Leveraging Prior Research Developments for Mechanical Damage Characterization Using ILI

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Kiefner

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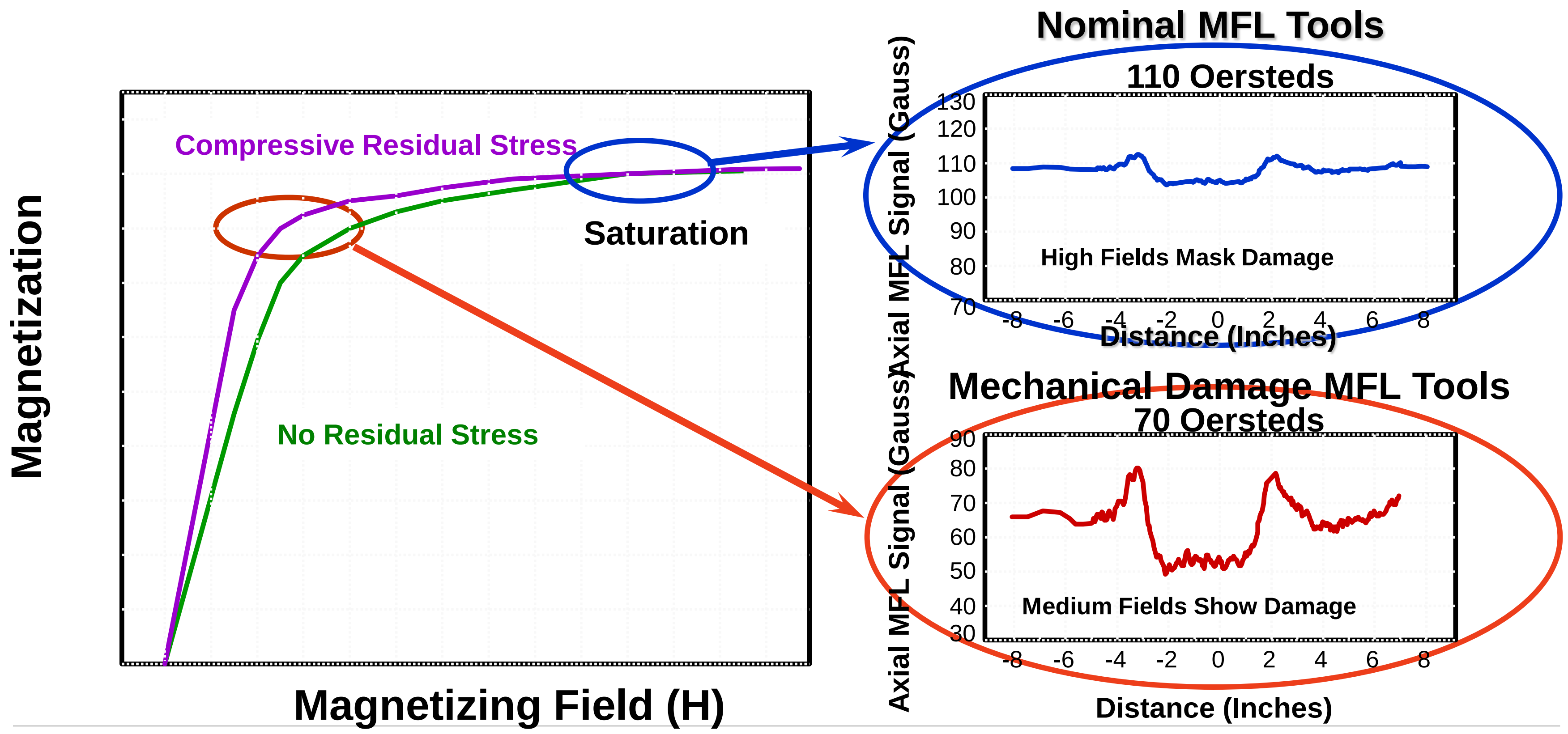
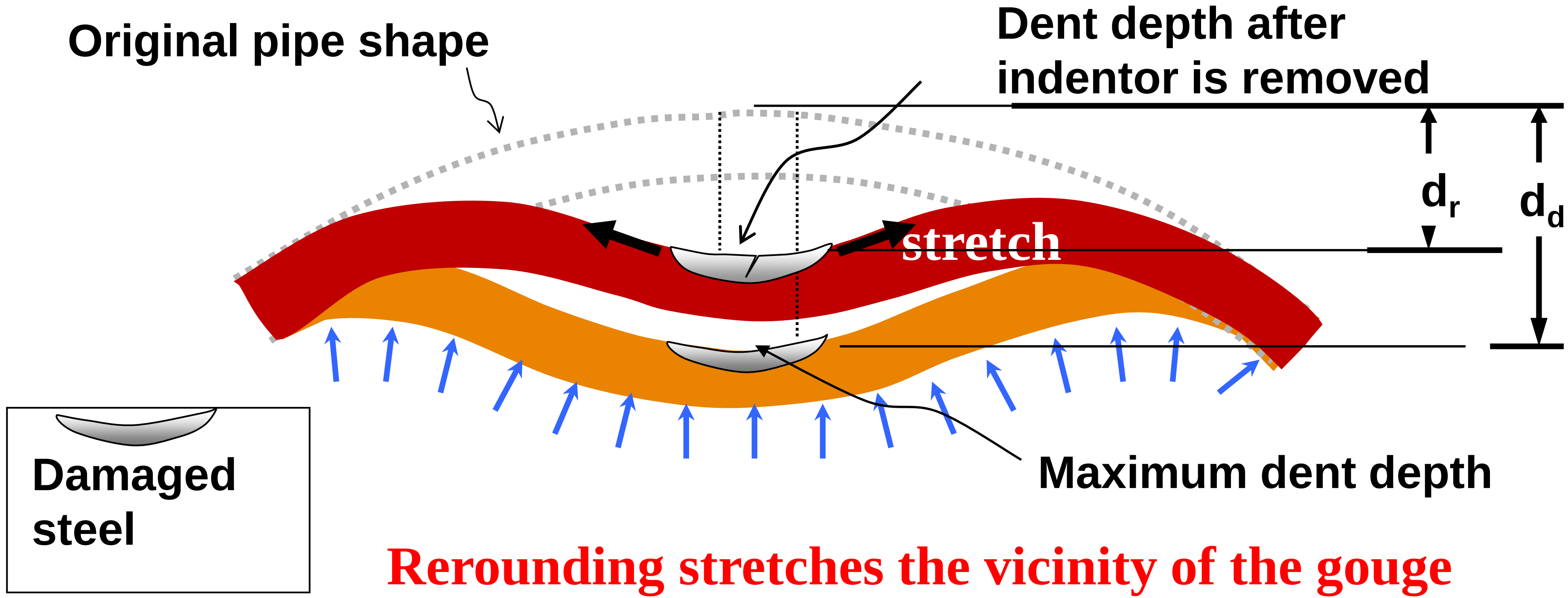
Initial research on dual field MFL for assessing mechanical damage

