ILI, In-Ditch and Permanently Installed Tools for Stress/Strain Imaging and Monitoring

AIMPIMG2019-1001

March 2019

Neil Goldfine, Todd Dunford, Andrew Washabaugh
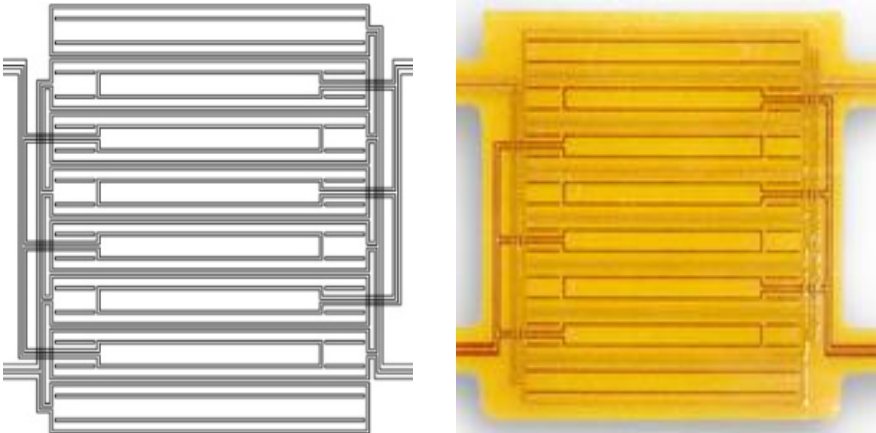
JENTEK Sensors, Inc.
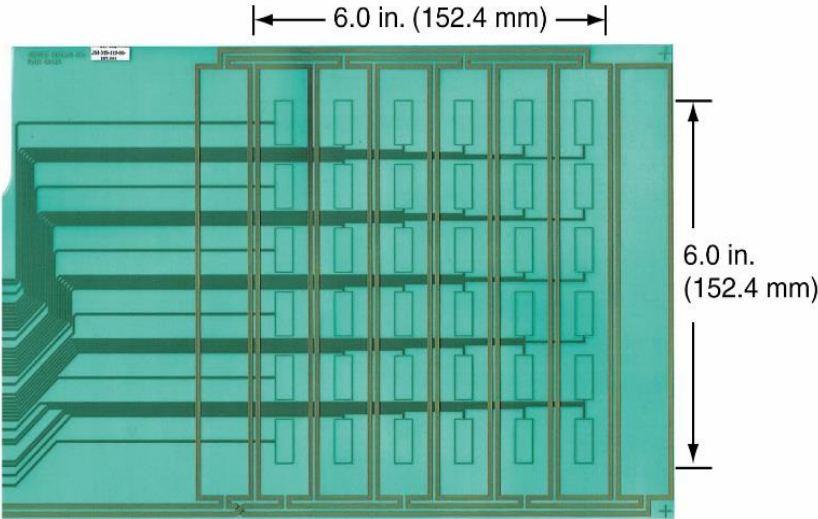121 Bartlett Street,
Marlborough, MA 01752-3025
Tel: 781-373-9700; Email: jentek@jenteksensors.com

jenteksensors.com

JENTEK® Sensors, Inc.

MWM & MWM-Array Sensors

Periodic MWM SENSOR

Periodic MWM-Array

6.0 in. (152.4 mm)

6.0 in. (152.4 mm)

