# GRI Contract: 8715
# DOT Contract: DTRS 56-04-T-001

# Nonlinear Harmonic-Based Mechanical Damage Severity Criteria for Delayed Failures in Pipelines

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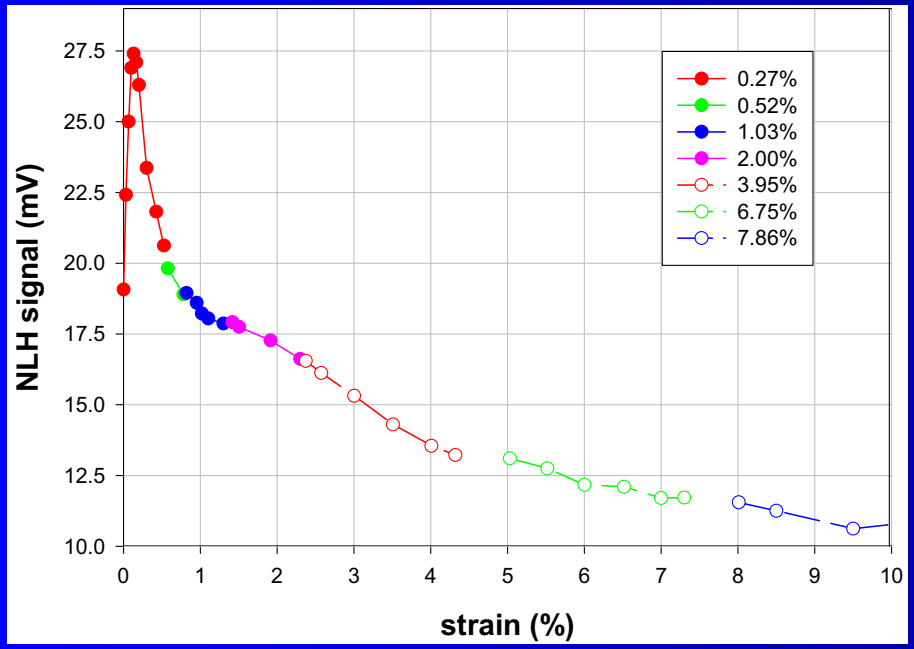
**Presentation by Al Crouch**
**Southwest Research Institute**
**San Antonio, Texas**
**to**
**DOT Project Review**

**March 24, 2005**
**Houston, Texas**

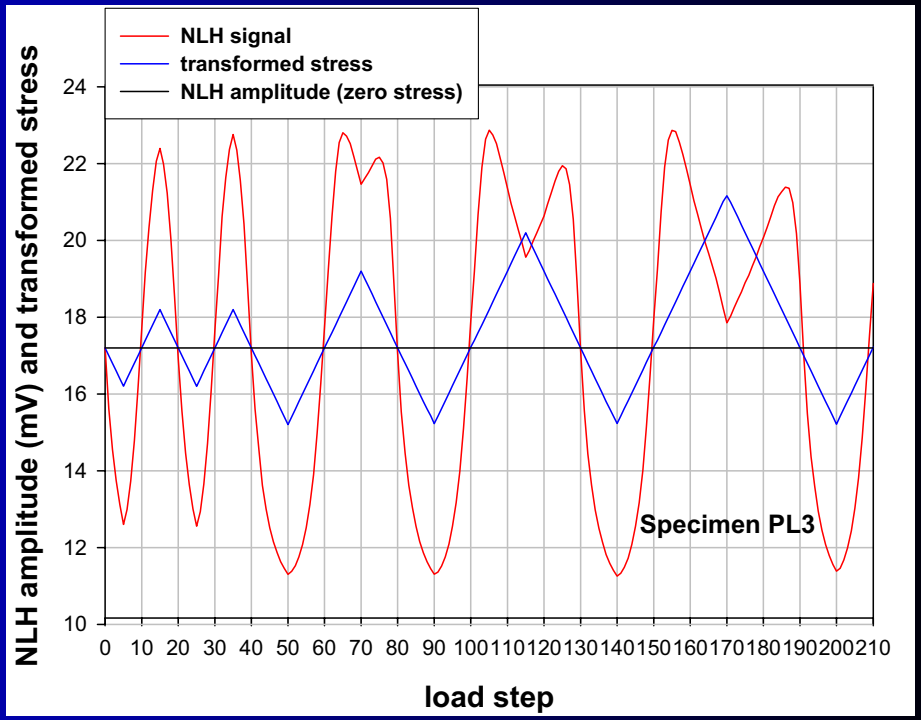
# Nonlinear Harmonics (NLH)

- An electronic method for detecting surface strain patterns
- Developed and refined at SwRI on rails, pipes, other steel products
- Uses an alternating magnetic field (10kHz), making it sensitive to surface strain changes
- Examines only a small area, requiring multiple sensors for complete coverage of pipe surface