- In 1995, in response to three pipeline failures, the Gas Research Institute (GRI) initiated some fundamental research at Battelle's Pipeline Simulation Facility
- Richard J. (Rick) Davis was the Physicist
- In 1996, Office of Pipeline Safety (OPS) wanted to start providing funding for research on pipeline inspection. This was an early cofunded research project.
  - DTRS56-96-C-0010 "In-Line Inspection Technologies for Mechanical Damage and SCC in Pipelines"

Magnetization Level & Mechanical Damage

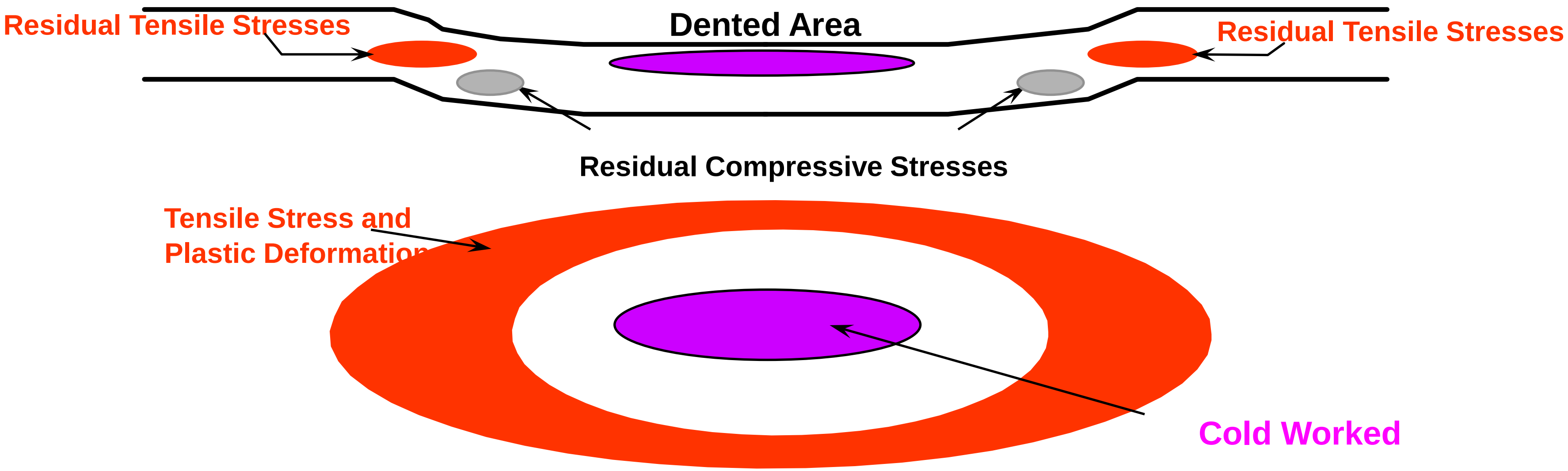


Rerounding



Rerounding stretches the vicinity of the gouge

Residual Stress at a Dent



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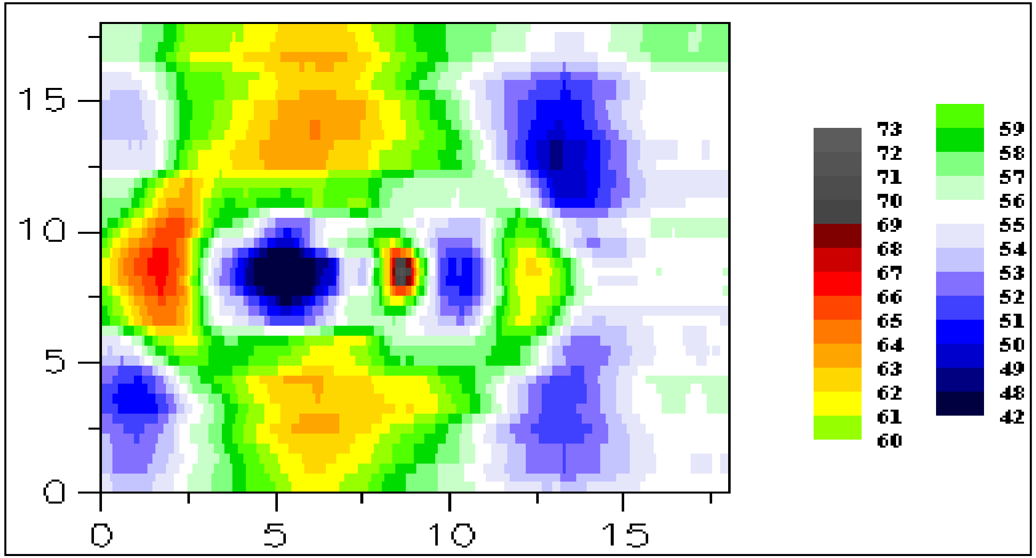
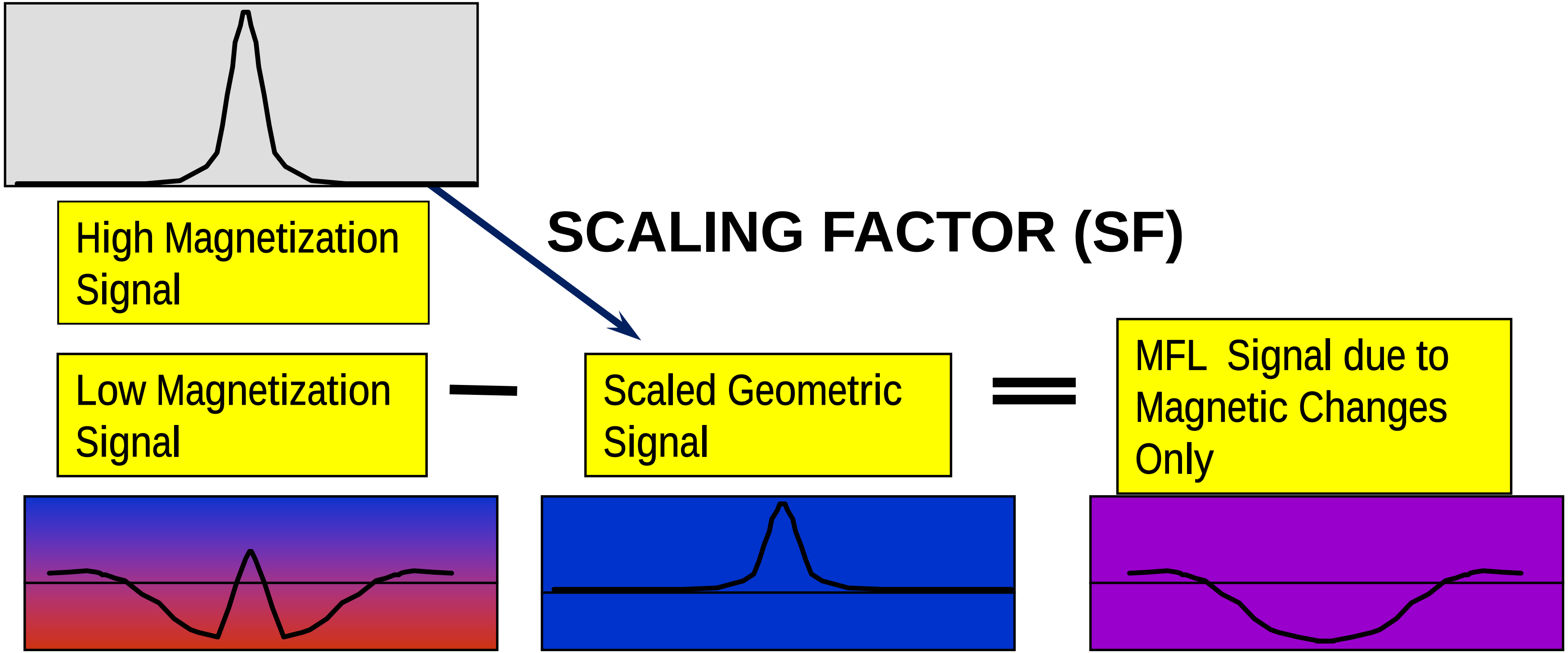
Low Magnetization Signal