(A)   **(B)**

MWM-ARRAY

(A) WITH A SINGLE RECTANGLE DRIVE WINDING

(B) WITH A DUAL RETANGLE DRIVE WINDING

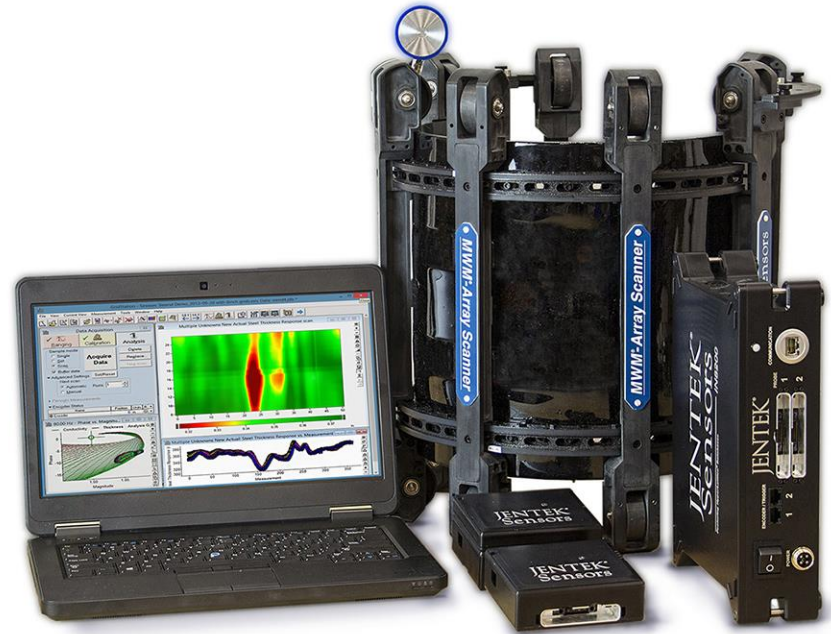# jET and GS8200 Impedance Instruments

jET

GS8200 GridStation

- ❑ 3 simultaneous frequencies
- ❑ 7, 19 or 39 parallel channels (stackable for more channels)
- ❑ High data rates for rapid scanning and monitoring
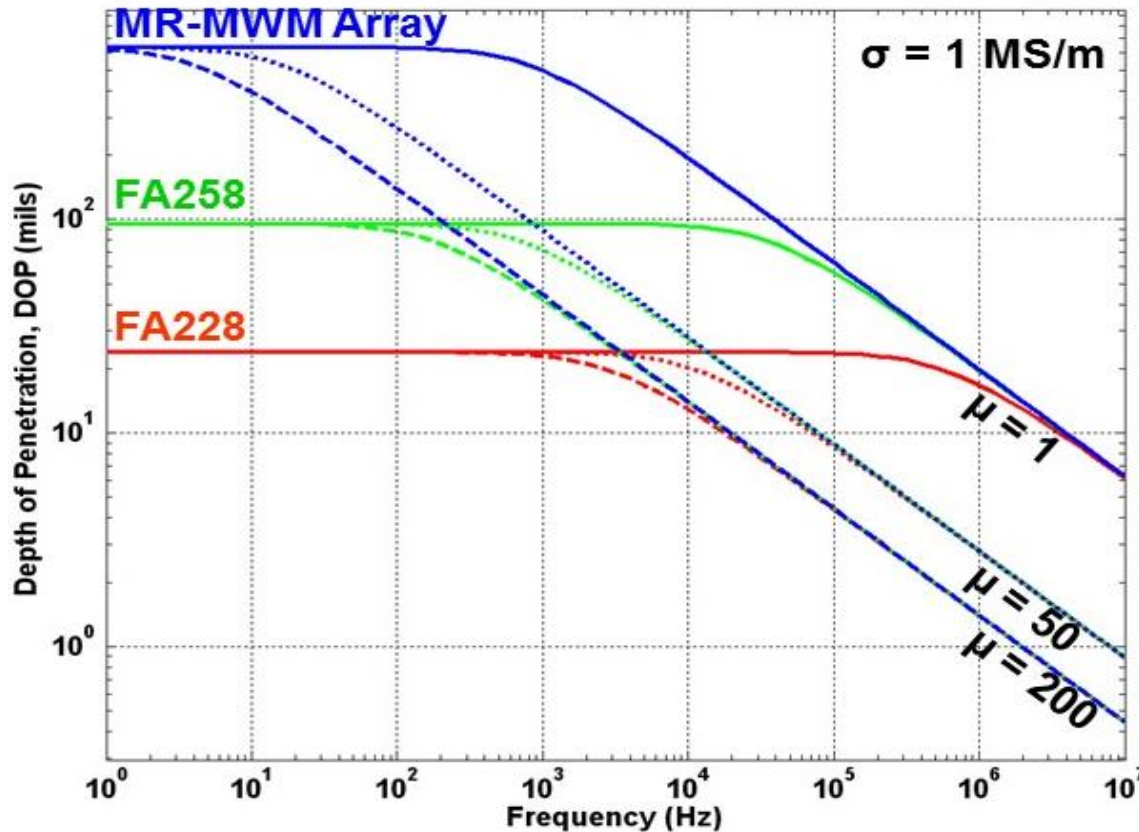- ❑ Handheld (jET < 1pound); portable (GS8200 <10 pounds)