# NLH Response to Strain (GRI 8076 and SwRI IR Program)



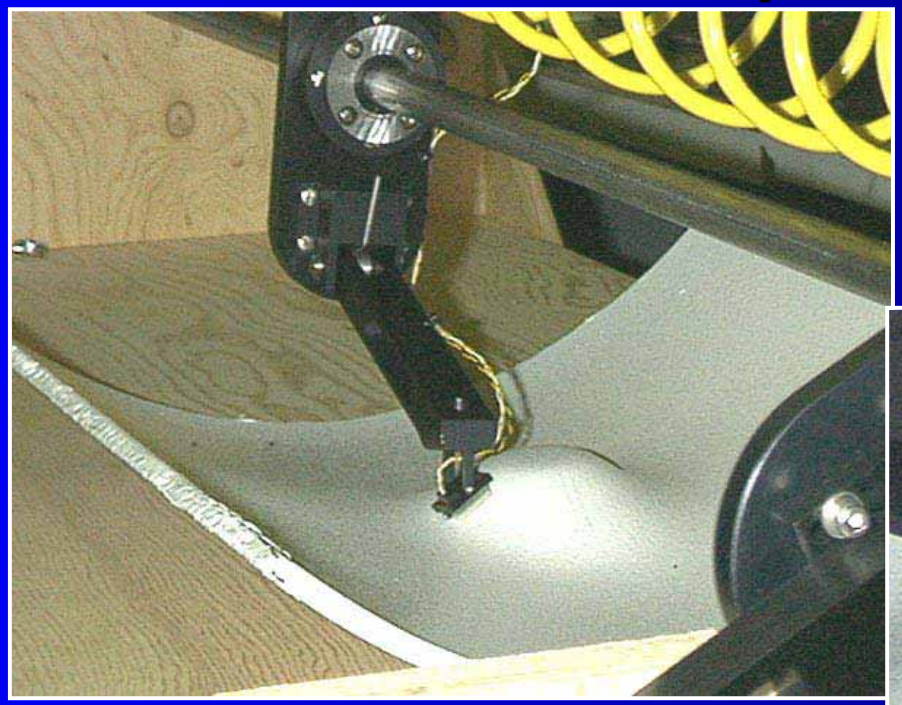

**NLH signals (red) respond to cyclic changes in strain (blue)**



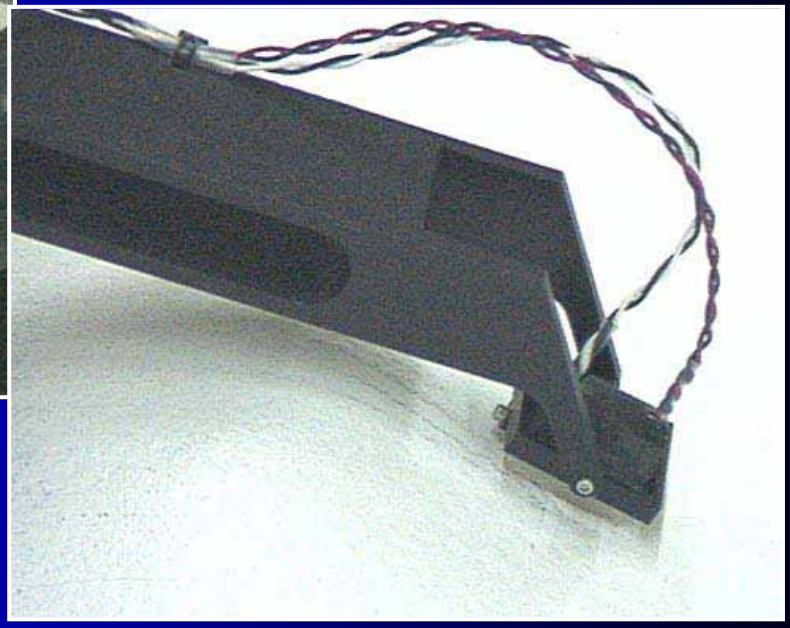

**NLH signal increases at small (elastic) strains, peaks (while strains still elastic) and decreases with increasing (plastic) strains.**

# NLH Scanner:

## Gimbal mounting facilitates scan over defect imprint on inner surface



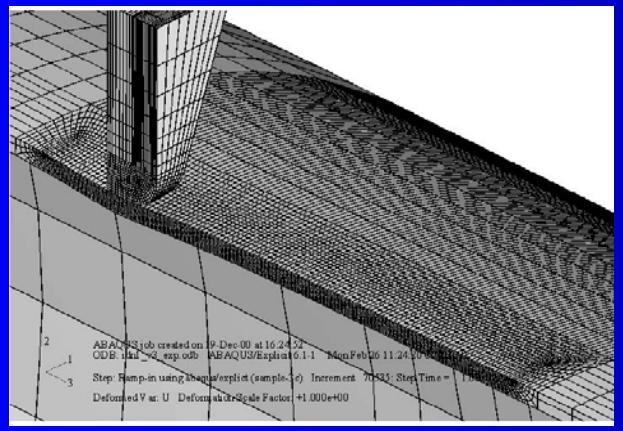
AC magnetic field causes production of odd-numbered harmonic frequencies in pipe surface by magnetic induction

