Mechanical Damage Inspection Using MFL Technology

Bruce Nestleroth, Rick Davis and Stephanie Flamberg

DOT Agreement DTRS56-02-T-0002

Cofunded by PRCI / GTI 8702

Defining Problems

- Mechanical or third-party damage is a leading cause of pipeline failures on natural gas and liquid pipelines
- In-line inspections are performed
  - Deformation tools are used to assess dent depth and length at the inner surface of the pipe
  - Aligning deformation and MFL data from separte runs to identify dents with metal loss is typically problematic
  - Some newer commercial MFL tools incorporate deformation sensors.
- However, the MFL tools have missed important damage (gouges) and cannot reliably detect many features that indicate severe mechanical damage defects

Summary

- This project developed an in-line inspection tool that can detect and provide improved assessment of mechanical damage
  - Augments traditional magnetic flux leakage (MFL) by using two magnetization levels
  - New tool design incorporates articulated magnet backing bars
  - Ready for commercialization and related field development

Presentation Outline

- Background on mechanical damage
- Background on prior projects on Inspection for Mechanical Damage
- Dual magnetization mechanical damage tool development: Review of the milestones.
- Review of the “Benchmarking Emerging Inspection Technologies” at the Pipeline Simulation Facility

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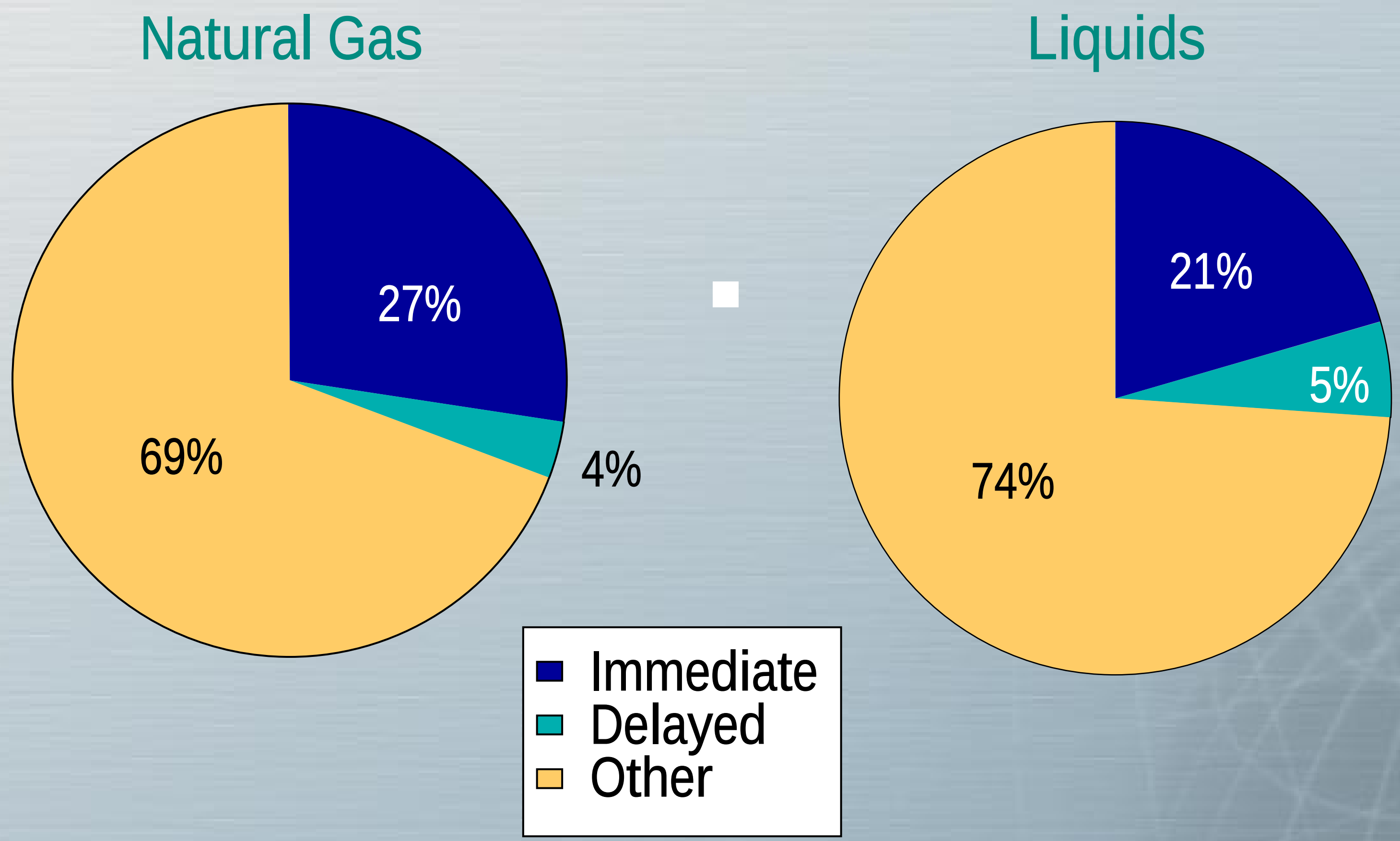
BACKGROUND ON MECHANICAL DAMAGE

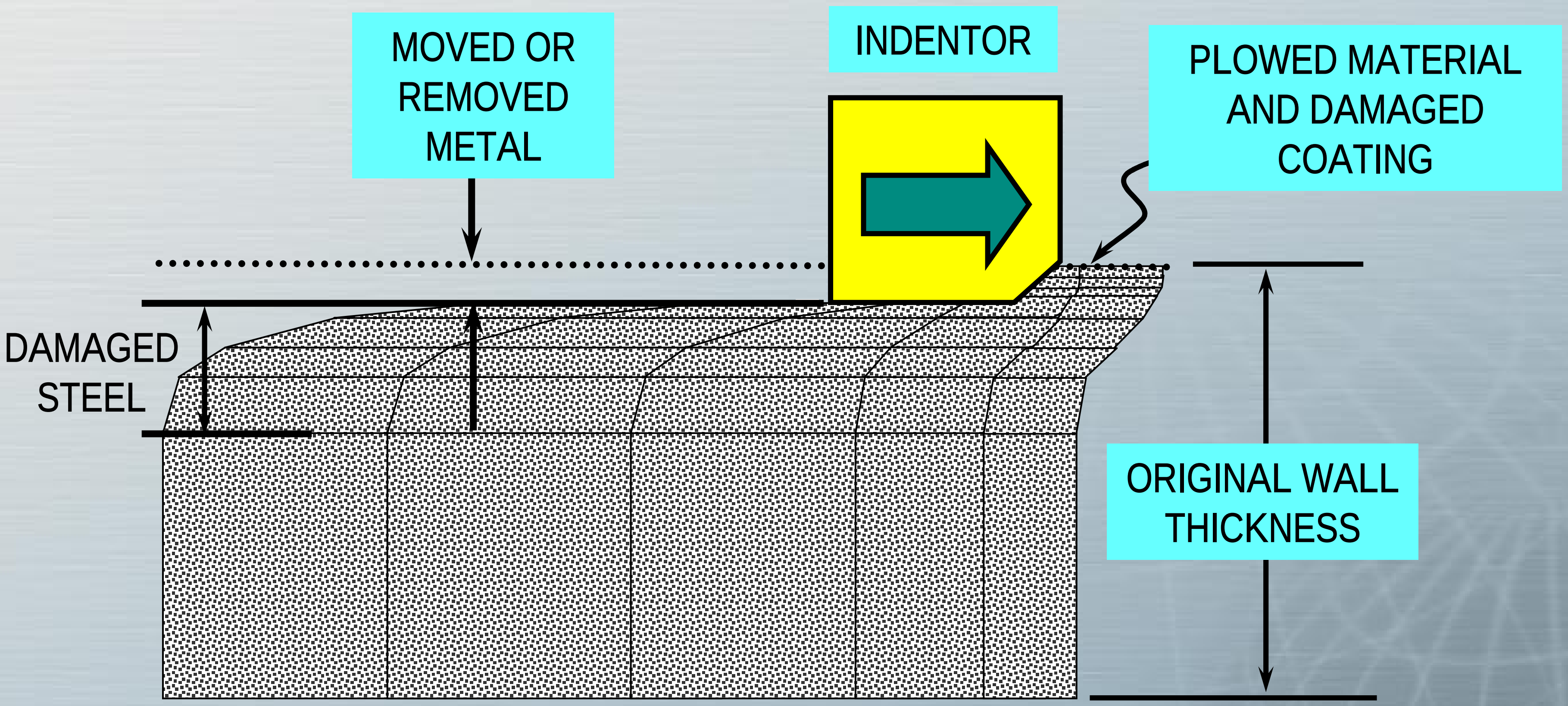
Incident Causes – Percentage of Total Reportable Incidents



What Happens During Mechanical Damage?

- The pipe ovalizes when the indentor first makes contact
- The pipe dents when the surrounding soil and internal pressure effectively prevent ovalization
- The indentor slides along the pipe, scraping or cutting away metal and coating
- The indentor is retracted, and pressure in the pipe pushes the dent partially out

What Happens at the Indentor?

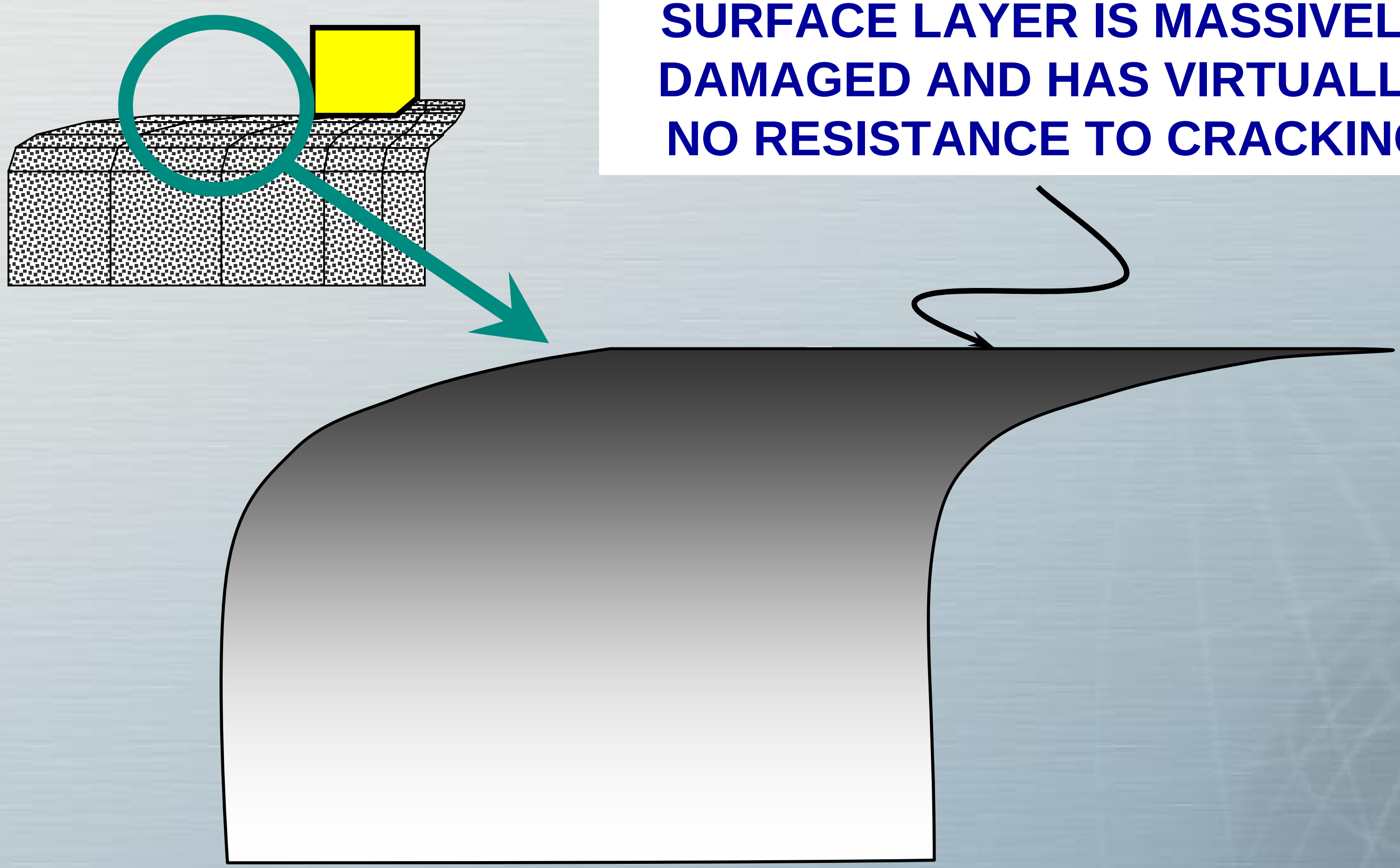


Severity

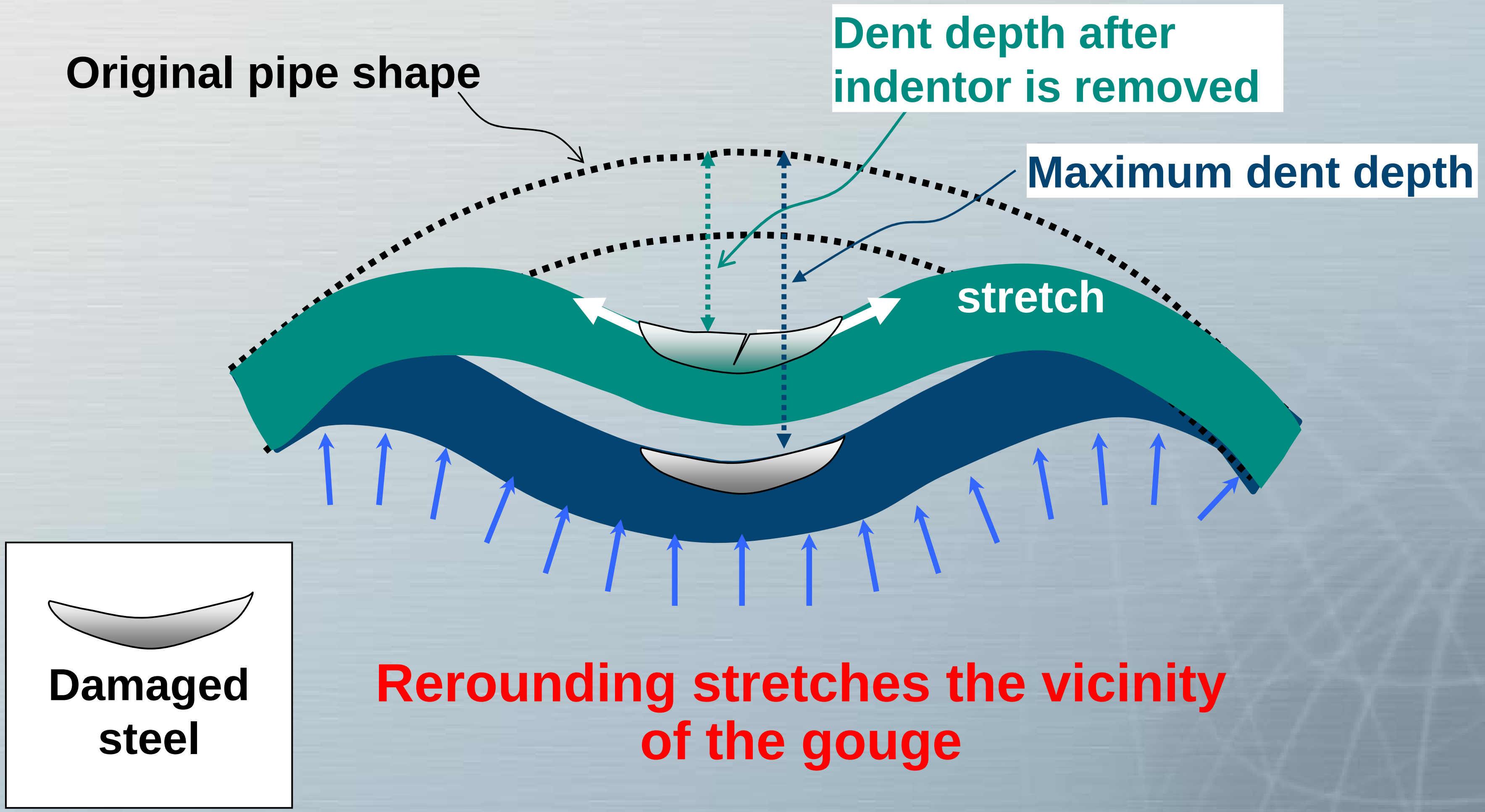
- Which damage components most strongly lead to delayed failures and, hence, must be reliably detected and accurately characterized?
  - Damage to the steel
  - High stresses and strains in the damaged area
  - Cracking

First, The Crack Resistance Drops

SURFACE LAYER IS MASSIVELY DAMAGED AND HAS VIRTUALLY NO RESISTANCE TO CRACKING



Gouge Area Stretched During Rerounding



Rerounding stretches the vicinity of the gouge

Mechanical Damage Summary Points

- Damage to the steel and rerounding promote cracking. These are components of mechanical damage that most strongly affect the possibility of delayed failures
- Pressure increases and pressure cycling can grow the initial cracks
- So, inspection tools should concentrate on damage to the steel, rerounding, and cracking. Parameters that influence rerounding, such as dent and gouge length, should also be targeted
- However, there are practical limitations on crack detection and sizing using pigs
  - *Basic rule of pig development: If you can't assess the anomaly in the ditch in an hour, it is difficult to design a pig that works at 5 miles per hour to do the same task.*

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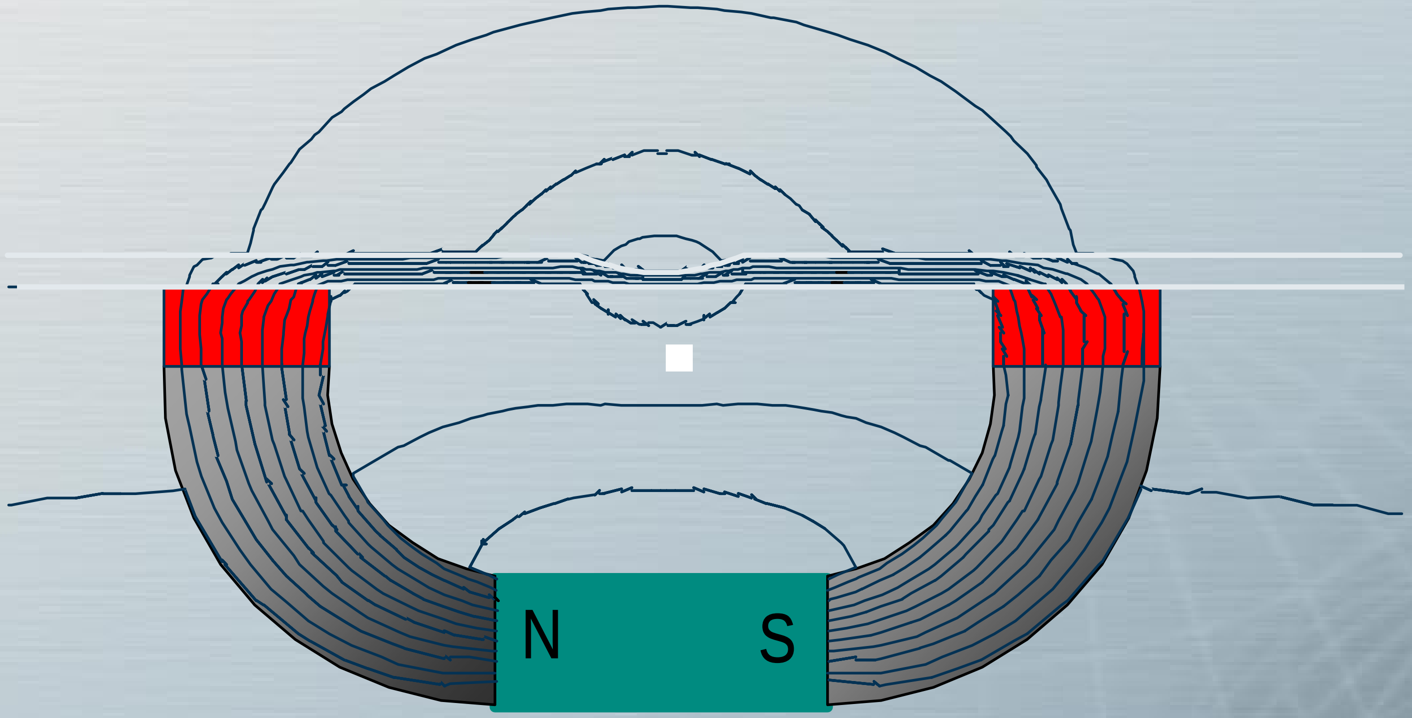
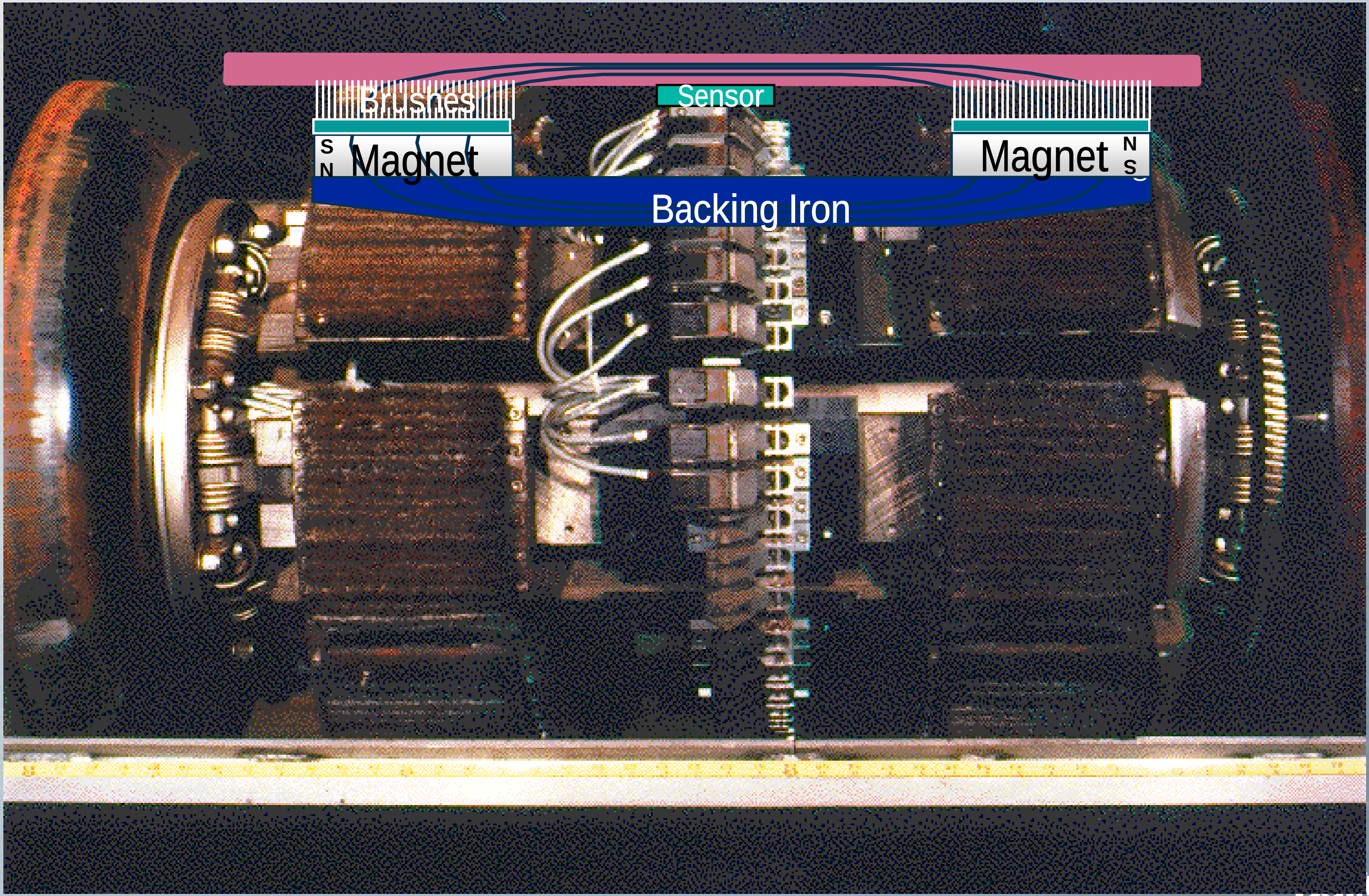
MFL Inspection Technology for Mechanical Damage

Magnetic Flux Leakage

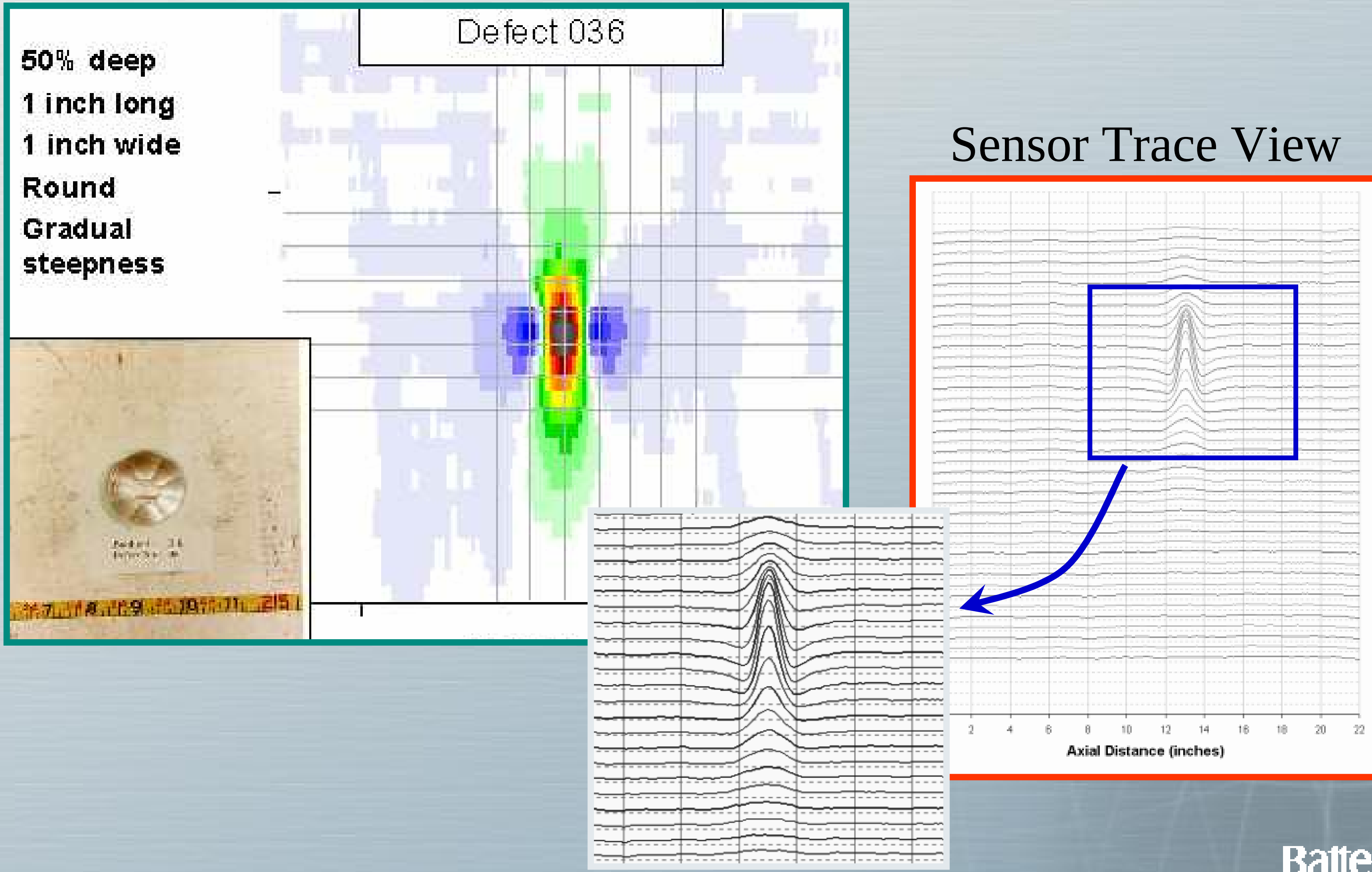


Metal loss, such as corrosion, causes magnetic flux to be diverted outside the pipe.