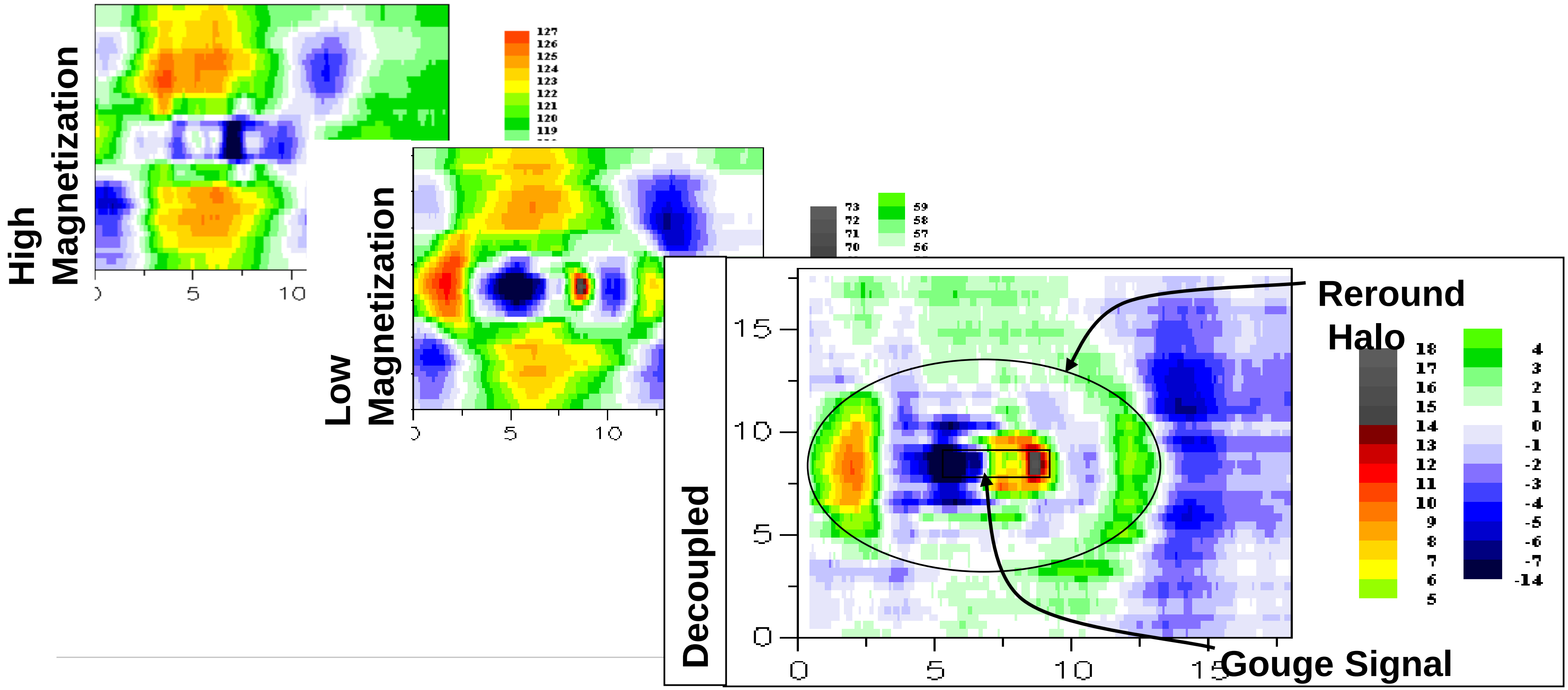


At low magnetization levels the signals are complex

Extracting the Magnetic Component: Decoupling



Decoupling Example



Can You Find the Dent and Gouge?
The Power of High and Low Fields

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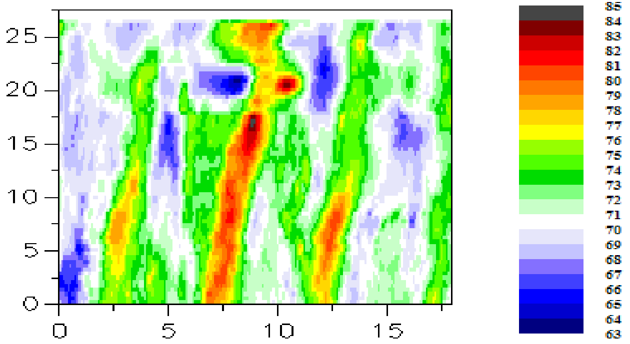
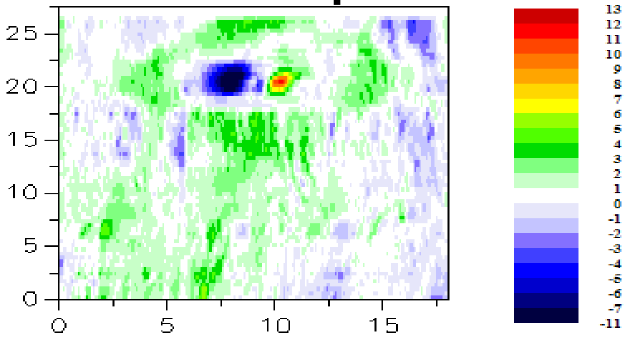
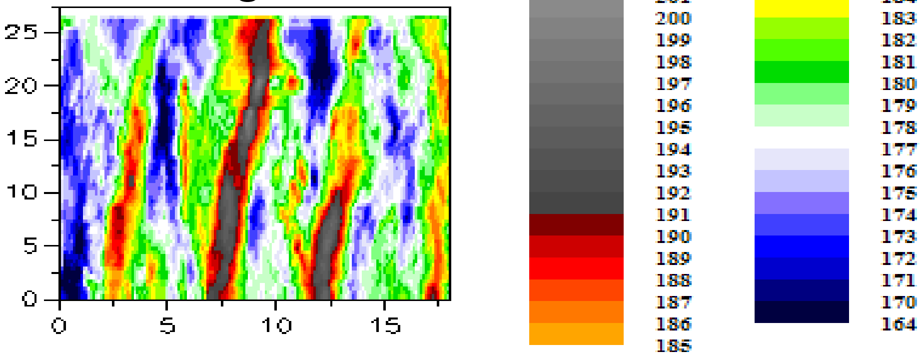
Low