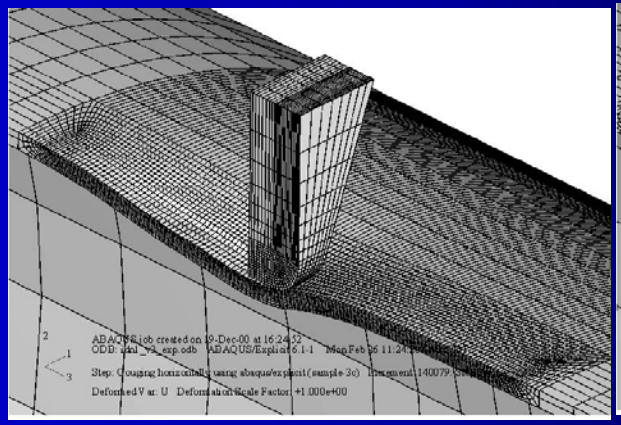


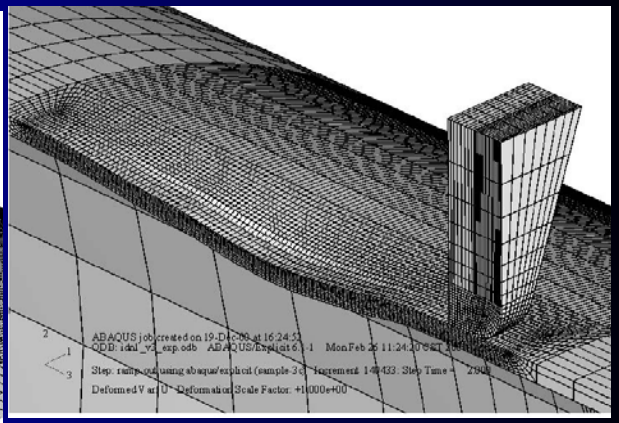
NLH measures amplitude of third harmonic frequency

**Strain changes magnetic properties and hence NLH signal amplitude**

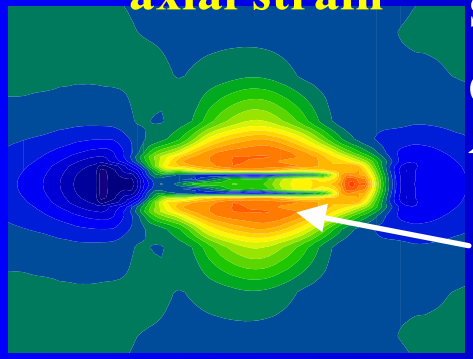
# NLH Signals and FEA Predicted Strains due to Gouging (GRI 8076)







