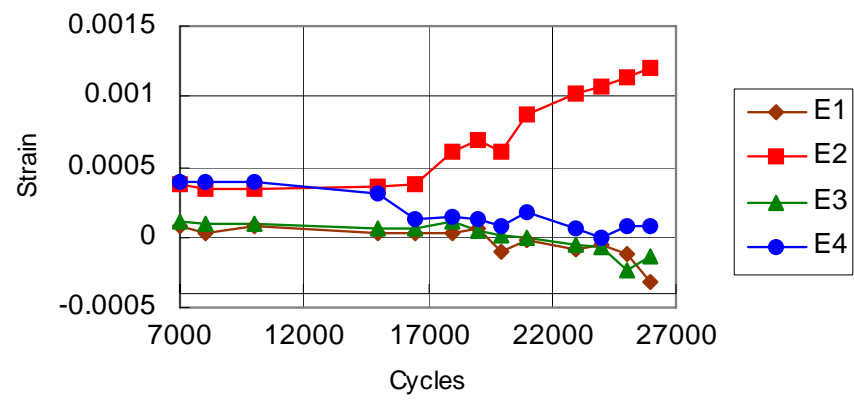


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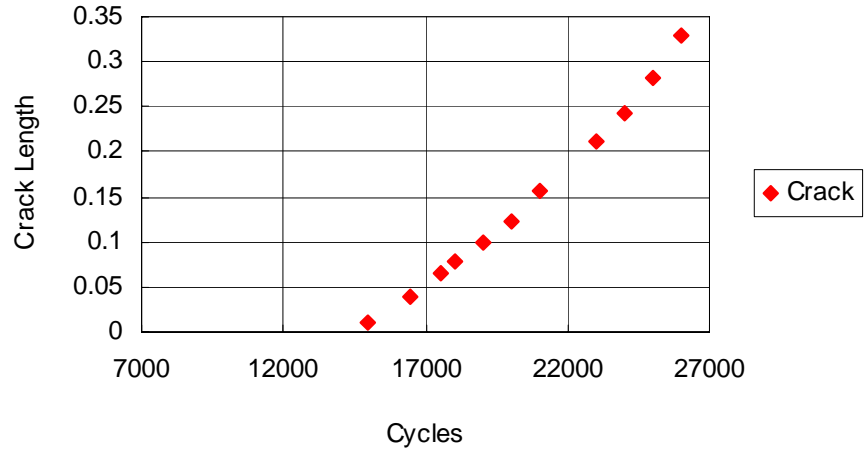
Gage 70 Cycles vs 3353 lb. Load Fatigue Data



Gage 70 300 lb. Load Cycles vs Strain Fatigue Data



Gage 70 Crack length vs Cycles

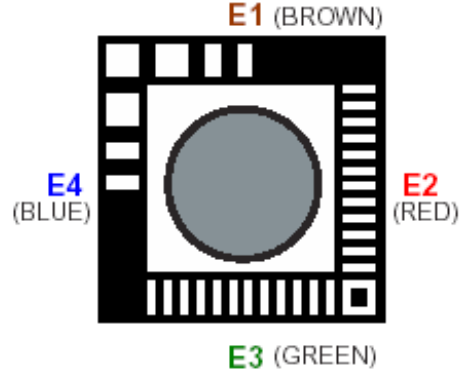
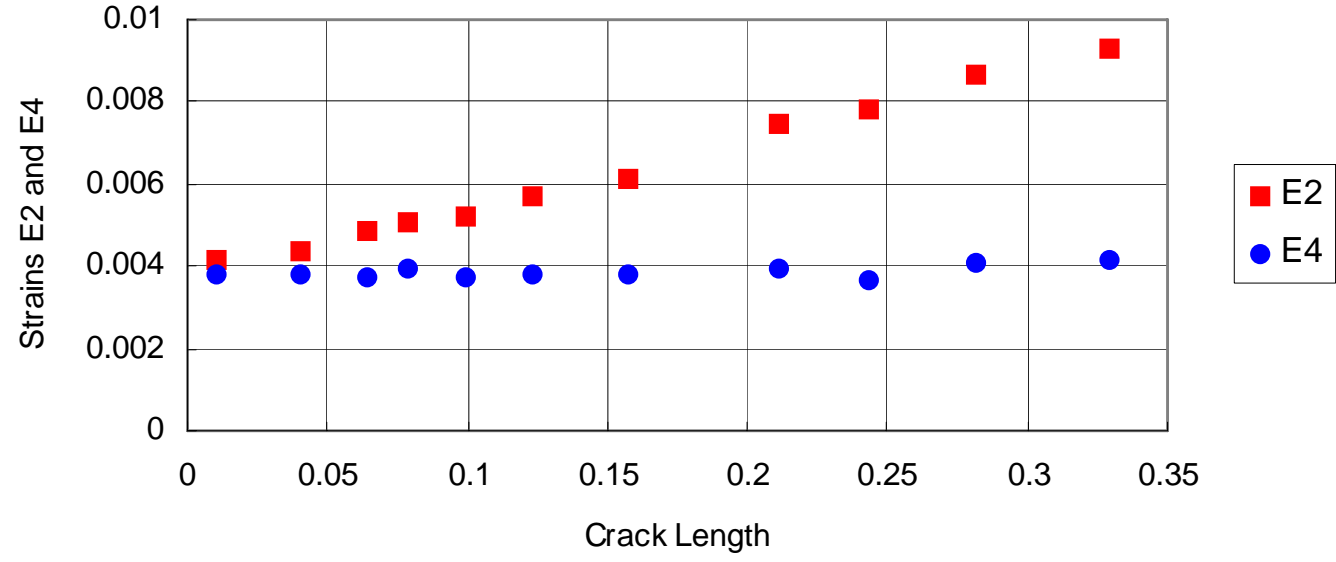