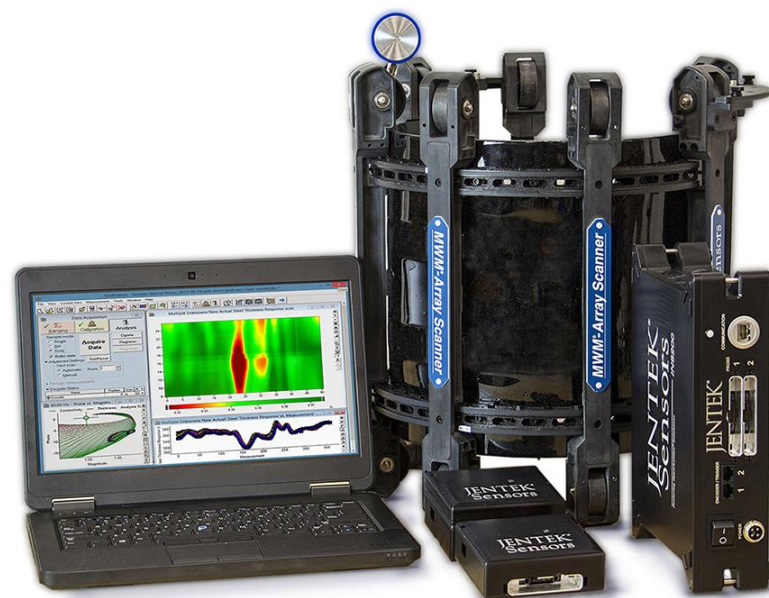
19 and 39 Channel GS8200 with MR-MWM-Array

Flexible MR-MWM-Arrays
(smaller arrays now available)

GS8200
with MR-MWM-Array

Depth of Penetration (DOP) Chart

MR-MWM-Array

for stress or temperature monitoring through insulation and weather jacket or through fireproofing
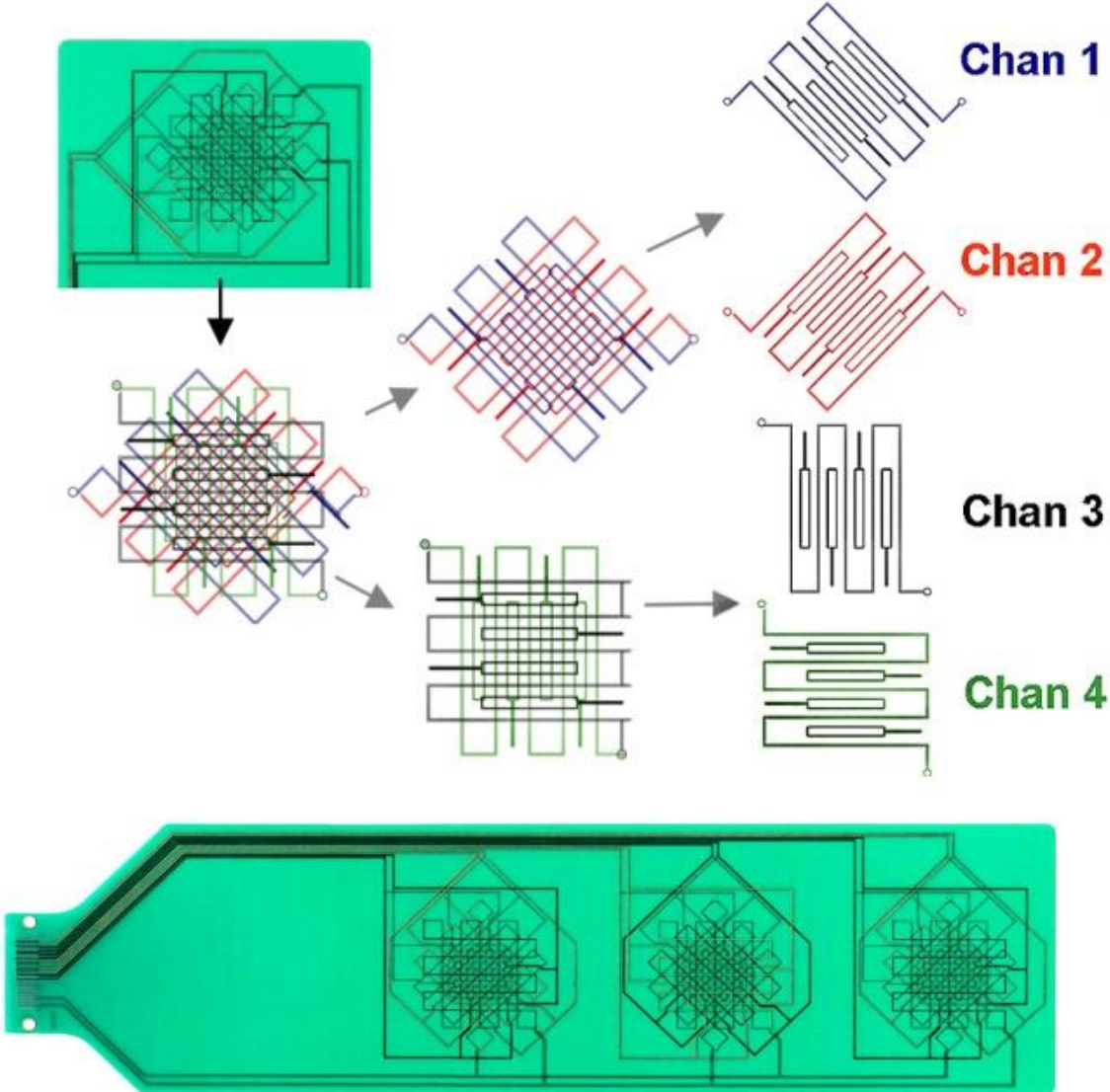
MWM-Array