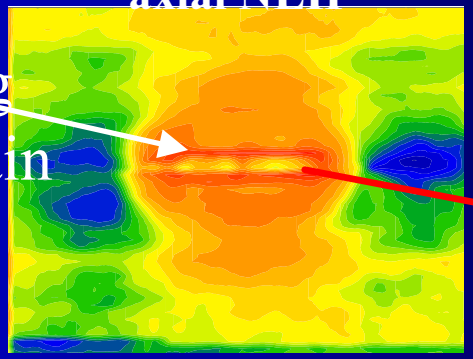
**axial strain**

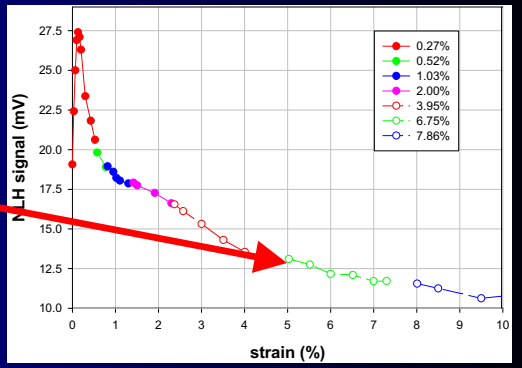


signal corresponding to intense strain

intense strain

**axial NLH**

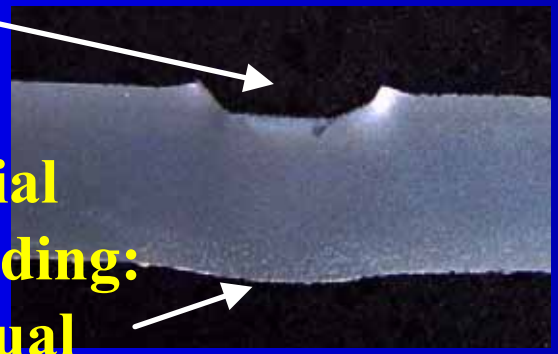




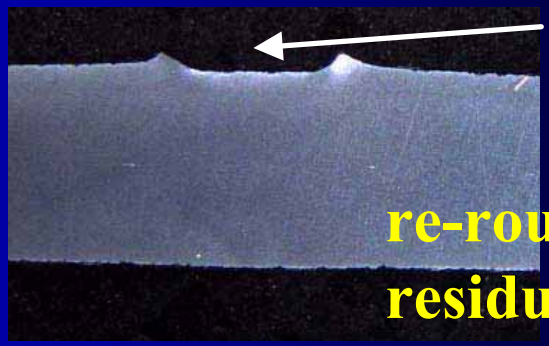

**2.5% OD, 6-inch long, rectangle gouge tool**

# NLH signals detect strain anomalies due to gouging (GRI 8076)

gouge

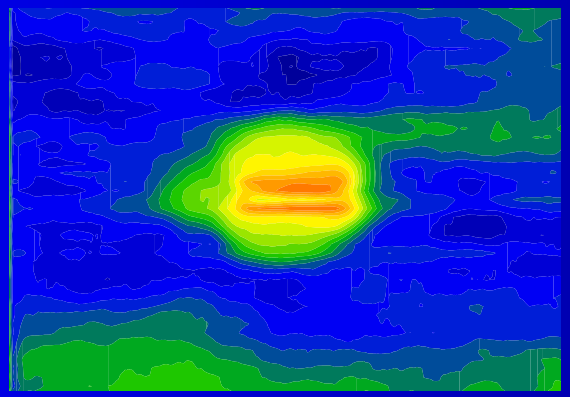


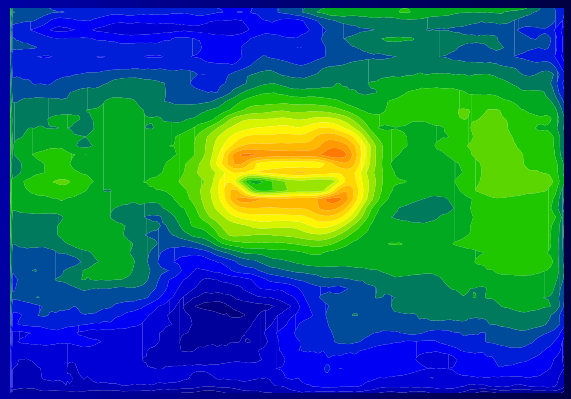
**partial re-rounding: residual deformation**



