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Detection Keynote:
Development of an Inspection Technology For Mechanical Damage

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Summary of Research for Mechanical Damage That Included Battelle

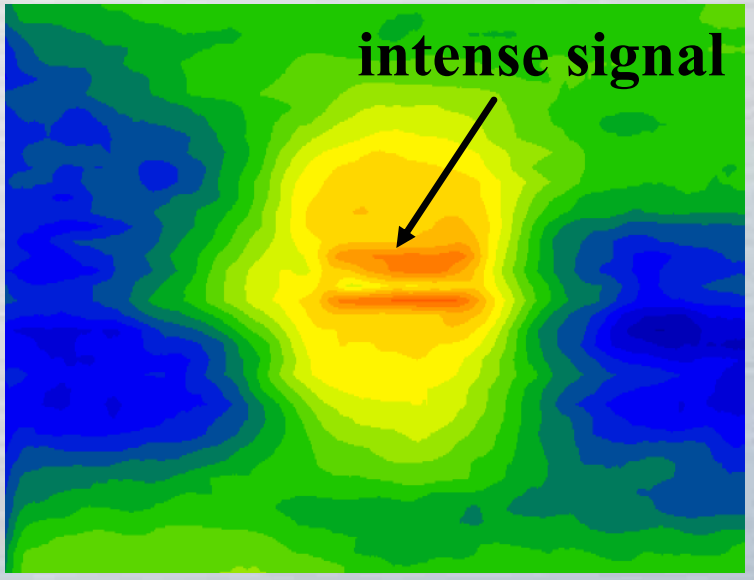
Start	End	Contractor(s)	Sponsor	Outcomes
Oct 1994	May 1996	Battelle, SwRI	GRI	Feasibility of MFL to better characterize mechanical damage.
Sep 1996	Dec 1999	Battelle, SwRI, Iowa State	DOT	Magnetic properties of pipeline steels an Dual magnetization. Non linear harmonics and neural networks.
May 2000	Jun 2003	Battelle, SwRI	GTI / DOT	Validation of decoupling and evaluation of circumferential MFL. Nonlinear harmonics and mechanical assessment.
Sep 2001	Sep 2003	Tuboscope	GTI	Technology transfer
Sep 2003	Mar 2005	Battelle	DOT / PRCI	Design of a dual magnetization tool. Technology demonstration
May 2006	May 2008	PRCI	DOT / PRCI	Testing of a tool in an operating pipeline

Non Linear Harmonics (NLH)

- Developed by Southwest Research Institute SwRI®
- An electronic method for detecting surface stress/strain patterns
- Uses an alternating magnetic field (10kHz), making it sensitive to only surface strain changes
- Examines only a small area, requiring multiple sensors for complete coverage of pipe surface
- A current SwRI project with DOT is evaluating the ability of NLH to monitor changes in gouged dents as they are cyclically loaded to failure.

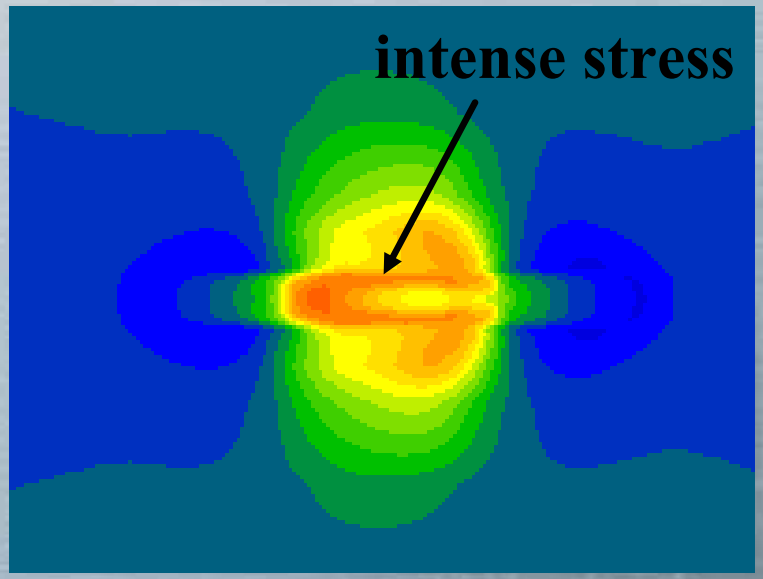
NLH signals reveal defect stress patterns on pipe inner surface