Background:
Axial MFL for Mechanical Damage



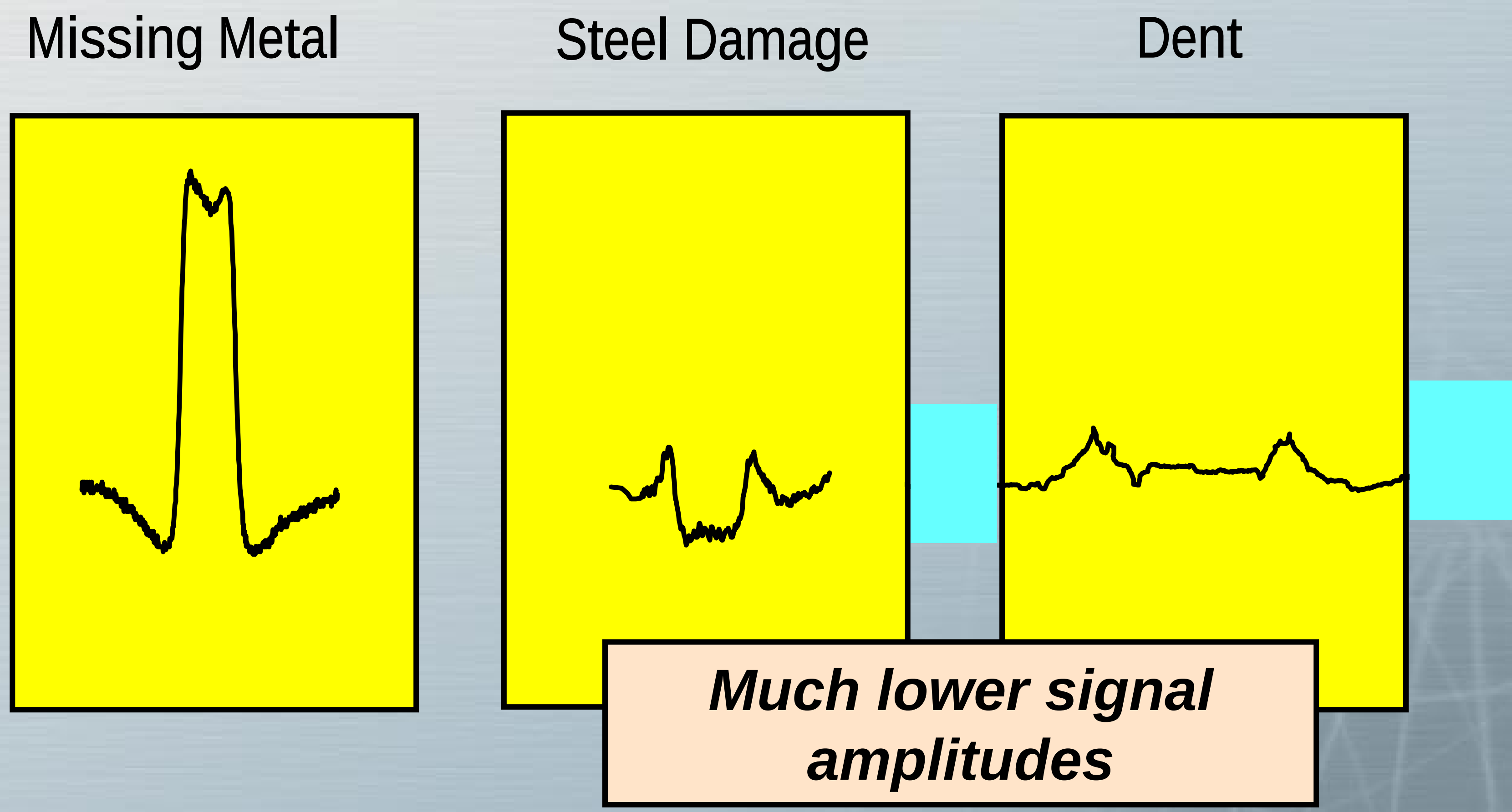
Flux Leakage Signals



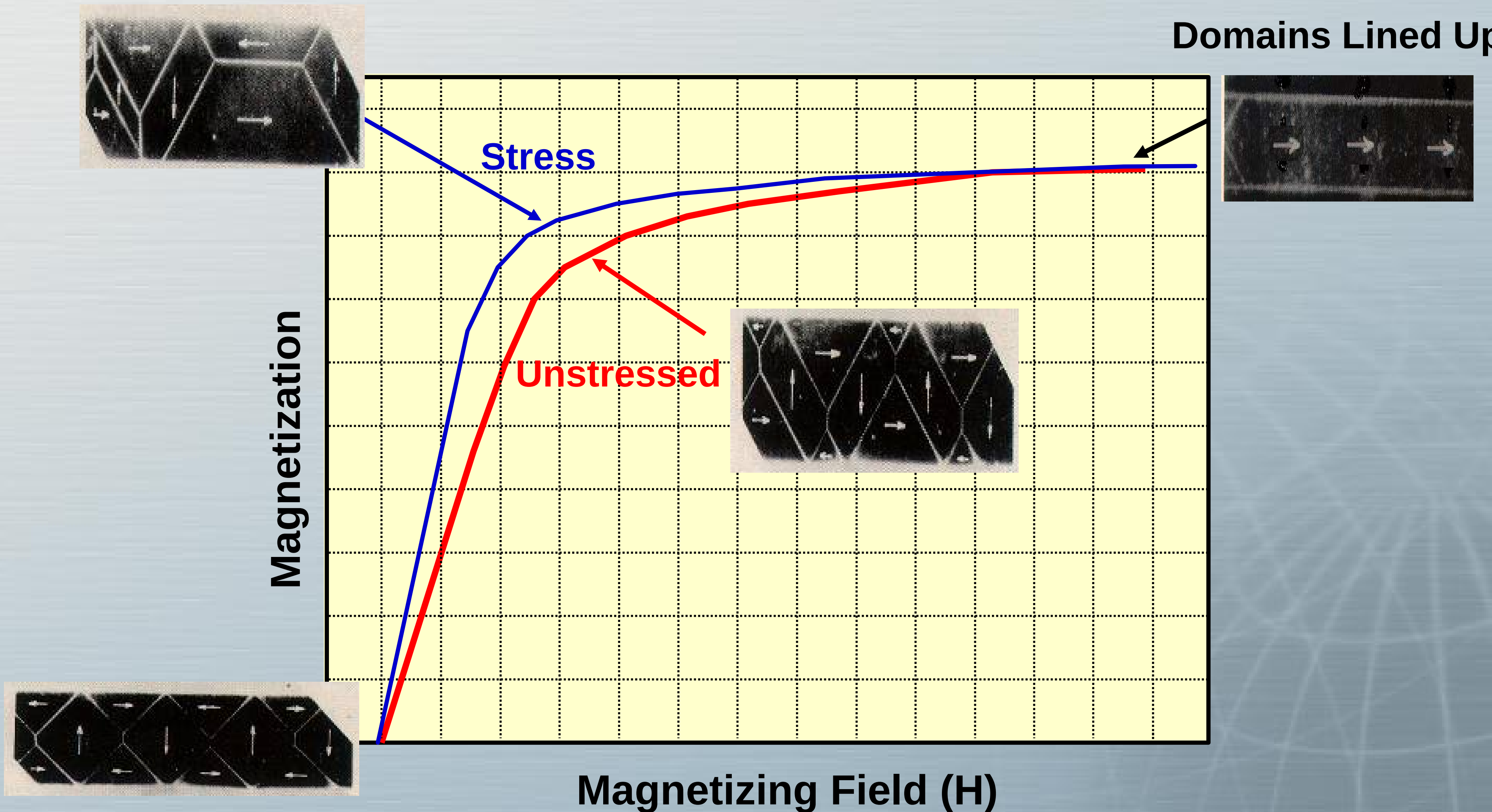
Prior Work

- Prior DOT OPS and GRI projects laid the groundwork by studying the feasibility of using MFL to detect mechanical damage
- We learned that different types of damage create different MFL signals:
  - Metal loss, damage to the steel, and denting produce unique signatures
  - Not all anomalies create signals in all situations
  - The inspection tool design strongly affects signal strengths
- The analysis technology was transferred to Tuboscope as part of a commercialization task.

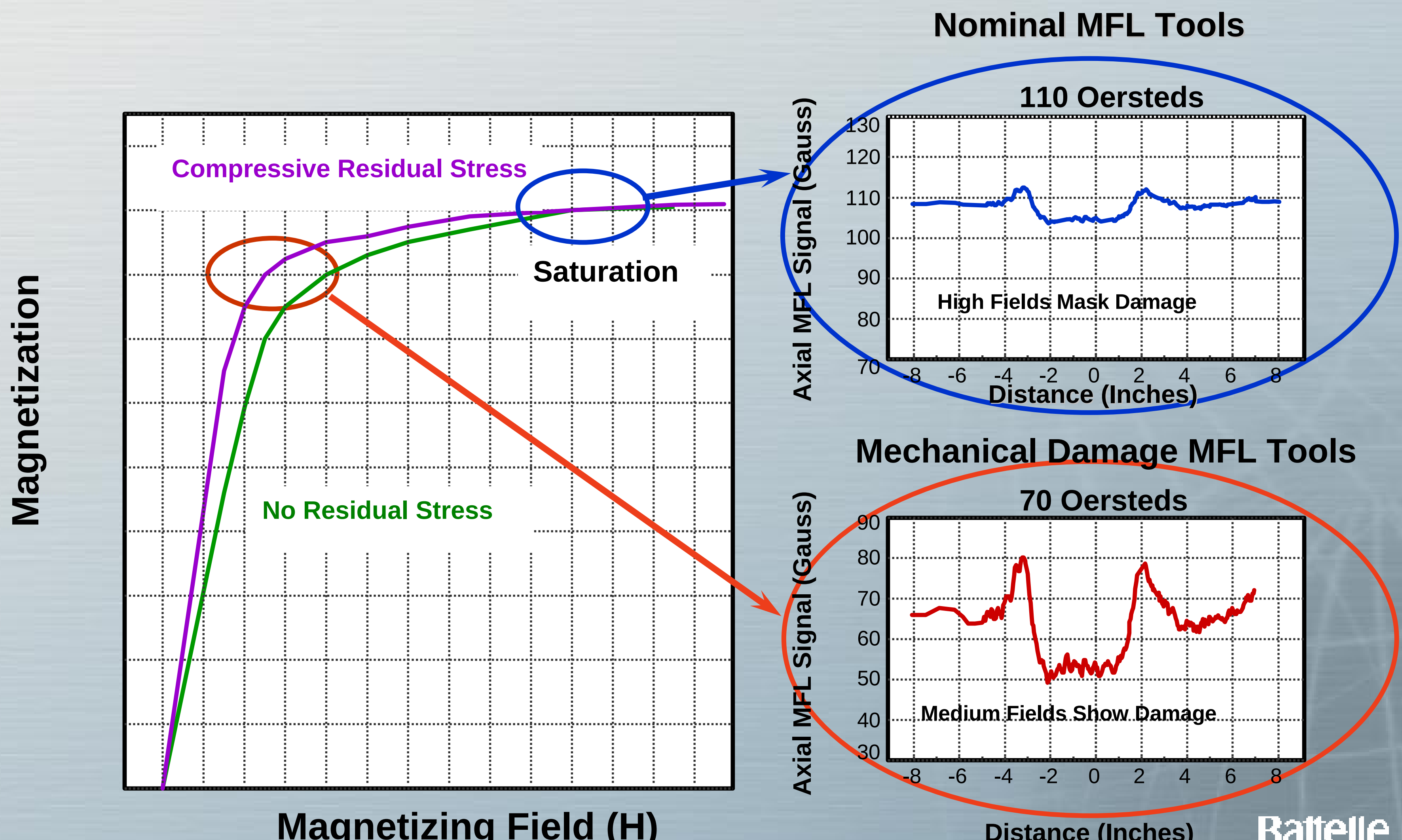
Unique MFL Signals from Mechanical Damage Components



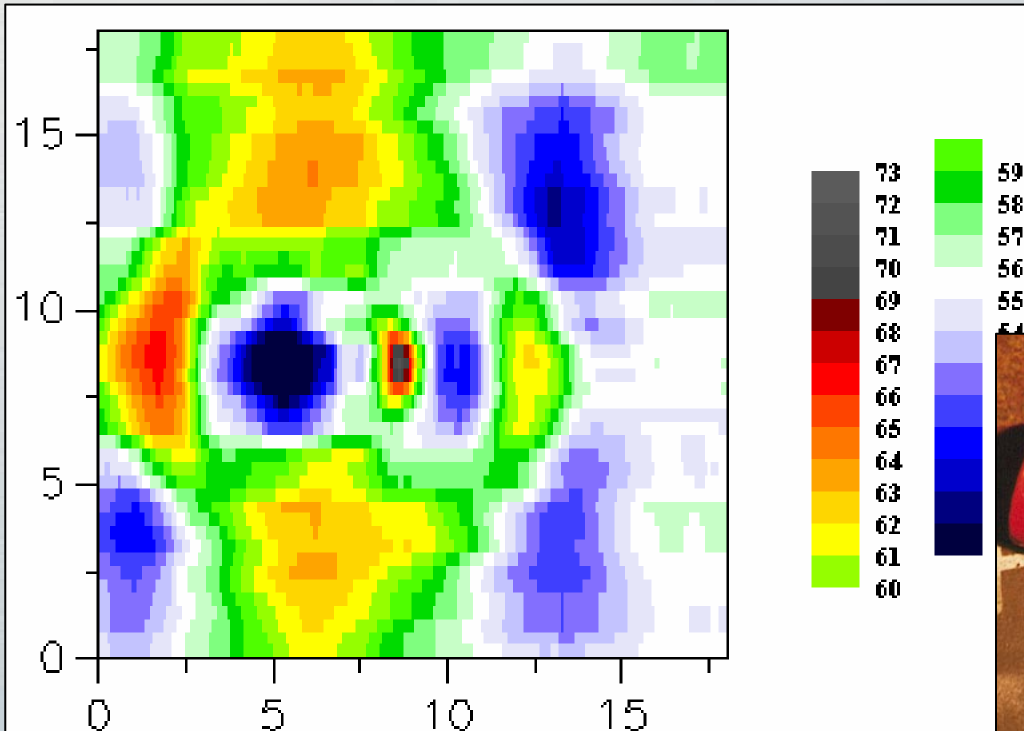
The physical principle



Magnetization Level & Mechanical Damage

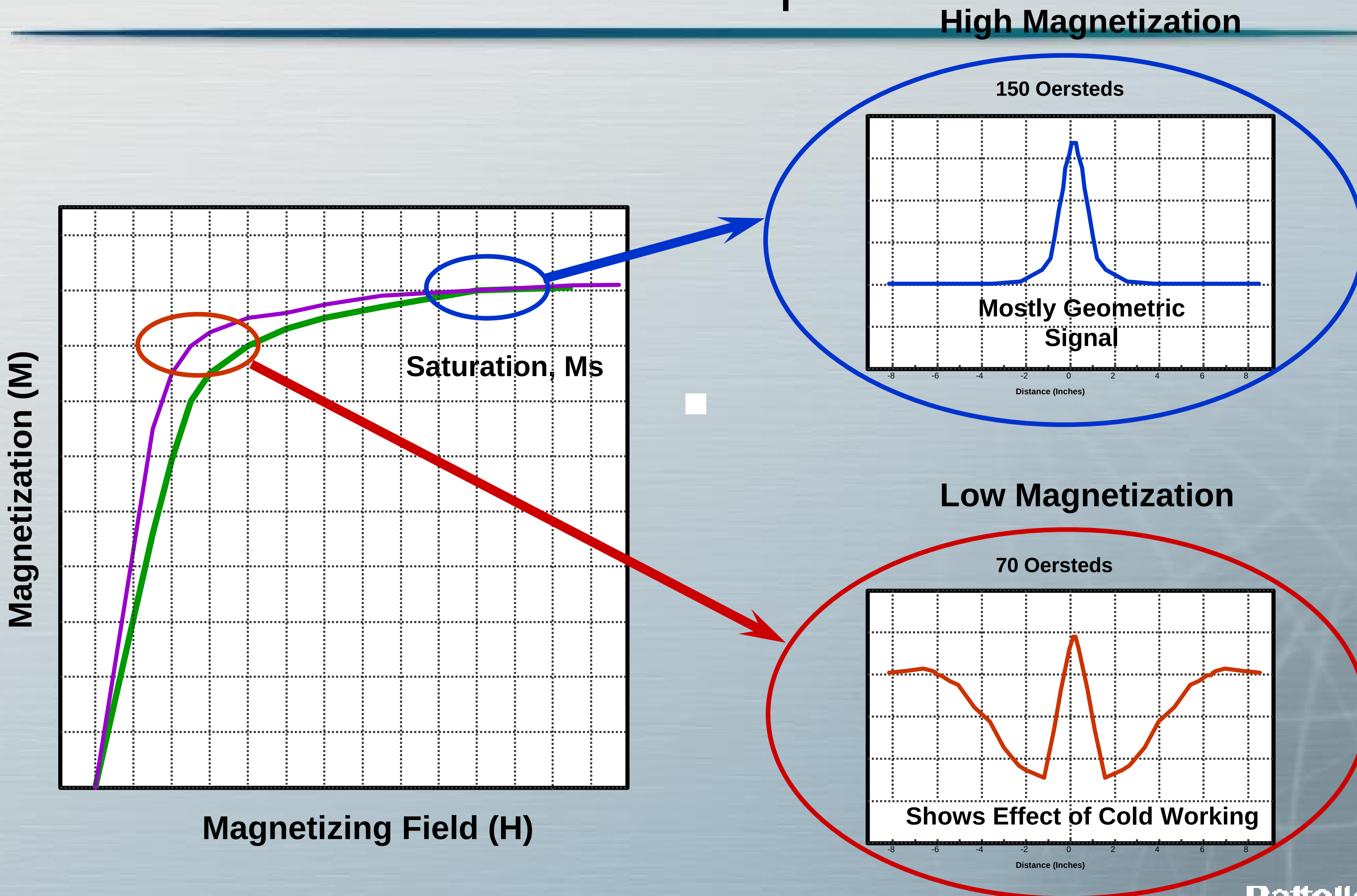


Low Magnetization Signal



At low magnetization levels the signals are complex

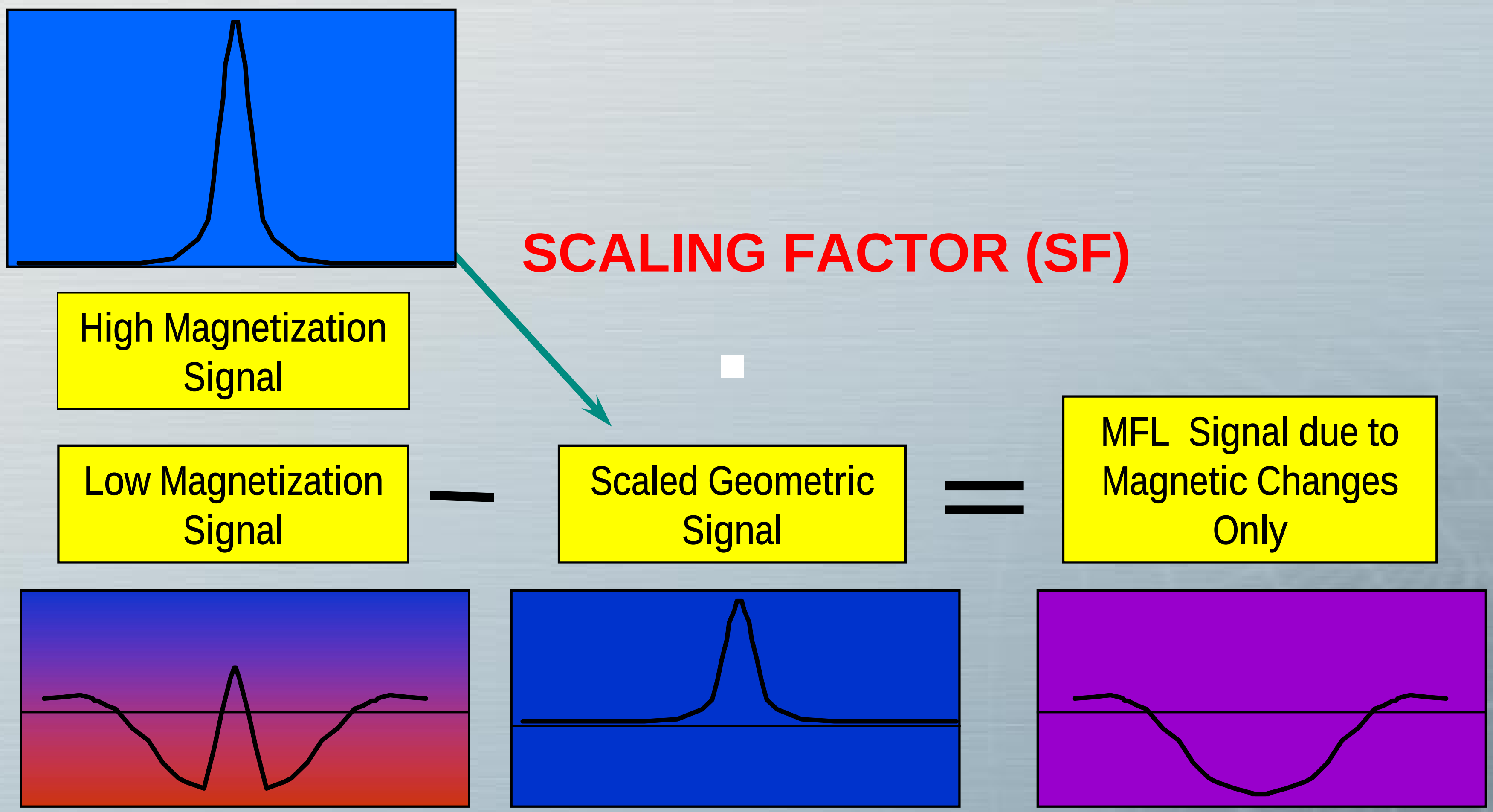
Multi-Level MFL Concept



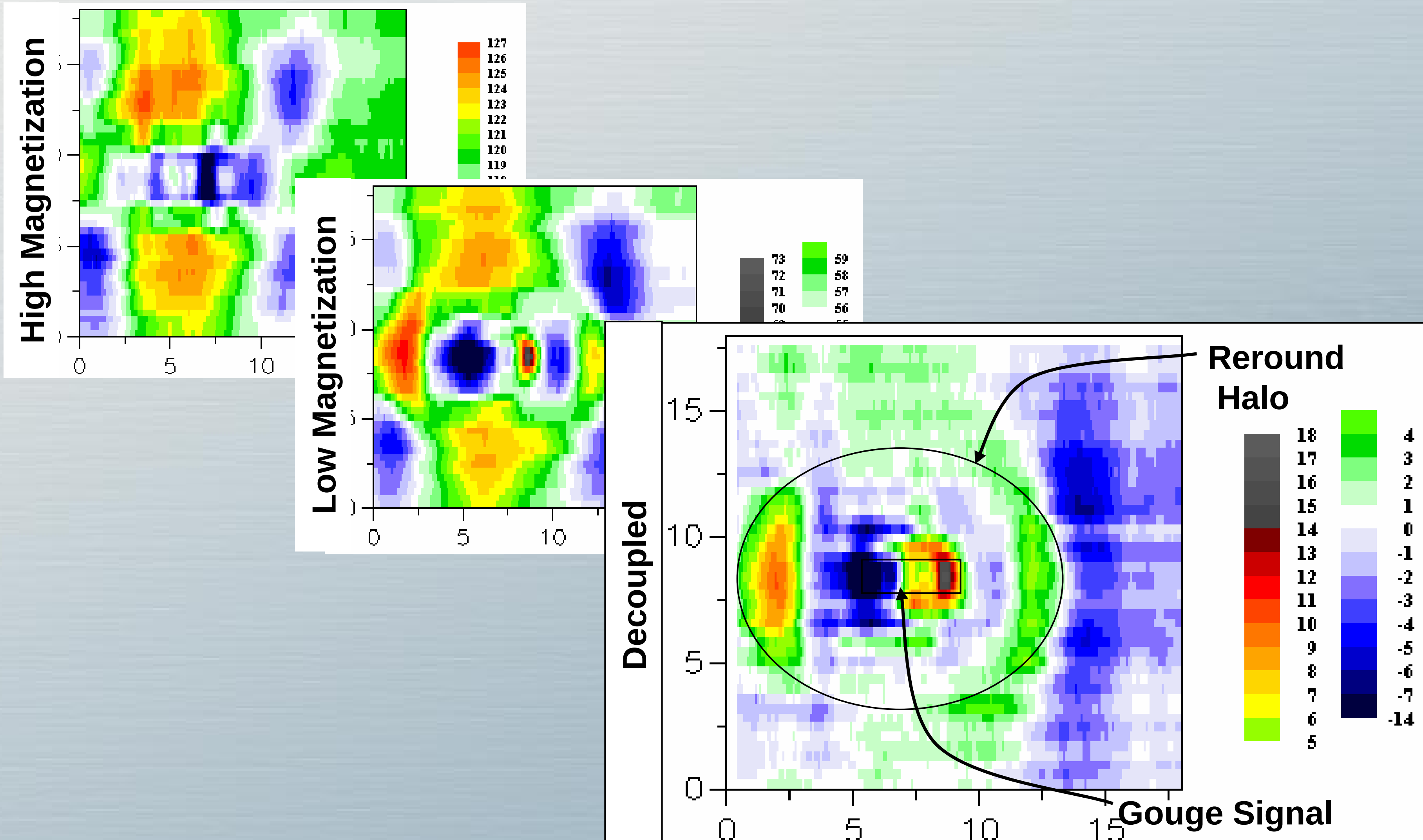
Multiple Magnetization Approach

- MFL signals at high magnetization levels are almost entirely due to geometry changes (missing metal and dents)
- MFL signals at low levels are due to both geometry and magnetic changes
- The difference is due to magnetic changes due to stresses in the pipe – an important component for assessment of mechanical damage

Extracting the Magnetic Component: Decoupling

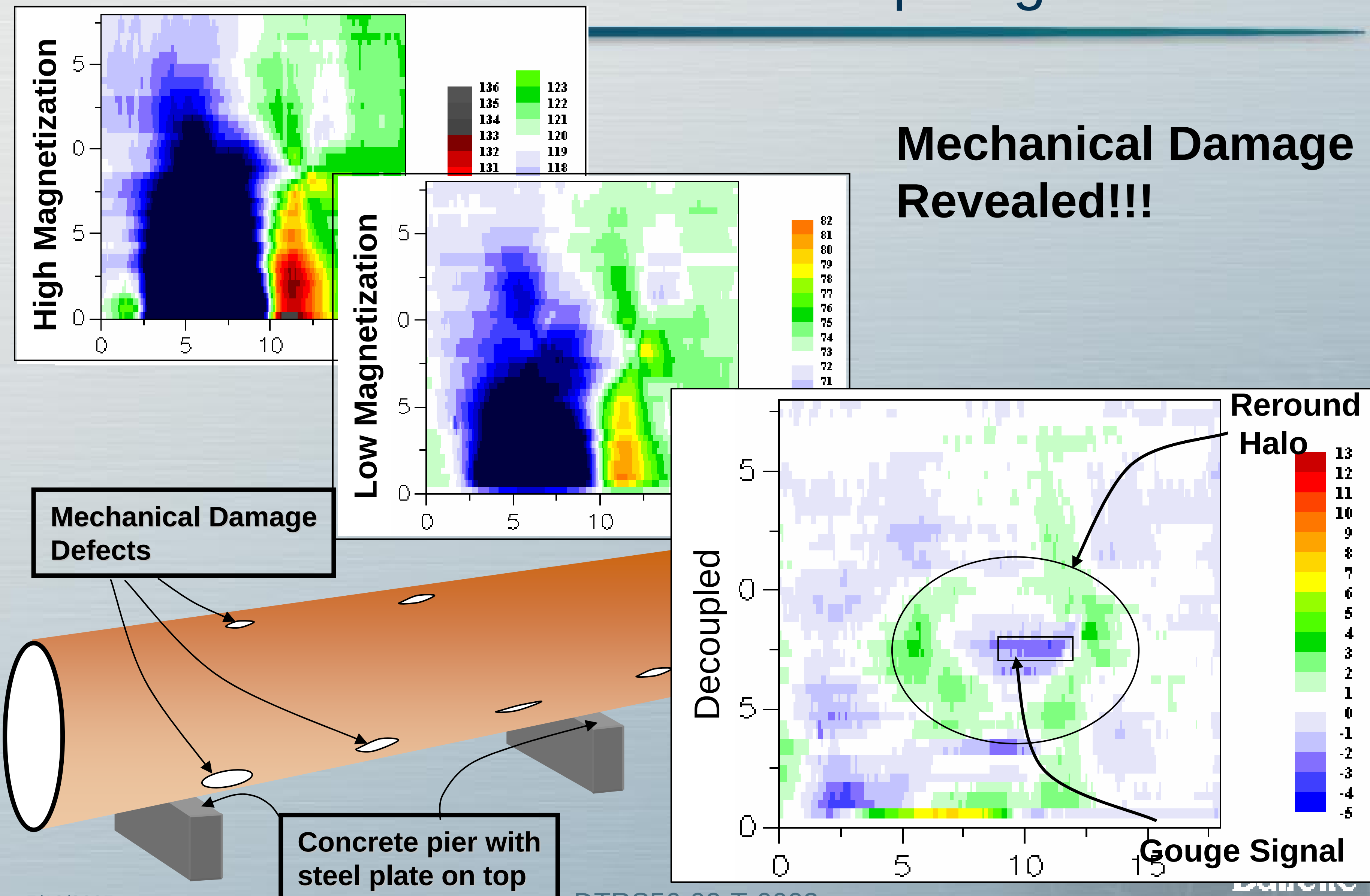


Decoupling Example



Demonstration that decoupling works

Mechanical Damage Revealed!!!