gouge

**re-rounding: no residual inside deformation**



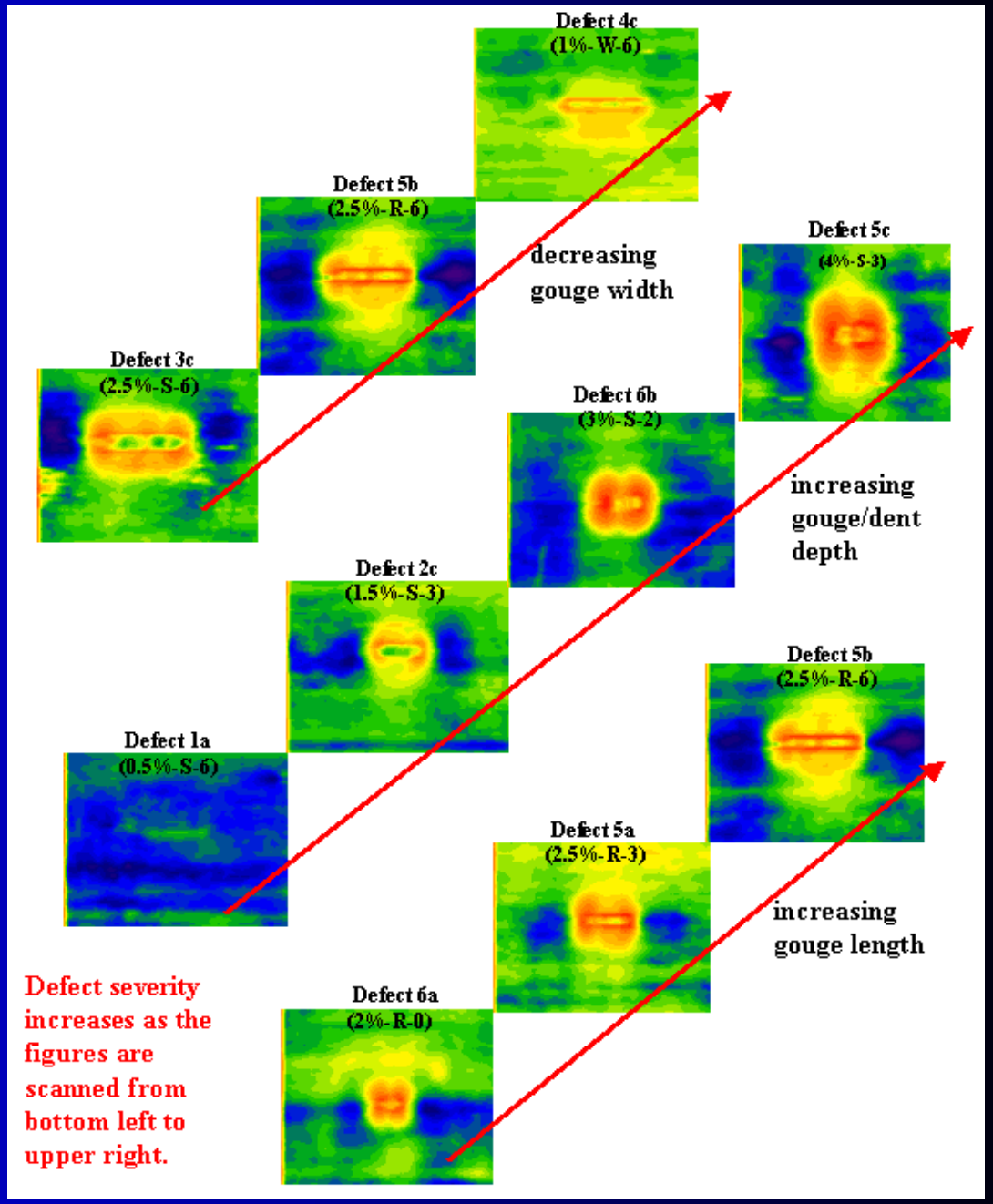


**NLH scans on inside surfaces of pipes detect strain anomalies due to defects on outside surfaces <u>even if residual deformation is absent</u>**

## NLH-Based defect severity criteria (GRI 8076)

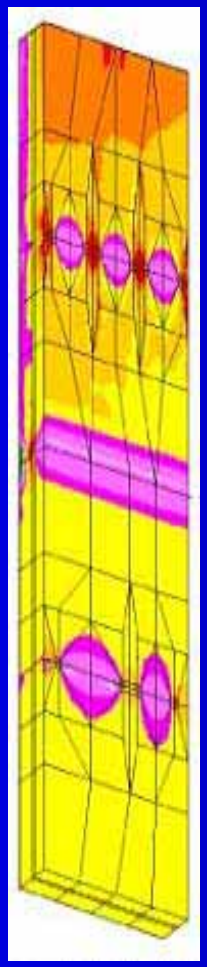
## NLH signals indicate:

- length of gouge
- width of gouge
- depth of gouge

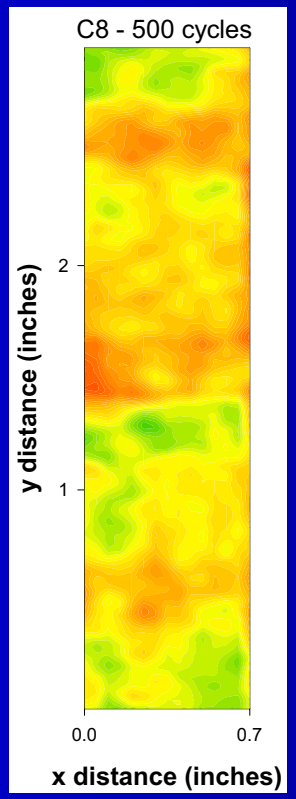


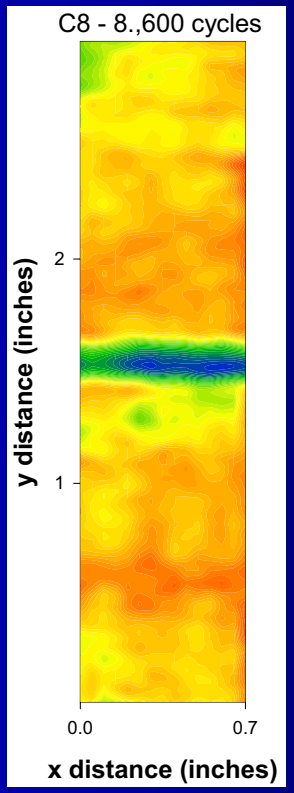
# NLH Signals Measured on Cracked Coupons Compared to Finite Element Analysis Results: SwRI IR Program