Decoupled

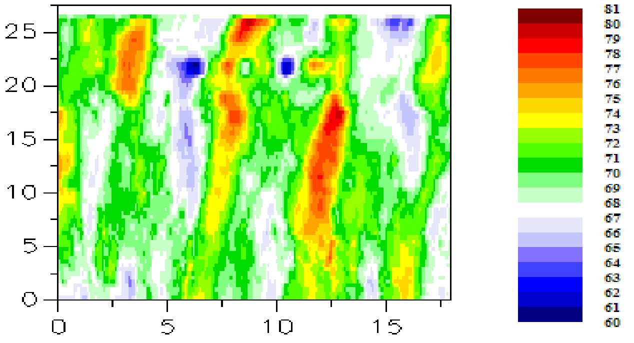


High

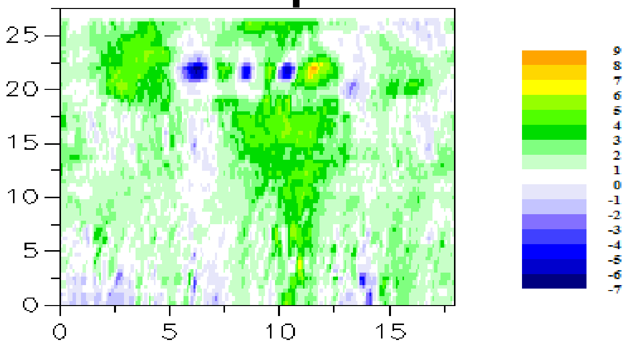


Noisy Pipe Material 2

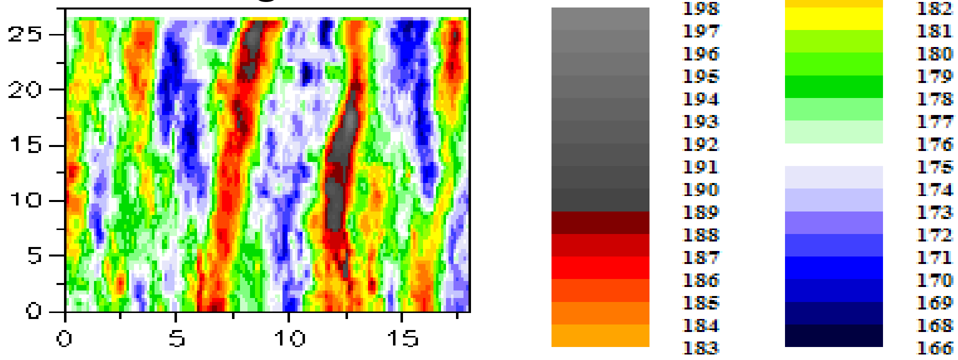
Low

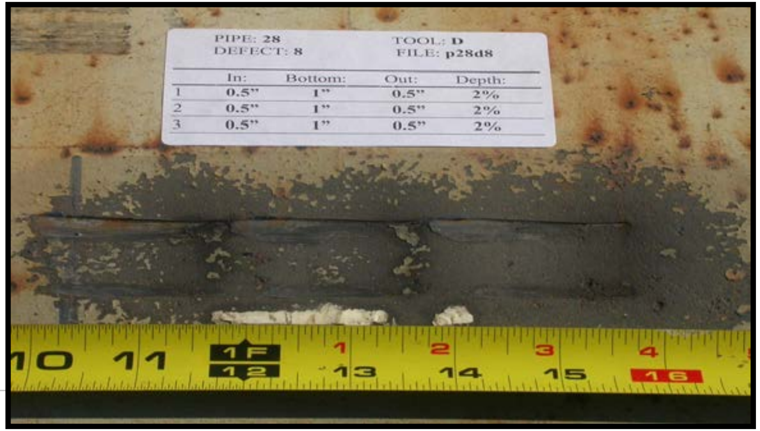


Decoupled

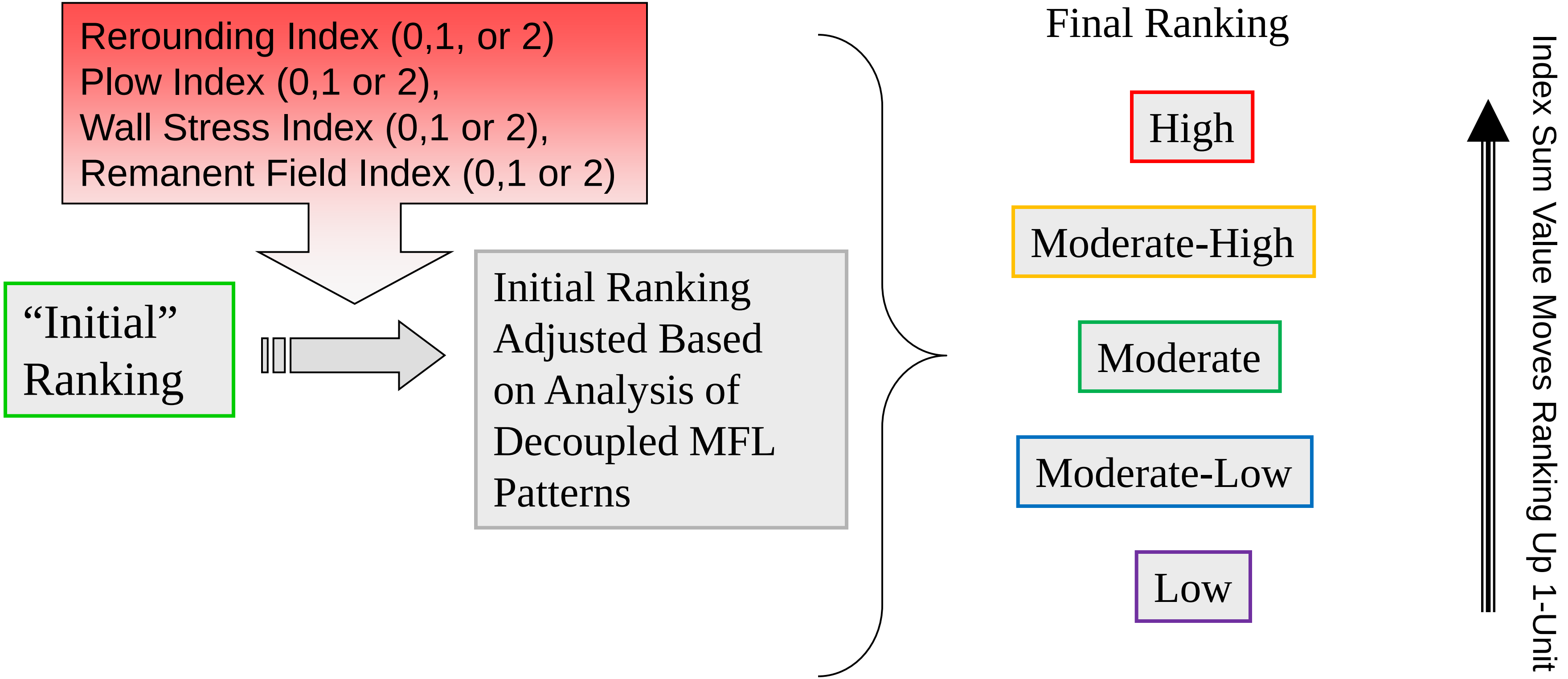


High





Final Priority Ranking



Implementation

- Implemented by (in chronological order)
  - Tuboscope with PRCI funding
  - Rosen with DOT/PRCI funding
  - TD Williamson
- Parallel PRCI work to define severity
  - Started in 2005 about the end of the MFL research
  - Failure models are maturing
  - Work on API standard for dents initiated this summer

Rosen Implementation

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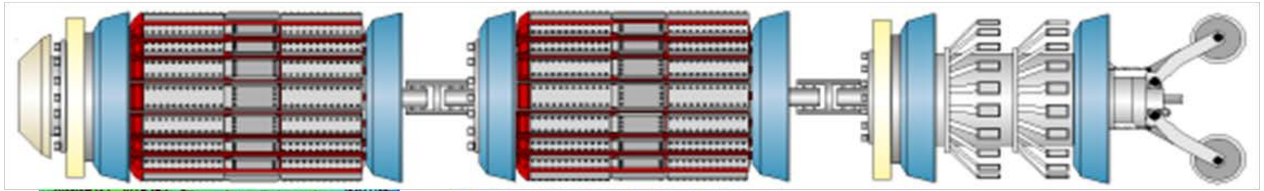
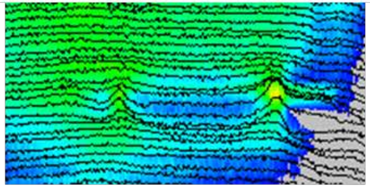
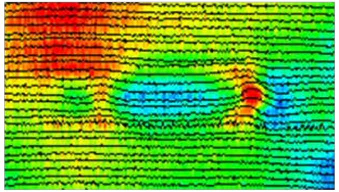
HIGH Field   LOW Field   Geometry

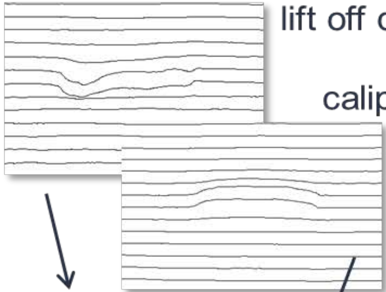






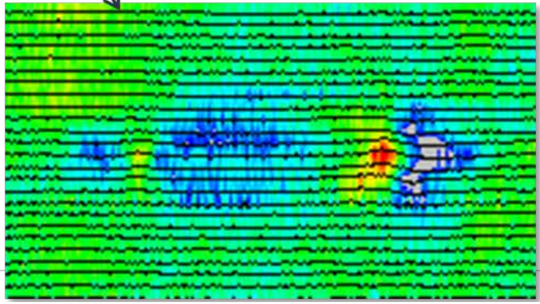
lift off data

caliper data

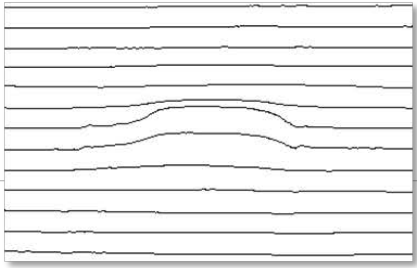


Dent