Detection Analysis

- Decoupling the MFL signal reveals the presence of damage to the steel. An anomaly with damage to the steel yields a distinct signature in the decoupled signal.
  - The gouge signal shows regions of deformed, moved and removed metal
  - A reround "halo" shows regions that were deformed but no permanent deformation
- Decoupling increases the probability of obtaining a *measurable* signal from significant mechanical damage and properly differentiates these signals from other "anomalous" signals

Dual Magnetization Summary

- The pipeline industry commonly uses deformation tools to assess dents in pipelines.
- Some newer commercial MFL tools incorporate deformation sensors to identify dents with missing metal.
- The dual field approach augments 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.
- As data storage cost and processing times decrease, this added inspection capability could be available for only a modest increase in cost.

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Program Review

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Milestone Revision Dates

Payable Milestone	Task	Planned Completion Date	Milestone Report Date
1	Magnetizer and Sensor Design	Nov 30, 2003	Jan 15, 2004
2	Magnetizer and Sensor Fabrication	June 30, 2004	Aug 12, 2004
3	Defect Set Fabrication	April 30, 2004	April 15, 2004
4	Data Collection	Sep 30, 2004	Nov 30, 2004
5	Data Analysis	Dec 31, 2004	Jan 31, 2005
6	Final Reporting	March 31, 2005	Mar 31, 2005
7	Benchmarking Emerging Inspection Technologies	Sep 30, 2004	Oct 25, 2004

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Milestone 1: Magnetizer and Sensor Design

Rick Davis and George Brand

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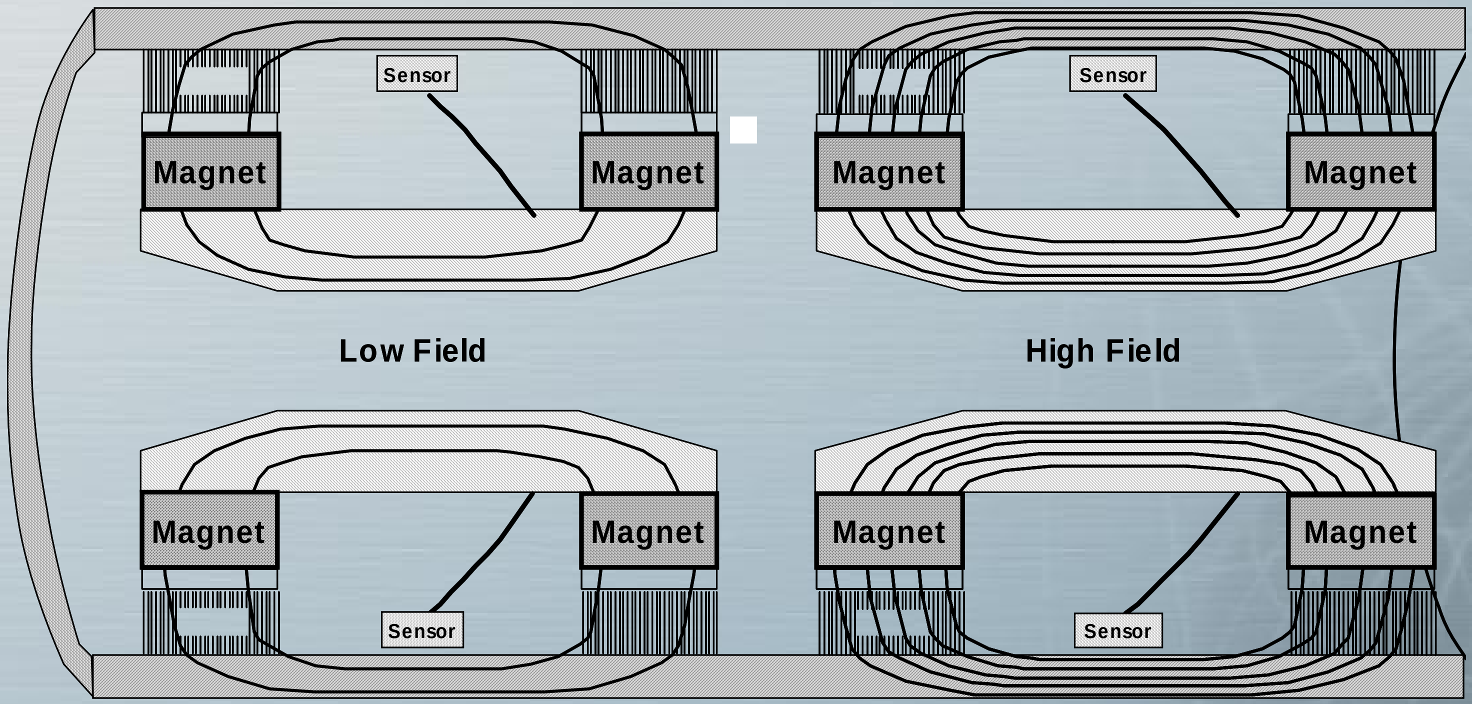
Benchmark: Two Magnetizers

Develop a New Multi-Level MFL Tool Design that Will Be as Good as Our Benchmark of Two Individual Magnetizers



Design Process

MFL Tool Design
Modeled Results

Design Optimization

Brassboard Tool
Linear Test Rig Experiments

Prototype Tool
Pull Rig Experiments

- Some Design Considerations Based on Previous Work
- Use Nonlinear Finite Element Modeling of Tool Designs for Initial Study
  - Previous Efforts Have Calibrated Well
  - Material Properties of Tool Components Known

Design Parameters and Considerations

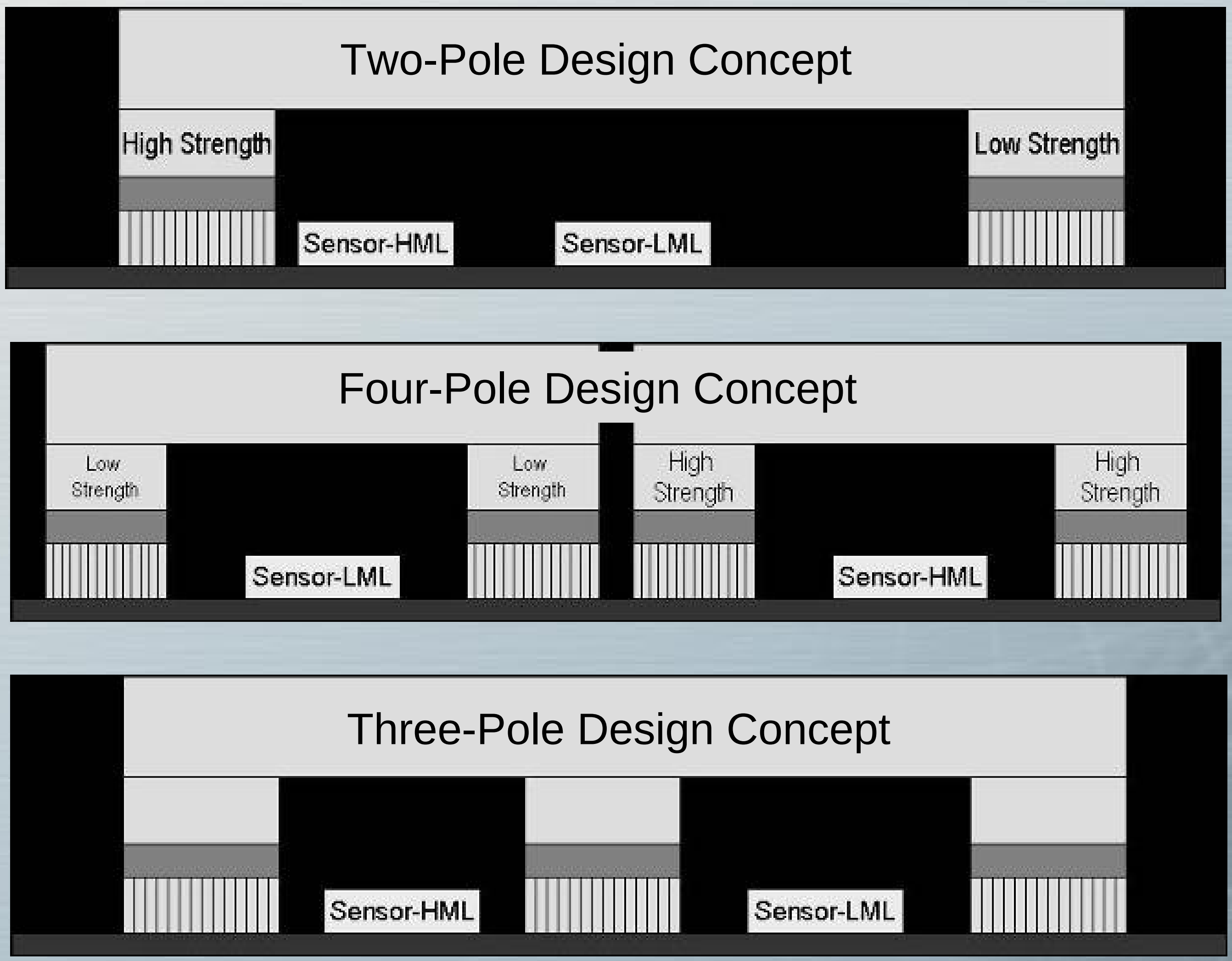
Magnetically Required

- Optimal Magnetization Levels
  - 140 to 160 Oersted for High Level
  - 50 to 70 Oersted for Low Level
- Uniform Axial Field Levels
  - Smallest Possible Axial Flux Gradient (3-inch Sweat Spot Needed)
- Magnetically Stable Design
  - Lift-Off Sensitivity Reduced
  - Velocity Effects Minimized
  - Pipeline Material Properties.

Tool Variables

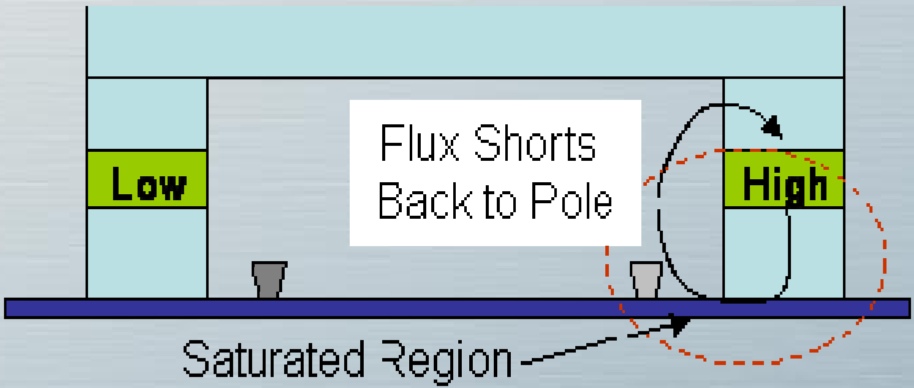
- Minimal Magnetizer Size
  - Physical Tool Size Restrained
- Basic Tool Geometry
  - Two, Three and Four Pole Designs
  - Size (Tool Length is Fixed)
  - Materials
- Magnet Strength
- Pole Size and Spacings
  - Widths, Lengths, Height
- Sensor Locations

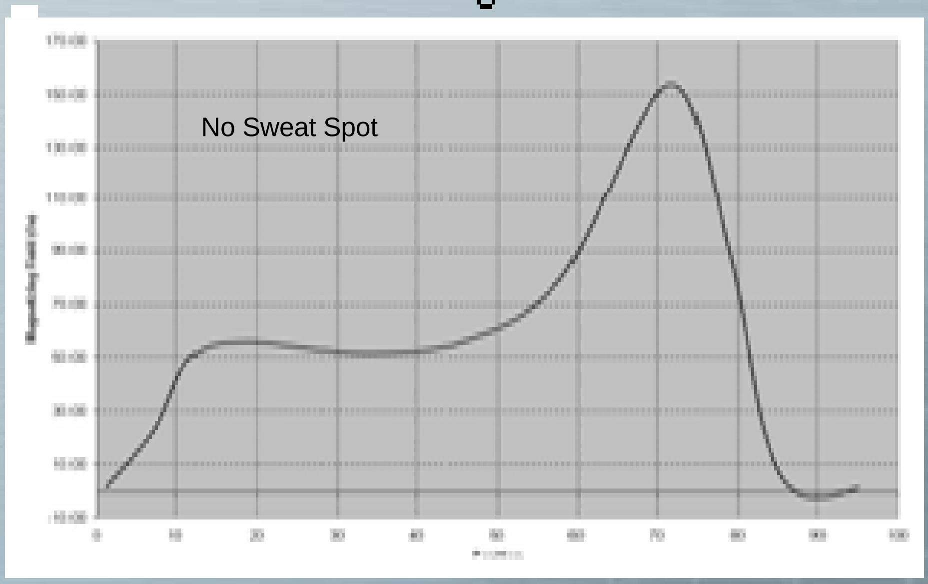
Various Pole Designs Considered



The Two-Pole Concept Does Not Work

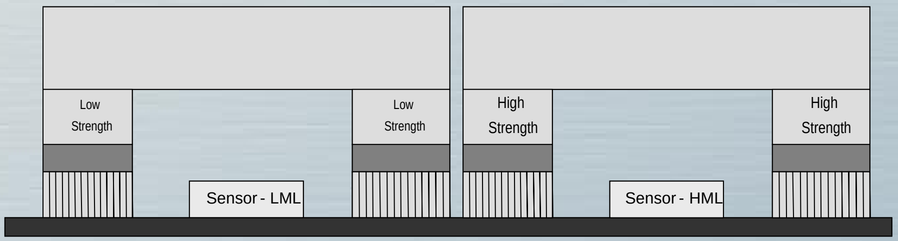
- Pro: simple design is appealing. It is similar to current MFL tools
- Con: no uniform field level for higher magnetizing strength
  - Large gradients
- Con: magnetic flux very unstable
  - Strongly affected by variables such as tool velocity, wall thickness, pipeline material properties.

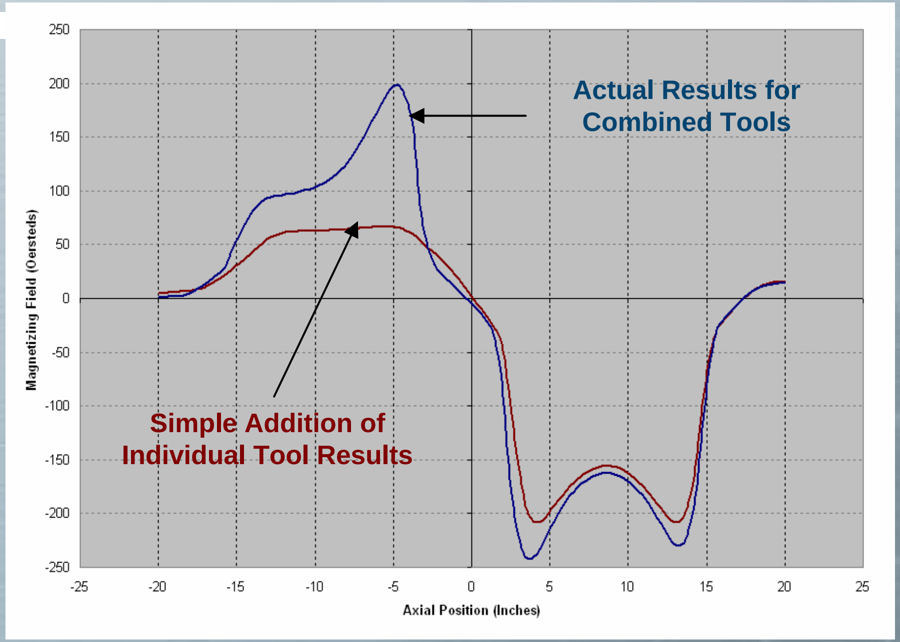




The Four- Pole Concept Does Not Work

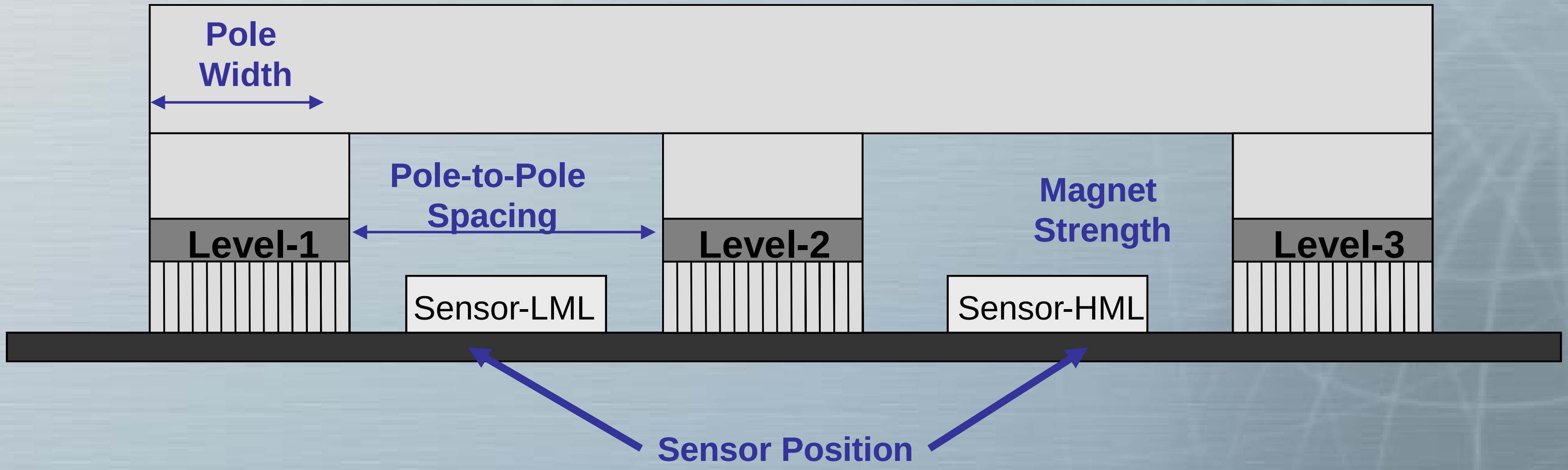
- Pro: design concept is simple. Join a high and low tool together.
- Con: tool gap has large effect on resulting magnetization levels.
  – Stable and uniform fields require very large gap yielding the benchmark of two individual tools.
- Con: magnetic flux non-uniform and unstable
  – Strongly affected by variables such as tool velocity, wall thickness, pipeline material properties.



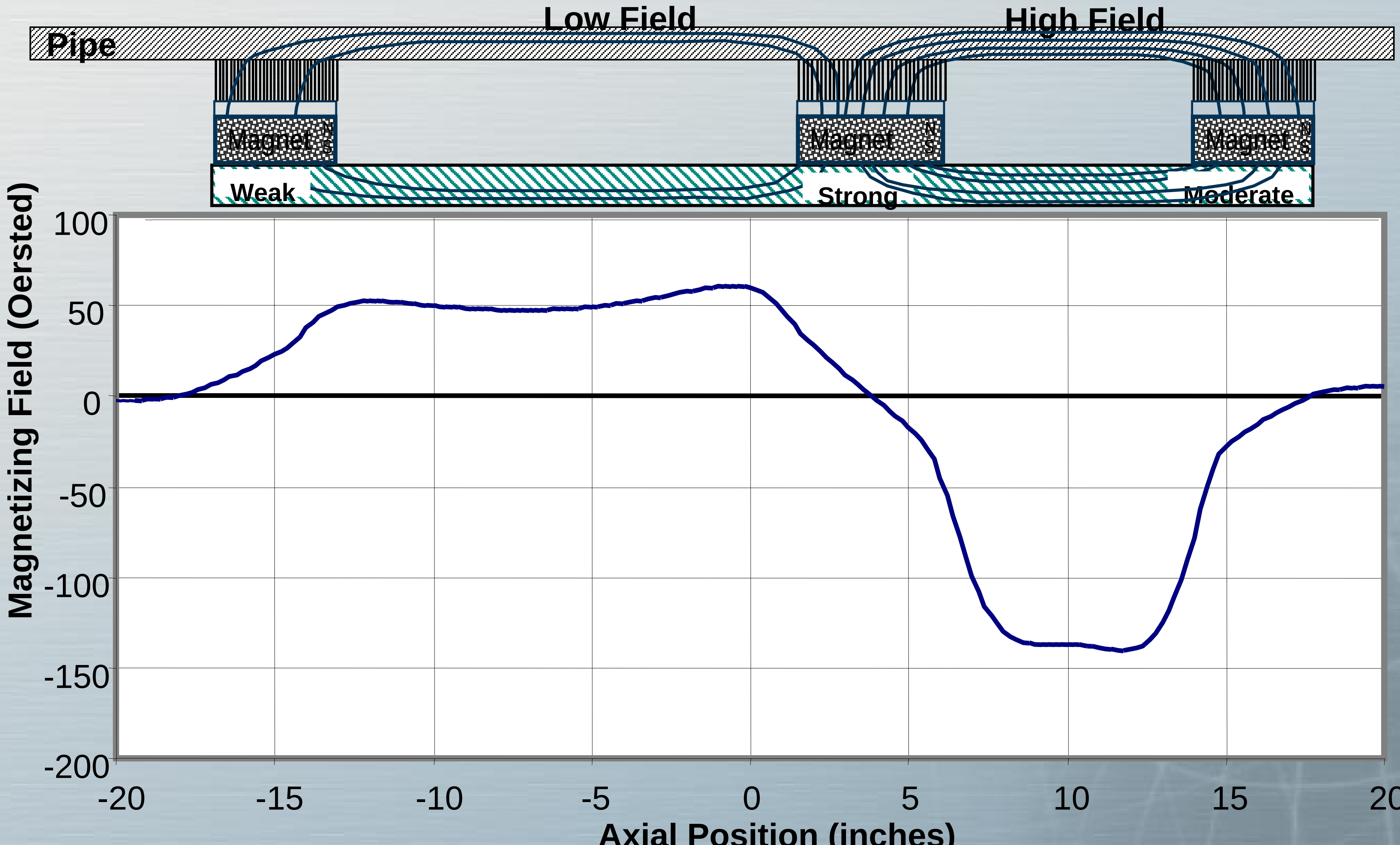


The Three- Pole Concept Does Work

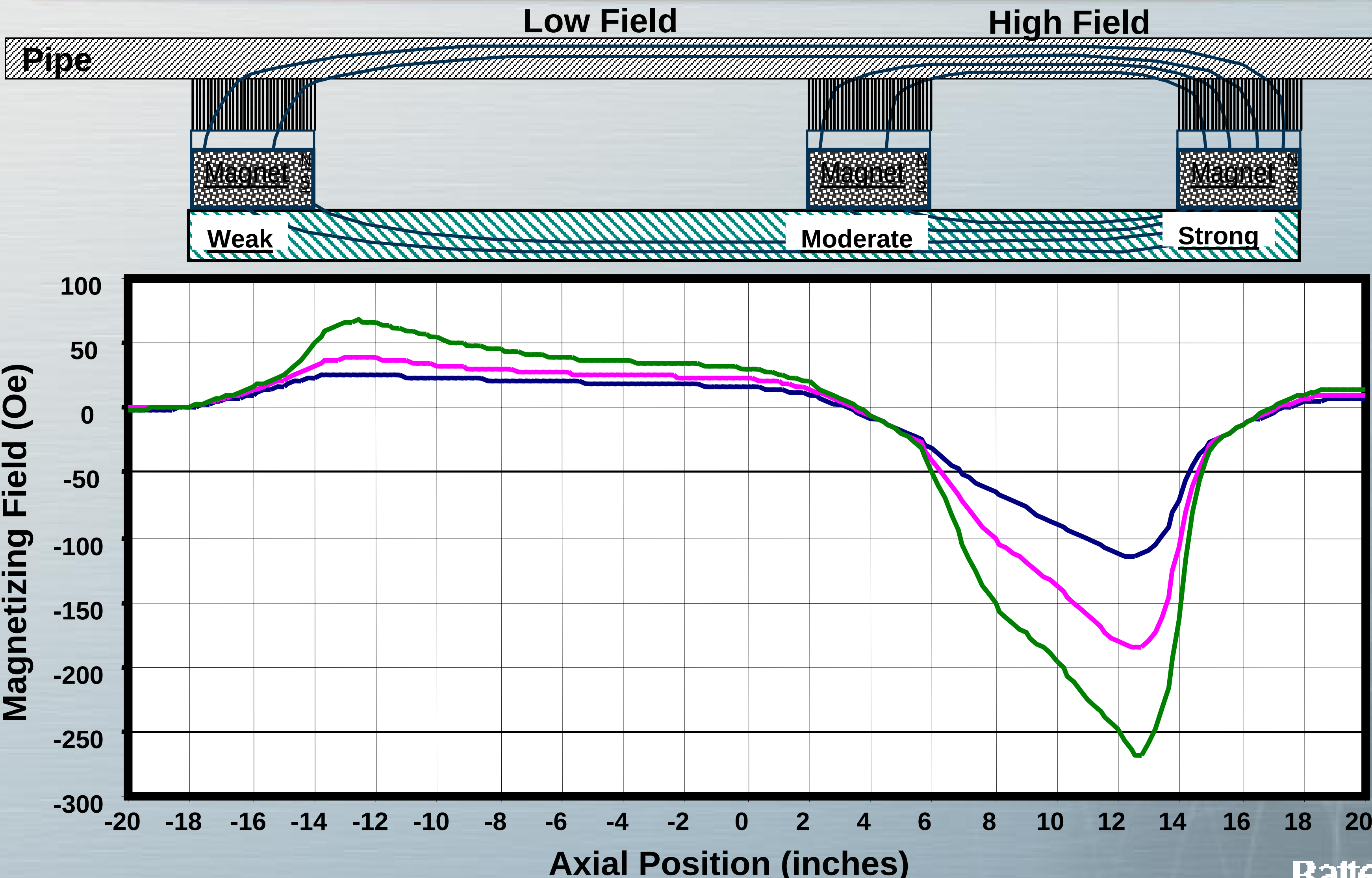
- Pro: design concept is simple.
- Requires correct phase and configuration for magnetizer pole pieces
- Uniform and optimal flux distributions obtainable for both high and low magnetizing fields
- Magnetic flux is stable



The Three- Pole MFL Magnetizer



Alternative 3-pole Configuration (Poor Performance)