NLH data from pressurized scan



Finite element stress analysis confirms NLH signals relate to stress

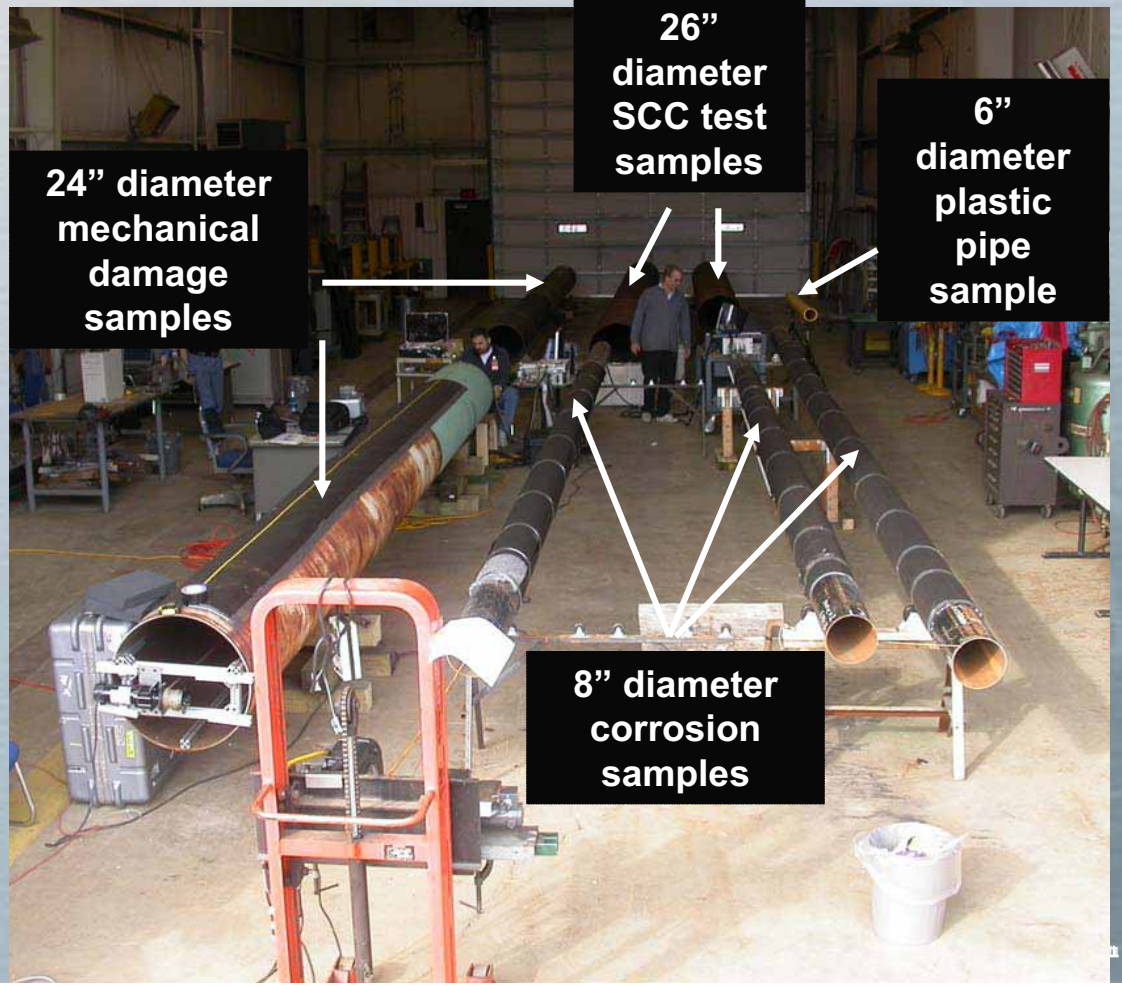
Defect stress pattern from FEA



Data Provided by SwRI

Technology demonstration at the Pipeline Simulation Facility

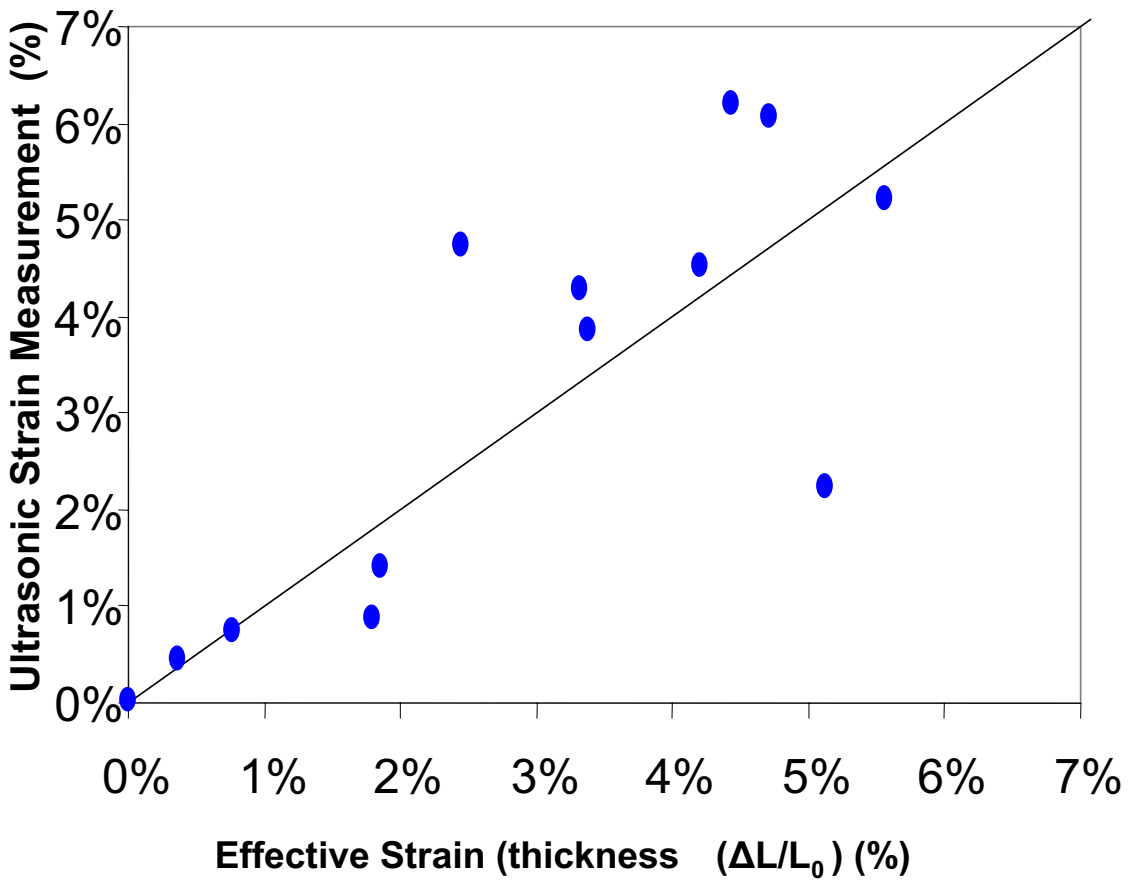
- DOT PHMSA and DOE NETL have conducted Technology Demonstrations in Sept 2004 and Jan 2006 examining:
  - **Corrosion sensors for crawlers (3)**
  - **SCC (1)**
  - **Mechanical Damage (2)**
  - **Plastic pipe**
- Blind tests
- Industry observers