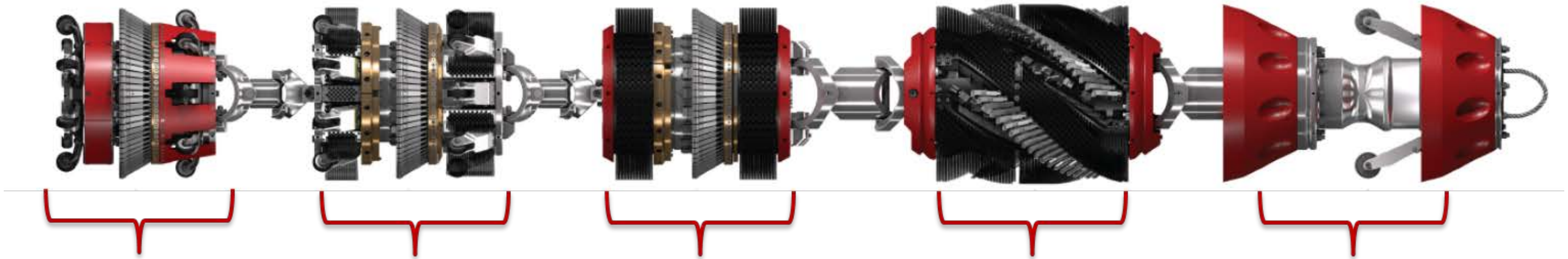
Decoupled MFL Data



Combined Profile



TDW Implementation



High Res Deformation

Low Field Axial MFL

High Field Axial MFL

SpirALL® MFL Technology

Drive Section with Odometers

Later DOT PHMSA Research
New Algorithm Development 2013

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- The Battelle priority index did not get widespread use
  - The method has been useful to a few companies
- New approach is to conservatively classify mechanical damage
  - Any gouging in dents is severe
  - Dismiss many corrosion anomalies in dents as not severe
- DTPH56-13-T-000009L

Mechanical Damage Classifier

- Distinguish *dent with corrosion* from *dent with gouge*
- Train a model to recognize these types based upon ILI signal features
  - Low and High field MFL amplitude
  - Number of metal loss signatures
  - Location of metal loss signatures (apex, shoulder, both)
  - Estimated metal loss depth
- 88 dent samples available from combination of actual ILI runs and pull tests through manufactured dents