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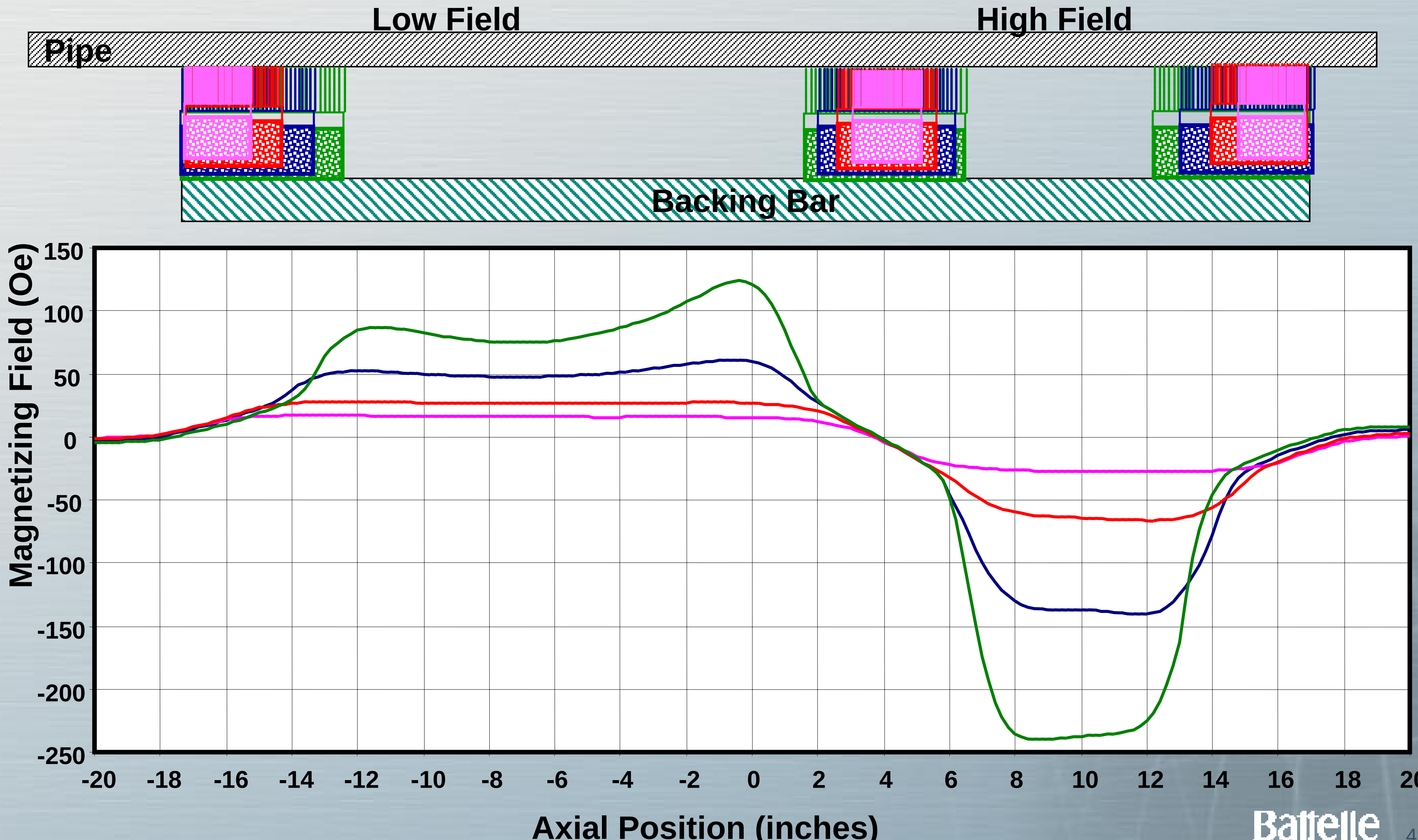
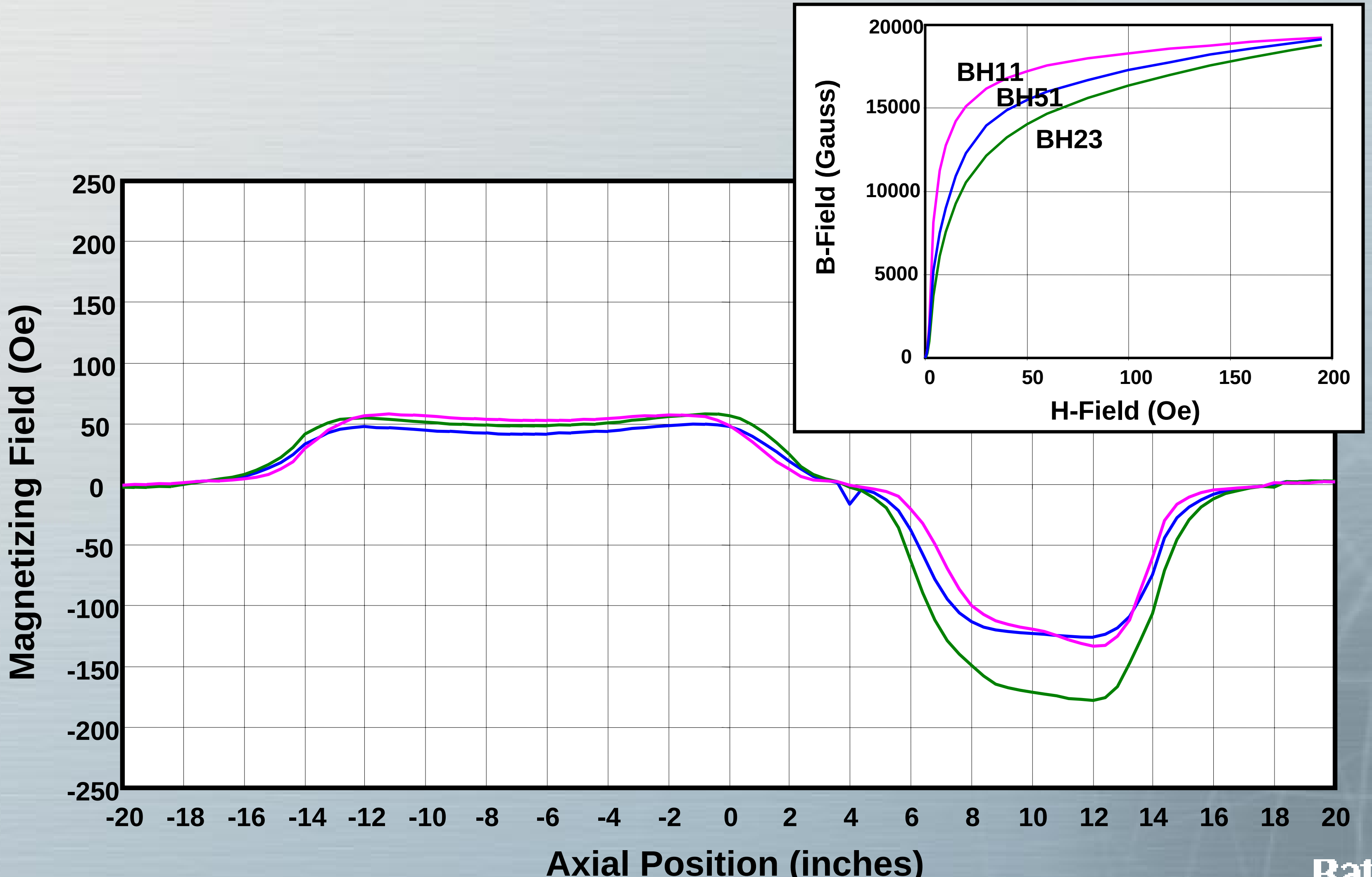
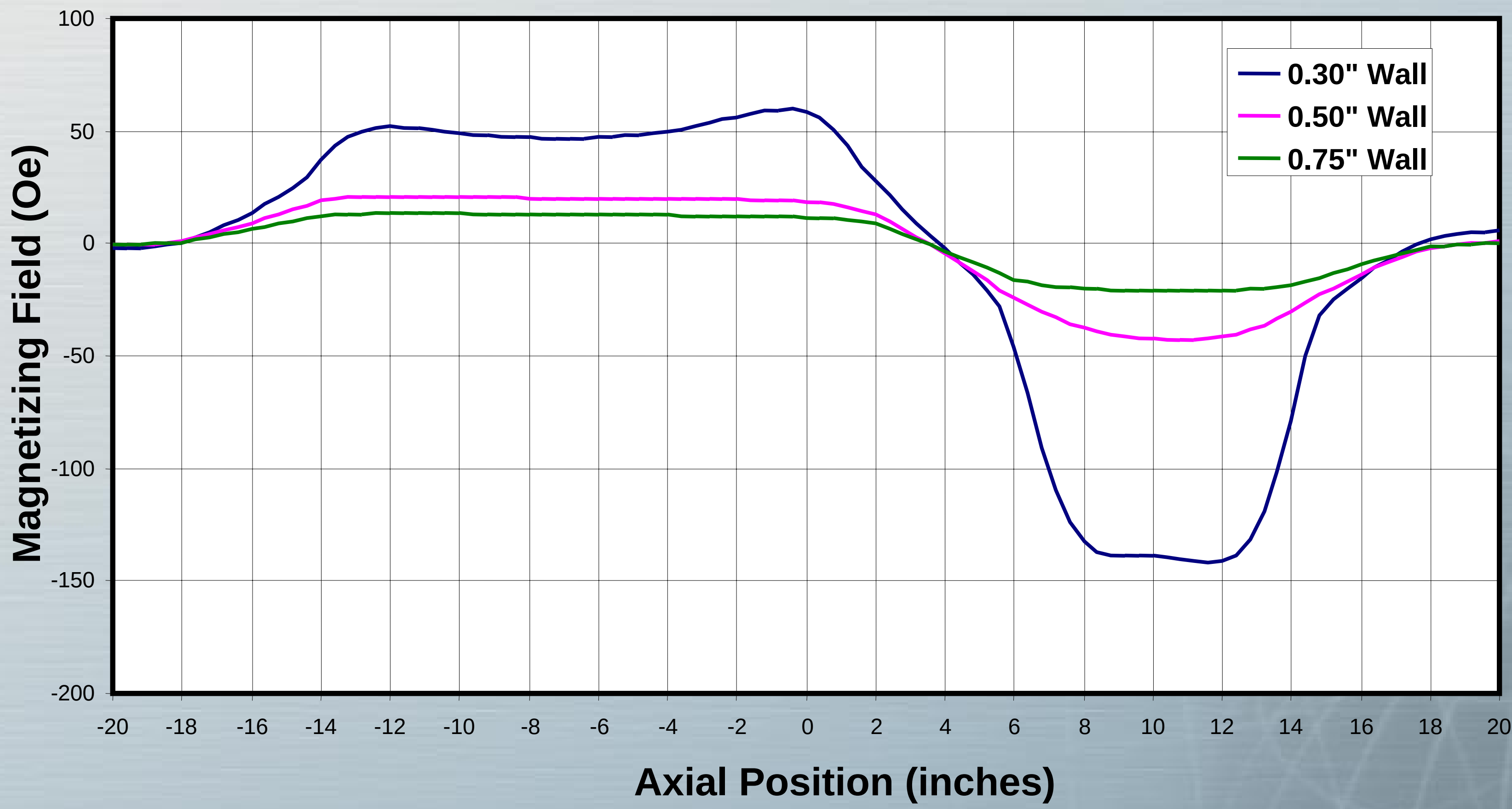
Field Strength Adjustable



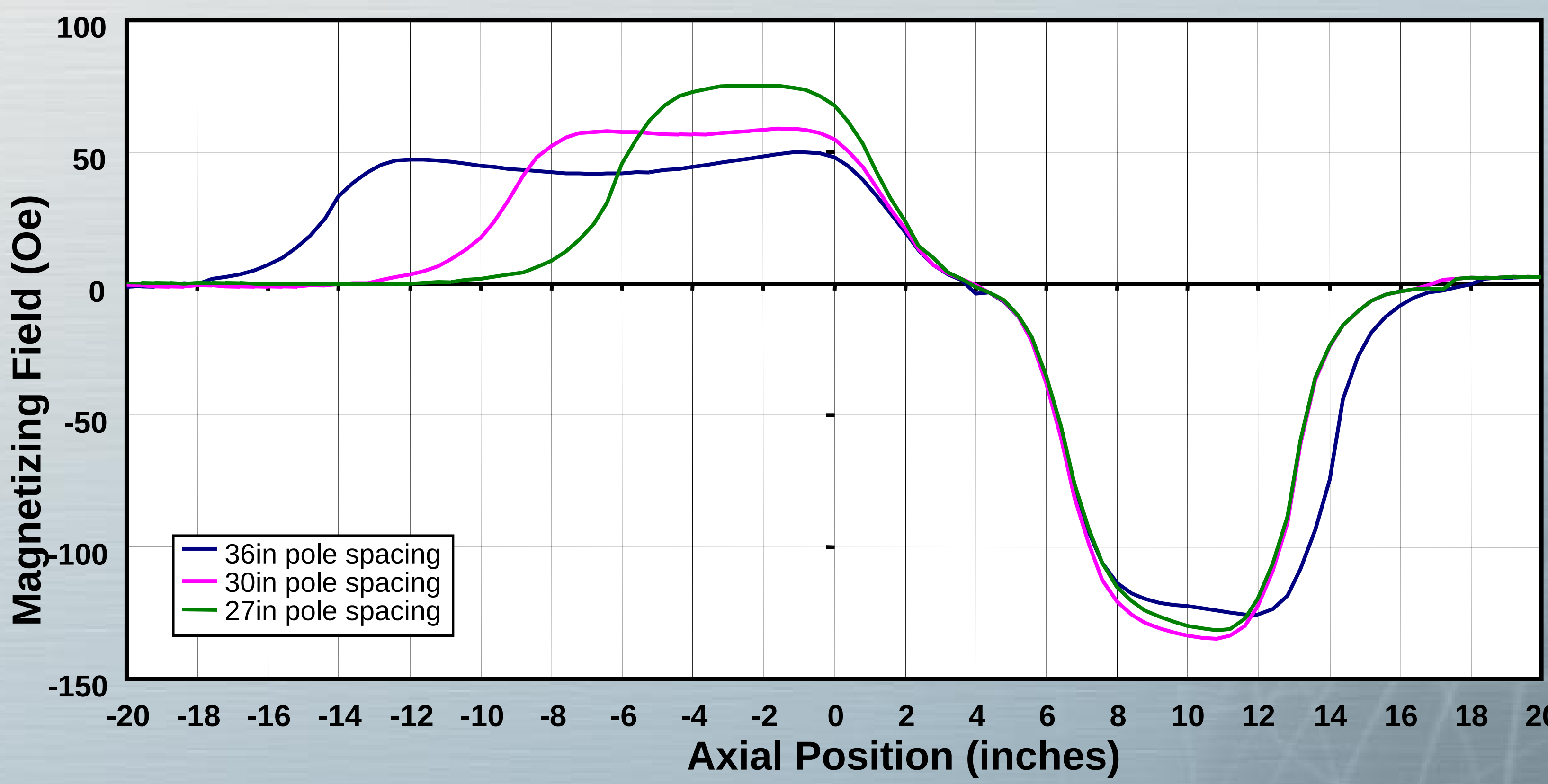
Inspection Variables Considered: Pipe material



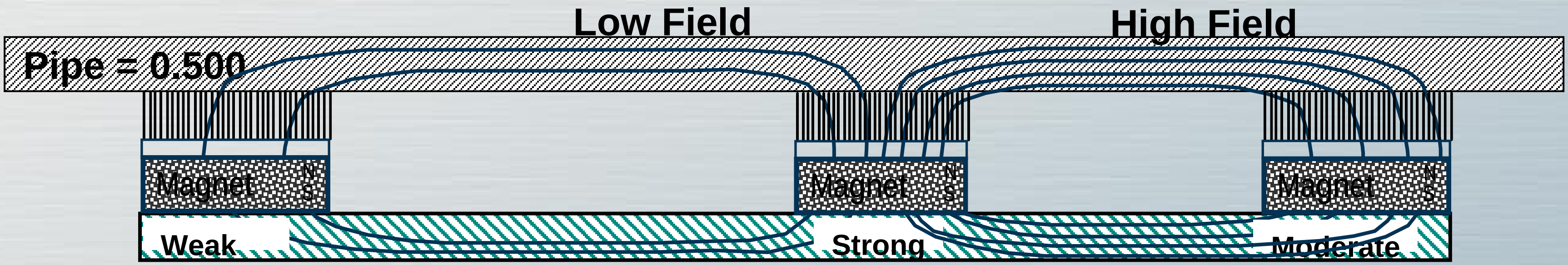
Inspection Variables Considered: Wall thickness

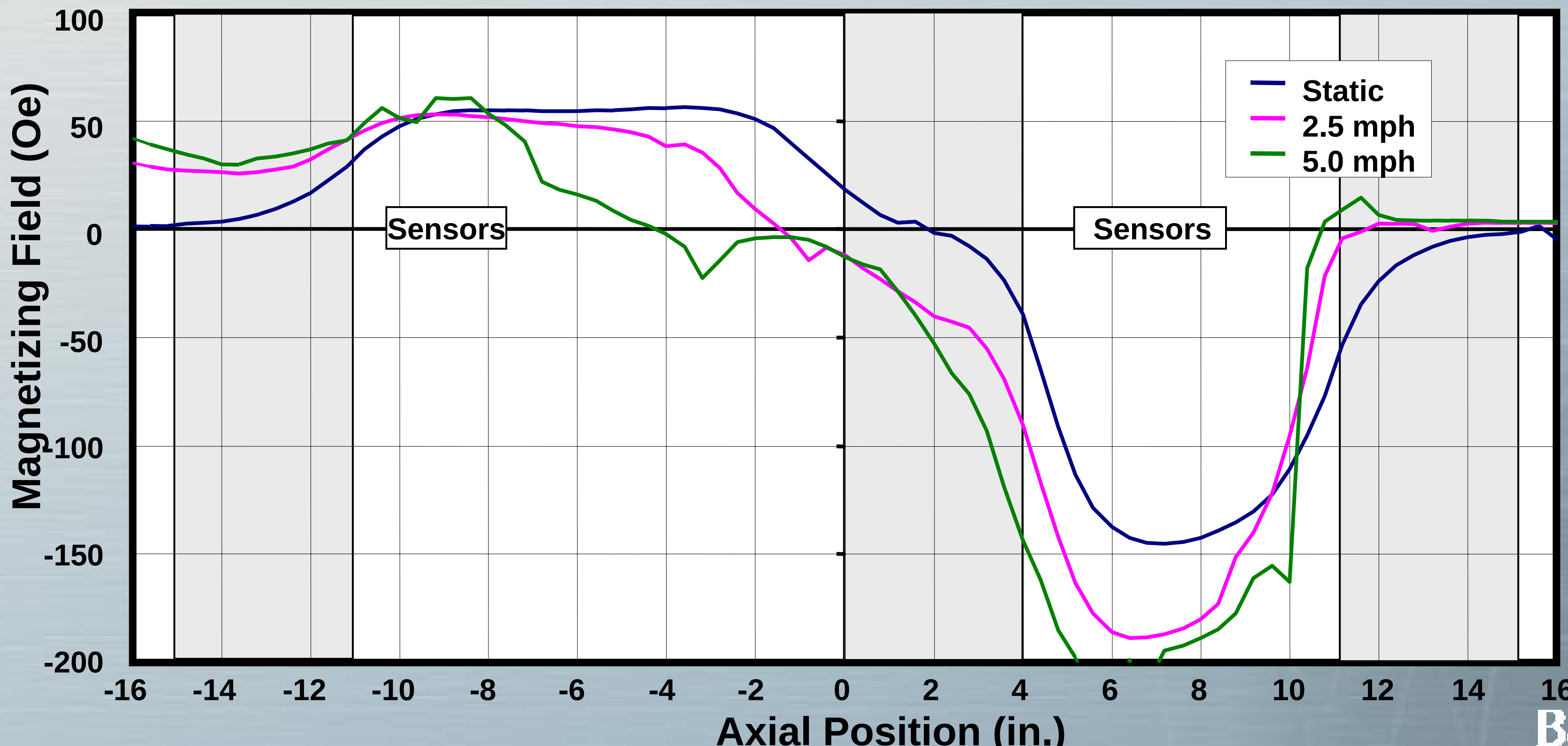


Inspection Variables Considered: Tool Length

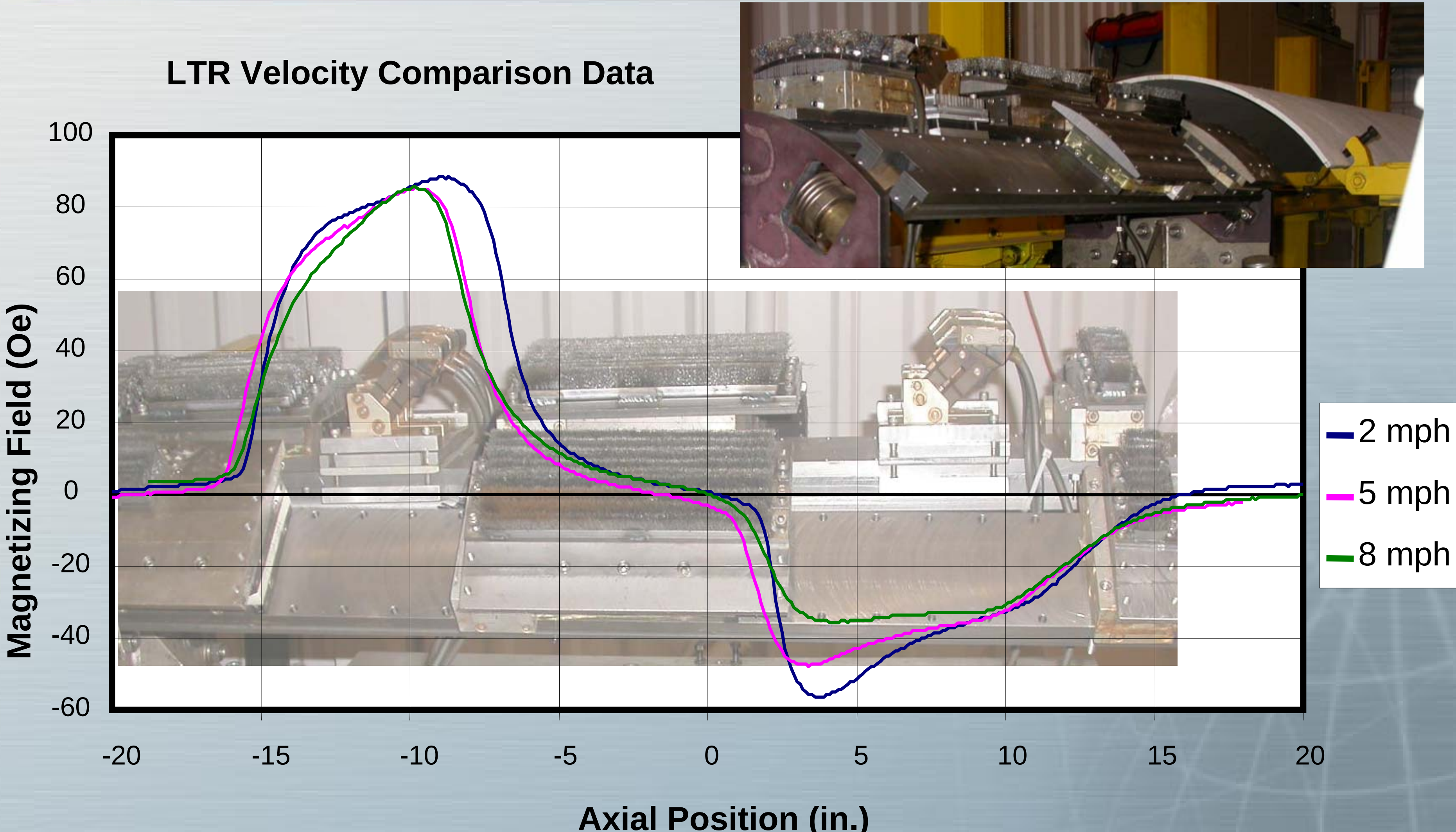


Inspection Variables Considered: Velocity Effect





Experimental Verification: Velocity effects



Milestone 1: Summary

- The two and four pole design concepts will not work. Two separate magnetizers with significant separation acceptable.
- The three pole design concept will work
  - Requires correct magnetizer pole pieces are configured correctly
  - Produces the correct magnetization levels required for decoupling
  - Produces uniform field levels at each magnetization level required for measurements
  - Provides a magnetically stable design and low “noise” (e.g., material, velocity, wall thickness)
- Design verified experimentally

Milestone 2: Magnetizer and Sensor Fabrication

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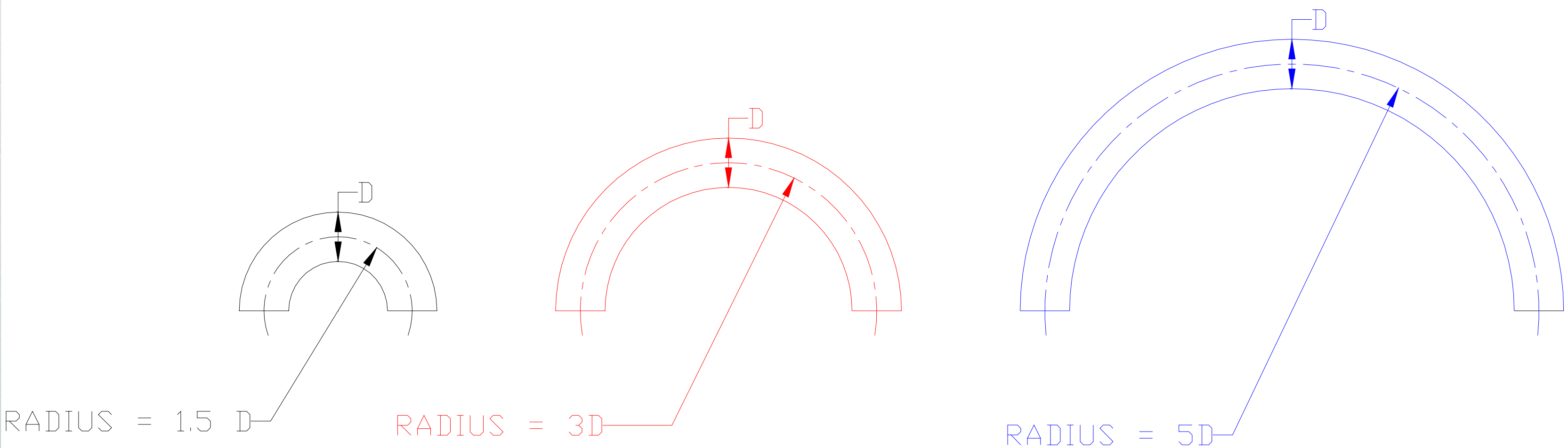
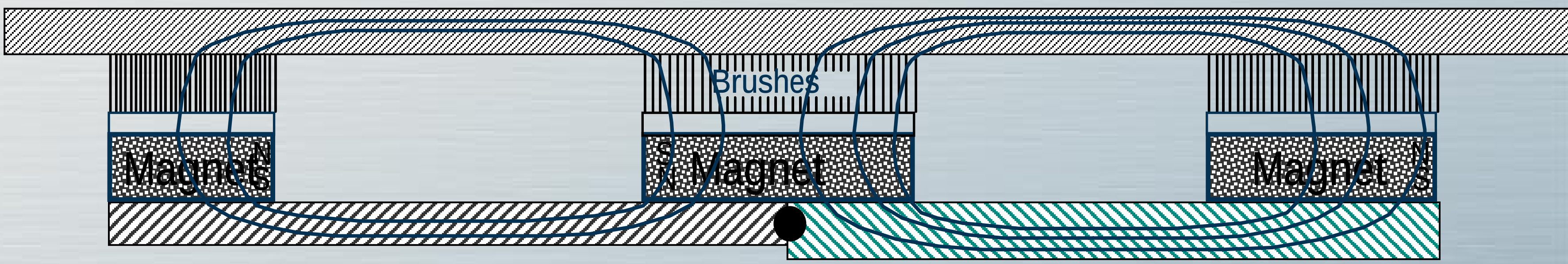
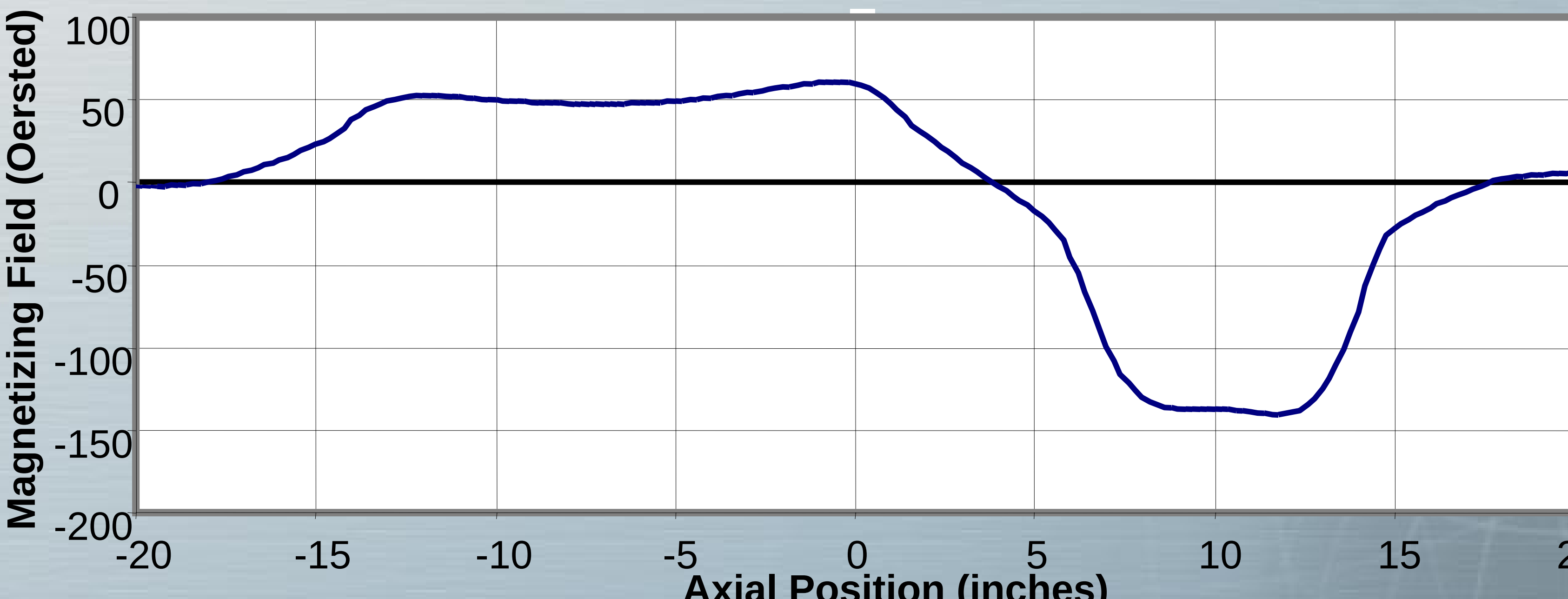
Design Driver: Curve Navigation
Pipe Bend Geometry Drawing