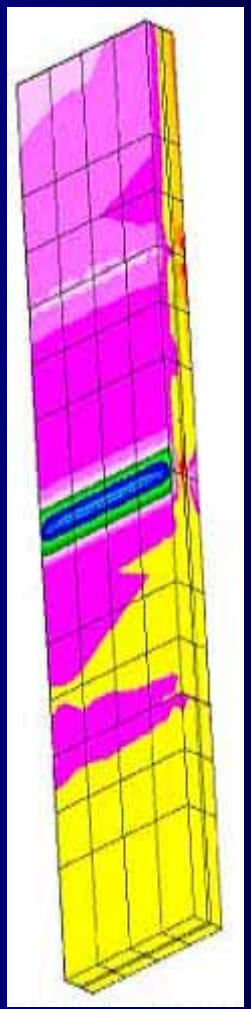
**FE Model: front face showing cracks**



**NLH scans on back face**

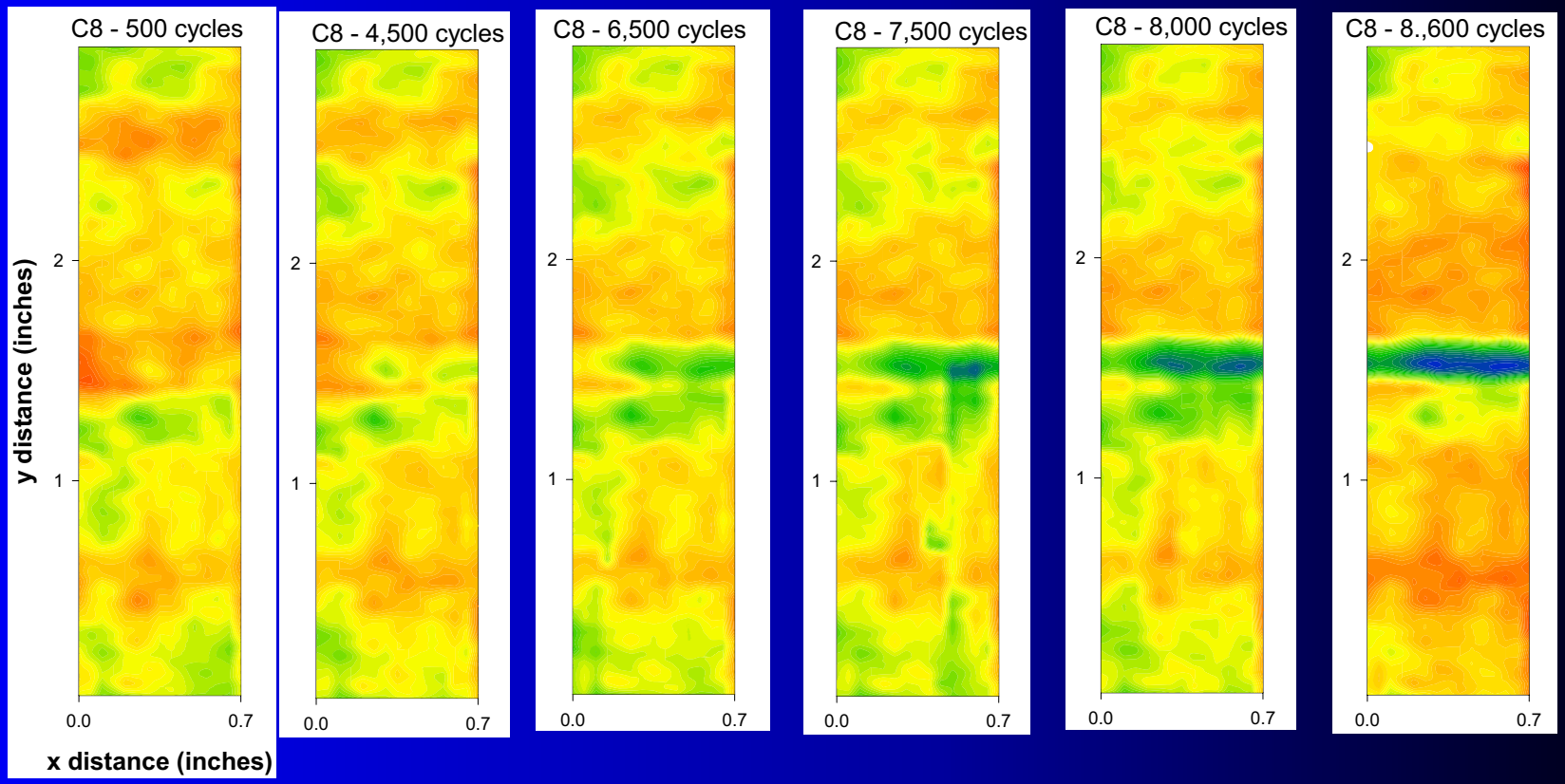


**FEA Model: crack-free back face**

# NLH Signals Indicate Fatigue Crack Growth in Laboratory Tests: SwRI IR Program




increasing number of load cycles

# Introduction to Current Program

- Delayed failures due to mechanical damage are small fraction of total pipeline incidents, but can have tragic consequences
- Delayed failures are related to time dependent accumulation of damage (e.g. fatigue cracking, stress corrosion cracking)
- Current ILI systems detect mechanical damage but cannot determine severity
- Nonlinear Harmonic method offers promising alternative ILI tool for detecting and characterizing severity of defects

# Objectives: DOT/PRCI Program

- **Characterize change in strain anomalies due to mechanical damage in terms of NLH signals and derive NLH-based defect severity criteria related to remaining fatigue life (delayed failure)**

  **Measure NLH signals as a function of pressure cycles on full-scale pipe segments containing realistic gouged dents.**

- **Transfer the developed NLH-based technology to ILI companies**

  **Cooperate with Tuboscope Pipeline Services, Inc. to develop methods for implementing NLH severity criteria in ILI equipment**

# Program Tasks

**Task 1**
**Procure Pipe, Fabricate Defects and EDM Notches, Characterize Material**

**Task 2**
**Fabricate NLH probes and set-up pressure test facilities**

**Task 3**
**NLH Scans on EDM Notched Pipe and Cyclically Pressurized Damaged Pipes**

**Task 4**
**Process NLH Signals**

**Task 5**
**Develop NLH-based Defect Severity Criterion**

**Task 6**
**Technology Transfer**

**Task 7**
**Project Reviews**

**Task 8**
**Management/Reporting**

# Schedule and Programmatic Issues

- Work started August, 2004, due to complete September, 2006 (DOT contract started October, 2004)
- Tasks 1 and 2 completed, Task 3 on-going
- Original work scope expanded to include NLH scanning of EDM notched pipe to support preliminary investigation of NLH capability for detecting SCC
- Fabrication of gouges more difficult than anticipated ( 12-inch pipe, 1400psi pressure)
- Cost of designing and fabricating four NLH scanners greater than anticipated