Strains E_2 & E_4 vs Crack Length - Plate Central Hole



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Gage 70 Crack Length vs Strains E_2 and E_4



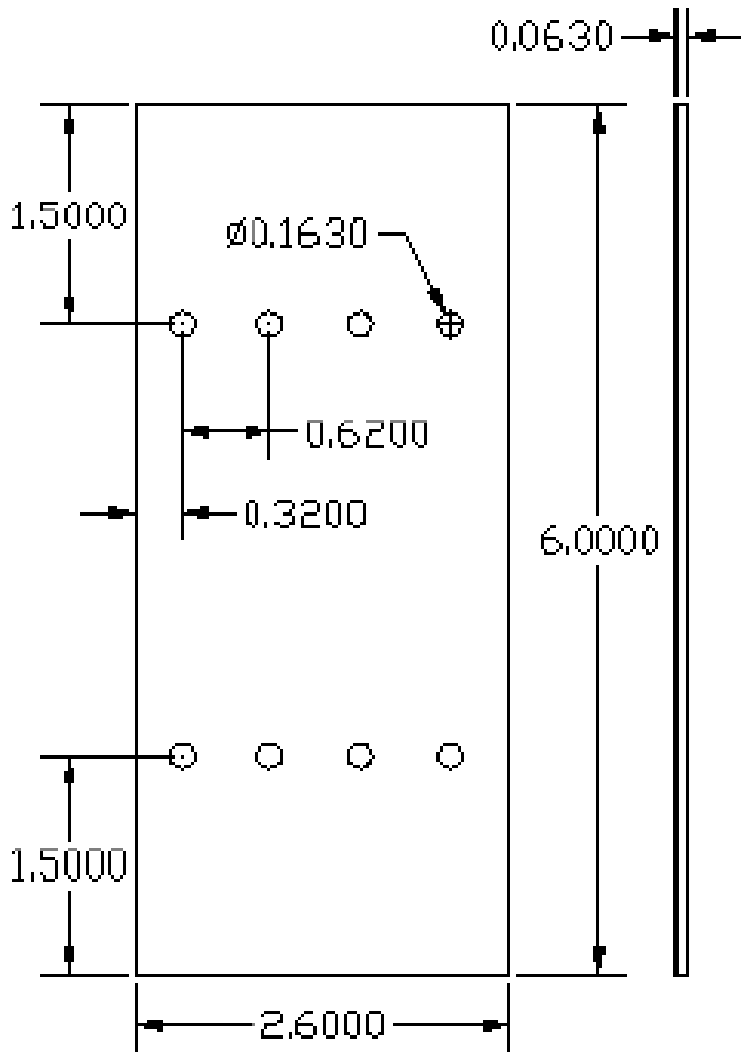
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AI 7075-T6 Doubler loaded thru HiloX HL 20 fasteners – fatigue 0-11091 lbs. tension