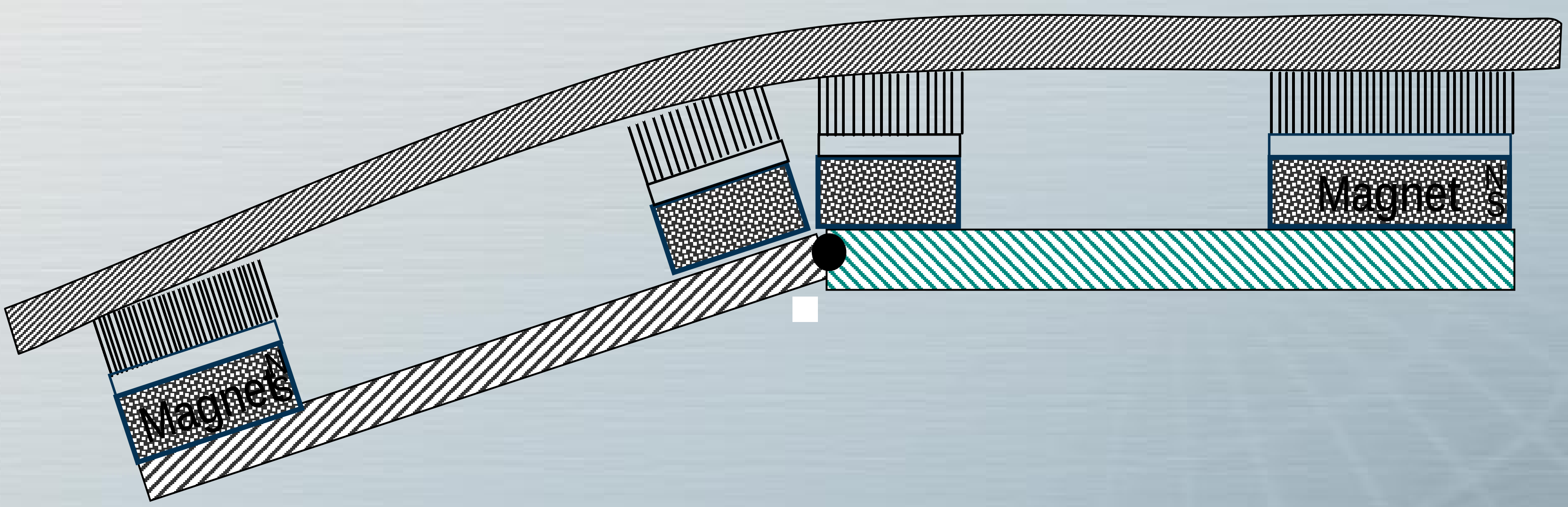
Mean bend radius typically identified as a factor of pipe diameter.

Taking advantage of the magnetic null



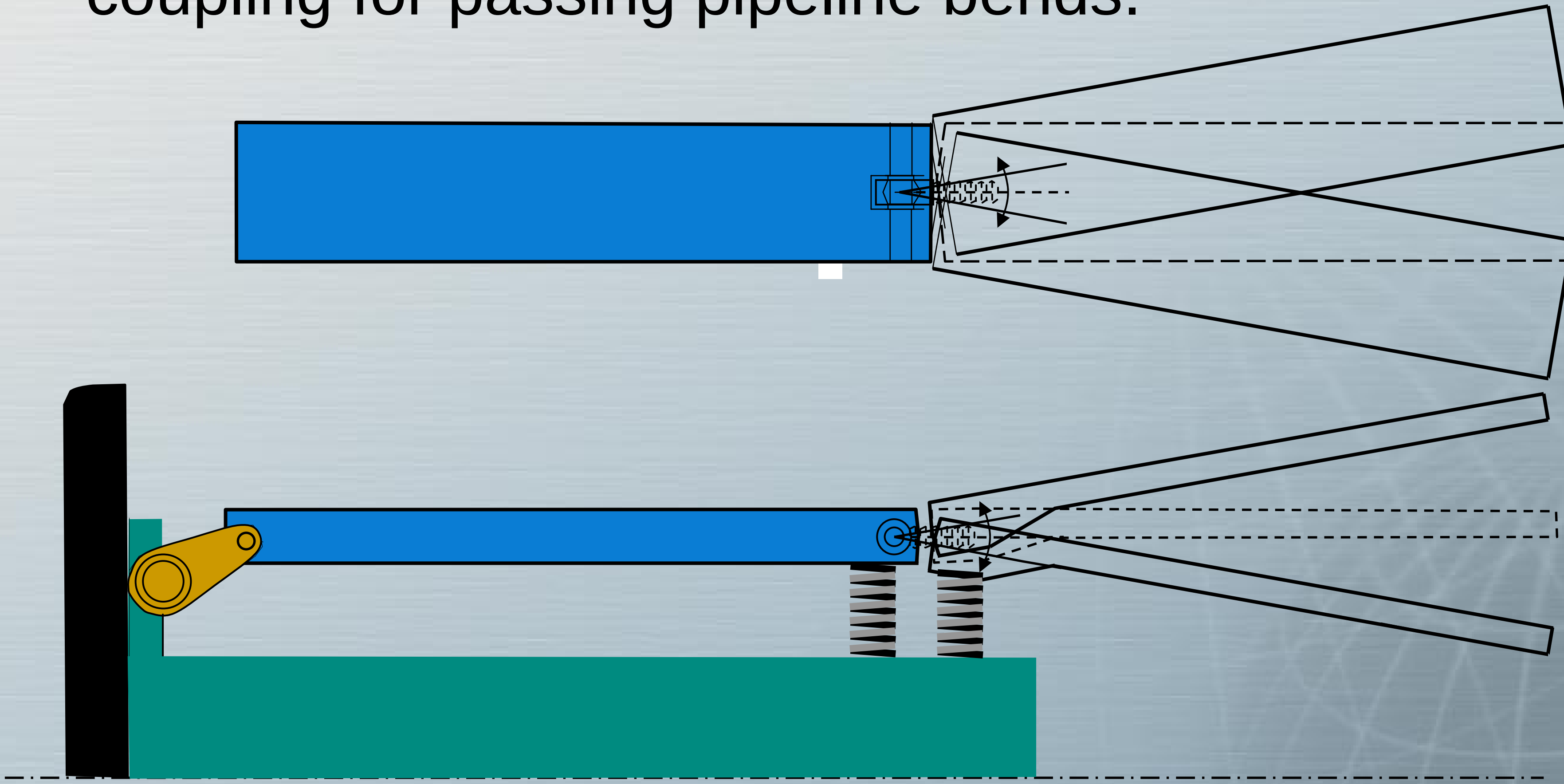


Articulating Magnet Bar

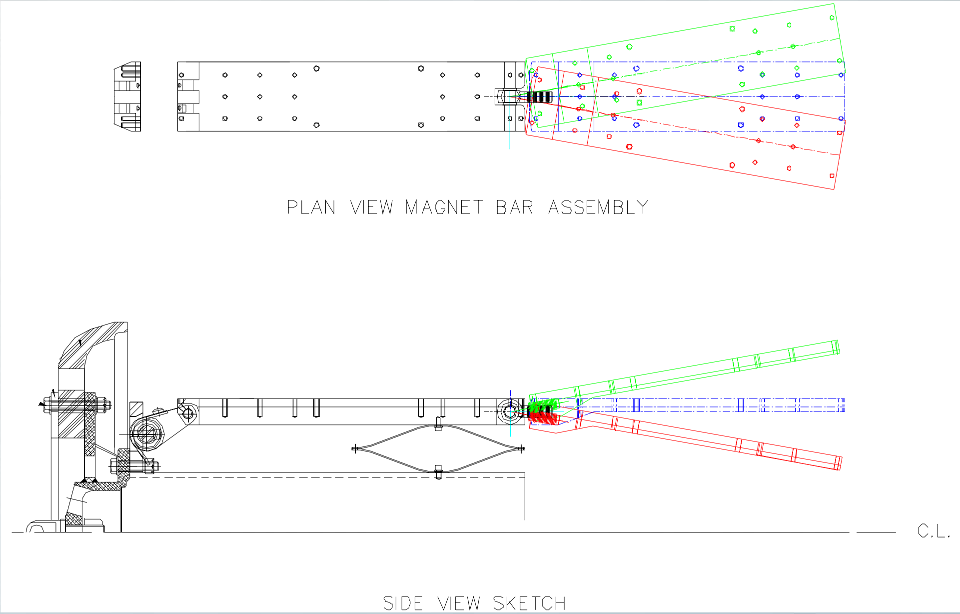


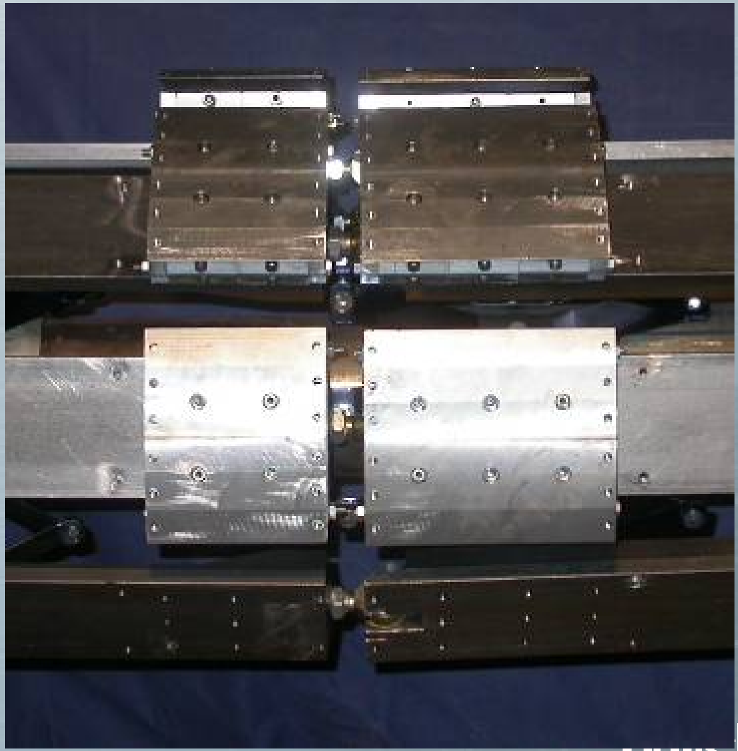
Articulating magnet bar

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



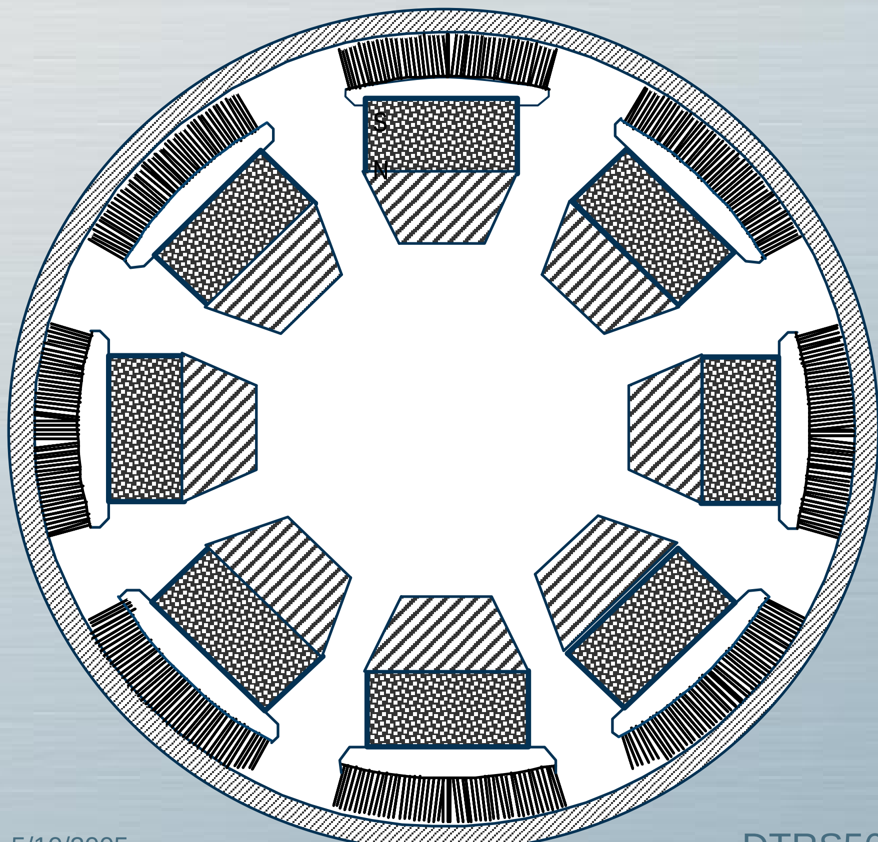
Flexible Backing Bar

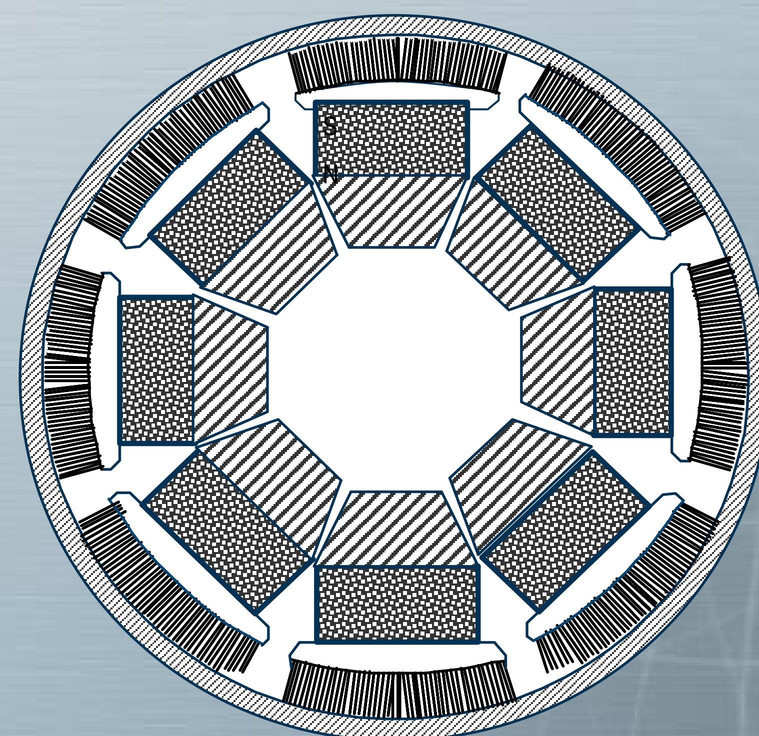




Passage of Restrictions

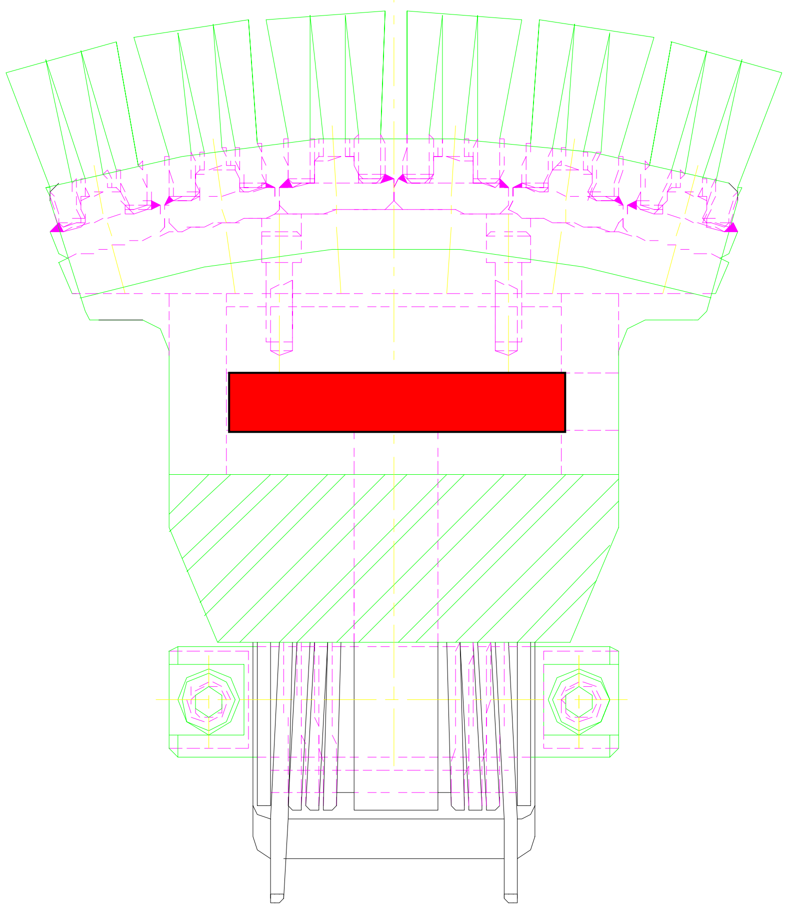
- MFL magnetizer tool collapses to pass through obstructions such as a 12 percent diameter restriction.



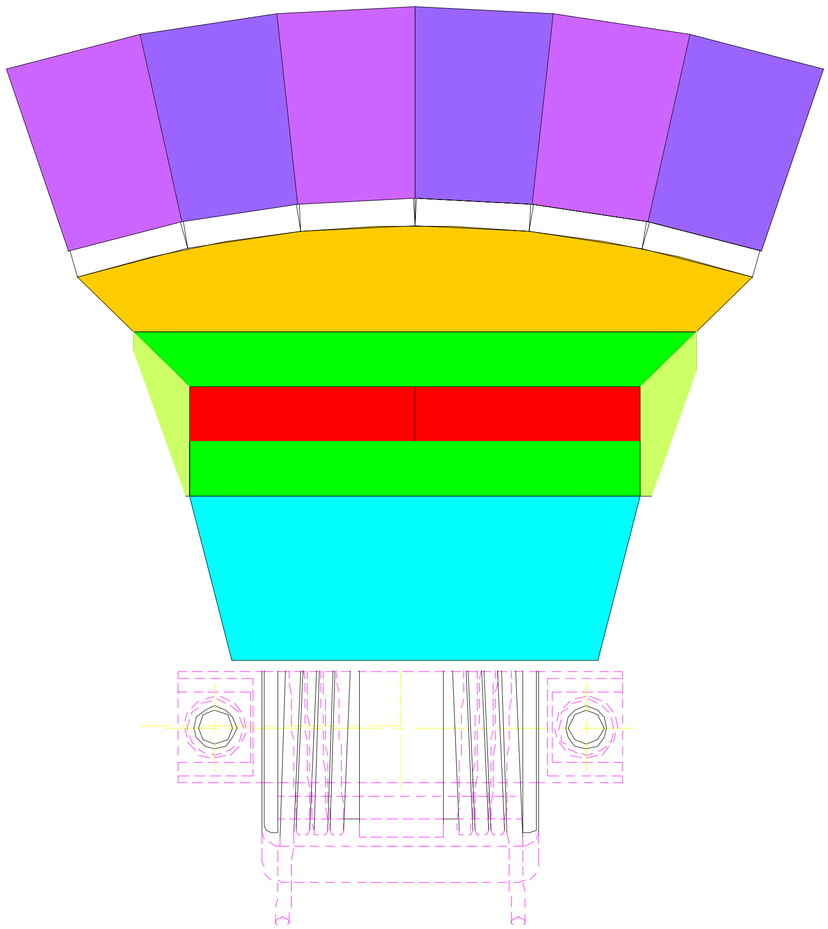


Improved Magnet Pole Piece

MFL TBV magnet design



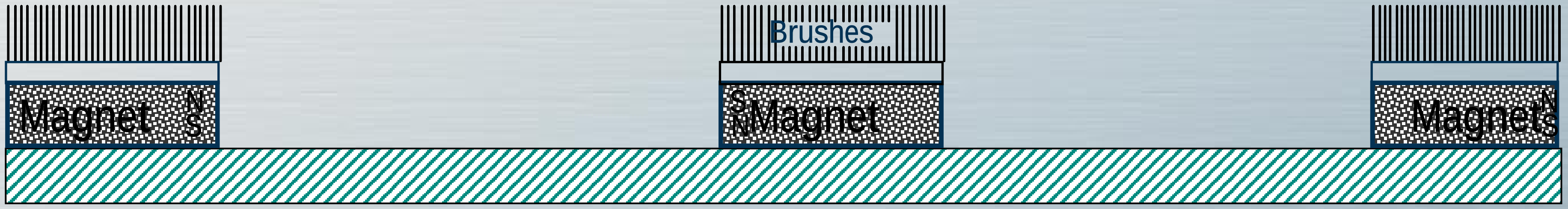
Dual Field Magnetizer magnet design

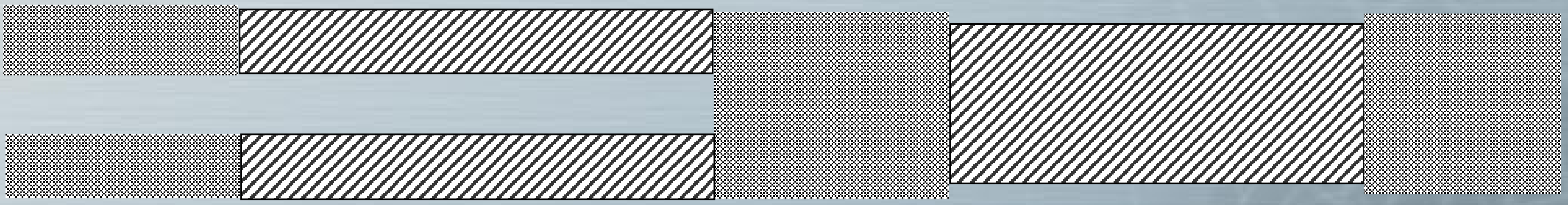


Reduced Magnetic Shorts

Split backing bar concept

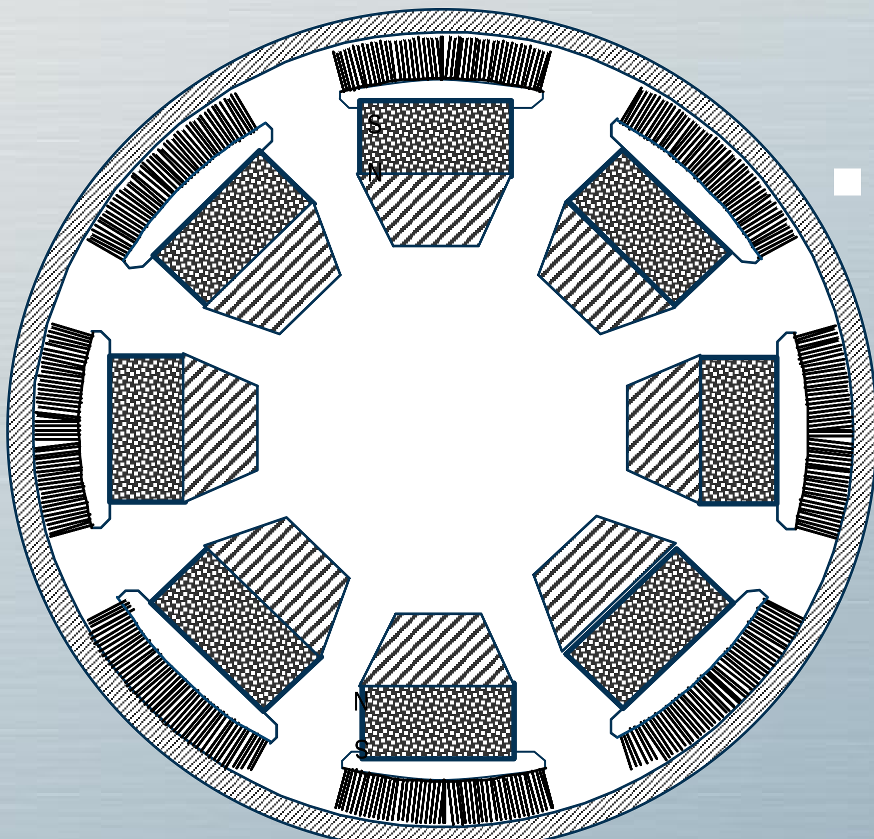
- A split low field backing bar attains appropriate field levels while increasing tool flexibility.

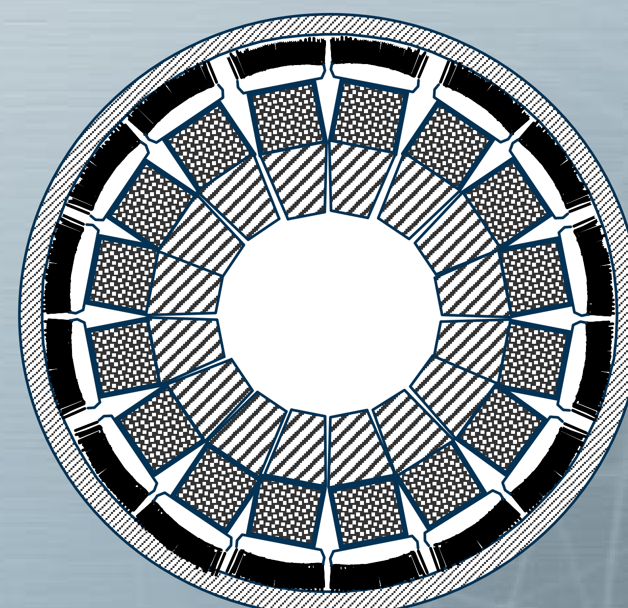




Split backing bar for improved collapse

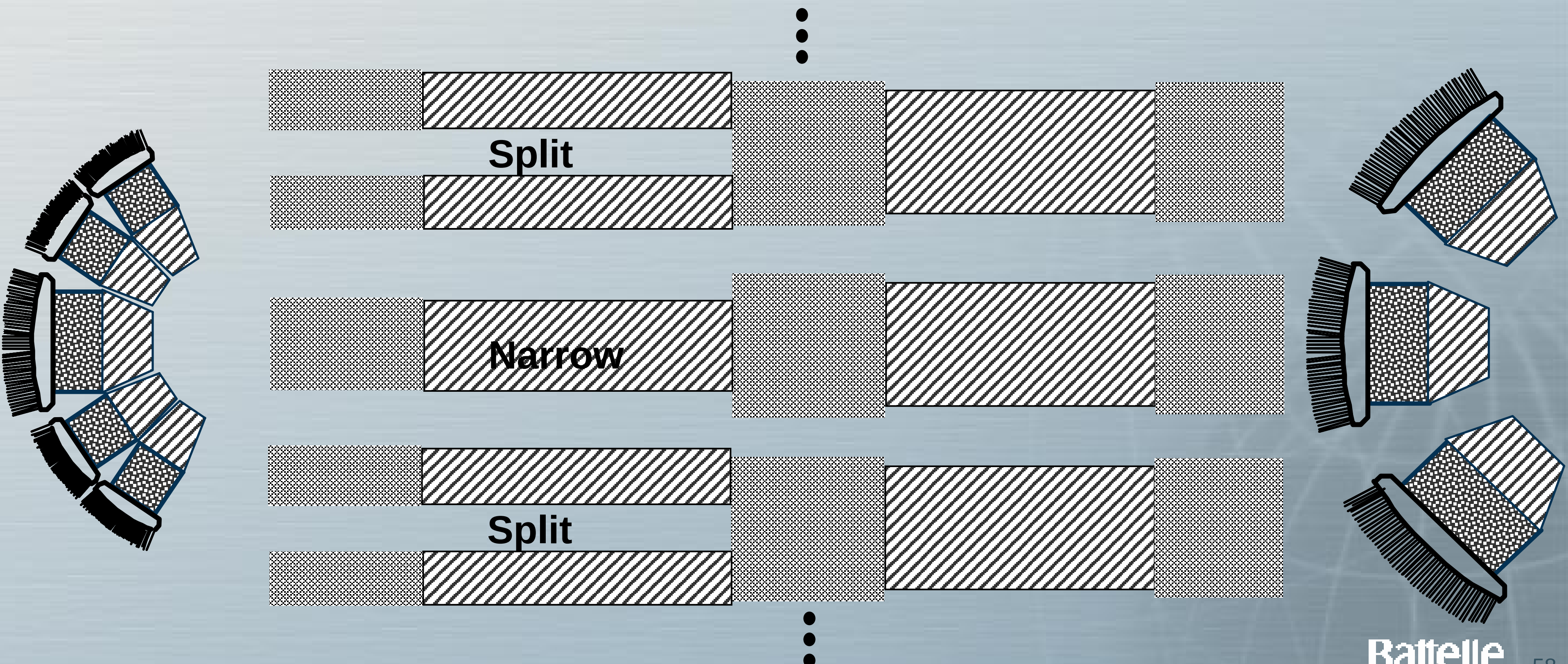
- Split backing bar collapses for the passage of obstructions such as a 30 percent diameter restriction as compared to a traditional MFL magnetizer capable of a 12 percent collapse.