FA258 for stress or temperature monitoring through coatings (up to 5mm thickness)

MWM-Array

FA228 for stress or temperature monitoring through thin coatings (up to 2mm thickness)

FA258 and **FA228** also provide external crack detection (and depth estimation) and corrosion imaging capability.
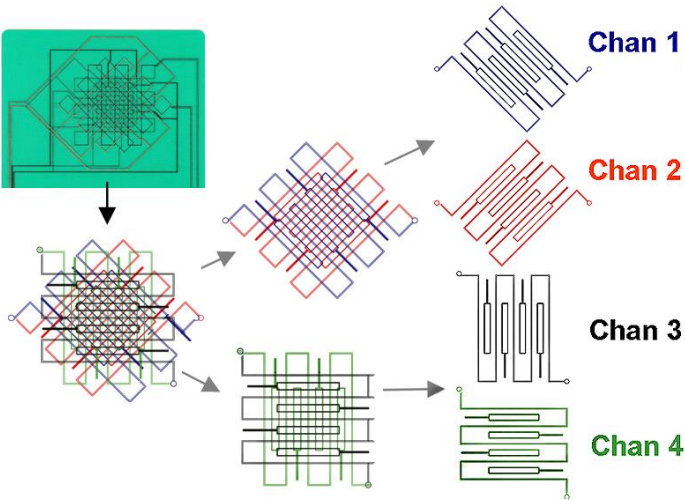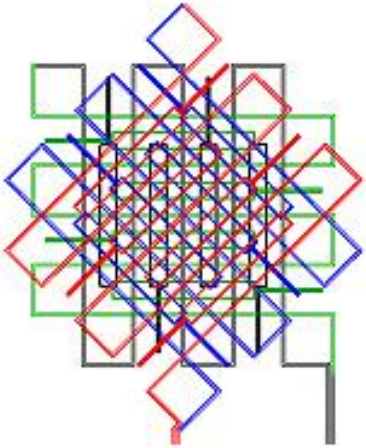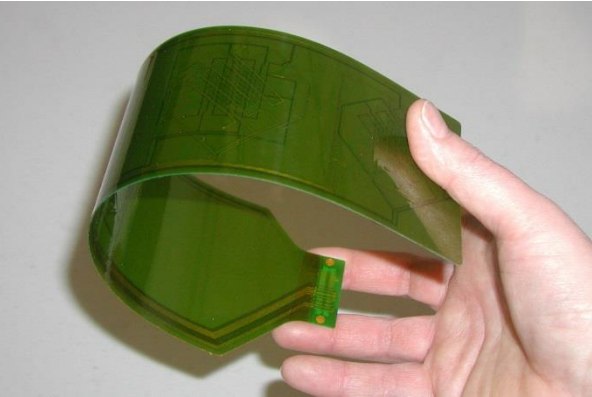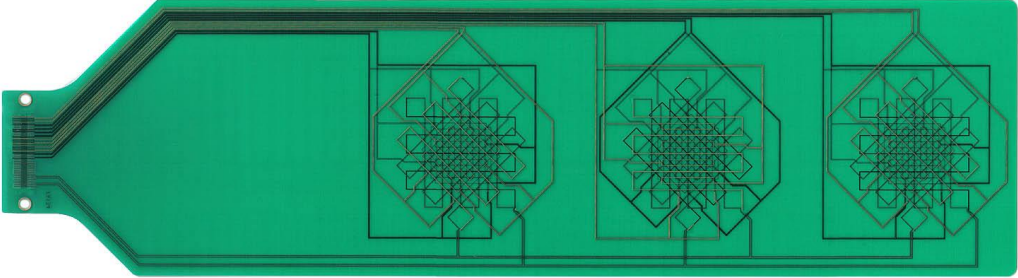
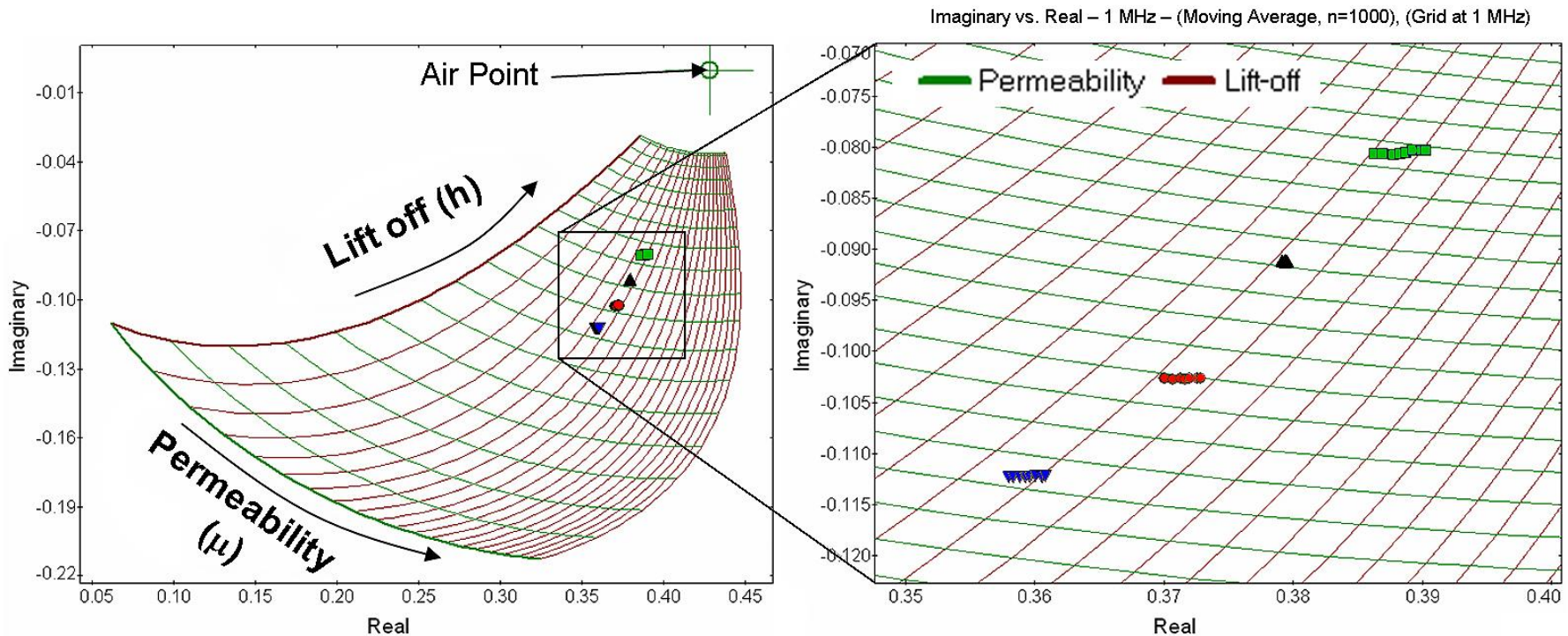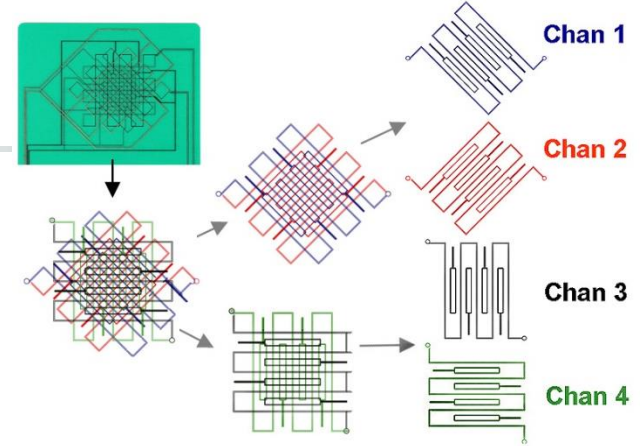# QD-MSG Quadri-Directional Magnetic Stress Gage