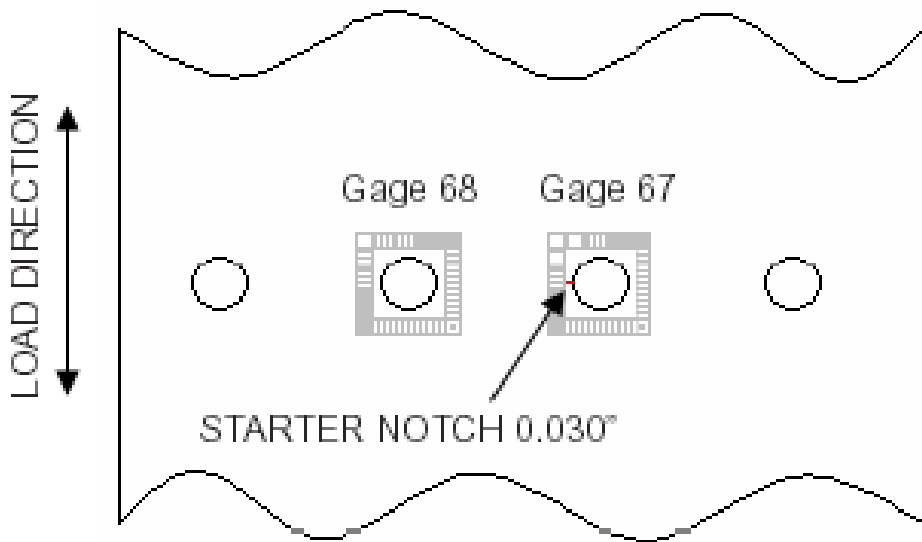
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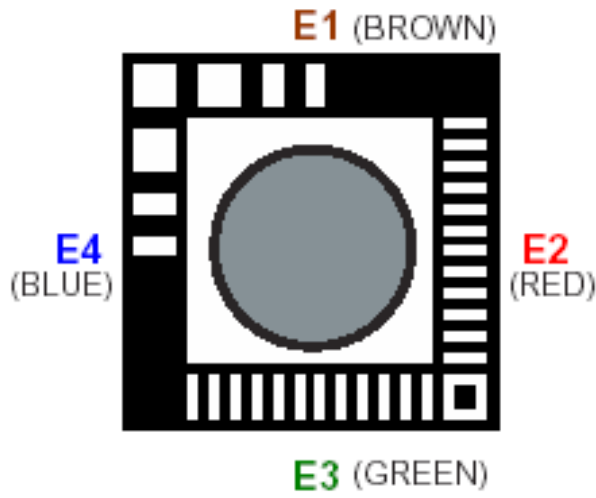
AI 7075-T6 Doubler Serialized Gage Locations



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Gages at fastener locations



Photoelastic pattern of a plate loaded through a rigid pin.