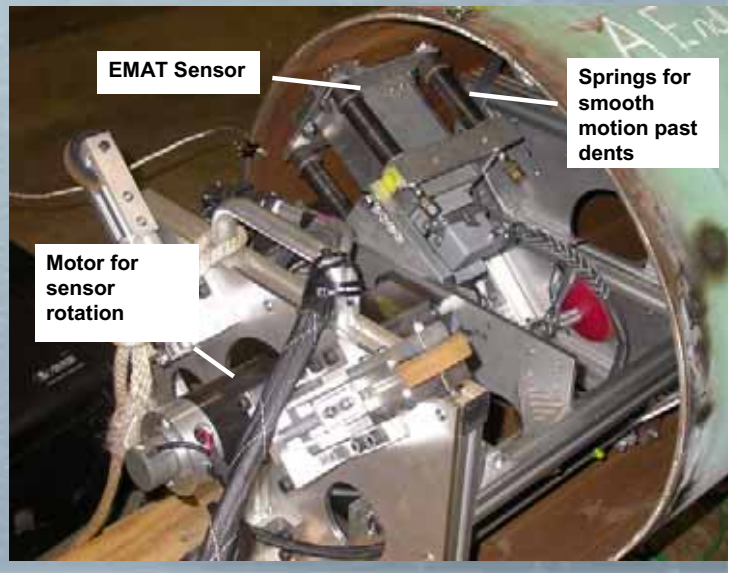


Ultrasonic strain measurements using EMATs

- Pacific Northwest National Laboratory (PNNL) is developing an ultrasonic sensor system for detecting and characterizing pipeline stress and strain caused by denting and other deformation
- Ranks the severity of smooth dents based on ultrasonic measurements of the mechanical properties and the presence of plastic strain, rather than dent dimensions or wall thickness
- Strain is measurable for uniaxial deformation
- Developing predictions of effective strain when the damage is more complex than a simple uniaxial deformation on deformed pipe

PNNL Ultrasonic strain measurements vs. effective strain from dimensional measurements of deformed pipe