Mechanical Damage Classifier Performance

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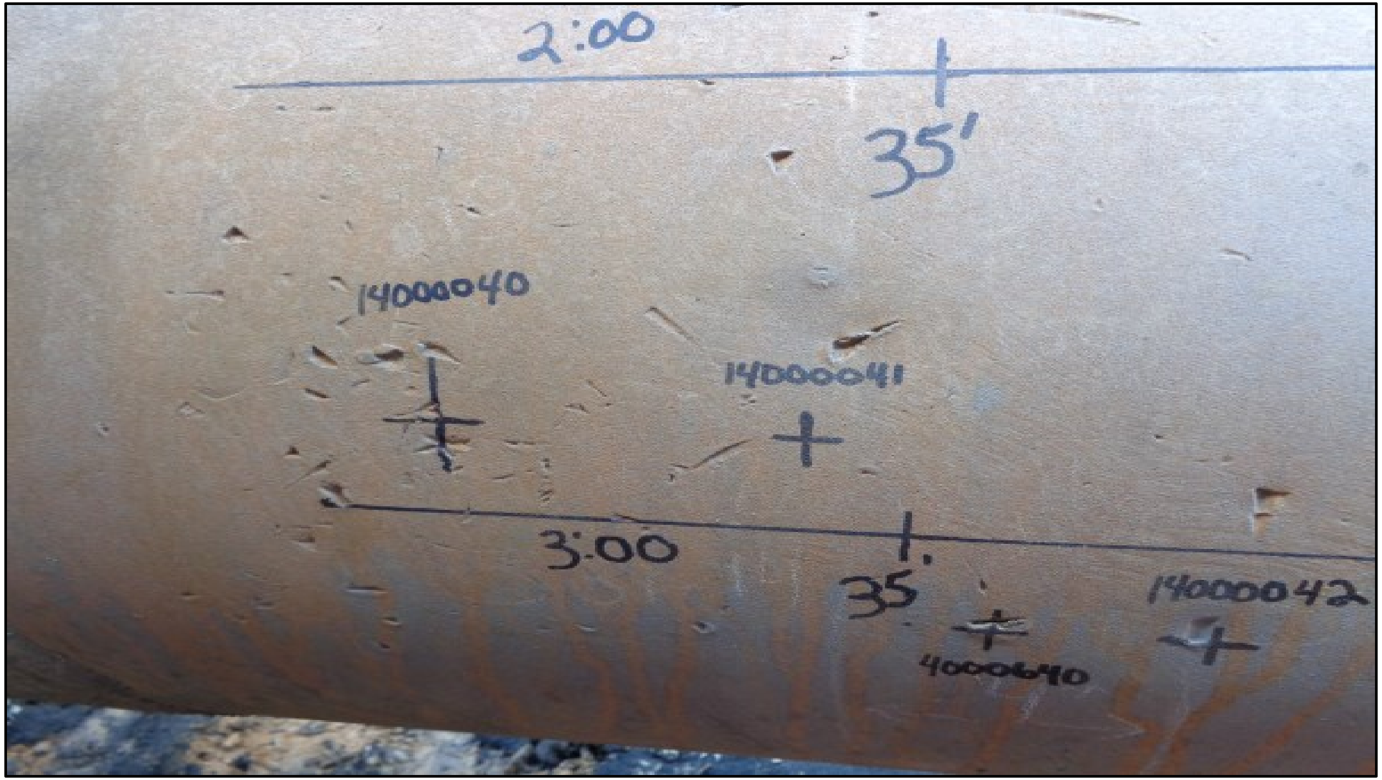
	Called Corrosion	Called Gouge	Called None
Is Corrosion	18	6	0
Is Gouge	1	48	1
Is None	2	8	4

Table 2. Classifier confusion matrix.

	Precision	Recall	Samples
Corrosion	0.86	0.75	24
Gouge	0.77	0.96	50
None	0.80	0.29	14
average / total	0.80	0.80	88

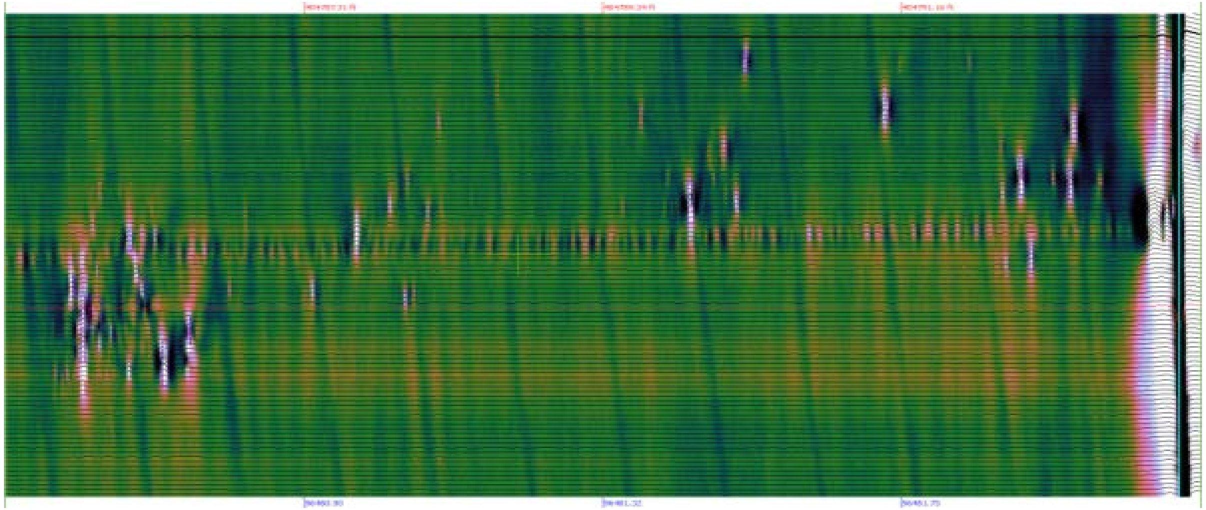
Table 3. Classifier performance summary.

The Gouging That was Call Corrosion

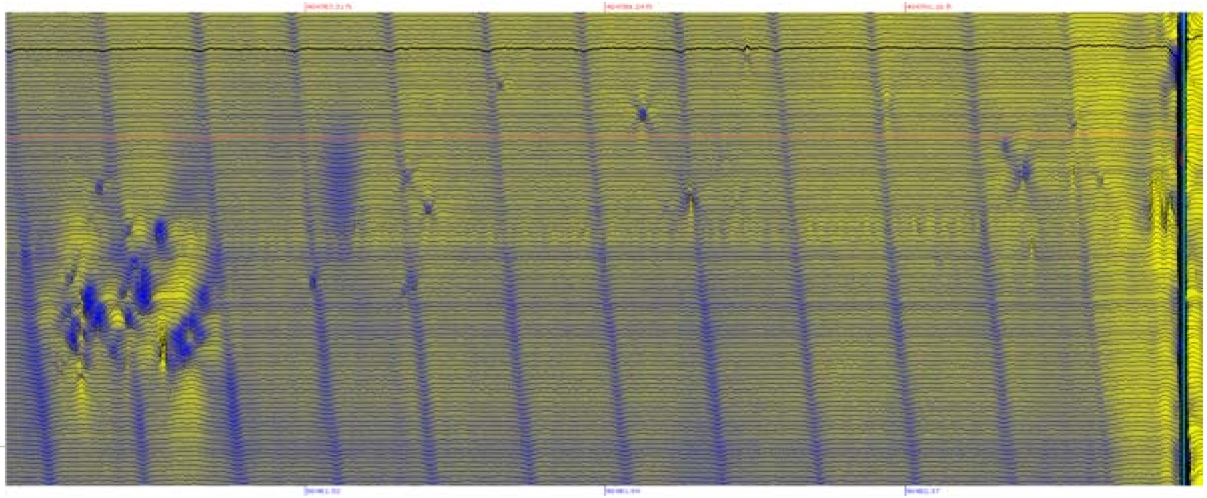


- Algorithm fooled by excessive number of hits
- Clear LF Signals would classify as Mechanical Damage if reviewed manually