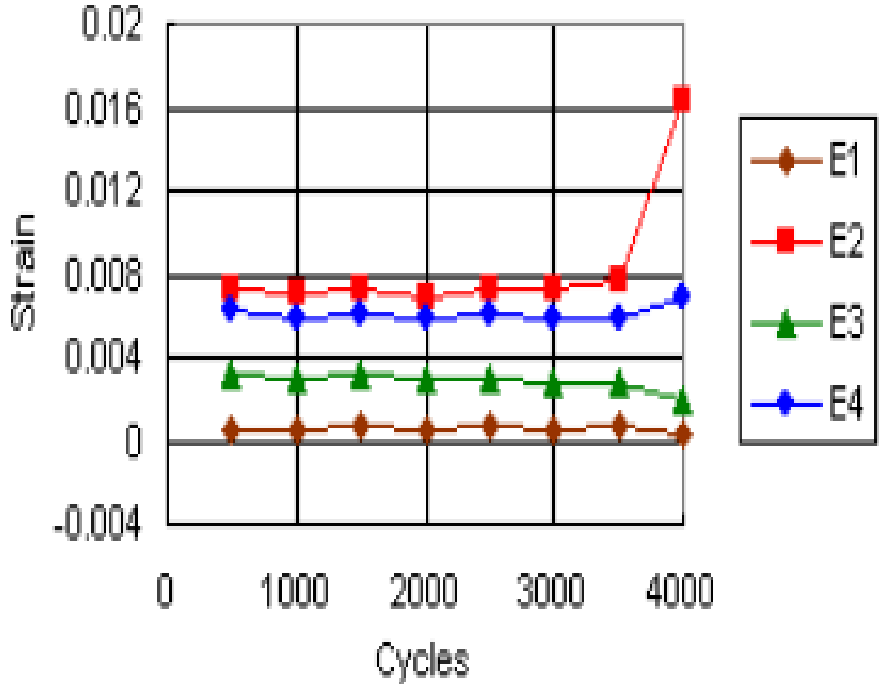


AI 7075-T6 Doubler Fatigue Results

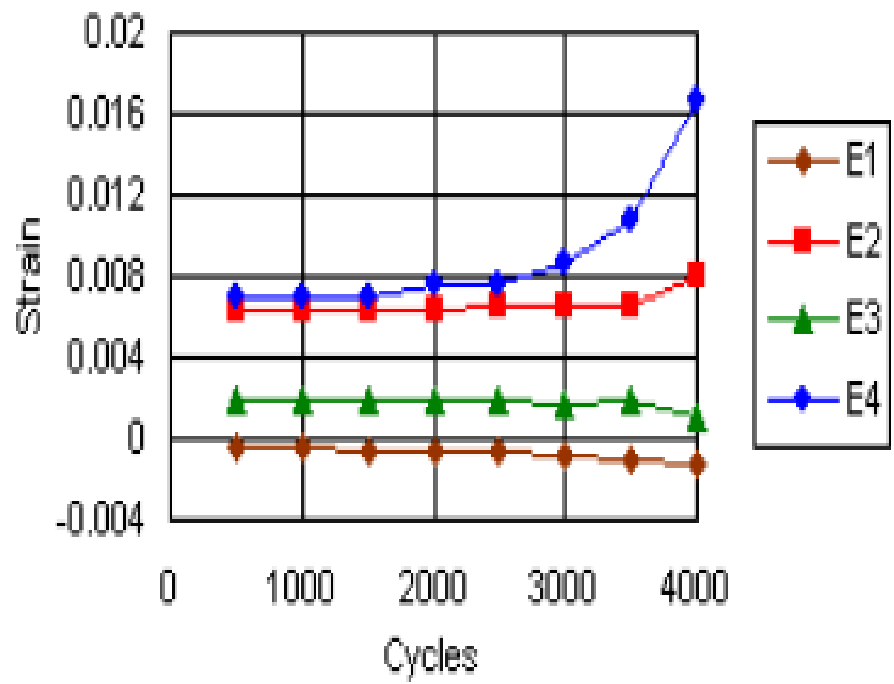


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Gage 68 11091 lb. Fatigue Data



Gage 67 11091 lb. Fatigue Data



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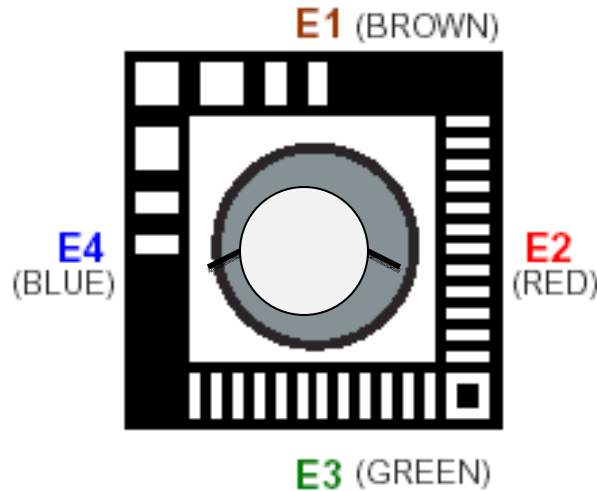