# Task 1: Pipe Procurement and Fabrication of Defects

**Pipe Material:**
**X52/X60**
**Pipe Dimensions:**
**OD 12.75 inches**
**Thickness 0.25 inches**

**Five 6-foot pipe samples**

**Six gouging defects in each of four samples**

**50 EDM notches in one pipe sample**

# Task 1: Defects Fabricated

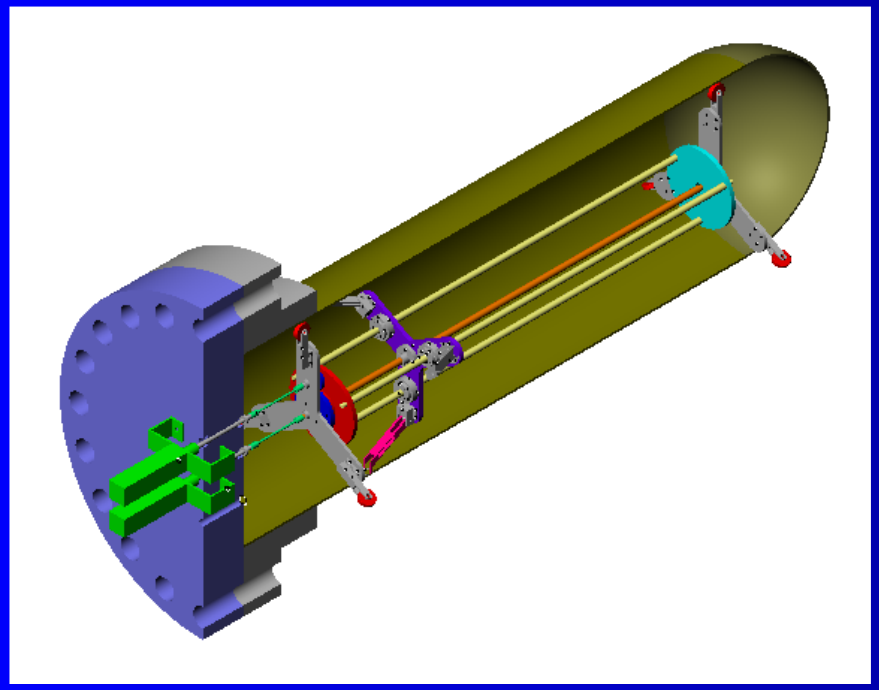
| Pipe No. | Gouge Sample Number | Gouge Depth (inches) | Gouge Depth (%, d/D) | Gouge Length (inches) | Gouge Tool | Wedge width (inches) | Severity Factor | Residual Gouge Depth (mils) |
|---|---|---|---|---|---|---|---|---|
| 2 | 2-1 | 0.40 | 3.14 | 3 | Rectangle | 0.46 | 0.60 | 25 |
| 2 | 2-2 | 0.35 | 2.75 | 3 | Wedge | 0.33 | 0.42 | 22 |
| 2 | 2-3 | 0.50 | 3.92 | 1 | Wedge | 0.33 | 0.44 | 50 |
| 2 | 2-4 | 0.36 | 2.82 | 3 | Rectangle | 0.46 | 0.40 | 20 |
| 2 | 2-5 | 0.48 | 3.76 | 3 | Square | 0.75 | 0.98 | 55 |
| 2 | 2-6 | 0.48 | 3.76 | 1 | Rectangle | 0.46 | 0.31 | 50 |
| 3 | 3-1 | 0.65 | 5.10 | 3 | Square | 0.75 | 3.30 | 191 |
| 3 | 3-3 | 0.60 | 4.71 | 3.5 | Wedge | 0.33 | 4.57 | 70 |
| 3 | 3-4 | 0.70 | 5.49 | 2 | Rectangle | 0.46 | 3.19 | 90 |
| 3 | 3-5 | 0.70 | 5.49 | 2.5 | Square | 0.75 | 3.40 | 205 |
| 3 | 3-6 | 0.70 | 5.49 | 1.75 | Wedge | 0.33 | 3.16 | 248 |
| 4 | 4-1 | 0.55 | 4.31 | 4 | Square | 0.75 | 2.64 | 75 |
| 4 | 4-2 | 0.45 | 3.53 | 6 | Rectangle | 0.46 | 2.96 | 32 |
| 4 | 4-3 | 0.60 | 4.71 | 2 | Rectangle | 0.46 | 1.72 | 55 |
| 4 | 4-4 | 0.60 | 4.71 | 1.5 | Wedge | 0.33 | 1.41 | 70 |
| 4 | 4-5 | 0.50 | 3.92 | 6 | Square | 0.75 | 3.54 | 25 |
| 4 | 4-6 | 0.50 | 3.92 | 4 | Wedge | 0.33 | 2.72 | 50 |
| 5 | 5-1 | 0.50 | 3.92 | 4 | Rectangle | 0.46 | 2.30 | 69 |
| 5 | 5-2 | 0.60 | 4.71 | 2.5 | Wedge | 0.33 | 2.76 | 145 |
| 5 | 5-3 | 0.50 | 3.92 | 4 | Wedge | 0.33 | 2.72 | 112 |
| 5 | 5-4 | 0.55 | 4.31 | 3.5 | Rectangle | 0.46 | 2.73 | |
| 5 | 5-5 | 0.60 | 4.71 | 3 | Square | 0.75 | 2.39 | |
| 5 | 5-6 | 0.55 | 4.31 | 3 | Wedge | 0.33 | 2.55 | |