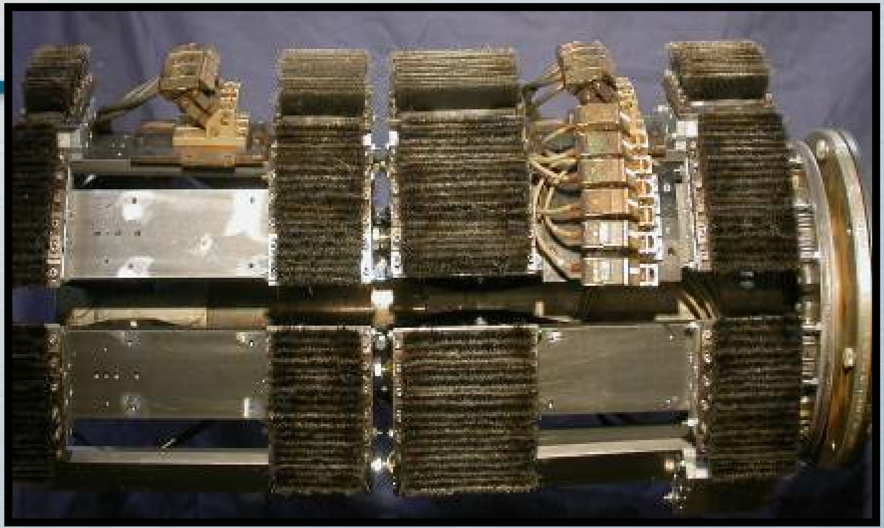
Backing bar combinations

- Combinations of split and standard (but narrow) backing bars can be used to attain optimal performance



Milestone 2 Summary

- Dual field tool fabricated in summer of 2004
- Includes deformation sensors



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Milestone 3: Defect Set Fabrication

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Stephanie Flamberg and Bob Gertler

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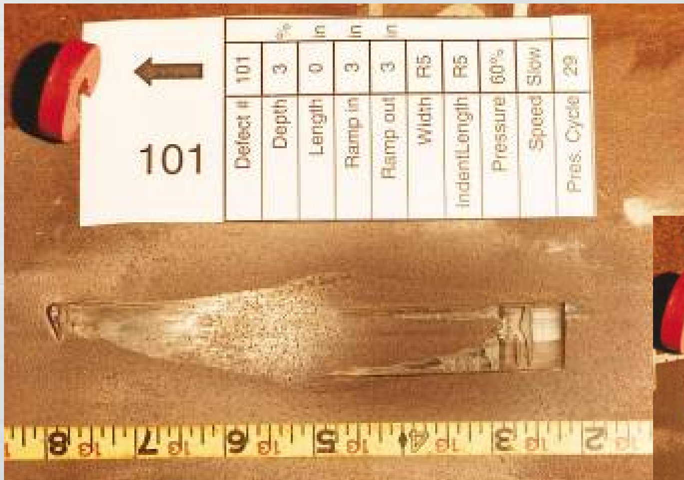
Milestone 3: Summary
Defect Set Fabrication

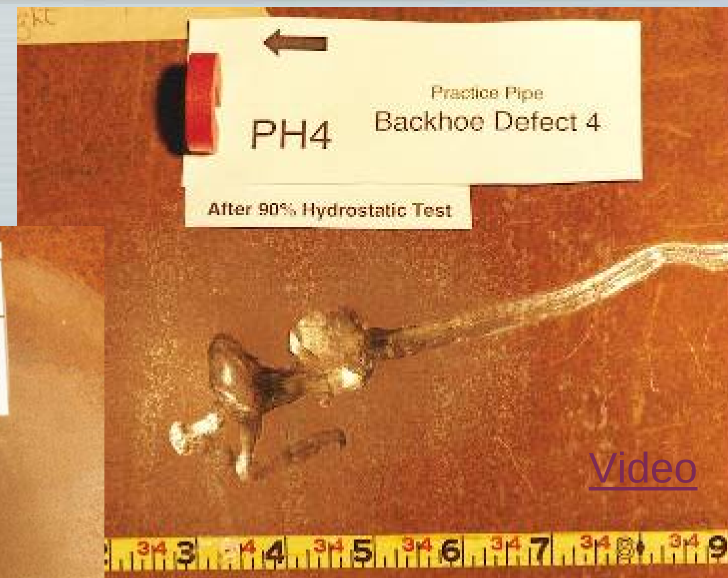
- Design and fabricate defect sets for pull rig and flow loop testing
- Augmented existing defect sets with
  - Multiple dents and gouges in close proximity
  - Dents and gouges in thicker pipe up to ½ inch wall
  - Track hoe made defects
- Total of 48 new mechanical damage defects
  - 34 produced with the Dent & Gouge machine
  - 14 produced with a track hoe
- Defects near failure were produced; one mechanical damage defect cracked during fabrication, leaked, but did not rupture. The crack closes when pressure drops below 150 psi

Existing Mechanical Damage Defect Set

- Consists of nearly a hundred defects
- Most are single defects produced using the Dent & Gouge machine
- Some defects made using a back hoe
- Range from 1% to 6% dent depth and 4” to 10” in length
- Pipe wall thickness 0.281”

Photos of Previous Defects



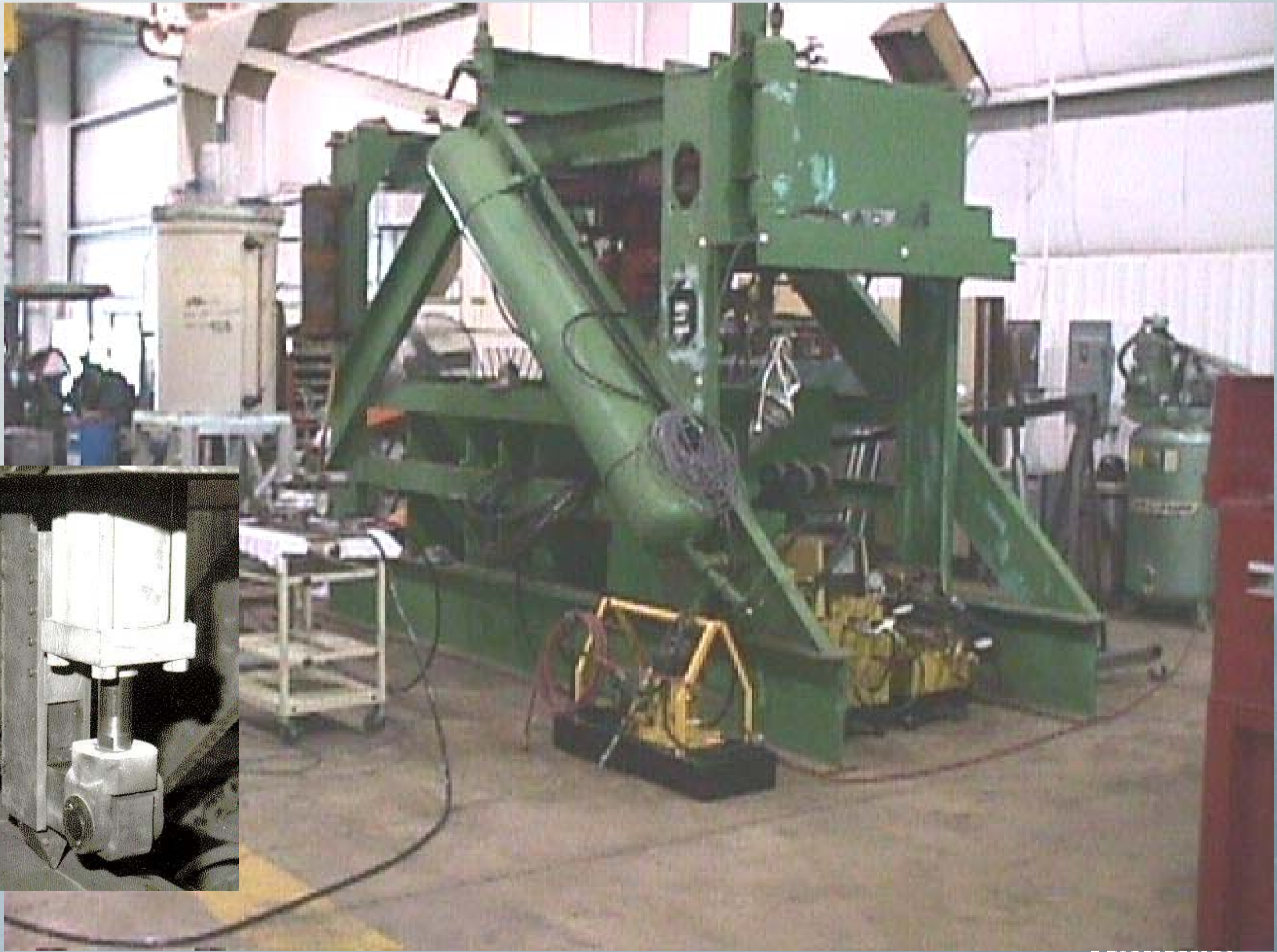


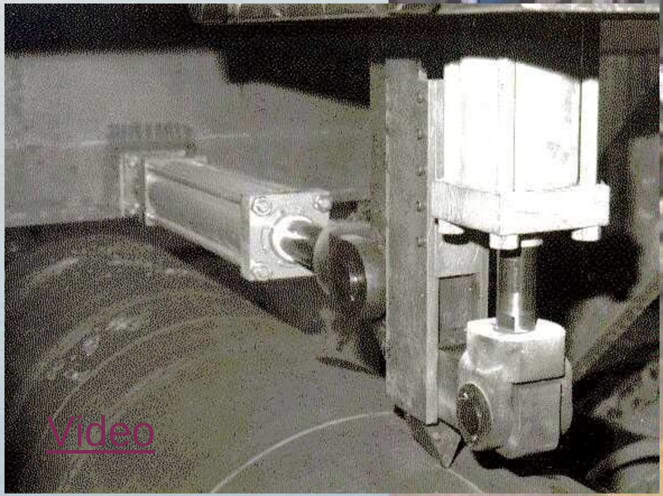
Video

Properties of New Pipe Samples

Property	P24-06	P24-28	P24-04	P24-07	P24-56
Diameter, in	24	24	24	24	24
Wall Thickness, in	**0.292**	**0.293**	**0.5**	**0.5**	**0.375**
Yield Stress	66 ksi	55 ksi	66 ksi	68 ksi	52 ksi
Ultimate Stress	84 ksi	73 ksi			
Toughness	22 ft-lbs	38 ft-lbs			
Remanent Mag	9,100 G	12,100 G			
Carbon	0.11%	0.23%			

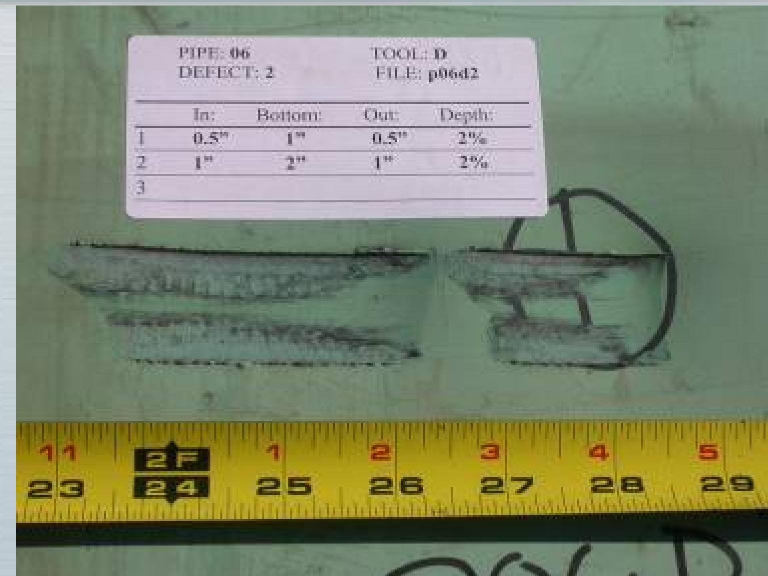
Dent & Gouge Machine





Video

Denting Tools



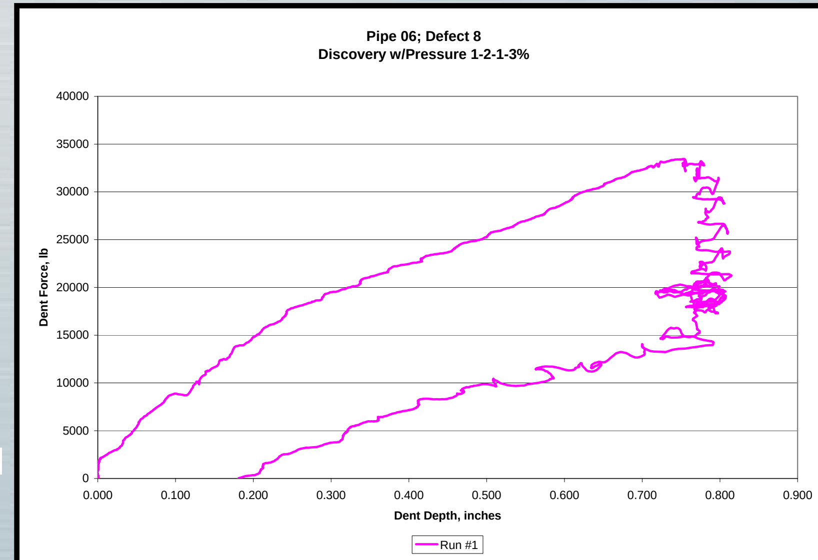
Mechanical Damage Defects Made – Thin Wall Pipe

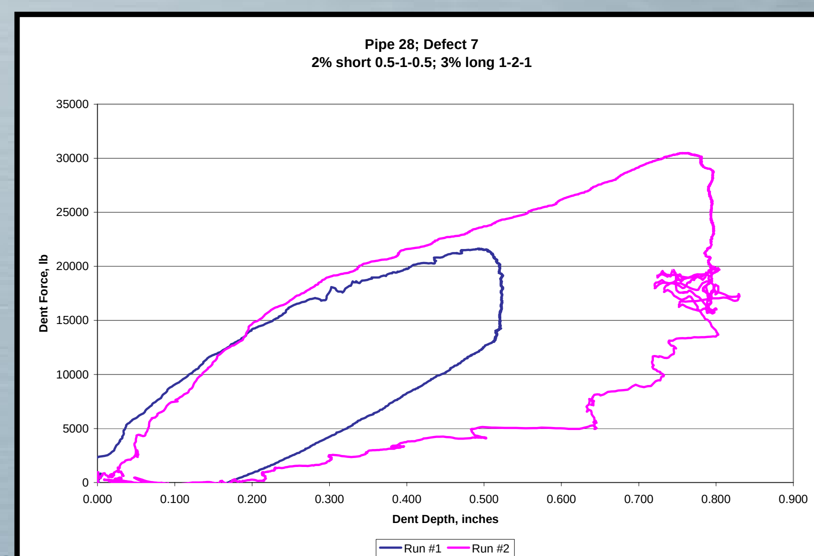
Defect	Description	Tool	Run #1				Gap	Run #2				Gap	Run #3			
PIPE 28			In	Bottom	Out	Depth		In	Bottom	Out	Depth		In	Bottom	Out	Depth
p28d2	Discovery w/Pressure	D	1”	2”	1”	3%										
p28d5	Deep Short Dent	D	0.5”	1”	0.5”	4%										
p28d8	3-Repeat	D	0.5”	1”	0.5”	2%	0”	0.5”	1”	0.5”	2%	0”	0.5”	1”	0.5”	2%
p28d11	Dot Dash	D	0.5”	1”	0.5”	2%	0”	1”	2”	1”	2%					
p28d14	Dash Dot	D	1”	2”	1”	2%	0”	0.5”	1”	0.5”	2%					
p28d1	3 Hits; 12” Total; Sharp	R	1”	2”	1”	1%	0”	1”	4”	1”	2%	0”	0.5”	1”	0.5”	1%
p28d4	3 Hits; 12” Total	D	1”	2”	1”	2%	0”	1”	4”	1”	2%	0”	0.5”	1”	0.5”	1%
p28d7	2% Short; 3% Long	D	0.5”	1”	0.5”	2%	0”	1”	2”	1”	3%					
p28d10	3 Hits with Gaps	D	0.5”	1”	0.5”	2%	1”	0.5”	1”	0.5”	2%	2”	0.5”	1”	0.5”	2%
p28d13	3 Hits 1%, 1%, 2%	D	0.5”	1”	0.5”	1%	0”	0.5”	1”	0.5”	1%	0”	0.5”	1”	0.5”	2%
Defect	**Description**	**Tool**	**Run #1**				**Gap**	**Run #2**				**Gap**	**Run #3**			
PIPE 06			In	Bottom	Out	Depth		In	Bottom	Out	Depth		In	Bottom	Out	Depth
p06d8	Discovery w/Pressure	D	1”	2”	1”	3%										
p06d5	3-Repeat	D	0.5”	1”	0.5”	2%	0”	0.5”	1”	0.5”	2%	0”	0.5”	1”	0.5”	2%
p06d2	Dot Dash	D	0.5”	1”	0.5”	2%	0”	1”	2”	1”	2%					
p06d9	3 Hits; 12” Total; Sharp	R	1”	2”	1”	1%	0”	1”	4”	1”	2%	0”	0.5”	1”	0.5”	1%
p06d6	3 Hits; 12” Total	D	1”	2”	1”	2%	0”	1”	4”	1”	2%	0”	0.5”	1”	0.5”	1%
p06d3	Dash Dot	D	1”	2”	1”	2%	0”	0.5”	1”	0.5”	2%					

Mechanical Damage Defects Made – Thick Wall Pipe

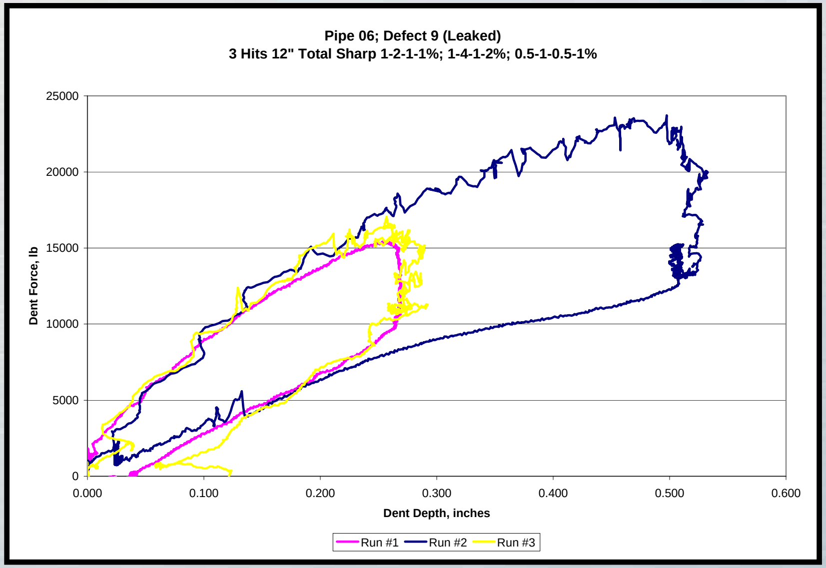
Defect	Description	Tool	Run #1				Gap	Run #2				Gap	Run #3			
PIPE 04			In	Bottom	Out	Depth		In	Bottom	Out	Depth		In	Bottom	Out	Depth
p04d05	3-1%, 1%, 2%	D	0.5	1	0.5	1%		0.5	1	0.5	1%		0.5	1	0.5	2%
p04d08	Dot dash	D	0.5	1	0.5	2%		1	2	1	2%					
p04d09	3-12” total, sharp	R	1	2	1	1%	0”	1	4	1	2%	0”	0.5	1	0.5	1%
p04d11	Dash dot	D	1	2	1	2%	0”	0.5	1	0.5	2%					
Defect	**Description**	**Tool**	**Run #1**				**Gap**	**Run #2**				**Gap**	**Run #3**			
PIPE 07			In	Bottom	Out	Depth		In	Bottom	Out	Depth		In	Bottom	Out	Depth
p07d12	Dash dot	D	1	2	1	2%	0”	0.5	1	0.5	2%					
p07d14	3-1%, 1%, 2%	D	0.5	1	0.5	1%	0”	0.5	1	0.5	1%	0”	0.5	1	0.5	2%
p07d15	3-12” total	D	1	2	1	2%	0”	1	4	1	2%	0”	0.5	1	0.5	1%
p07d17	Dot dash	D	0.5	1	0.5	2%	0”	1	2	1	2%					
p07d18	3-12” total, sharp	R	1	2	1	1%	1”	1	4	1	2%	2”	0.5	1	0.5	1%
Defect	**Description**	**Tool**	**Run #1**				**Gap**	**Run #2**				**Gap**	**Run #3**			
PIPE 56			In	Bottom	Out	Depth		In	Bottom	Out	Depth		In	Bottom	Out	Depth
p56d21	3-1%, 1%, 2%	D	0.5	1	0.5	1%		0.5	1	0.5	1%		0.5	1	0.5	2%
p56d23	3-12” total, sharp	R	1	2	1	1%	0”	1	4	1	2%	0”	0.5	1	0.5	1%
p56d24	Dot dash	D	0.5	1	0.5	2%	0”	1	2	1	2%					
p56d26	3-12” total, sharp	R	1	2	1	1%		1	4	1	2%		0.5	1	0.5	1%
p56d27	Dash dot	D	1	2	1	2%		0.5	1	0.5	2%					
p56d29	3-12” total	D	1	2	1	2%		1	4	1	2%		0.5	1	0.5	1%
p56d30	2% short, 3% long	D	0.5	1	0.5	2%	0”	1	2	1	3%	0”	0.5”	1”	0.5”	1%
p56d32	3 with gaps	D	0.5	1	0.5	2%	1	0.5	1	0.5	2%	2	0.5	1	0.5	2%
p56d33	Discovery with press.	D	1	2	1	3%	0”	0.5”	1”	0.5”	2%					

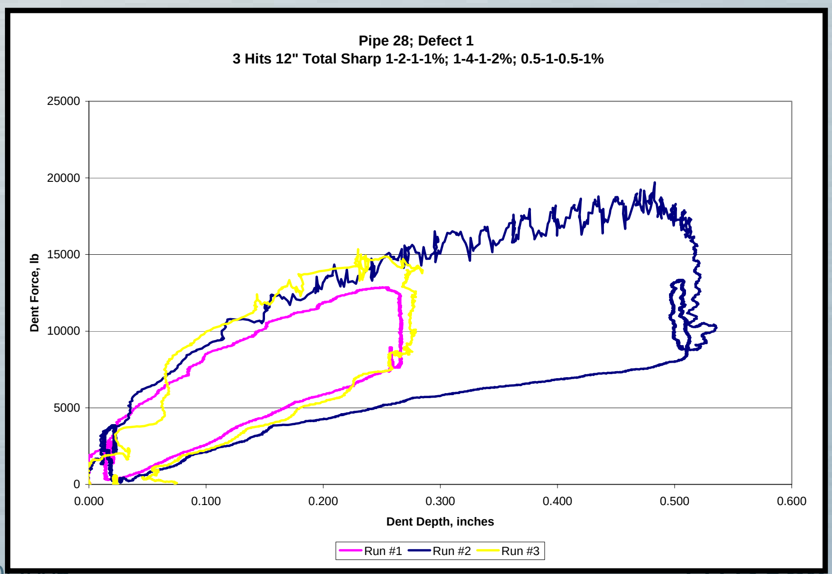
Load Displacement Measured



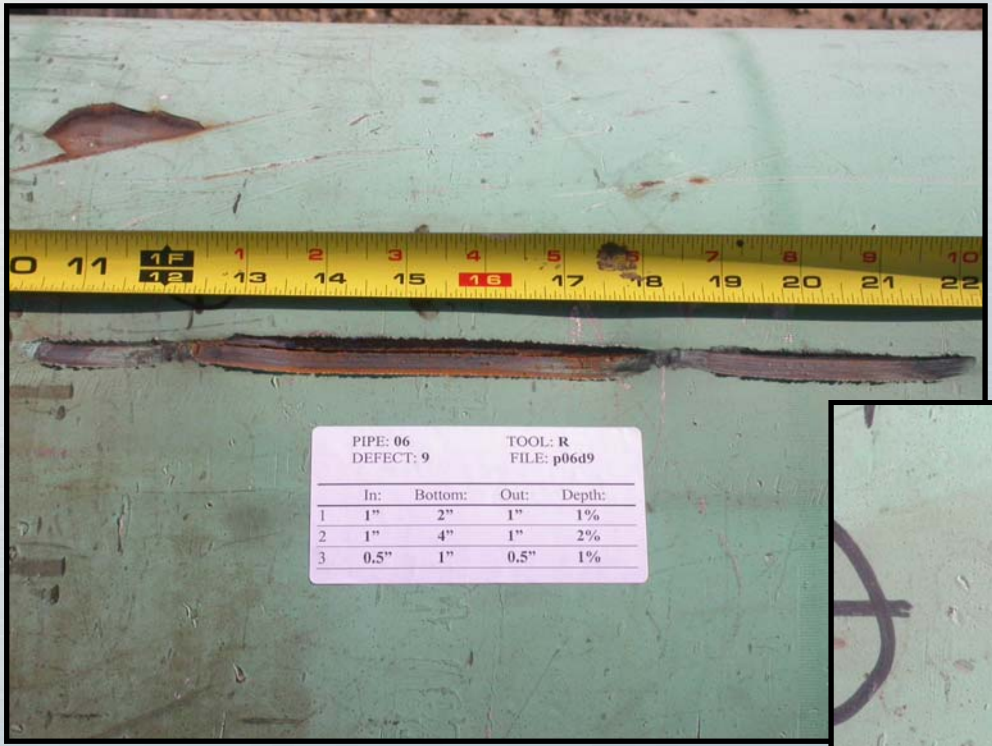


Load Displacement Measured (cont.)