Conventional MFL



Low Field MFL



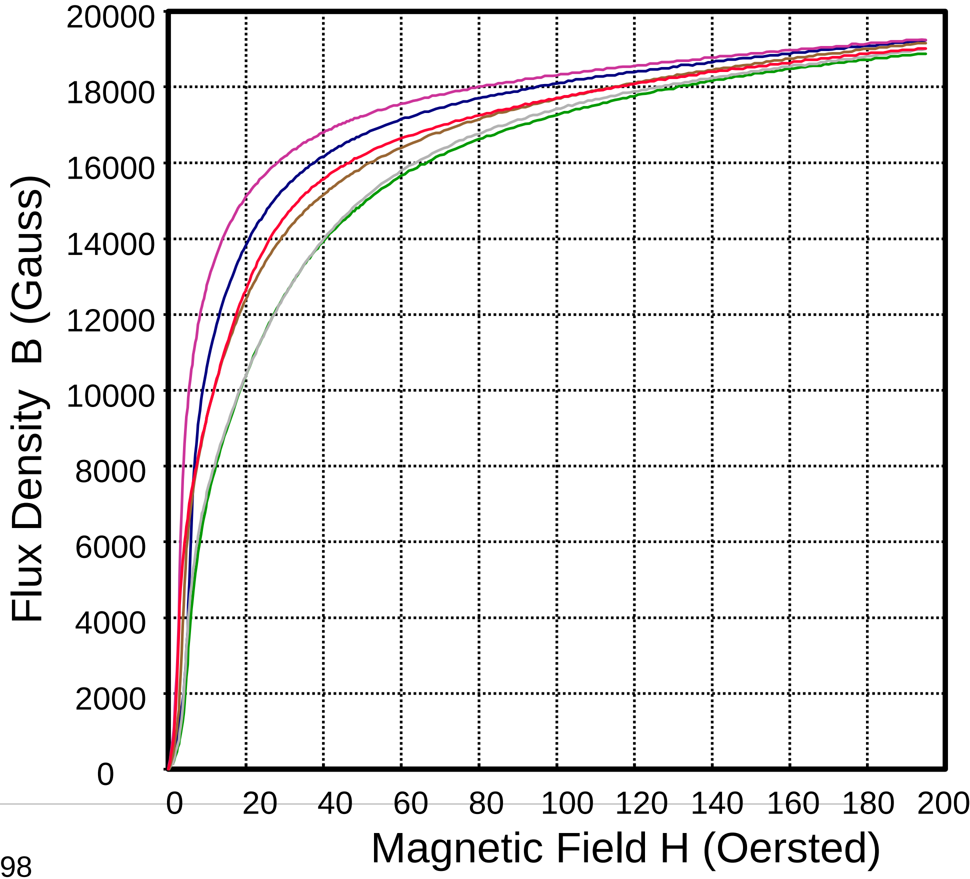
TDW MFL and LFM data

Review of recent dual field MFL

- New ILI tools produce higher magnetic fields the those in the 1990s
- The high field level was at 350 Oe. In the development of the decoupling process, fields never were greater than 200 Oe
  - The high magnetization signal does not exhibit the classical trend of mainly geometry
- At high field, a clear signal was now present for magnetic variation
  - Different than low field signal
    - Shape
    - Polarity
  - About the same magnitude as the low field signal
- A new model will need to be developed to assess anomalies that combines variation in
  - Permeability
  - Saturation

Variation of Magnetic Properties in Pipeline Steels 1998

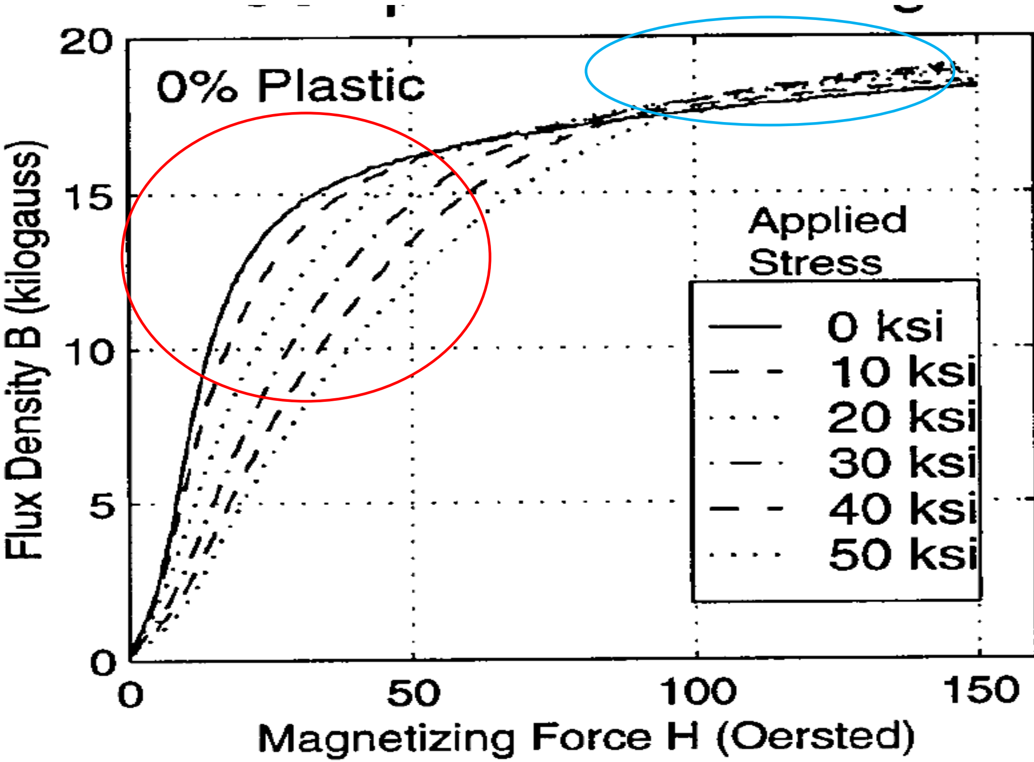
- Three objectives
  - Evaluated correlations between magnetic properties and mechanical properties.
  - Quantify magnetic property changes with the application of stresses and strains.
  - assemble a database of both magnetic and mechanical properties for future development activities.