Typical Observation

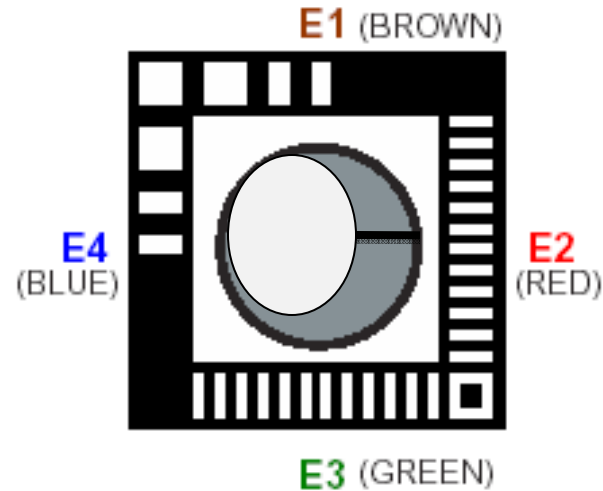


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CRACK EACH SIDE



CRACK ONE SIDE



$$E4_{t+dt} - E4_{t \text{ baseline}} = \text{Change}$$

$$E2_{t+dt} - E2_{t \text{ baseline}} = \text{Change}$$

$(E2_{t+dt} - E2_{t \text{ baseline}})$
is greater than

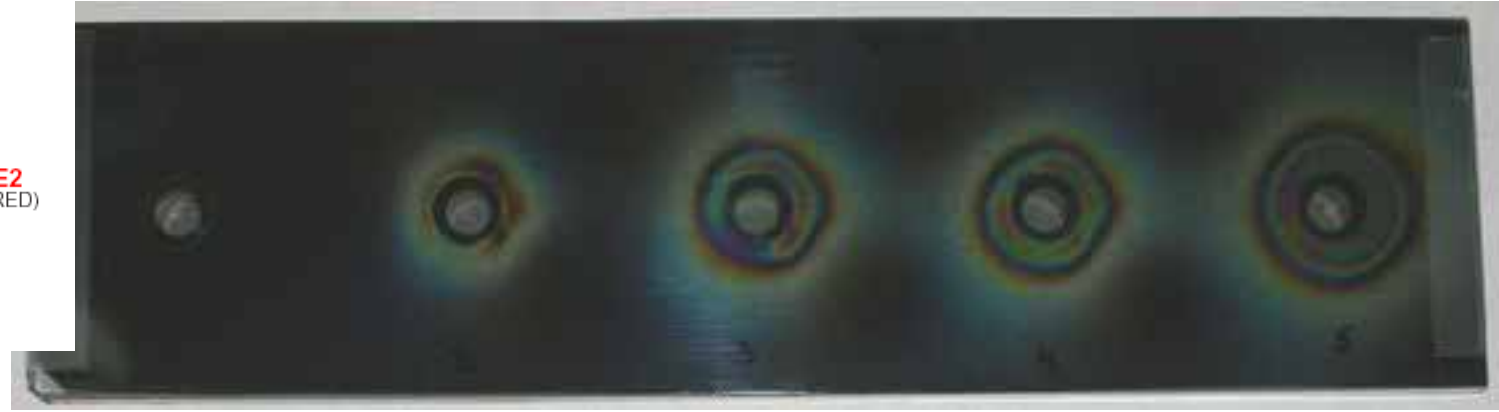
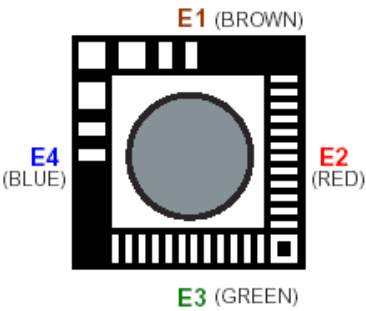
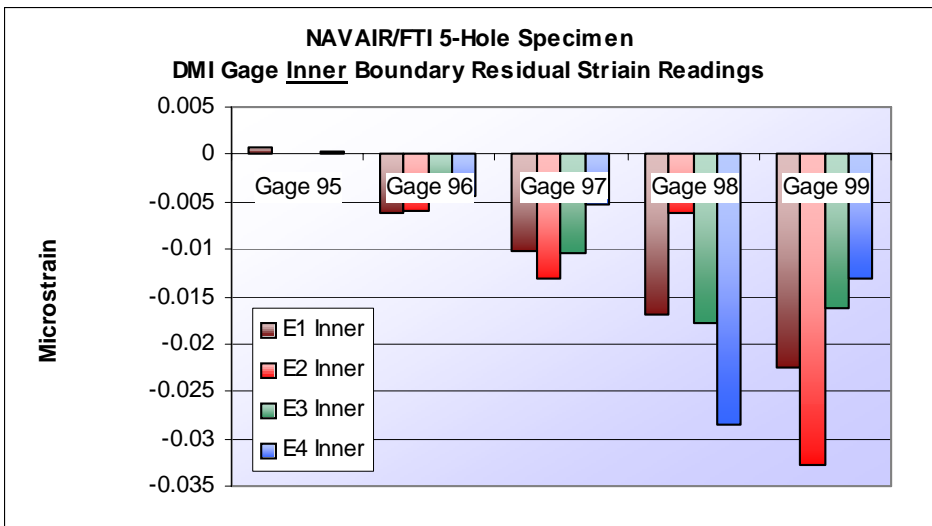
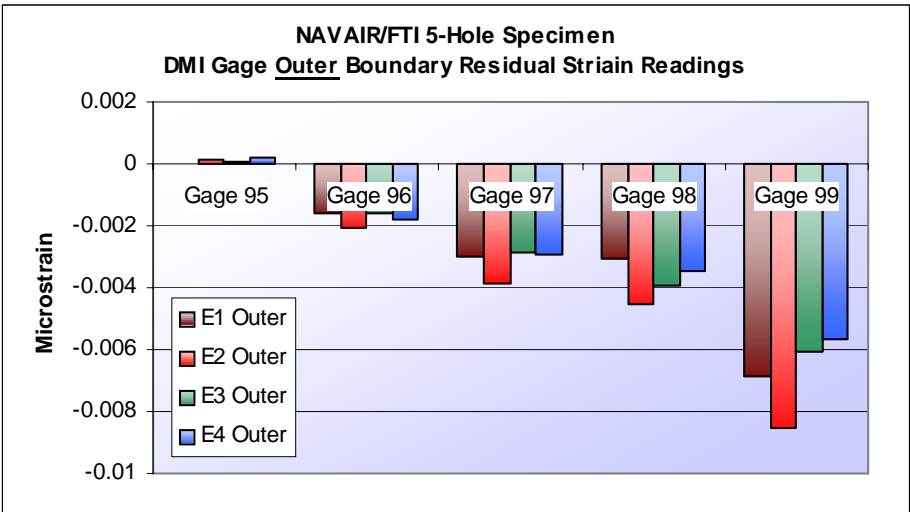
$$(E4_{t+dt} - E4_{t \text{ baseline}})$$