QD-MSG ◄ BD-MSG ◄ MWM

Chan 1

Chan 2

Chan 3

Chan 4

Quadri-Directional Magnetic Stress Gage
(QD-MSG™) (MWM-Array FA134)

Chan 1

Chan 2

Chan 3

Chan 4

Quadri-Directional Magnetic Stress Gage (QD-MSG)

Measurement grid method with one point air calibration

Chan 1
Chan 2
Chan 3
Chan 4

Imaginary vs. Real – 1 MHz – (Moving Average, n=1000), (Grid at 1 MHz)

Air Point

Lift off (h)

Permeability (μ)

— Permeability   — Lift-off

$$\text{Transinductance} = \frac{V_2}{j\omega i_1} = \text{Re}\left(\frac{V_2}{j\omega i_1}\right) + j\,\text{Im}\left(\frac{V_2}{j\omega i_1}\right)$$

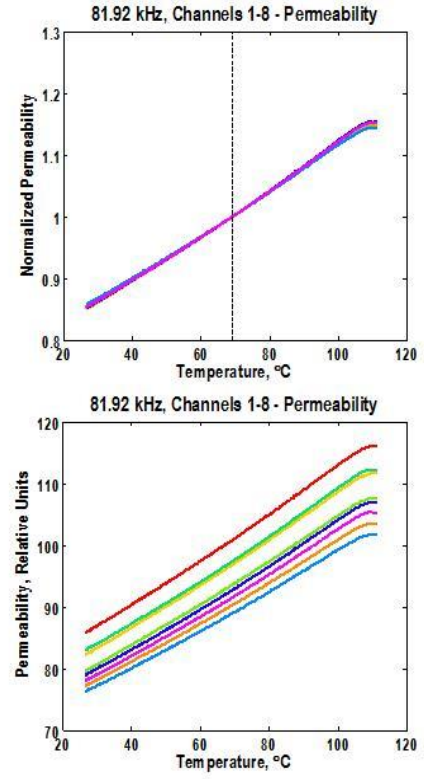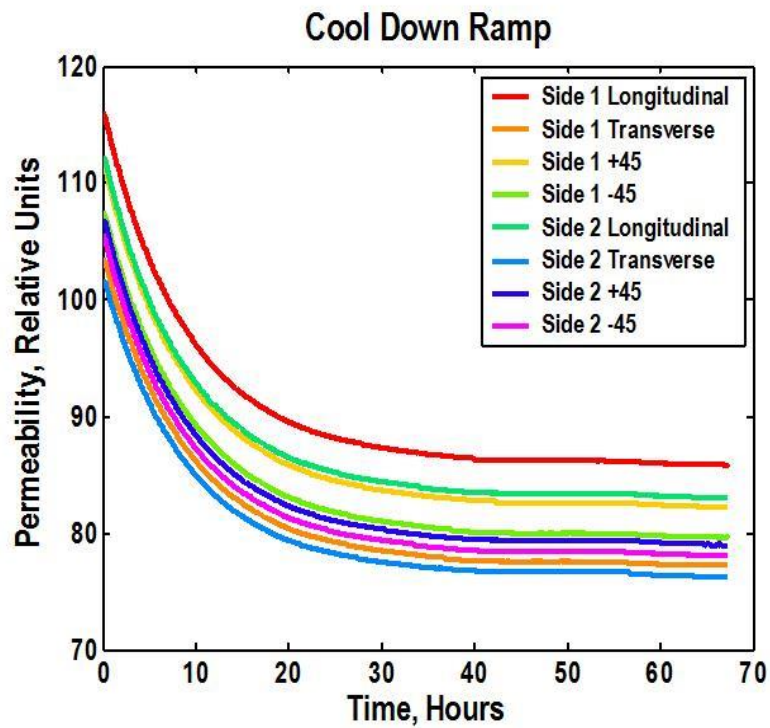## 3- Unknown Lattic Method (delta-h Grids) for Stress, Temperature or Monitoring
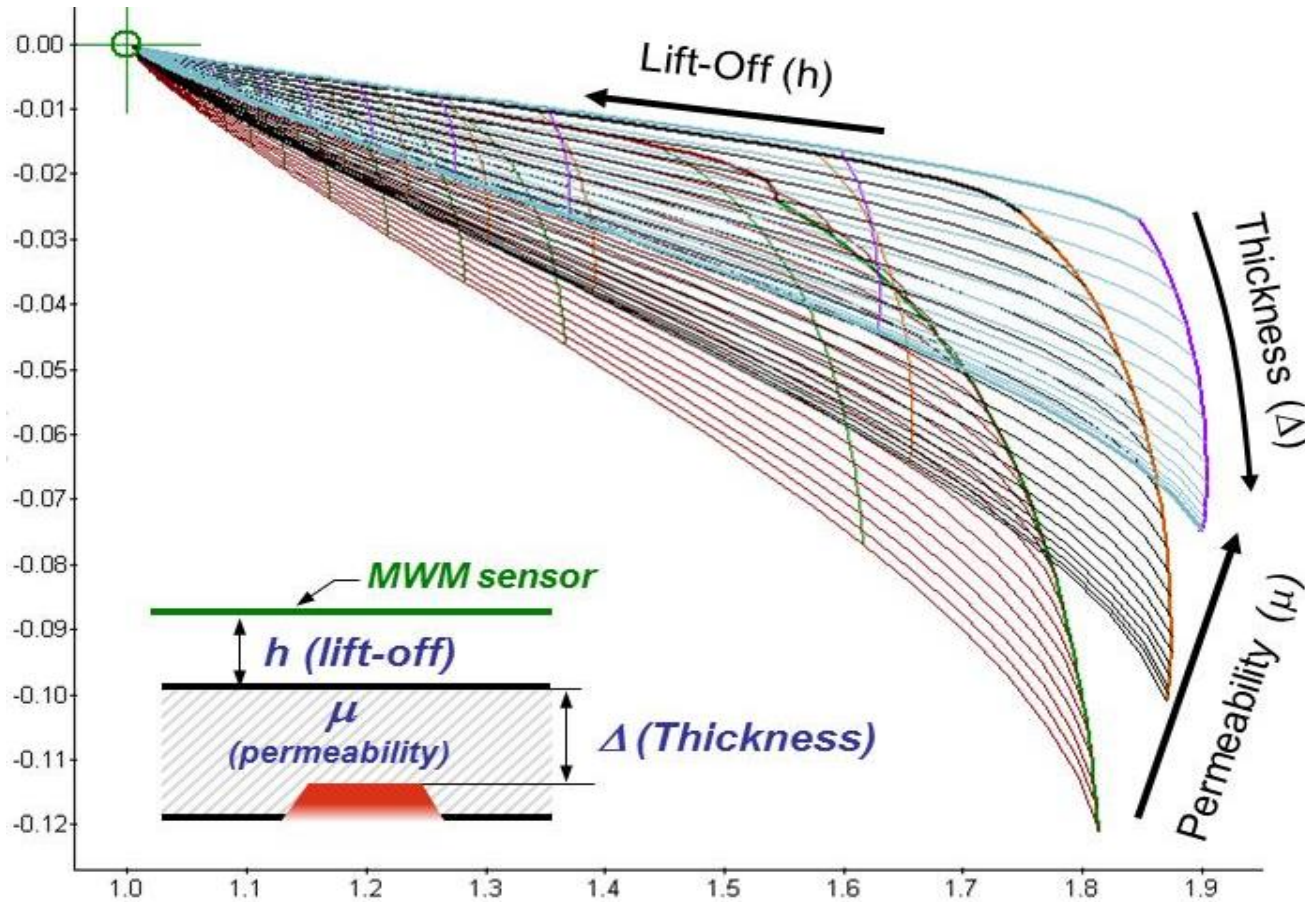
HyperLattices are for 4 or more unknowns, e.g. for **CUI** or **CUF** and **stress monitoring** though insulation and fireproofing
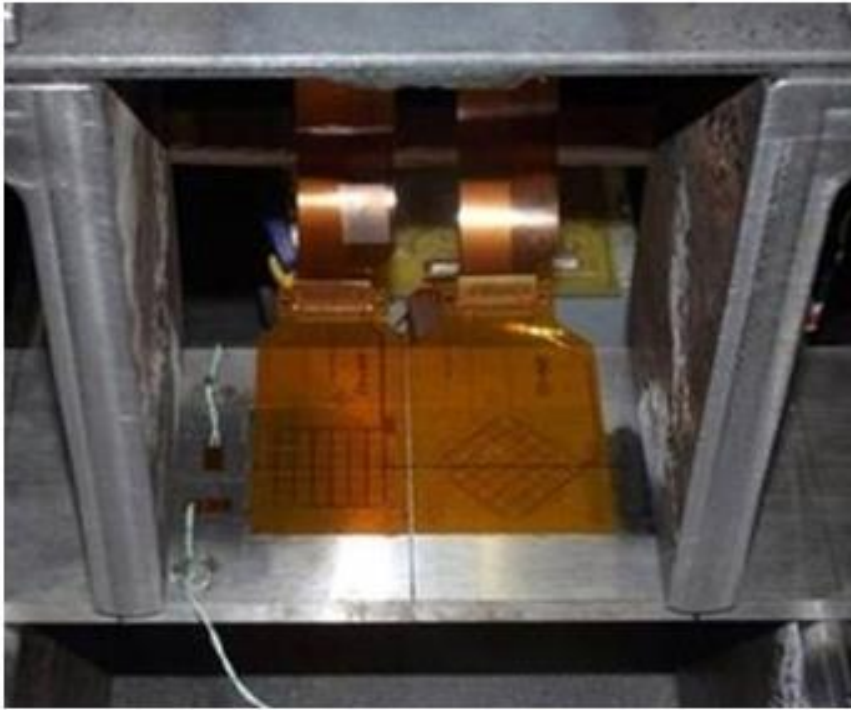
Temperature Monitoring with BD-MSGs or QD-MSGs