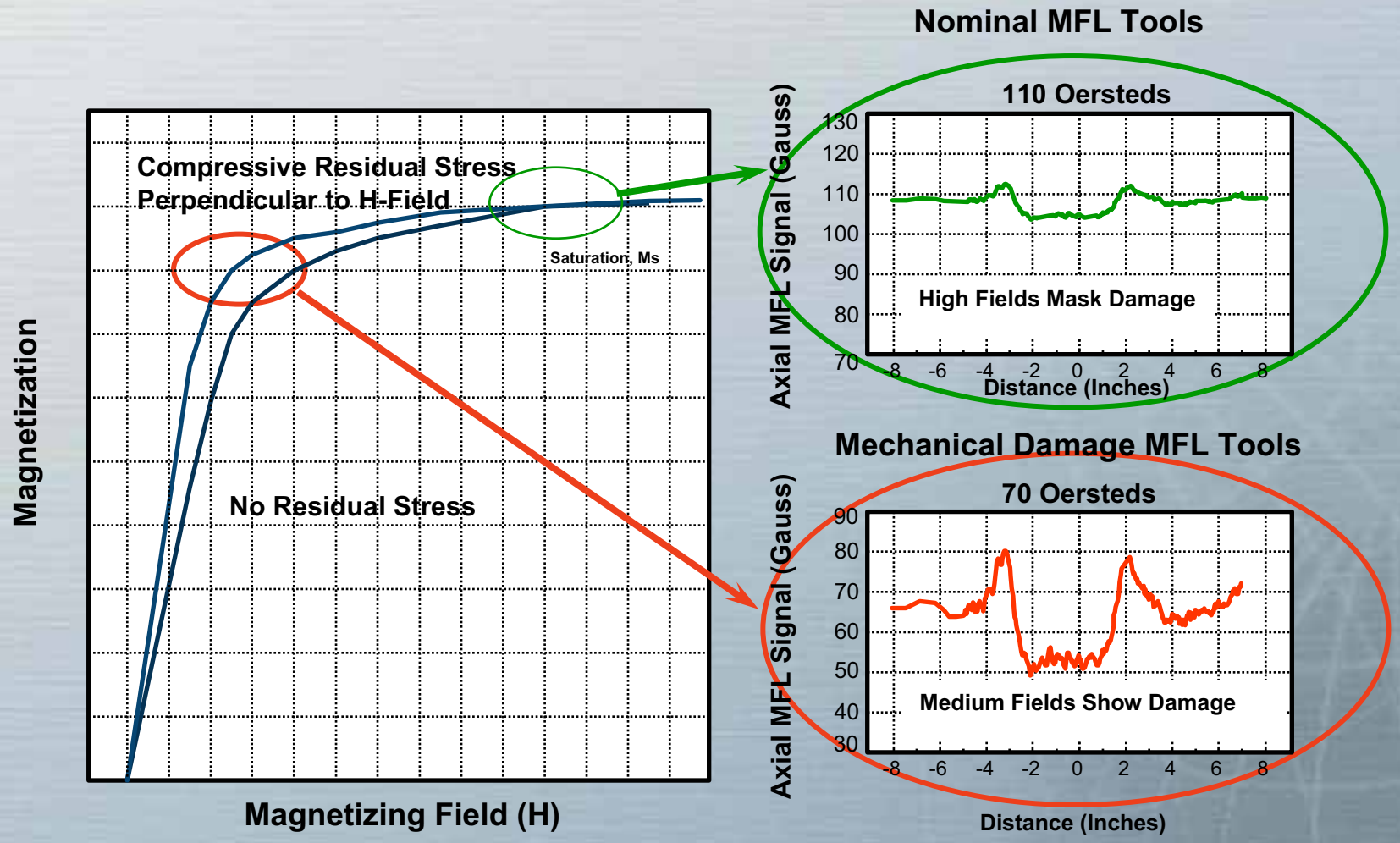




Dual Magnetization MFL Inspection for Mechanical Damage

- Inspection Goal:
  - Increase the probability of obtaining a *measurable* signal from significant mechanical damage and properly differentiates these signals from other "anomalous" signals
  - Function reliably under pipeline conditions
- Dual magnetization MFL technology
  - Can detect magnetic property variations due to stress associated with dents and gouges
  - Is an extension of the most successfully used pipeline inspection technology

Initial Result: Low magnetic fields are sensitive to stress and cold work



Data from the GRI Mechanical Damage Program

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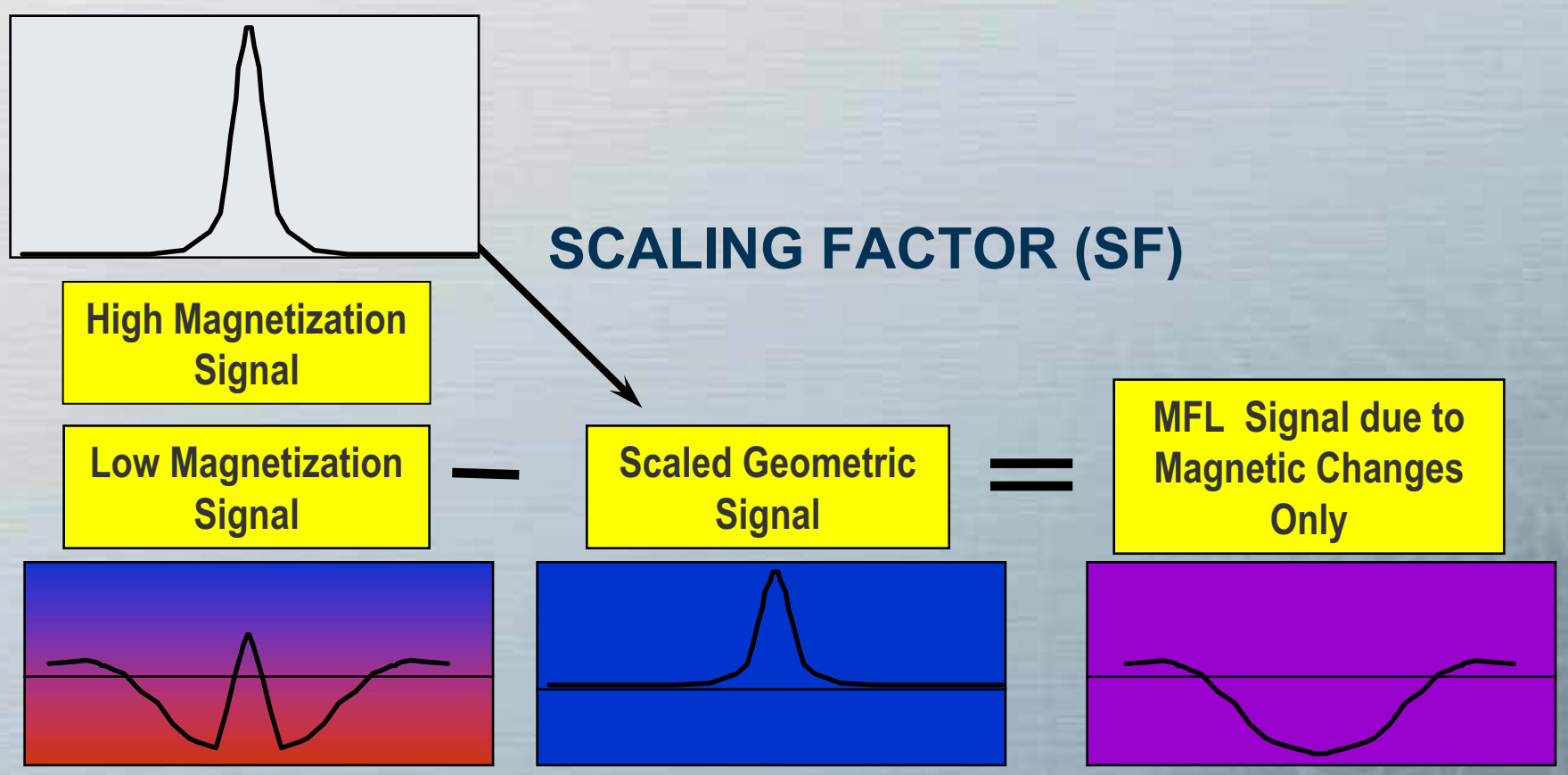
Dual Magnetization Approach