Defect Near Failure



Track Hoe Defects

Video

Video

Mechanical Damage Defects Made – Thin Wall Pipe Track Hoe

PIPE 24-28, Internal Pressure of 200 psig													
Defect	Description	Tool	Number of Strikes	Strike Direction	Bucket Tooth Position	Dent Depth Range (inches)						Dent Length , in.	Comments
p28dTH1	Parallel, direct	TH	3	parallel	direct	0.62		0.59		0.58		29	
p28dTH2	Parallel, straddle	TH	3	parallel	straddle	0.51	0.35	0.60	0.29	0.60	0.28	26	
p28dTH4	Transverse, direct	TH	2	transverse	direct	0.32		0.25		0.10		27	
PIPE 24-06, Internal Pressure of 200 psig													
Defect	Description	Tool	Number of Strikes	Strike Direction	Bucket Tooth Position	Dent Depth Range (inches)						Dent Length , in.	Comments
p06dTH1	Parallel, direct	TH	3	parallel	direct	0.51		0.52		0.50		20	
p06dTH2	Parallel, straddle	TH	3	parallel	straddle	0.30	0.30	0.24	0.41	0.20	0.40	18	
p06dTH3	Transverse, direct	TH	1	transverse	direct	0.20			0.11			8	

Mechanical Damage Defects Made – Thick Wall Pipe Track Hoe

Defect	Description	Tool	Number of Strikes	Strike Direction	Bucket Tooth Position	Dent Depth Range (inches)						Dent Length, in.	Comments
PIPE 24-04, Internal Pressure of 200 psig													
p04dTH1	Parallel, direct	TH	3	parallel	direct	0.10						Min.	
p04dTH2	Parallel, straddle	TH	3	parallel	straddle	0.12		0.13		0.17		Min.	Track Hoe scraped and dragged on the 2nd hit.
PIPE 24-07, Internal Pressure of 200 psig													
p07dTH1	Parallel, direct	TH	3	parallel	direct	0.12		0.11		0.17		27	
p07dTH2	Parallel, straddle	TH	3	parallel	straddle	0.18	0.15	0.08	0.08	0.11	-	Min.	Track Hoe scraped and dragged slightly on the 3rd hit.
PIPE 24-56, Internal Pressure of 200 psig													
p56dTH1	Parallel, direct	TH	2	parallel	direct	0.22			0.28			23	
p56dTH2	Parallel, straddle	TH	3	parallel	straddle	0.12	0.10	0.10	0.10	0.10	0.11	15	
p56dTH3	Parallel, direct, scrape & drag	TH	2	parallel	direct	0.48			0.31			29	Track Hoe scraped and dragged on the 2nd hit
p56dTH4	Transverse, direct	TH	2	transverse	direct	0.12			0.11			21	

Track Hoe Defects (cont.)
Thin Wall Pipe


Parallel, teeth straddle pipe

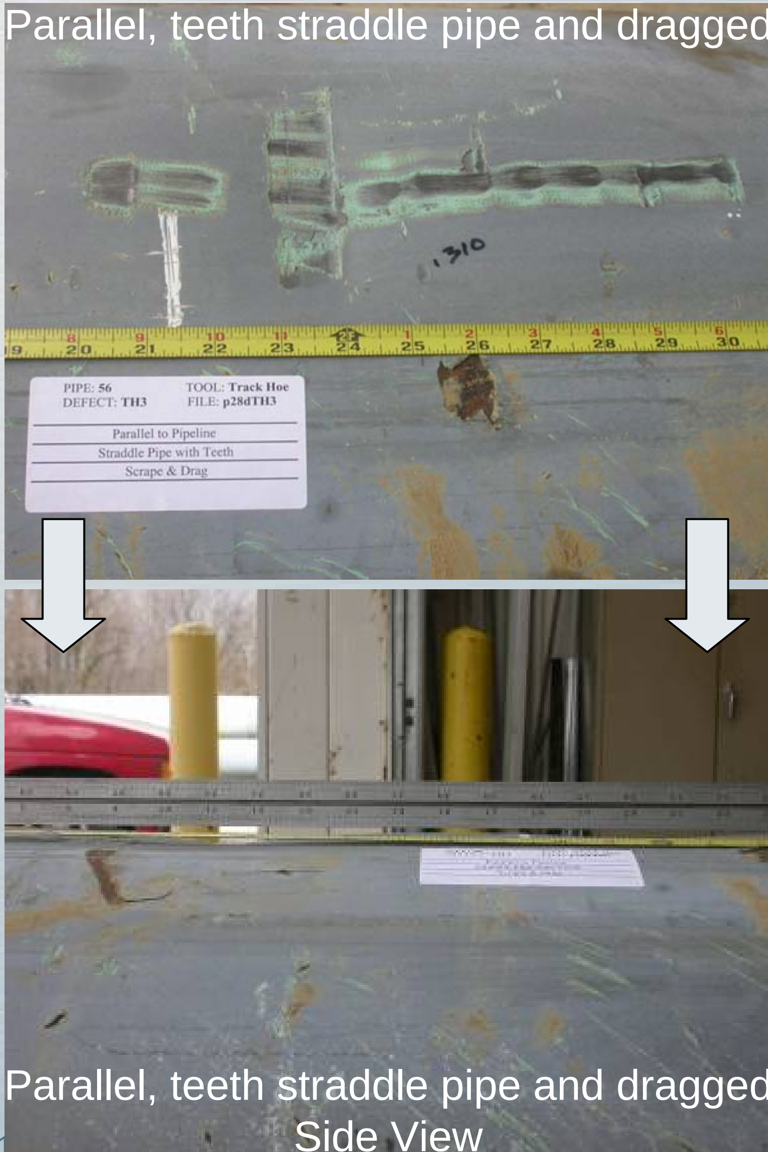

Track Hoe transverse to pipe


Parallel, teeth straddle pipe
Side View


Parallel, teeth direct impact on pipe

Track Hoe Defects (cont.)
Thick Wall Pipe

Parallel, teeth straddle pipe and dragged

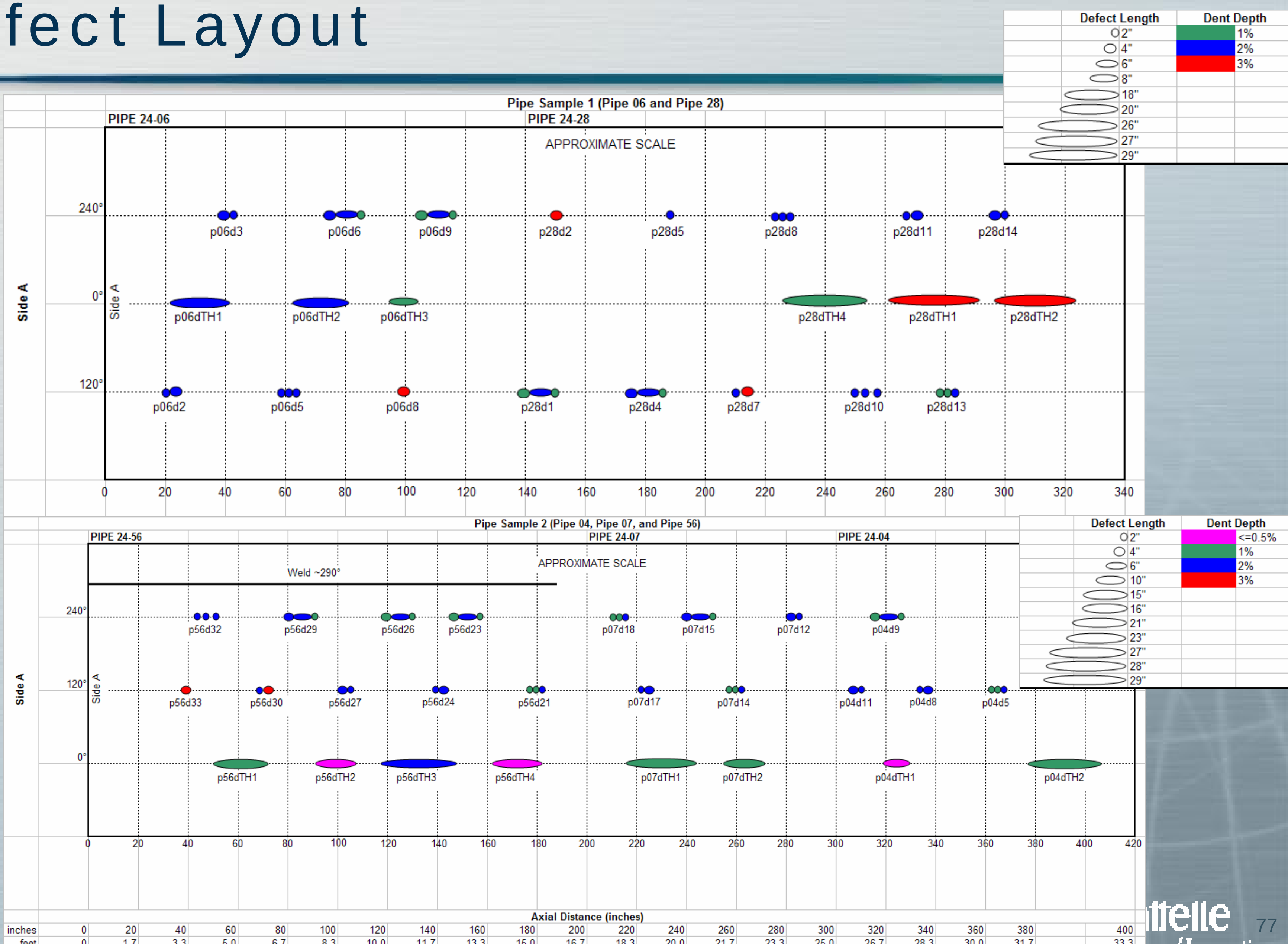


Parallel, teeth straddle pipe and dragged
Side View

Parallel, teeth direct impact on pipe

Parallel, teeth direct impact on pipe
Side View

Defect Layout



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Milestone 4: Data Collection using Dual Mag MFL Tool

Bruce Nestleroth, Jim Bergner and Bob Gertler

Mechanical Damage Inspection

Using MFL Technology

Milestone 4: Data Collection using Dual Mag MFL Tool

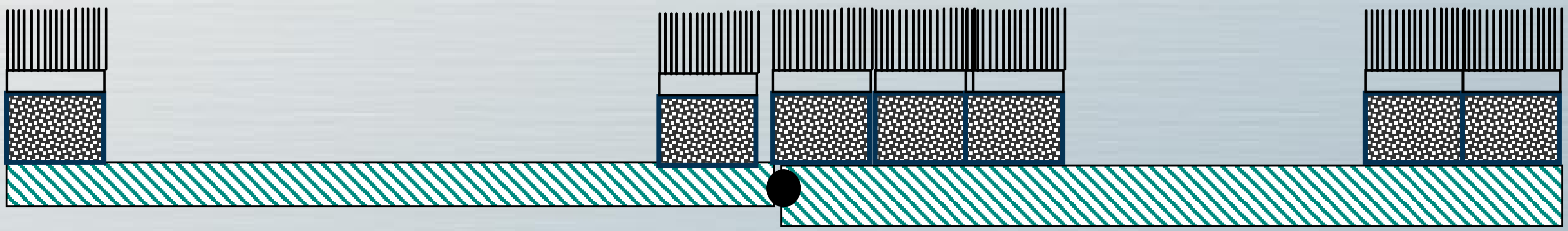
- Pipe samples
  - 160 feet of pipe with mechanical damage fabricated in previous projects. Over 100 anomaly sites, 4 pipe types
    - 80 feet of pipe with mechanical damage anomalies in 5 pipe samples made with the dent and gouge machine and a track hoe.
    - 80 feet of pipe with over 100 metal loss anomalies
- Inspection variables
  - Velocity
  - Pressure

Pull Rig

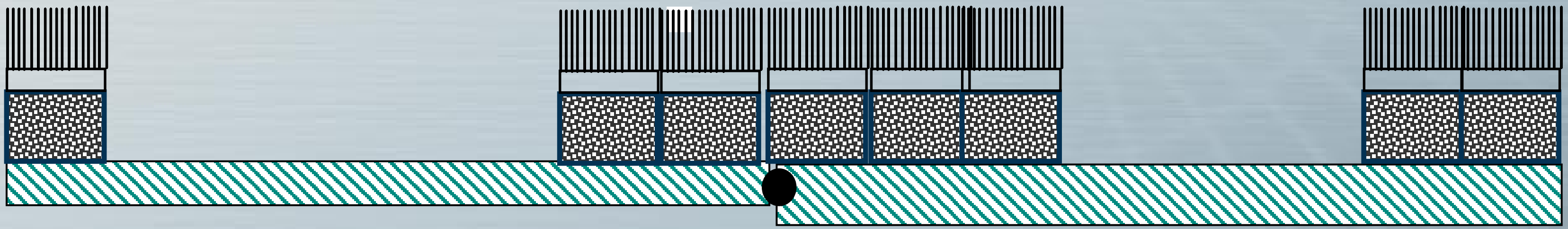
- Full scale studies under controlled conditions (unpressurized)
- Bridges gap between lab test and applications in the flow loop (or operating pipelines)
- Consists of:
  - Four 300-foot pipe lengths with removable defect sections (12”, 24”, 30”, and 36” diameter)
  - Metal-loss, mechanical damage, and SCC defect sets available
  - Pulling speeds up to 25 mph
  - Pull forces up to 56,000 pounds

Tool Configurability

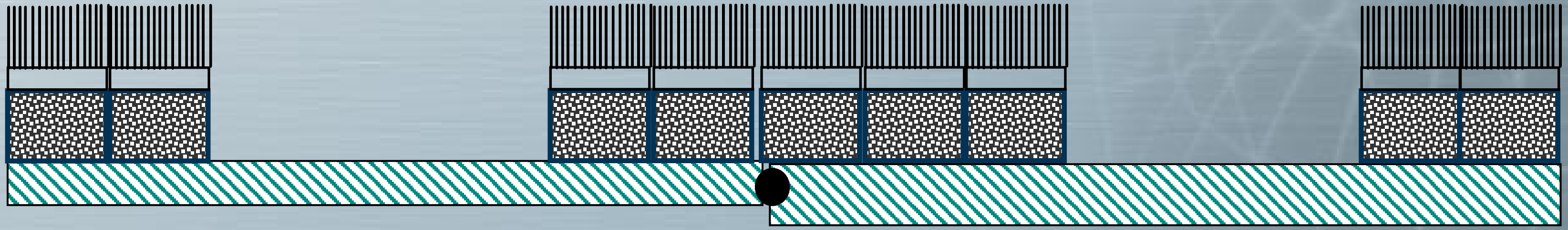
- Wall thickness < 0.325



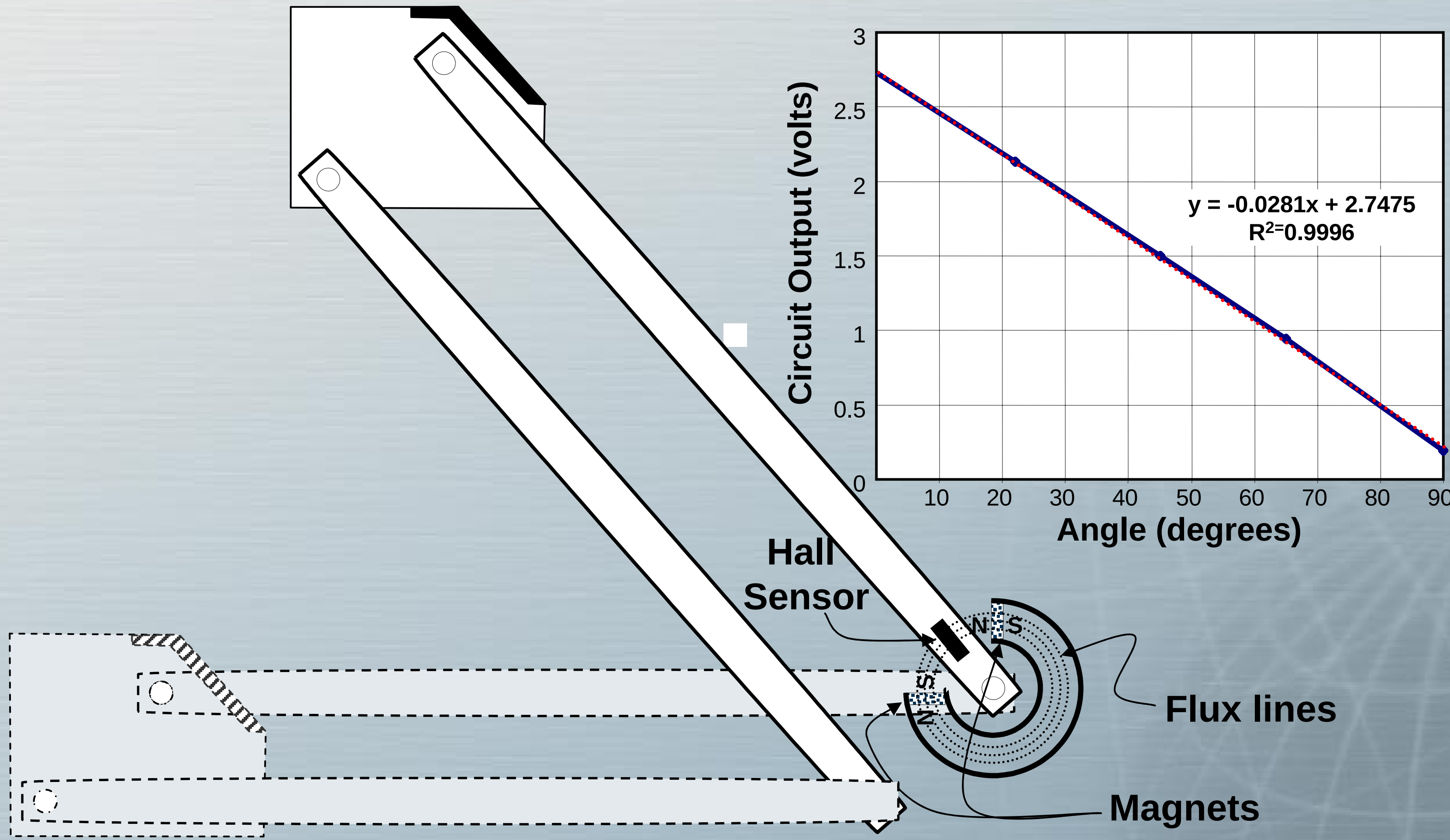
- Wall thickness 0.325 – 0.400



- Wall thickness 0.400 – 0.500

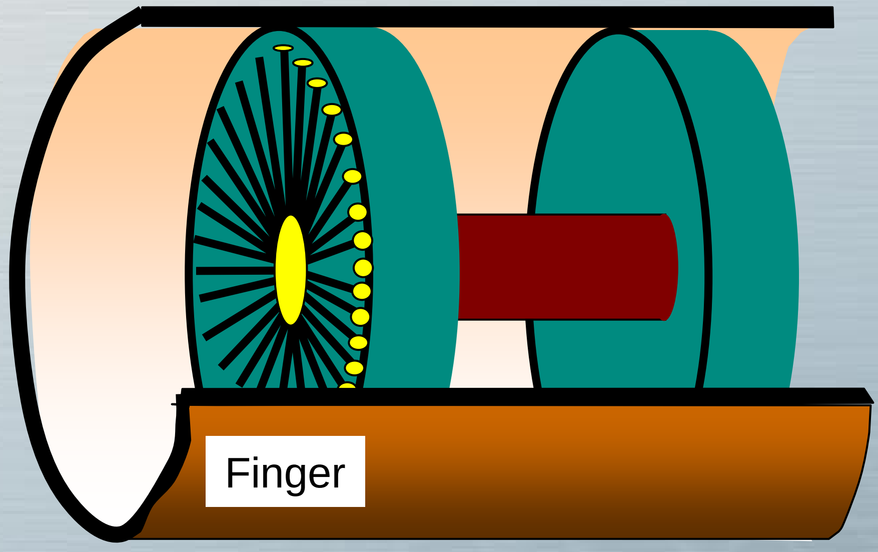


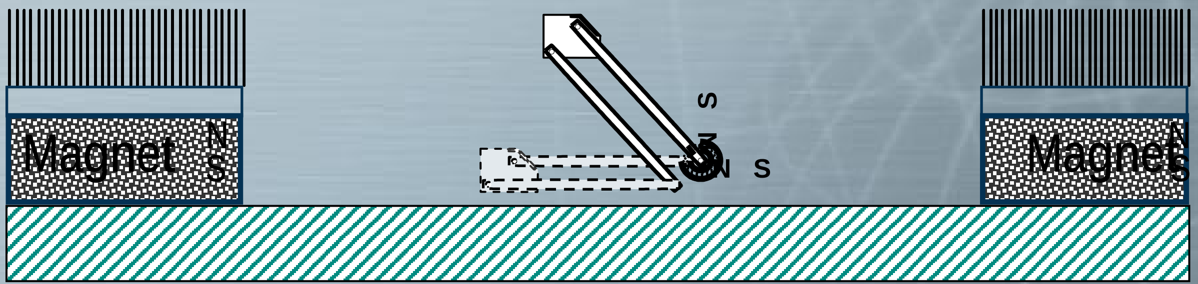
Deformation



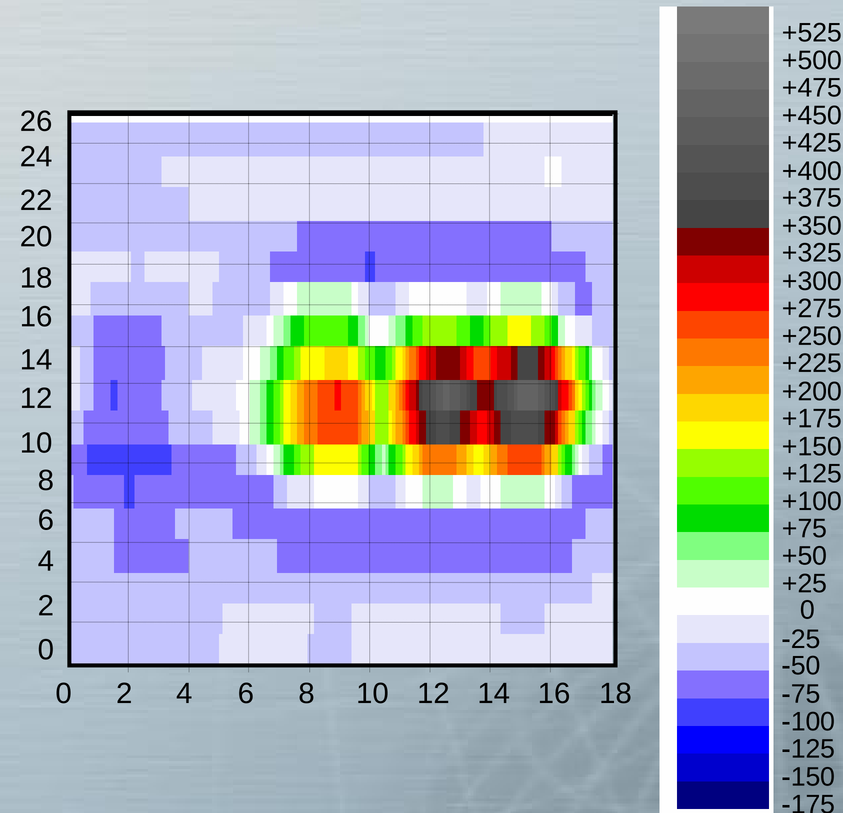
Caliper measurement comparison

	Other Dents	Ovality
Finger	Handles well	Ovality must be removed
Magnetizer	Errors if brush is on 2^{nd} dent	Handles well

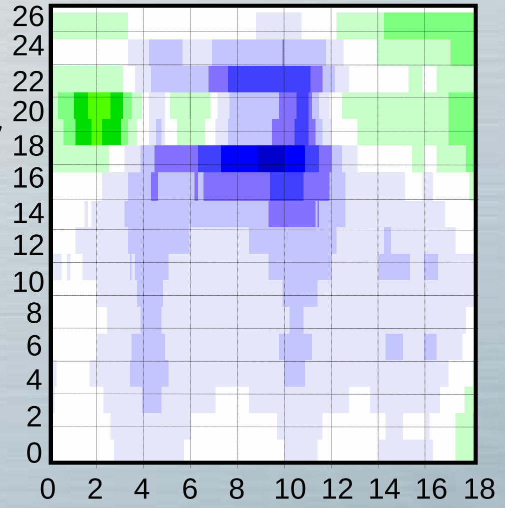


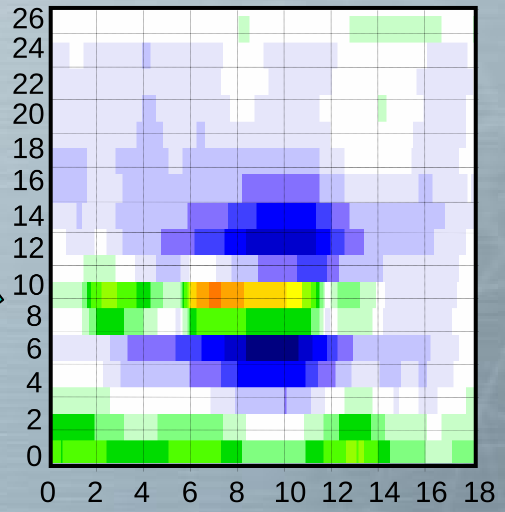


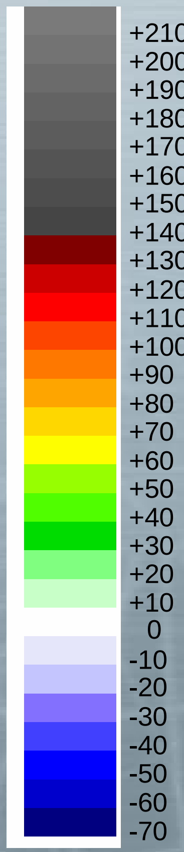
Deformation Data
Track Hoe



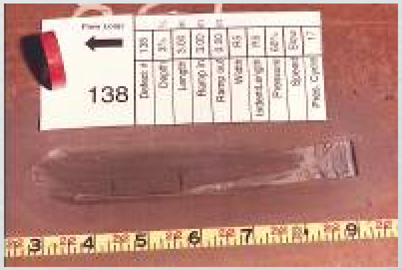
Deformation Data
Cracked Defect





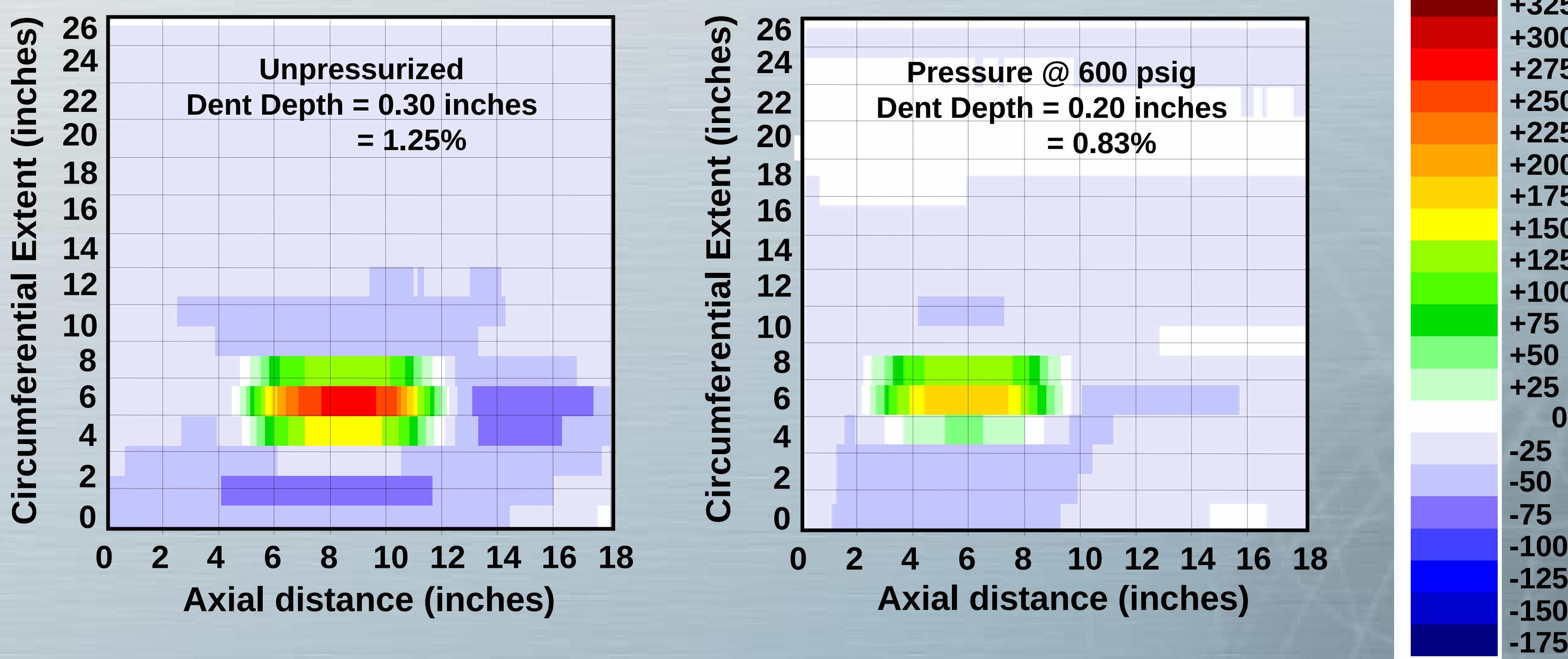


Pressure changes dent depth



Design Dimensions

- **0.72 inch (3%) deep**
- **6 inch long**



Milestone 4 Summary
Data Collection

- 29 pulls using the pill rig
  - Mostly at 2 mph
  - 6 at 5+ mph
- 6 pulls (3 high/3 low pressure) at the flow loop
- Thousand of defect files produceded
  - Deformation
  - Magentic flux leakage
- Some gouges significantly reround when stresses of 50 percent SMYS