Test Setup for Calibration Derivation in Oven

Magnetic Permeability vs Temperature Plots

Bending Coupon Test with Two BD-MSGs

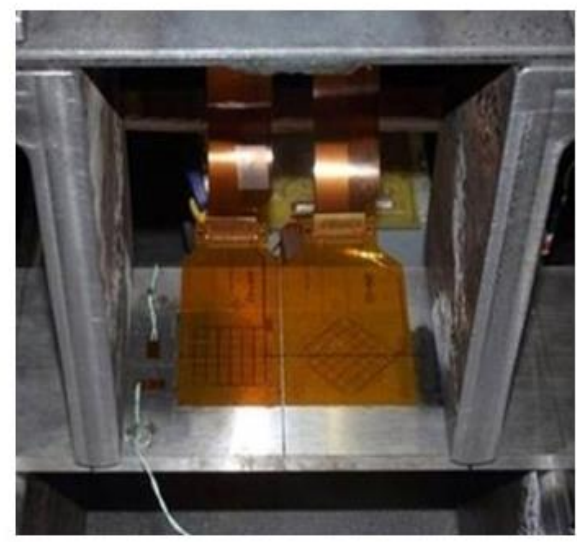**Longitudinal Stress**
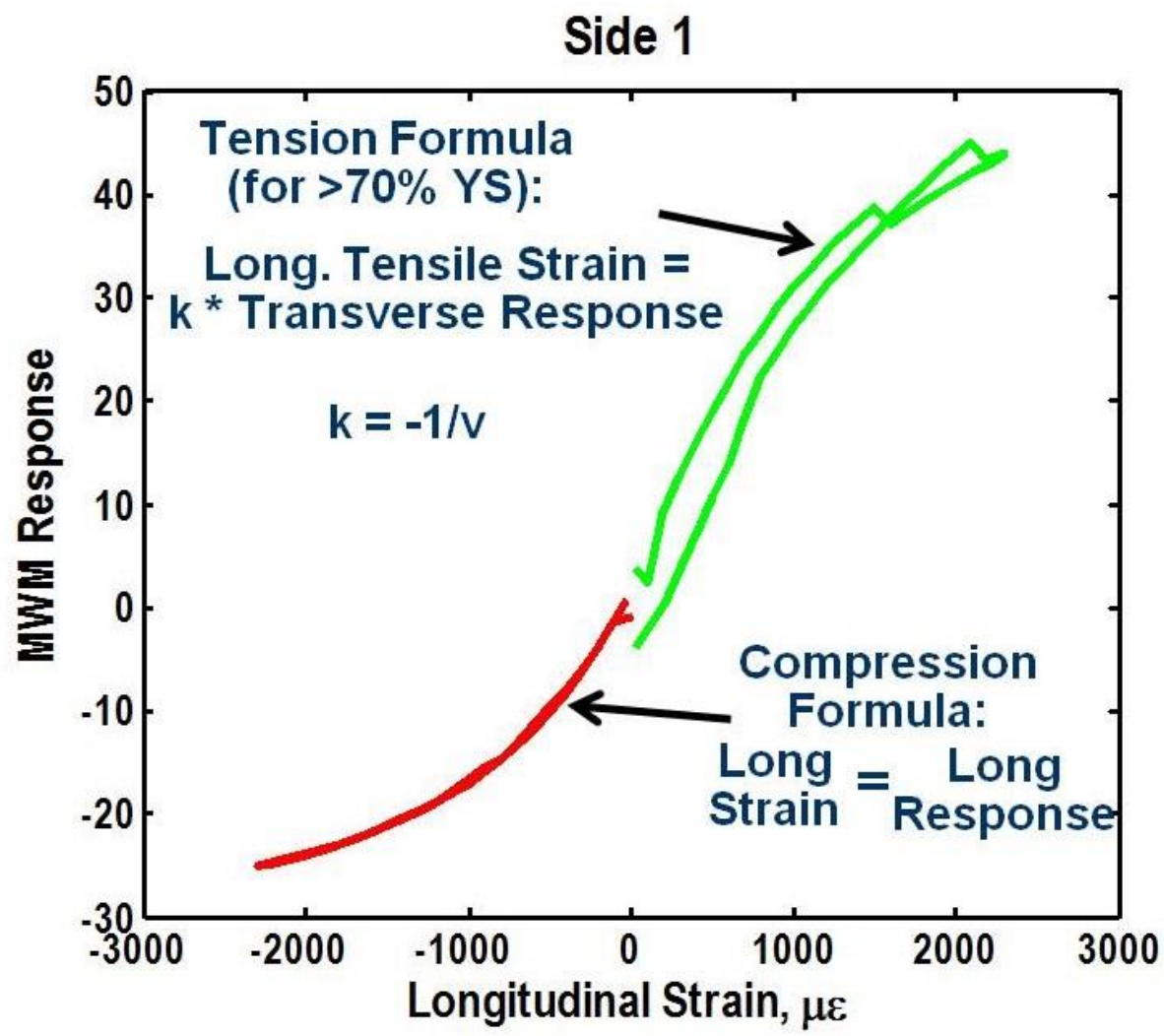
Compression response is monotonic

Tension response peaks at about 70% of Yield, and Hysteresis occurs after approaching yield

Two BD-MSGs at ± 45 degrees and 0/90 degrees on bending coupon

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Need to Combine Longitudinal and Transverse Permeability Responses for Stress Monitoring

Side 1

Tension Formula (for >70% YS):

Long. Tensile Strain = k * Transverse Response

$k = -1/v$

Compression Formula:
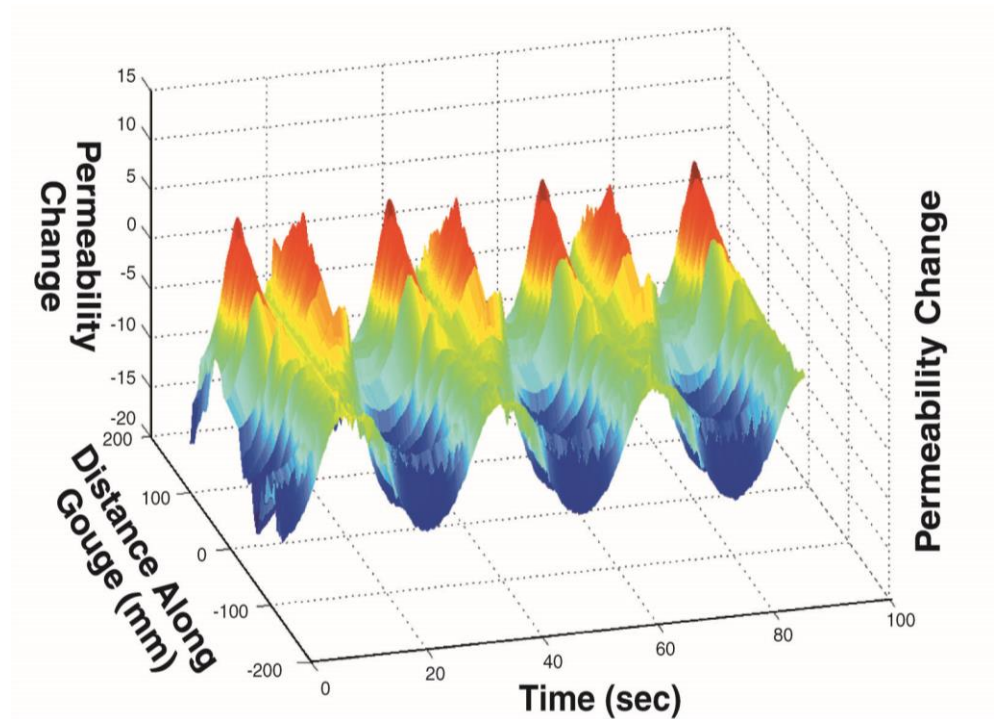
$$\text{Long Strain} = \text{Long Response}$$

BENDING COUPON TEST WITH MOUNTED BD-MSGs

# Dynamic Stress Testing on a Pipe at GDF Suez

PHOTOGRAPH GDF TEST SETUP FOR CRACK GROWTH AND STRESS MONITORING USING AN INSTALLED MWM-ARRAY AT A MECHANICAL DAMAGE SITE

DYNAMIC STRESS DATA SHOWING VARIABLE PERMEABILITY AS THE PIPE SECTION PRESSURE IS VARIED CYCLICALLY OVER TIME.