B. Nestleroth & A. Crouch, VARIATION OF MAGNETIC PROPERTIES IN PIPELINE STEELS, NTIS Report No. DTRS56-96-C-0010 March 1998

Stress and Flux Density

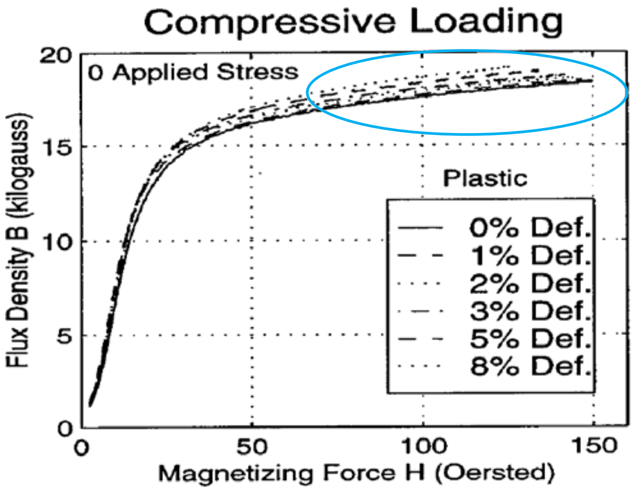
- Flux leakage levels governed by the magnetization (BH) curve
- Decoupling analysis mainly considered permeability variation
- For the BH curve shown
  - the decoupling focused on the differences in the BH curves at low fields circled in **red**
  - the differences in the BH curves at high fields circled in **blue** were considered small
- The area in **blue** is the referred to as saturation differences

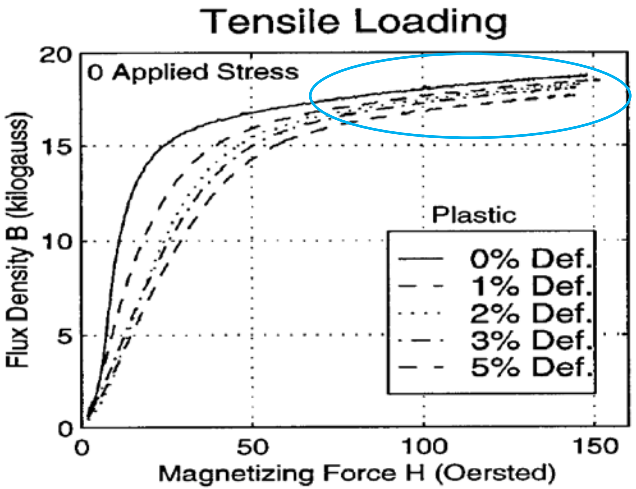


B. Nestleroth & A. Crouch, VARIATION OF MAGNETIC PROPERTIES IN PIPELINE STEELS, NTIS Report No. DTRS56-96-C-0010 March 1998

Saturation differences and deformation

- The 1998 report on magnetic properties showed the saturation flux density were quite different for compressive and tensile loading.
- Unfortunately, the curves did not go out to 350 Oe





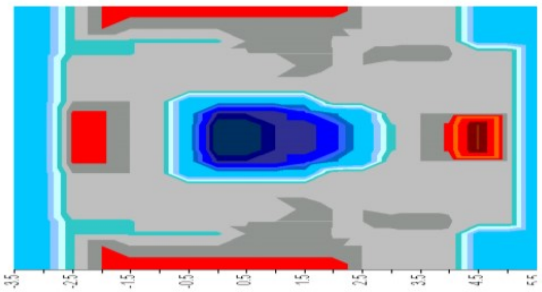
Switching to Cracks in Welds

- API 1176 Crack Management Standard generally favors ultrasonic methods to detect cracks over magnetic
- But API 1176 states:
  - Magnetic flux leakage inspection technology is often described as both a direct and indirect measurement technology.
    - the common application for metal loss directly detects metal loss but indirectly measures the depth.
  - The circumferential flux leakage methods systems have the potential to directly detect axial cracks and also indirectly detect cracks by noting changes in the magnetic condition and could be associated with presence of crack.
- There is the potential for multiple magnetic field MFL inspection to detect cracks by detecting the local increase in stress

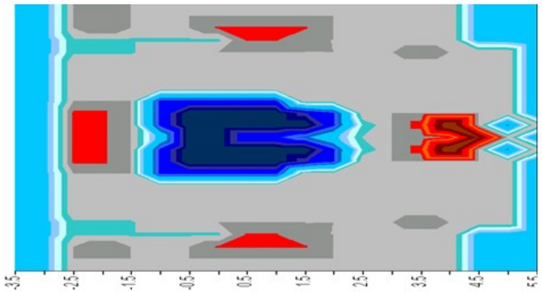
Time Based Signal Analysis of Decoupled MFL Signals

Dent/Gouge Model (Decoupled Signals)

Time – 1 (Gouge Signal)



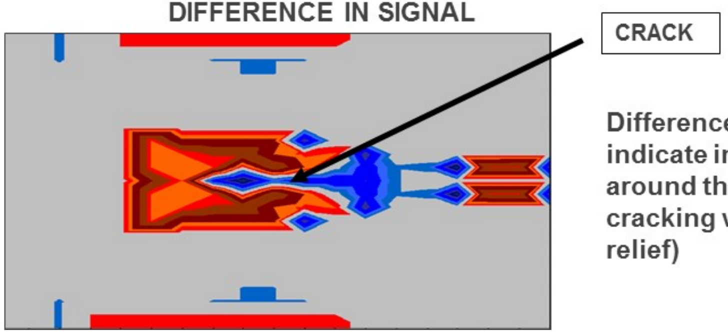
Time – 2 (After repeated cycling)



DIFFERENCE IN SIGNAL

Decrease in Stress

Increase in Stress



Difference in signal over time indicate increase in stress around the defect and the start of cracking within the gouge (stress relief)

Potential Research Ideas

- Magnetization for modern magnetizers exceed 300 Oe
  - Historic magnetization curves tested up to 150 - 200 Oe
  - A new decoupling approach? Three fields?
  - New magnetization (B-H) curves needed
- Research Idea: Time Based Dual Field MFL
  - Absolute magnetic reading finicky
  - But changes can in instructive. Caused by something:
    - Crack Growth
    - Dent fatigue due to pressure cycles
  - Both involve changes in local stresses which change the magnetic response of the pipe

Summary

- MFL is the workhorse of pipeline inspection
  - Gas or Liquid
  - Rugged and forgiving
- DOT PHMSA research on multiple magnetization level MFL provided the fundamental data and concepts for ILI vendors to advance into commercial applications
- The 10-20 year old research might need some updating
  - Magnets are much stronger now
  - Detection of cracks and other anomalies

Be interested

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