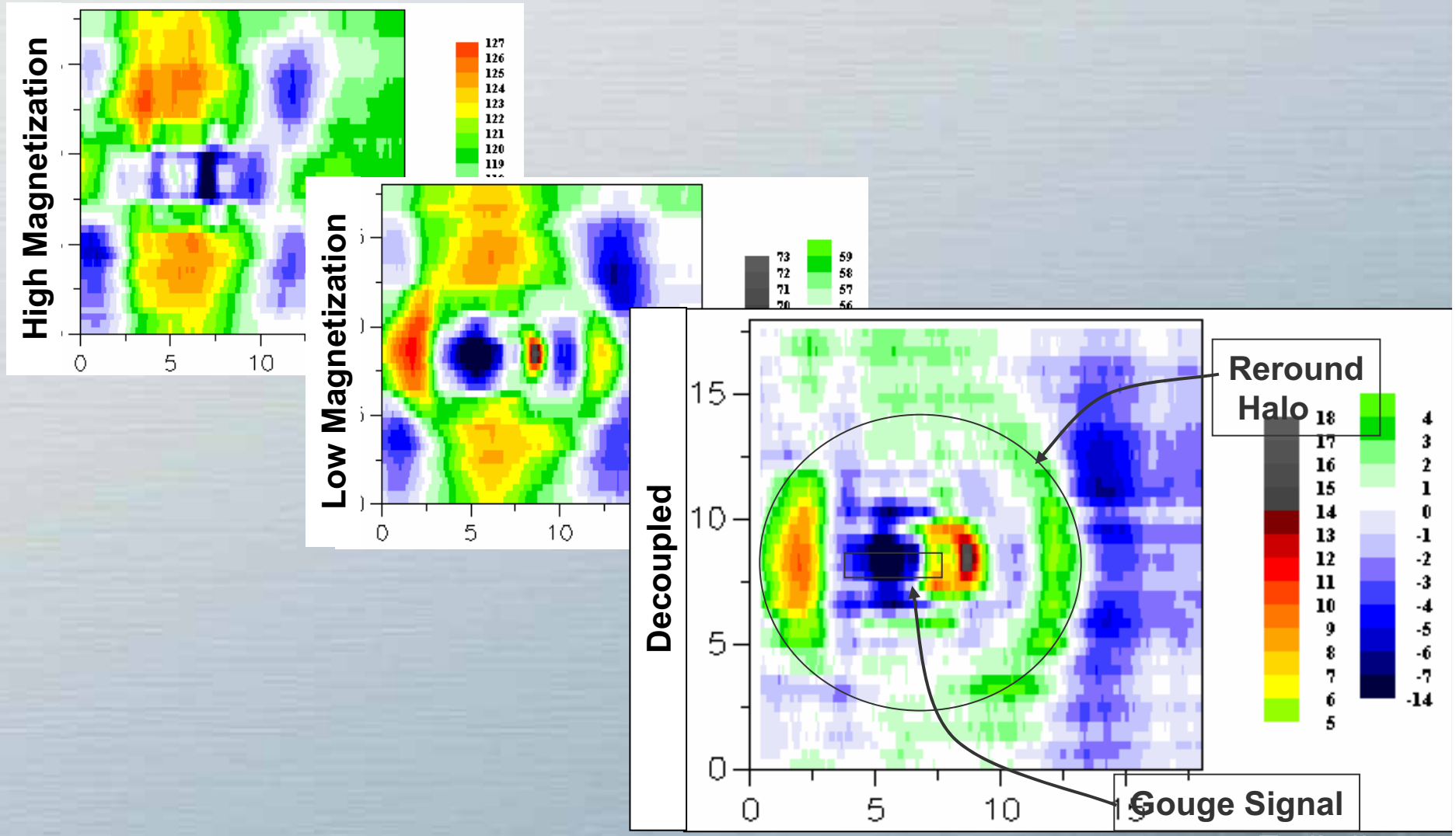
Dual magnetization level signal processing (decoupling)

1. MFL signals at high magnetization levels are almost entirely due to geometry changes (corrosion and removed metal)
2. MFL signals at low levels are due to both geometry and magnetic changes
3. The difference is due to magnetic changes - the most important components of mechanical damage