Full-Scale Fatigue Test at Mechanical Damage Site

under DOT and PRCI funding with GDF Suez

FA178 MWM-Arrays

Crack at max pressure at end of test
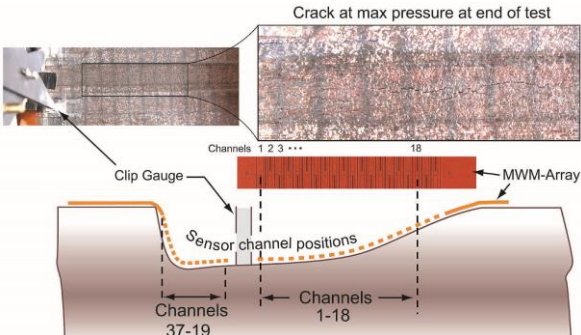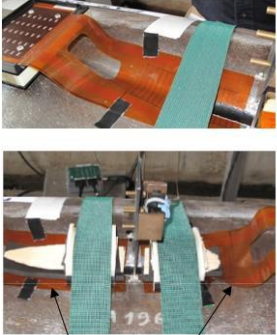
Damage Monitoring

During dynamic cycling

Set	Cycles
1	11
10	114
20	228
30	343
40	457
50	572
59	675
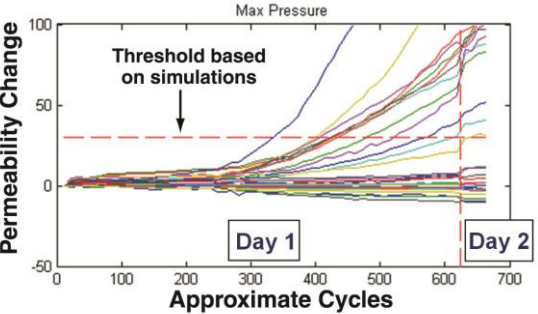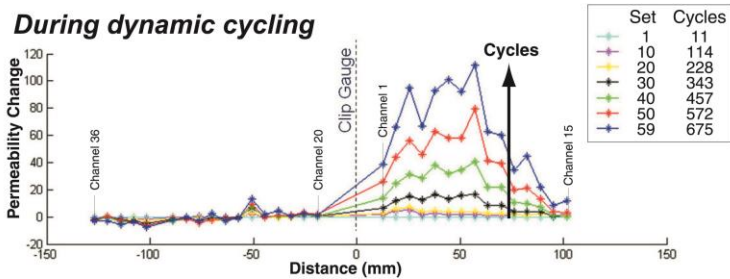
Stress Monitoring

Dynamic pipeline pressure testing
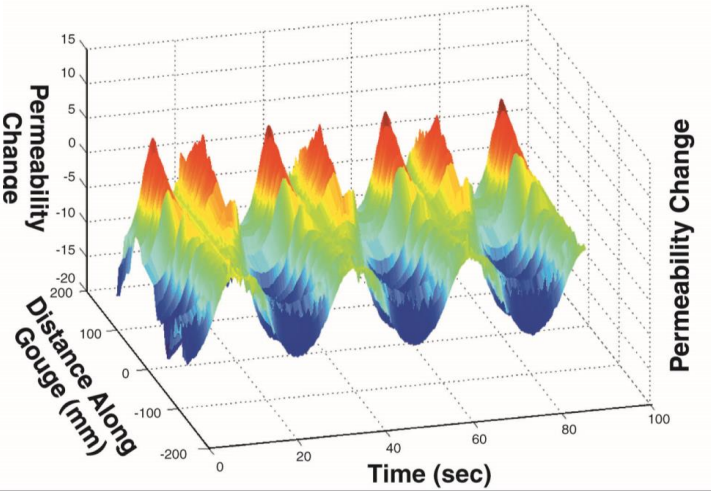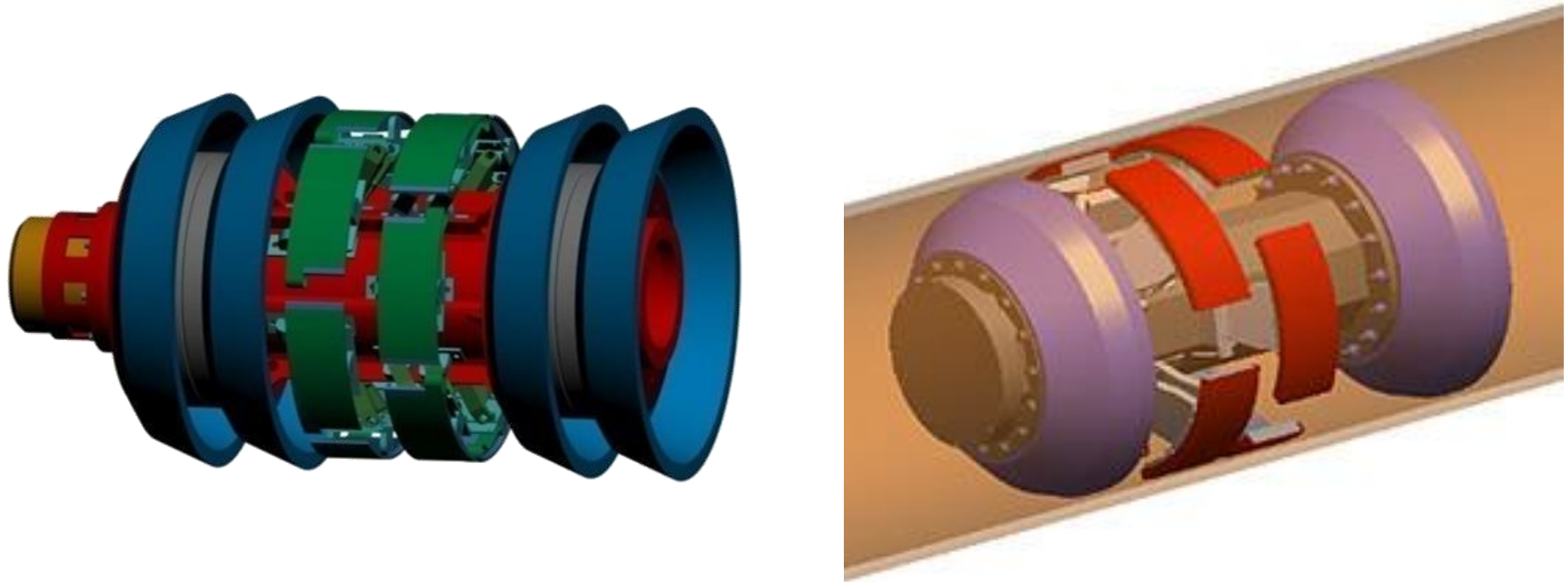
PROTOTYPE ILI TOOL FOR INTERNAL CORROSION IMAGING, CRACK DETECTION, AND STRESS ESTIMATION USING MWM-ARRAYS.