FTI Cold Work 5-hole NDI test plate (0.250 in.)



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Photoelastic fringe pattern

DMI Technology Applied to the Rainbow Fitting



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Example of DMI gage for rainbow fitting



Close-up view



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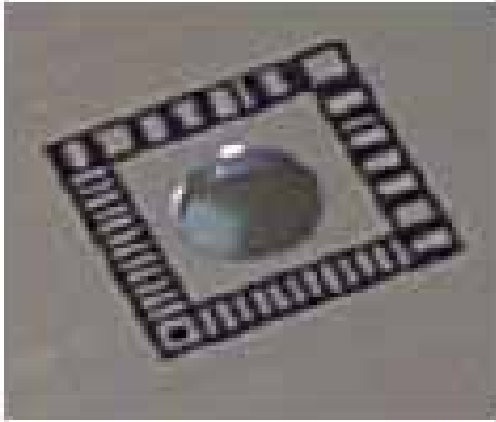
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Gage Application Techniques

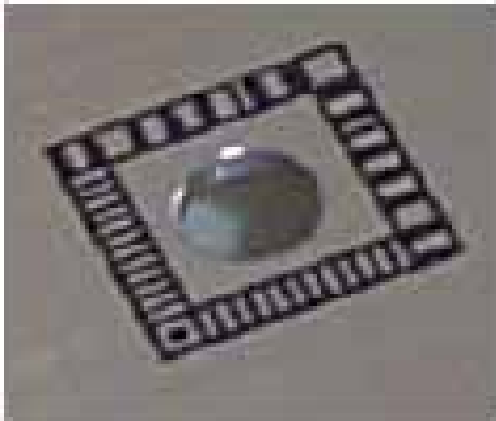


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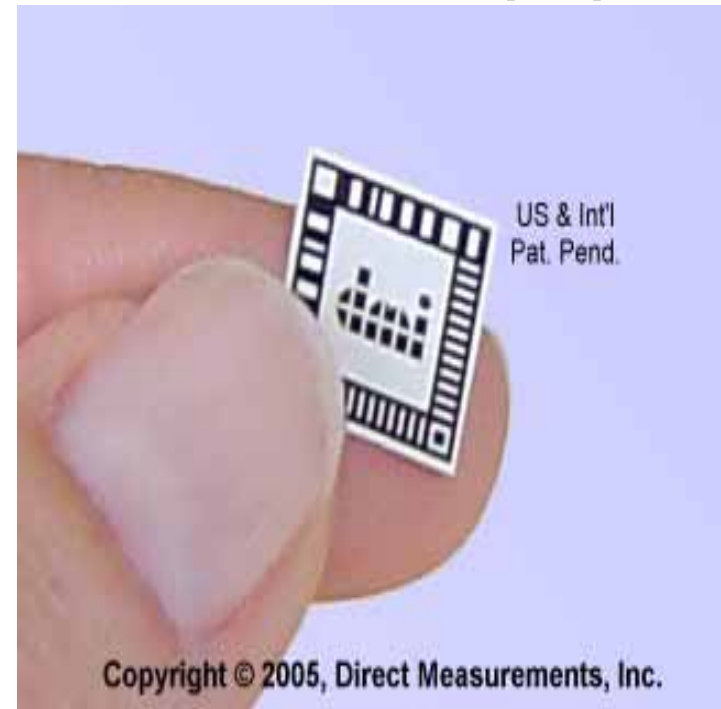
LASER BOND - metals



LASER DISCOLOR - composites



POLYMER – multi-purpose



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Test Shows DMI Gage Adhesive Strength