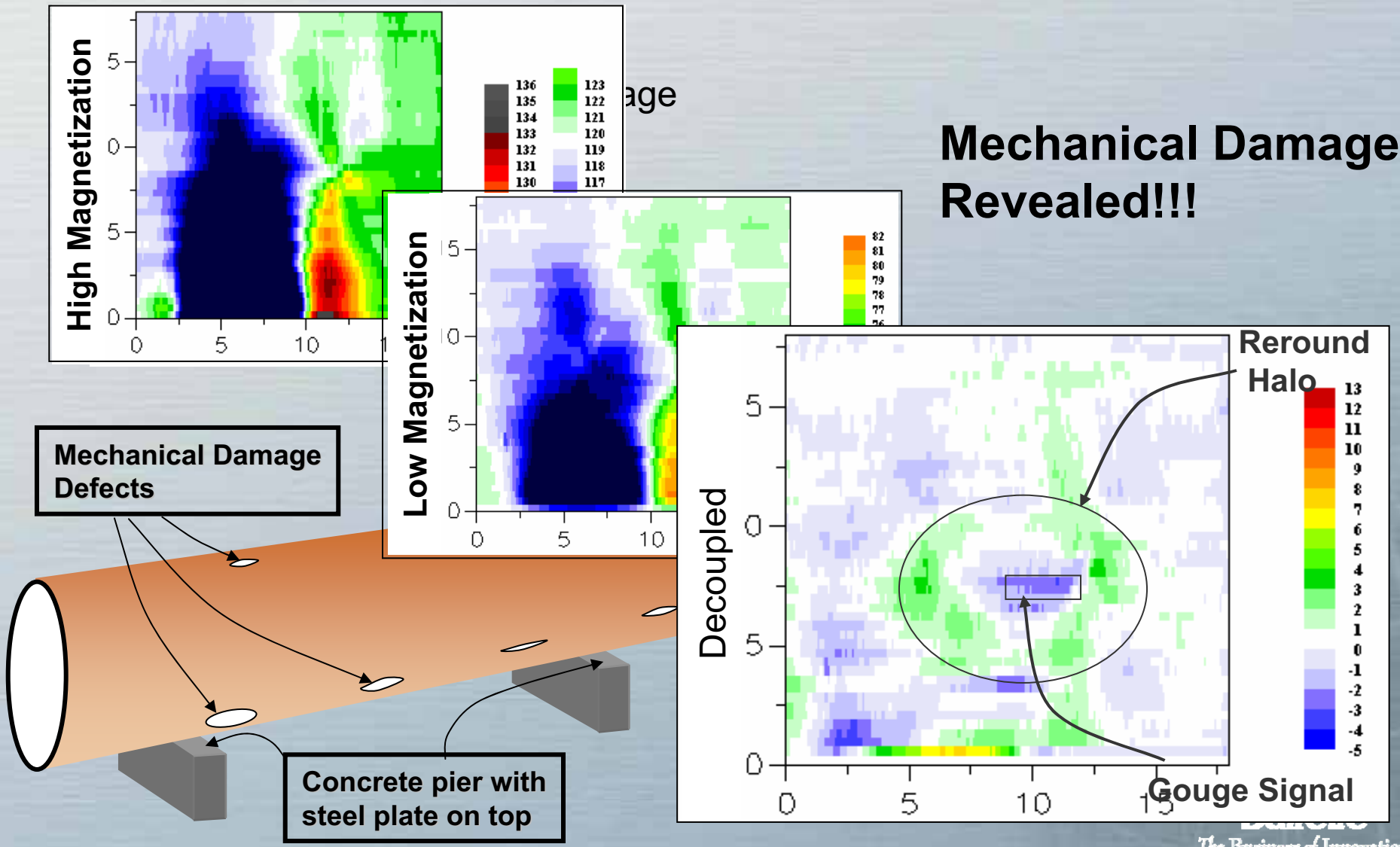
Extracting the Magnetic Component: Decoupling