# Task 1: EDM Notches Fabricated

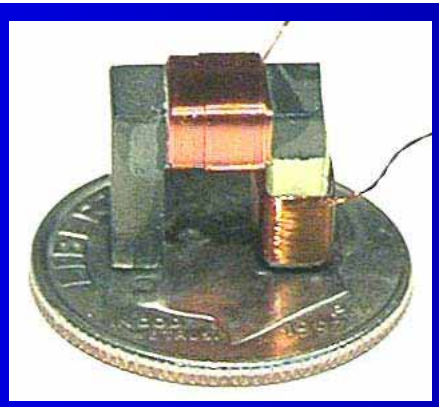
**Clusters of notches (simulating SCC) fabricated on outside of pipe.**

**In Task 3: NLH scans will be performed on inside of pipe at various static pressures.**

# Task 2: NLH Scanner and Pressure Test Facilities Set Up



NLH sensor on US dime



# Task 2: Fabrication of NLH Scanners

Four NLH scanners designed and fabricated.

These will be inserted in the four damaged pipes and remain inside during cyclic pressure testing (800psi to 1400psi).

In Task 3, NLH scans will be made periodically as pipes fatigued to failure. Failed defects will be weld repaired.

# Ongoing Work:
## Task 3: NLH Scanning of Full-scale Pressurized Damaged Pipes

- Perform NLH scans of EDM notched pipe at various pressures up to 2000 psi

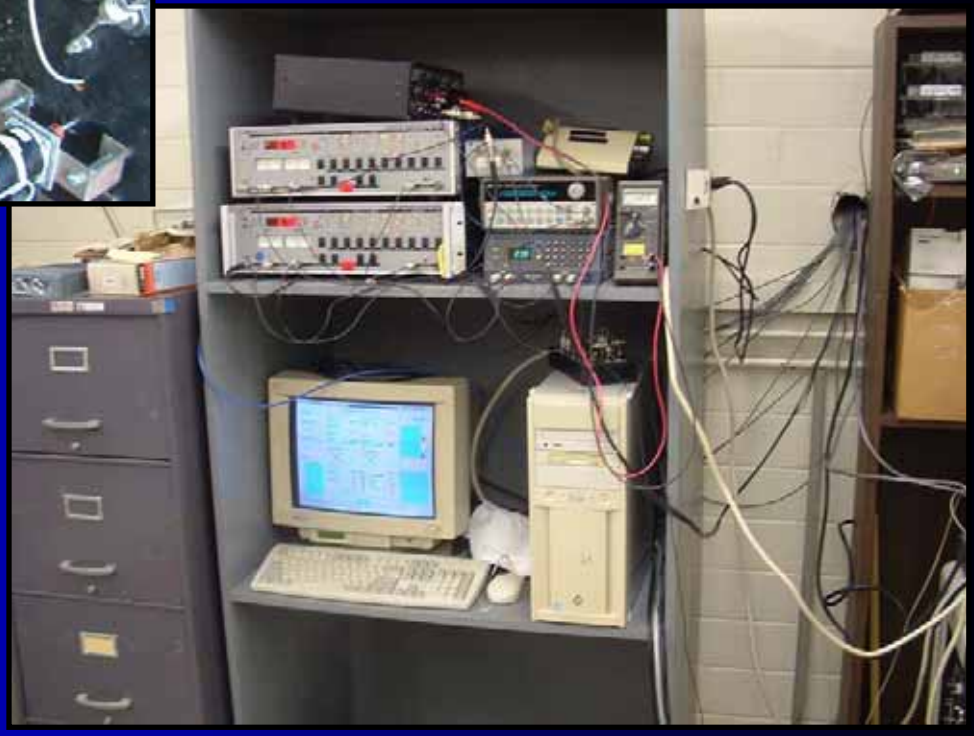
- Cyclically pressurize gouged and dented pipes between 800 psi and 1400 psi while periodically performing NLH scans under pressure

- Weld repair defects that fail and continue cycling until all defects have failed

- Analyze NLH scan results on gouged pipes as they become available

Test Chambers

Instrumentation



| | |
|---|---|
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| Pressure Test Technician | Tony Huron |
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