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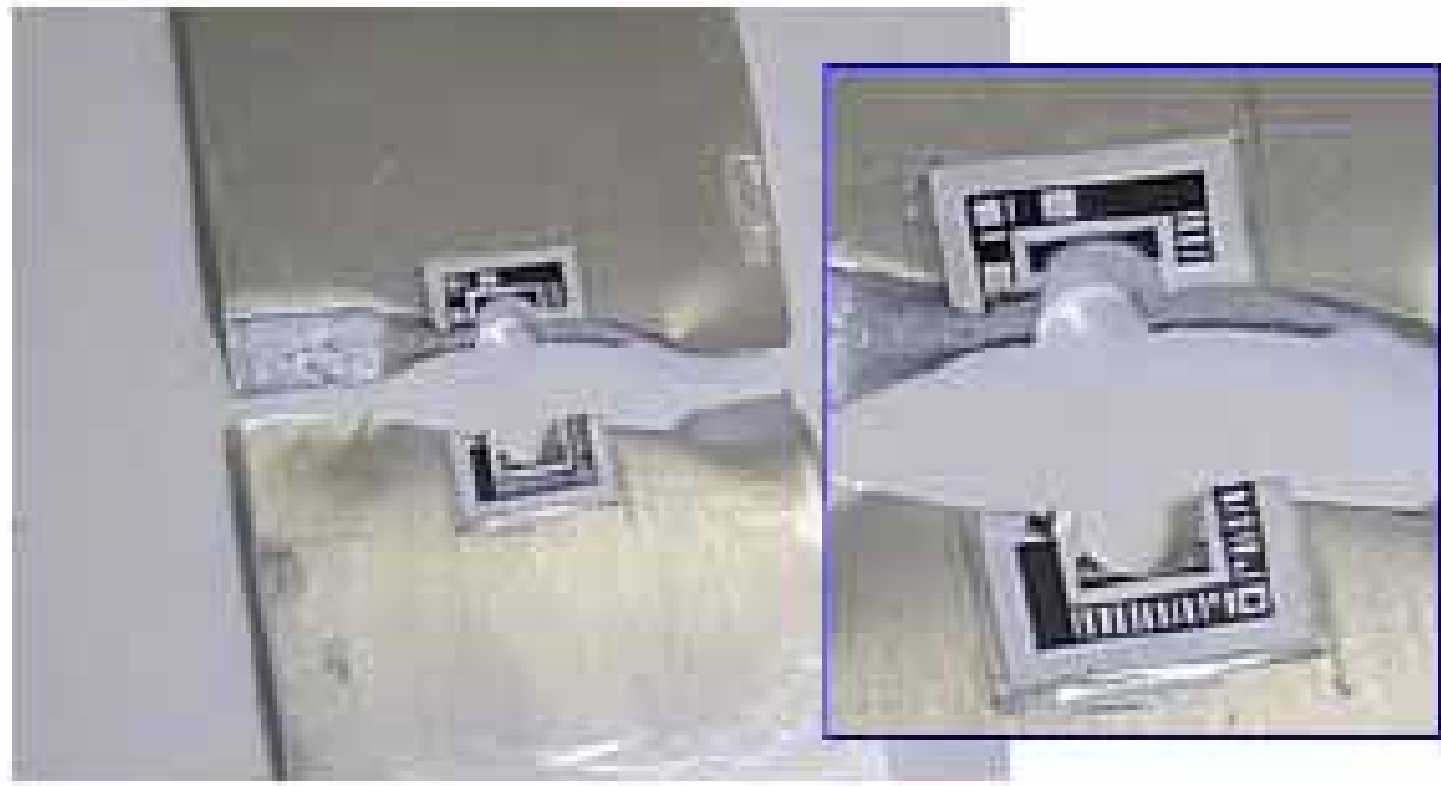


Figure 18. Fatigue coupon after failure

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GAGE:

- ***INDEPENDENT OF ORIENTATION TO LOAD***
- ***EASY AND QUICK TO APPLY***
- ***LONG-TERM DURABILITY***
- ***DEFORMS AND STORES CUMULATIVE DAMAGE***
- ***FLYABLE***

SR-2 READER/INSTRUMENT:

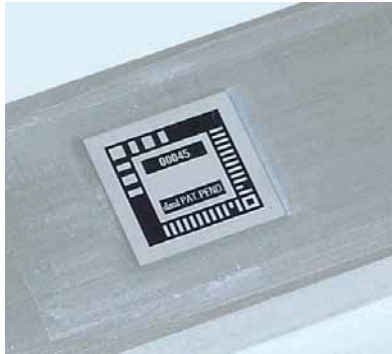
- ***EASY TO USE WITH DIRECT READOUT***
- ***SELF ALIGNMENT OF SENSOR TO GAGE***
- ***STORES AND TRANSMITS DATA***



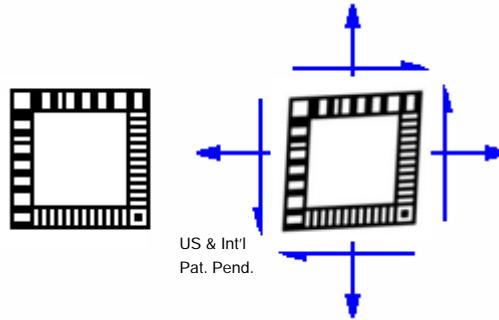
What was covered



US & Int'l Pat. Pend.