Decoupling Example

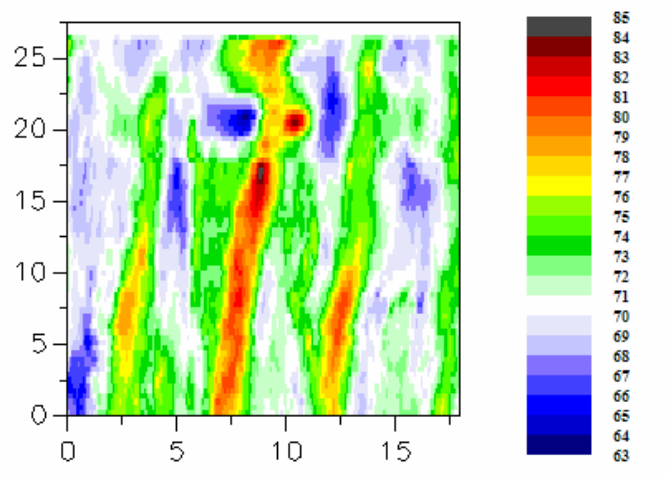


Demonstration that decoupling works

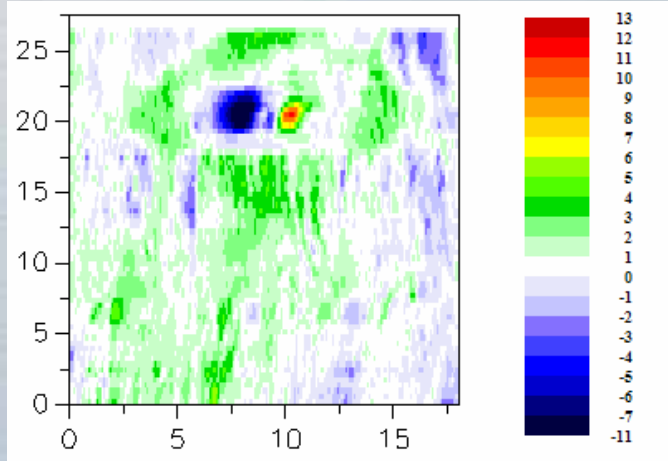


Decoupling method was tested in a variety of pipe materials

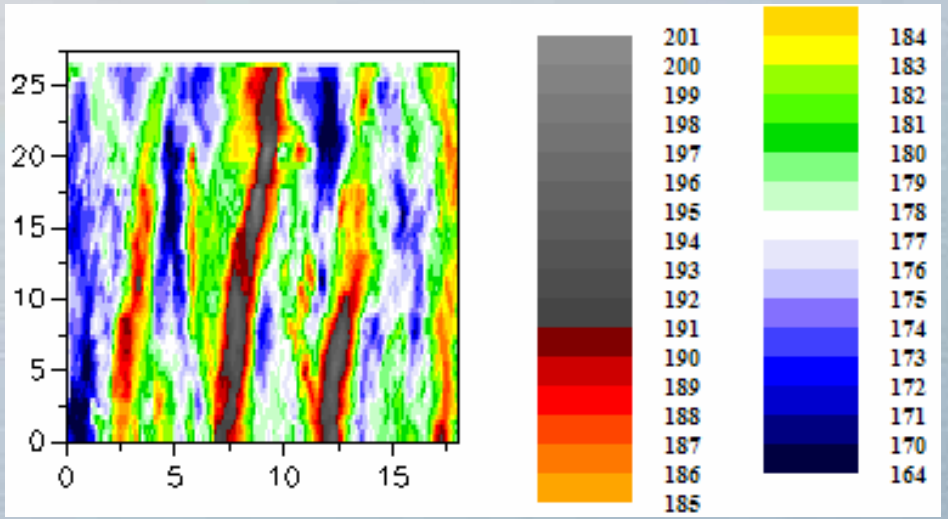
Low



Decoupled

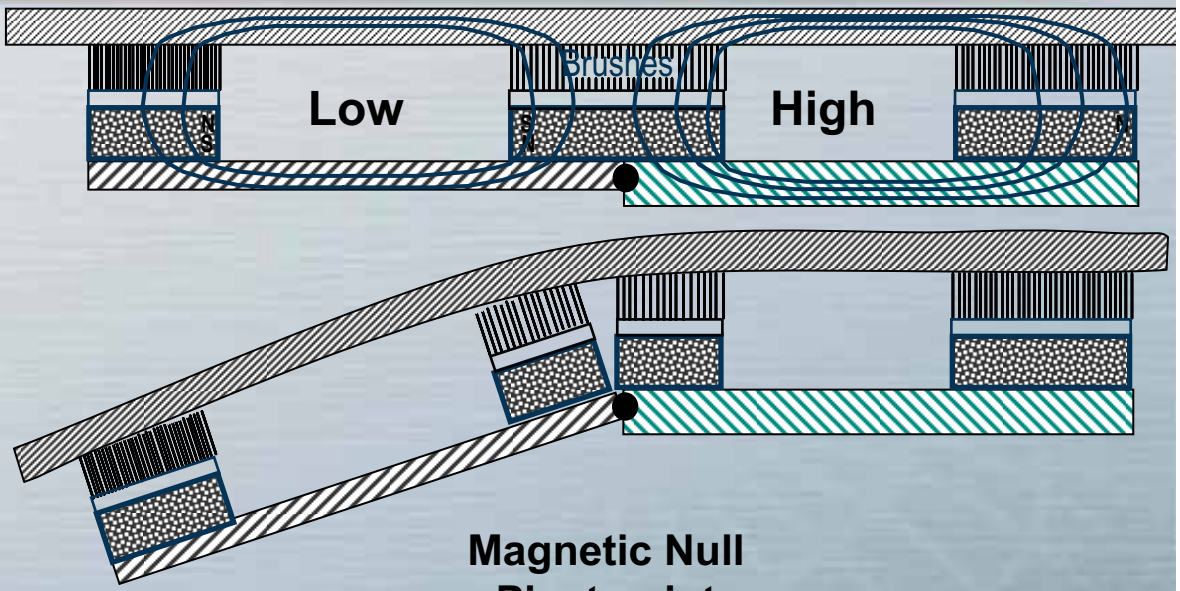


High

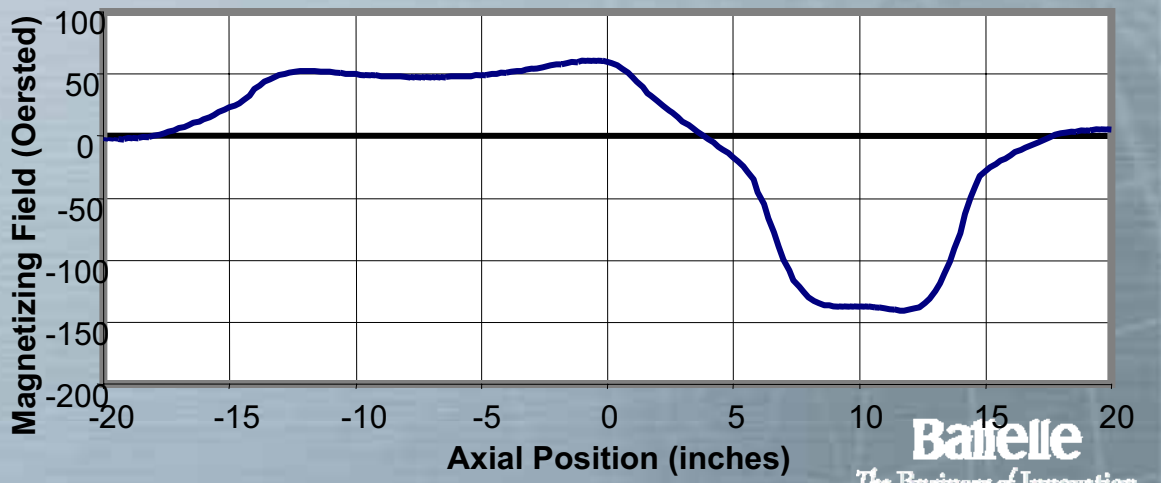


The Most Recent Project: Design of a dual magnetization tool

- Prior projects established:
  - Theory
  - Signal processing
  - Functional in pipeline materials
- Built and tested a prototype tool at the pipeline simulation facility