Bending Stress Pattern Recognition

Bending stresses will be identified using pattern recognition

- Stresses will have a well-defined pattern around the circumference
- For a given location, we can estimate:
  - Bending magnitude
  - Bending direction
  - No-load permeability
  - Permeability variations (material noise)
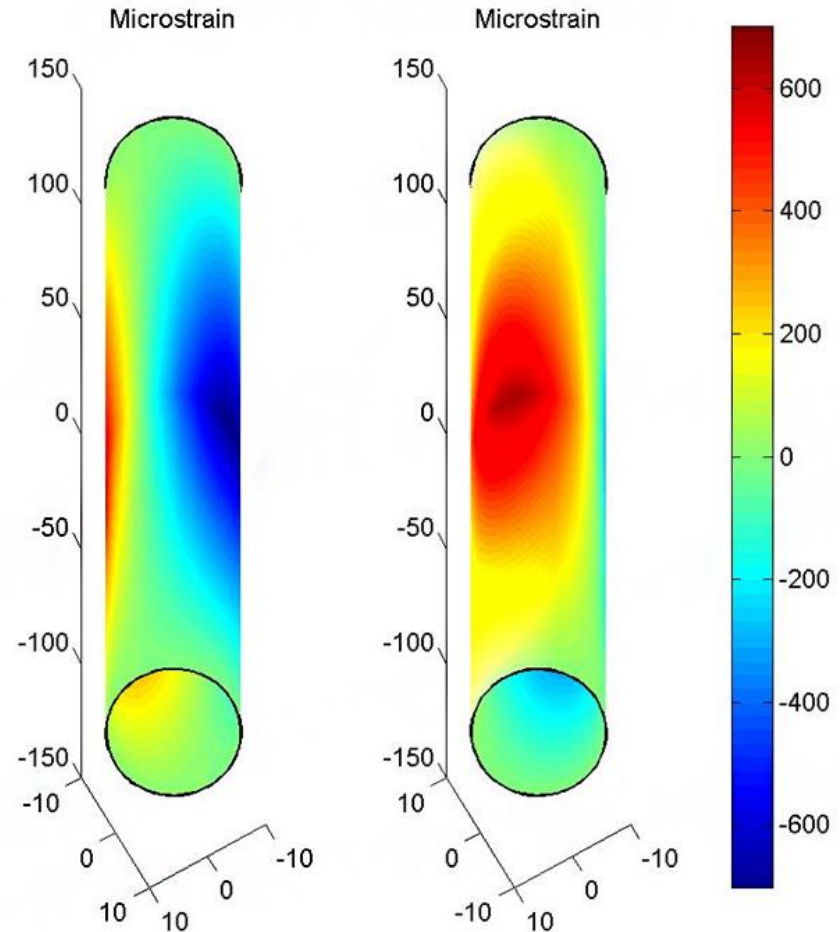
Generation 2 Technology

Enhanced capability demonstration in September 2011

- – Two medium MWM-Arrays (VWA005) mounted on a 2nd generation tool for straight sections
- – Larger MWM-Arrays to accommodate larger lift-offs (e.g., 0.25-in.)
- – Integrated electronics with only power supply tether
- – Similar flaw images as pull Test 1, but both sides imaged at same time
- – Generally see local change in effective lift-off and permeability for flaws

Example of Residual Stress Imaging at Welds
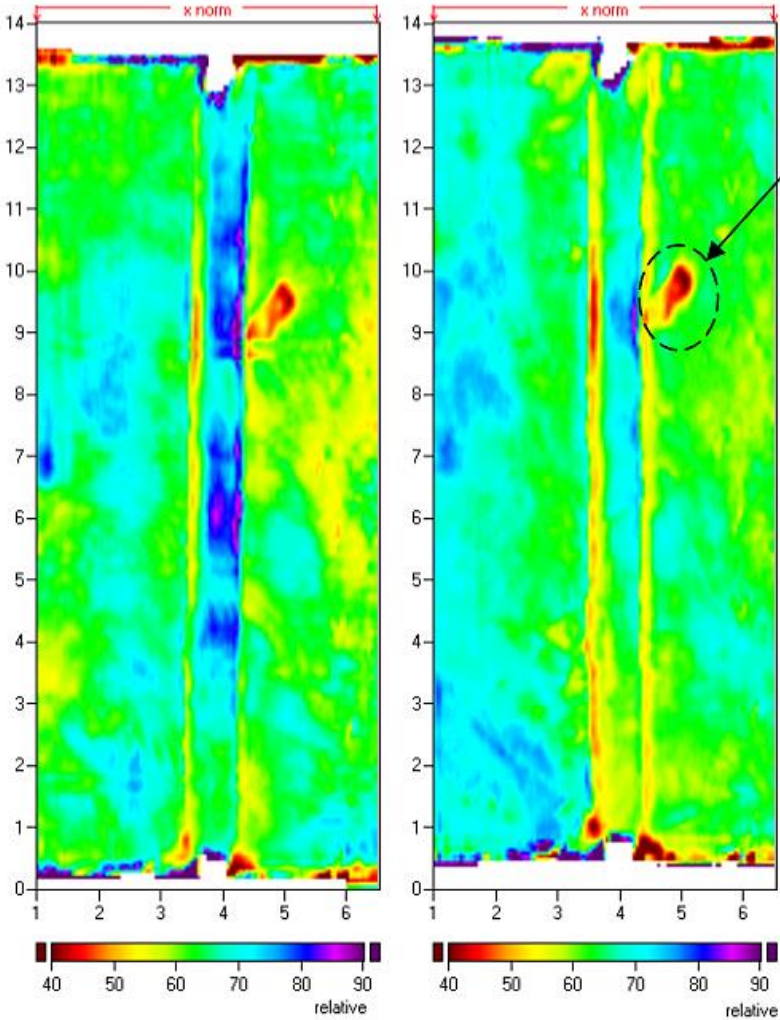
Large dent on coupon

MAGNETIC PERMEABILITY MAP FOR WELD WITH MECHANICAL DAMAGE SITE, BEFORE AND AFTER POST WELD HEAT TREATMENT (PWHT)

HIGHER PERMEABILITY CORRELATES TO HIGHER TENSILE STRESS.

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Summary

- ❑ MWM & MWM-Arrays designed to enable model-based multivariate inverse methods (MIMs)
- ❑ HyperLattice and Grid Methods provide rapid and reliable data analysis
- ❑ QD-MSGs and BD-MSGs enable stress monitoring through insulation/coatings and non-contact
- ❑ Dynamic Stress and Temperature can be monitored (but not independently)
- ❑ Residual Stress can be imaged
- ❑ In-Line-Inspection, Nondestructive Testing and Structural Health Monitoring is practical (ILI not yet available, NDT and SHM are available)

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