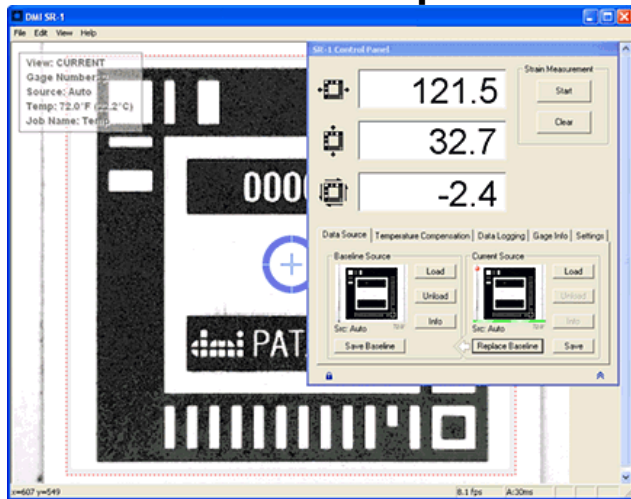
DMI gage permanently affixed to AC part



As part deforms, so does the DMI gage.



Strain measured directly from DMI gage.



Control & Data Display

DMI software interface:

- Runs on a rugged tablet PC
- Handles data collection, analysis, strain calculation, display, logging, remote-access



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- ***Accurate data (+/- 5 microstrain)***
- ***Field and maintainer friendly***
- ***Low cost***





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What can be done- Inspect for Anomalies & Validate Cold-Working to Extend AC Life



- *Meet Mission Requirements*
- *Reduce Costs*



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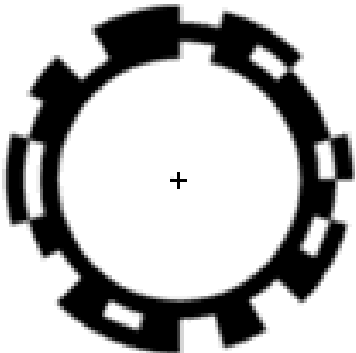
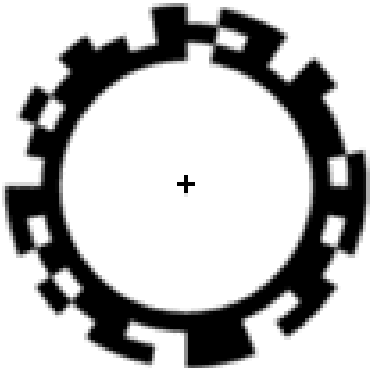
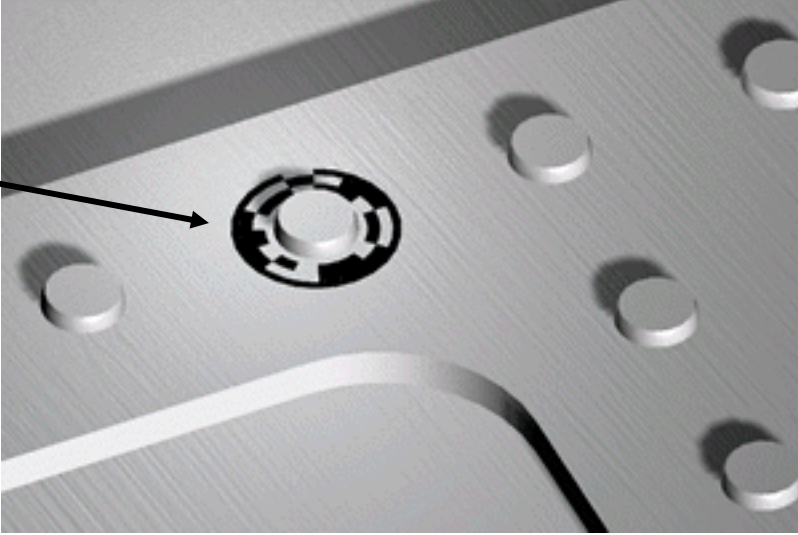


Dr. Bill Ranson- President
Dr. Reggie Vachon- Chairman
Dr. Gregg Hovis - CTO
Mr. Lex Pavlo- V.P. Sales & Marketing





Circular Gage



Typical circular gage serialization geometries
US Patent. Pending