Magnetic Null
Pivot point



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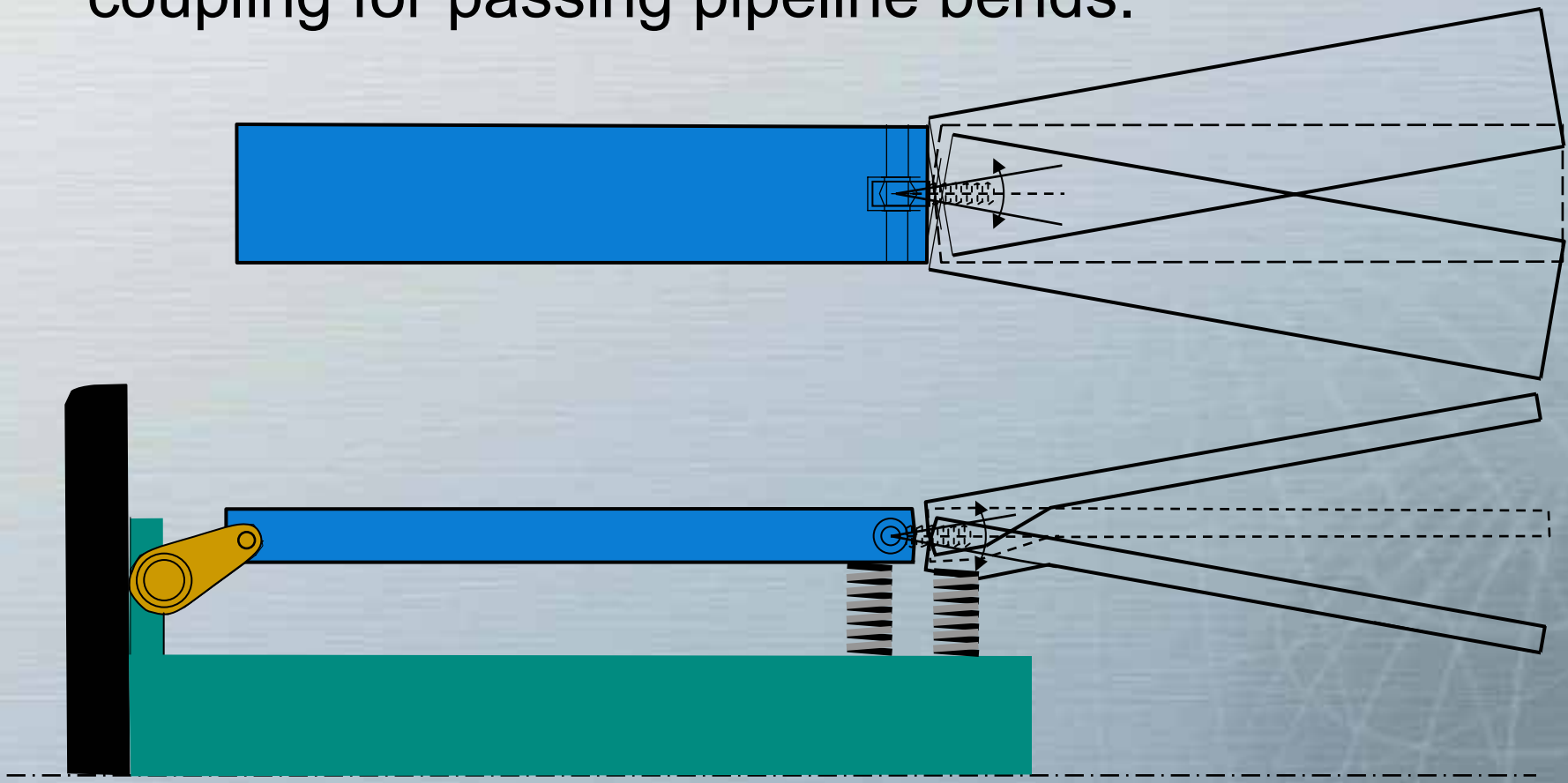
Articulating magnet bar

- Magnet bar split at the null point with a ball joint coupling for passing pipeline bends.



Prototype tool built and tested at Battelle's Pipeline Simulation Facility

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Dual Magnetization Summary

- Deformation tools have been used to assess dents in pipelines for years.
- Some newer commercial MFL tools incorporate deformation sensors to identify dents with missing metal.
- The dual field approach has the potential to augment current MFL technology to identify and provide additional information on dents that are the result of third party excavation.
  - The dual field method exposes areas of stress, re-rounding and cold work.
  - In particular, the decoupled signal can expose a region of cold work where the ductility of the steel has been exhausted and the re-rounding of the dent applies a tensile load to the anomaly.

Future project

- A PRCI project has been recommended for a DOT PHMSA award to start gaining field experience
- Pigging vendor will build a dual magnetization tool for use on an operating pipeline
- Pipelines have been designated for evaluation of dual magnetization technology
- Single magnetization MFL technology will be evaluated