Milestone 5: Data Analysis

Bruce Nestleroth and
Stephanie Flamberg

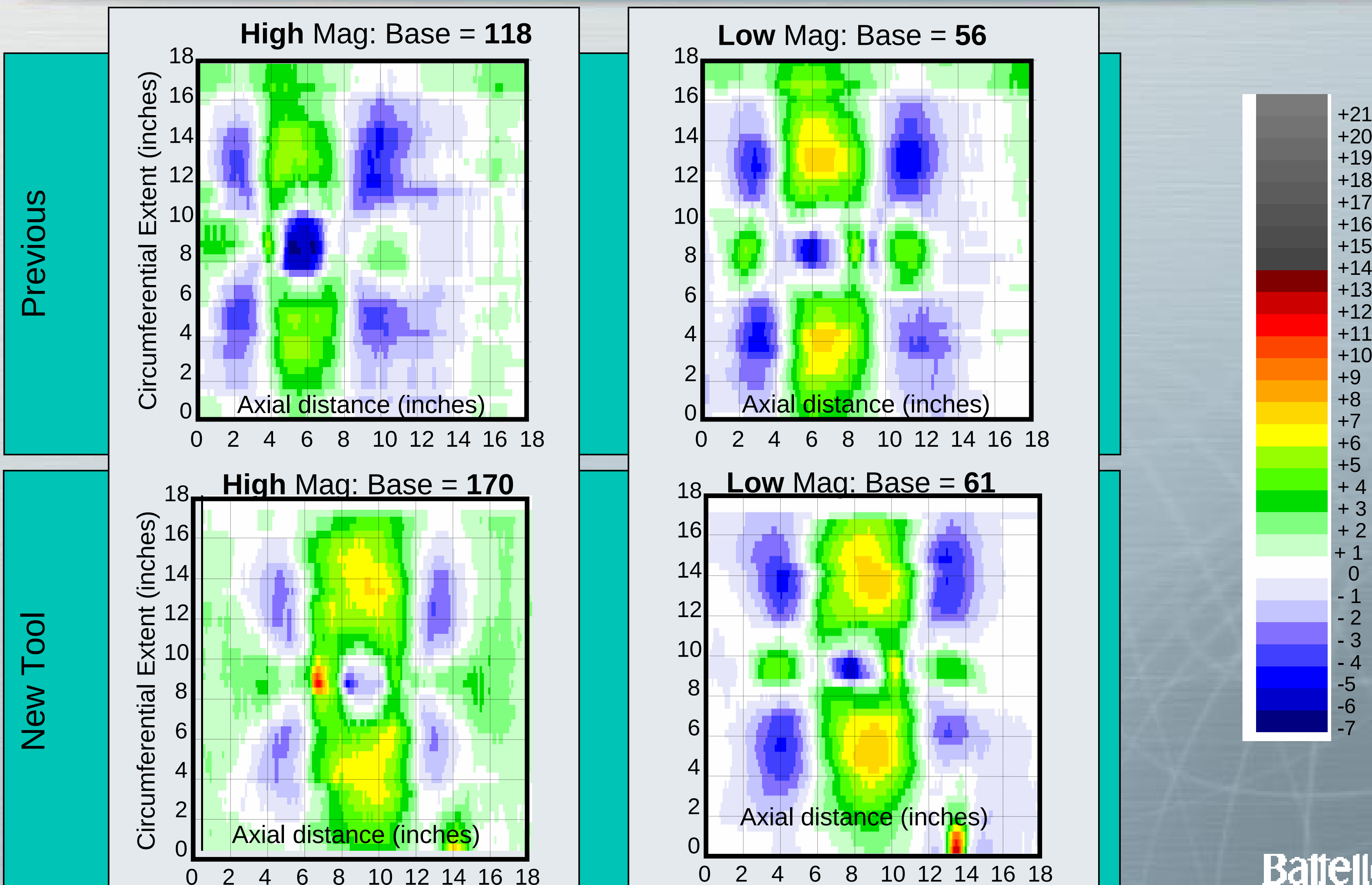
Mechanical Damage Inspection

Using MFL Technology

Milestone 5: Data Analysis

- Data from the dual field level MFL tool was analyzed and compared with those of the previous two magnetizer approach.
- Used decoupling analysis methods for detecting re-rounding and gouging.
  - Previous vs New Tool
  - Velocity Effects
  - Noisy Pipe Material
  - Cracked Mechanical Damage
  - Mechanical Damage made with a Track Hoe
  - Pressure effects

Previous vs New Tool – High and Low



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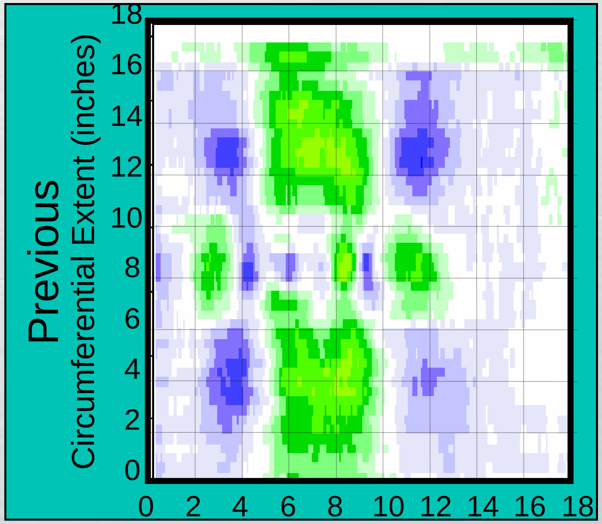
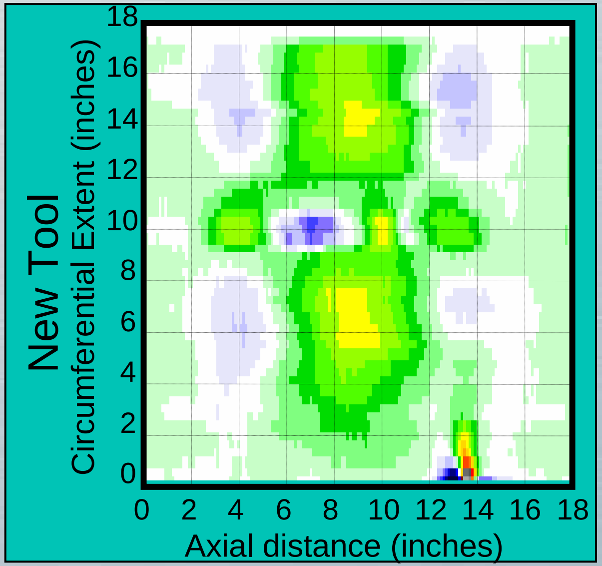
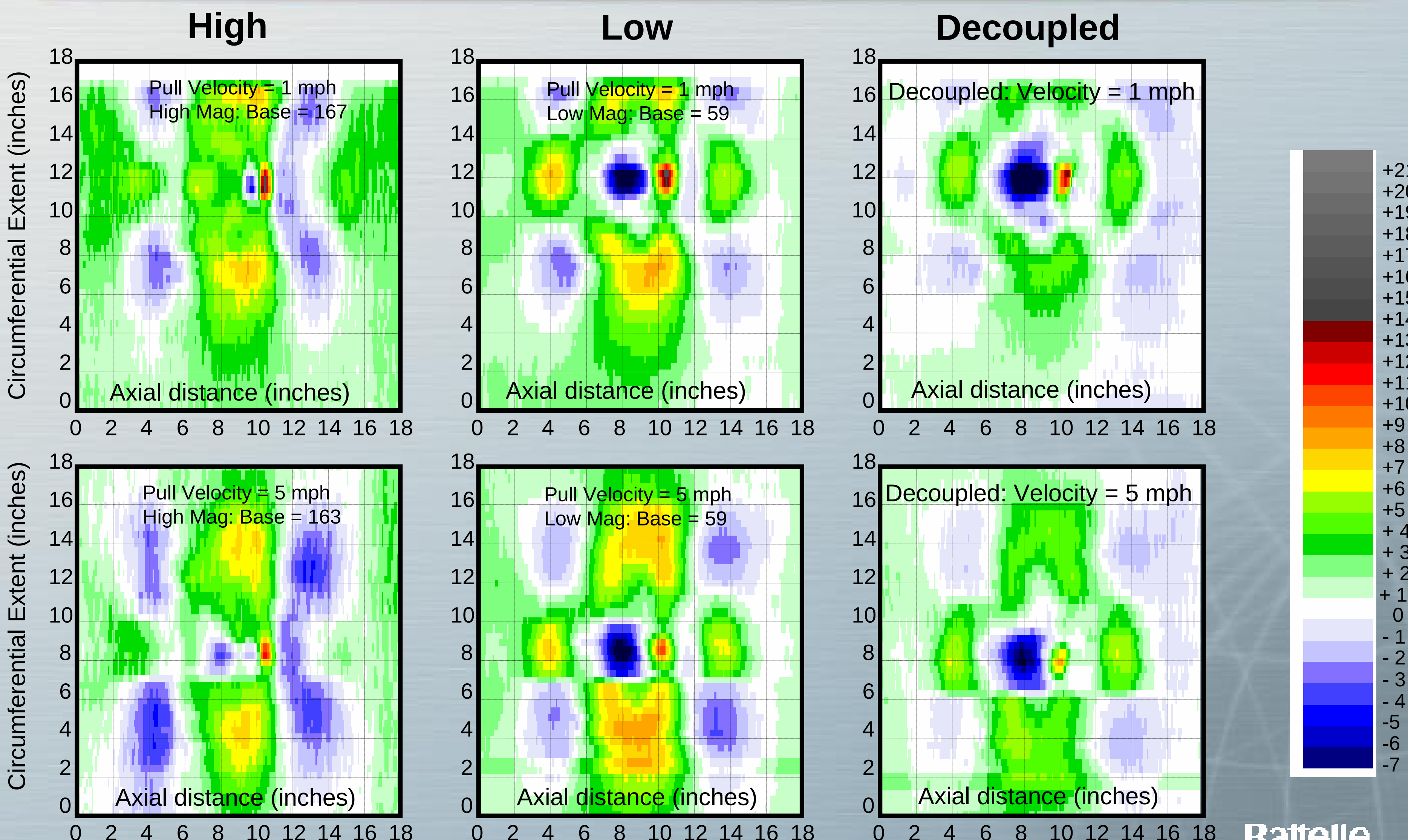
Previous vs New Tool - Decoupled





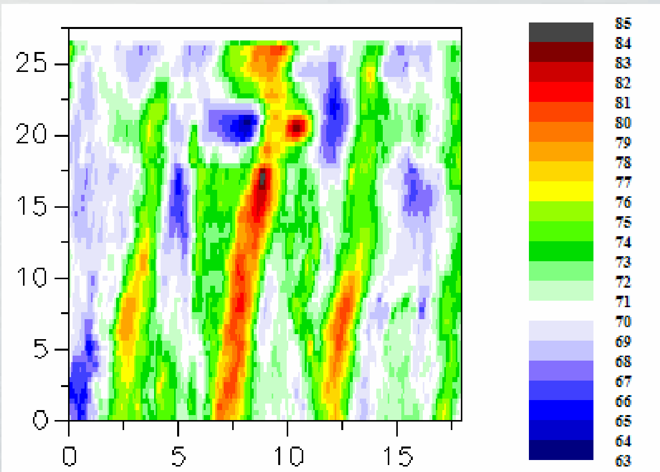
- More appropriate high field
- Nearly identical low field
- Clearer decoupled signal from improved high field

Velocity effects (1 and 5 mph)

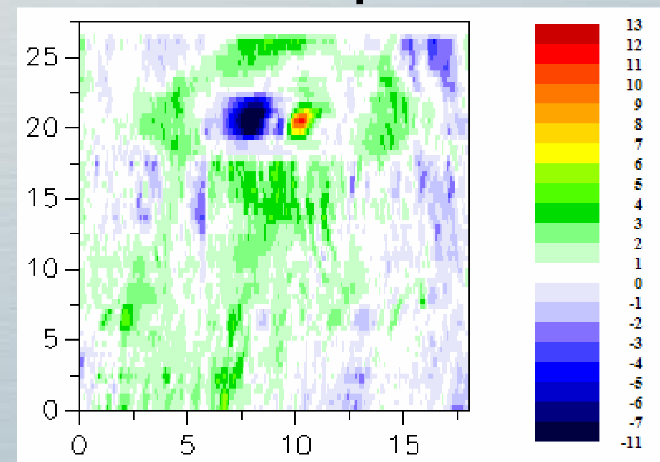


Noisy Pipe Material 1

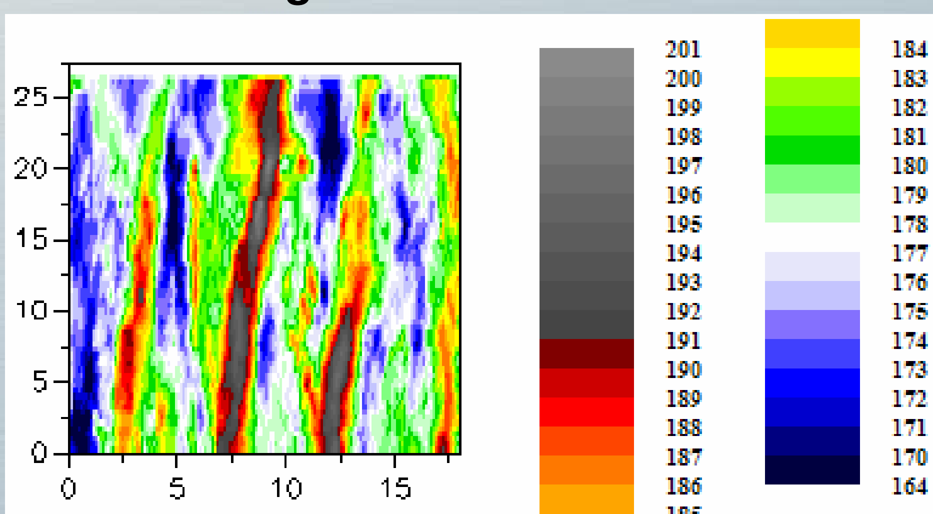
Low



Decoupled

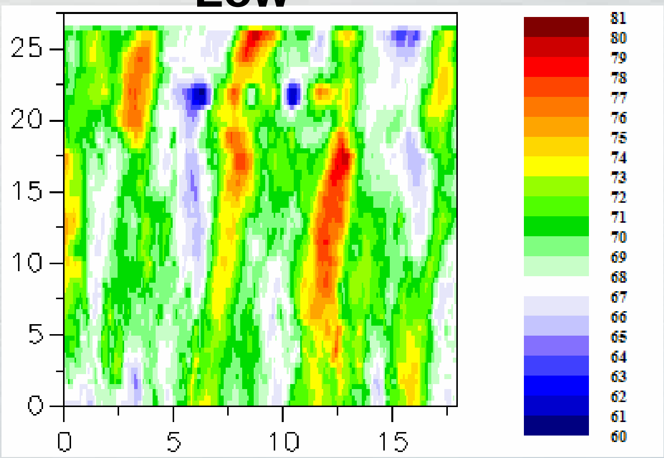


High

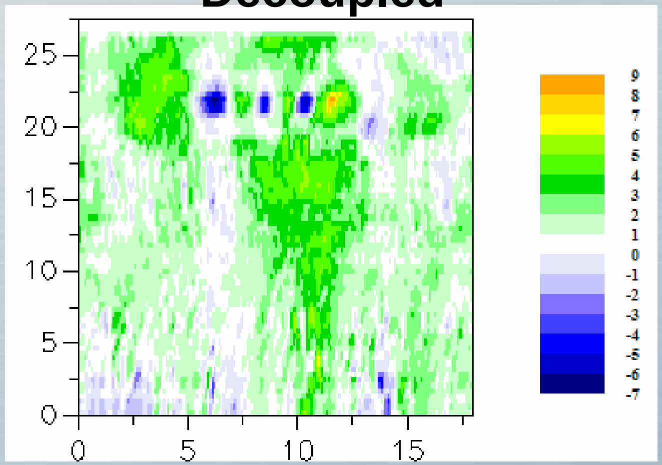


Noisy Pipe Material 2

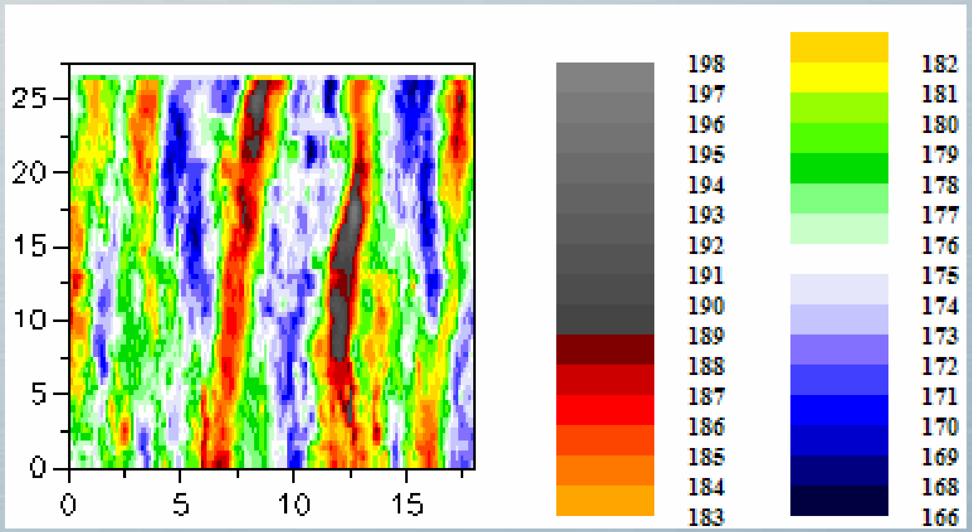
Low



Decoupled

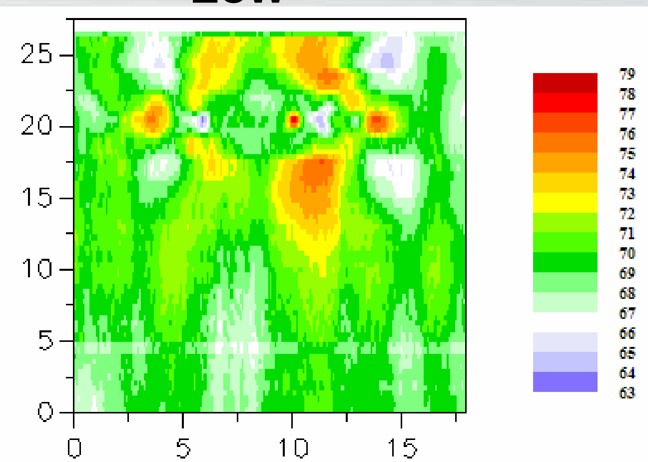


High

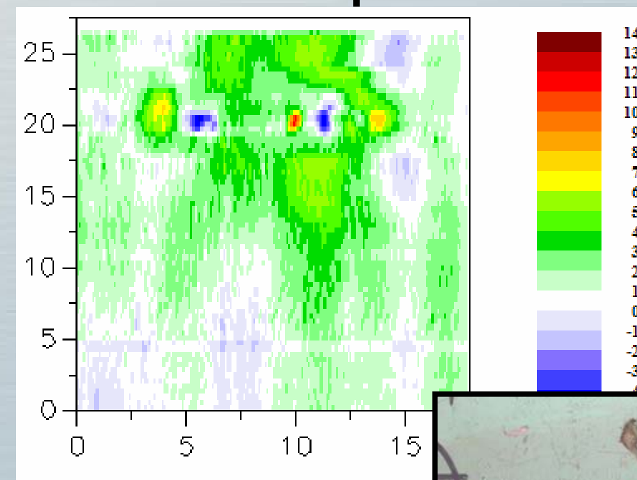


Cracked Mechanical Damage

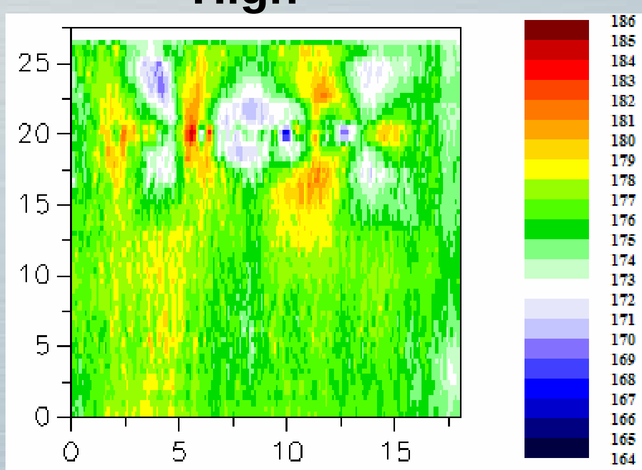
Low



Decoupled

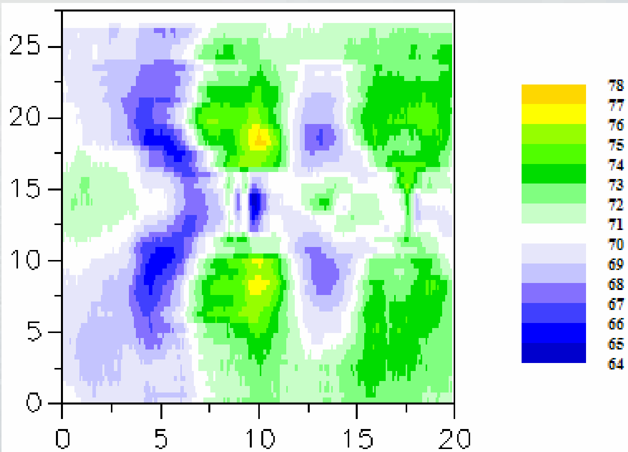


High

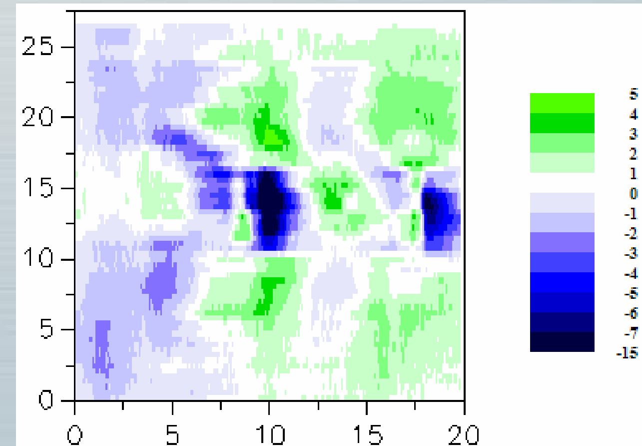


Track Hoe 1

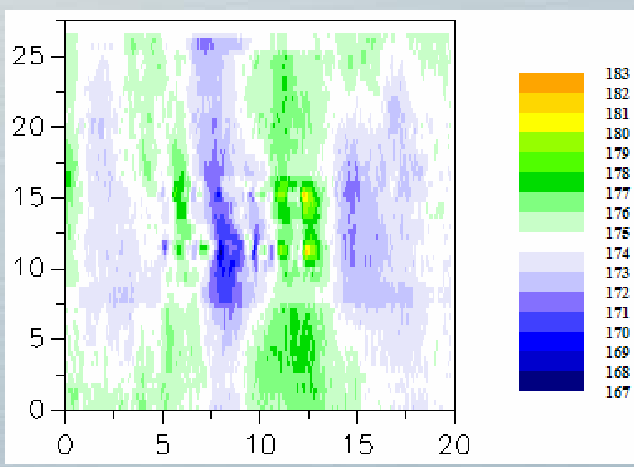
Low



Decoupled

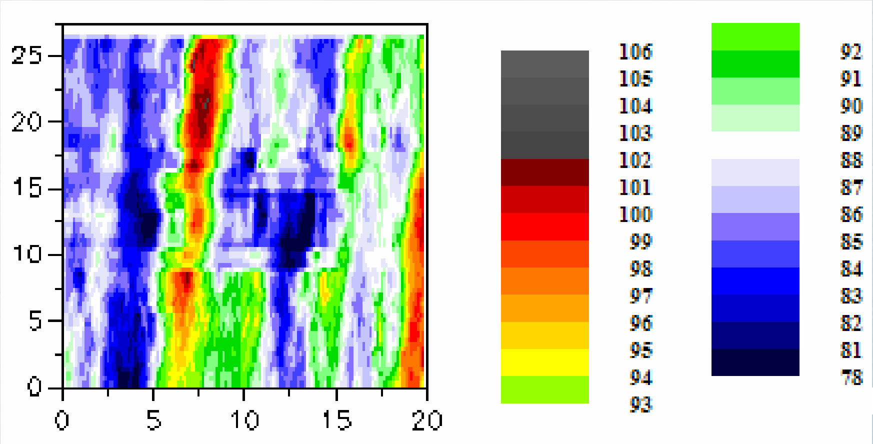


High

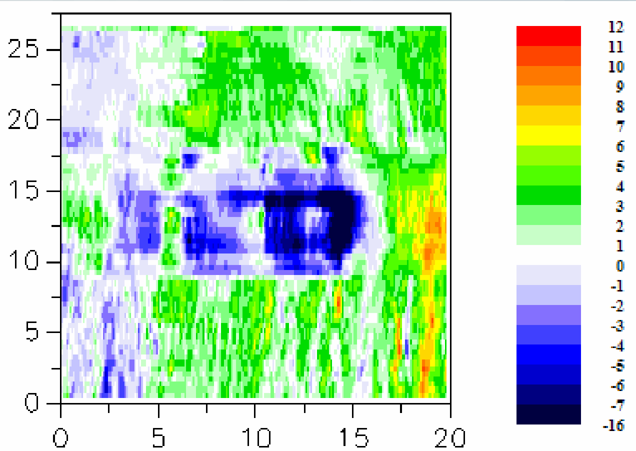


Track Hoe 2

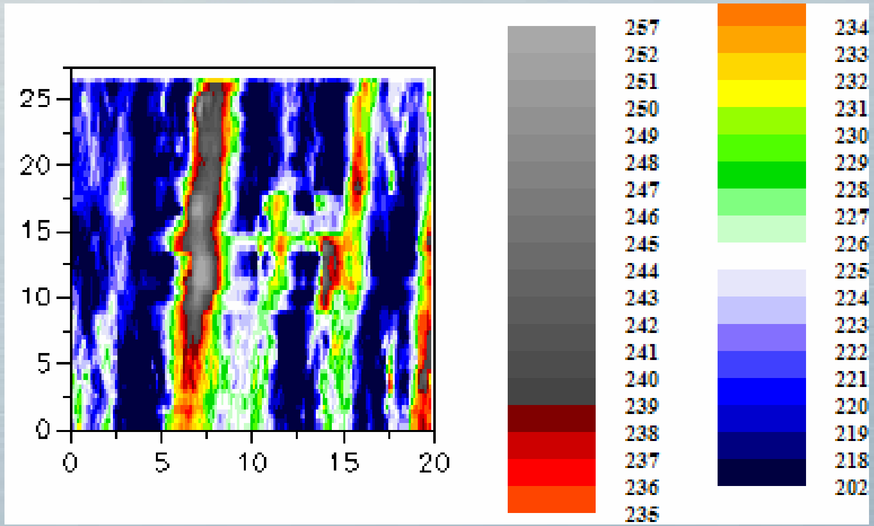
Low



Decoupled

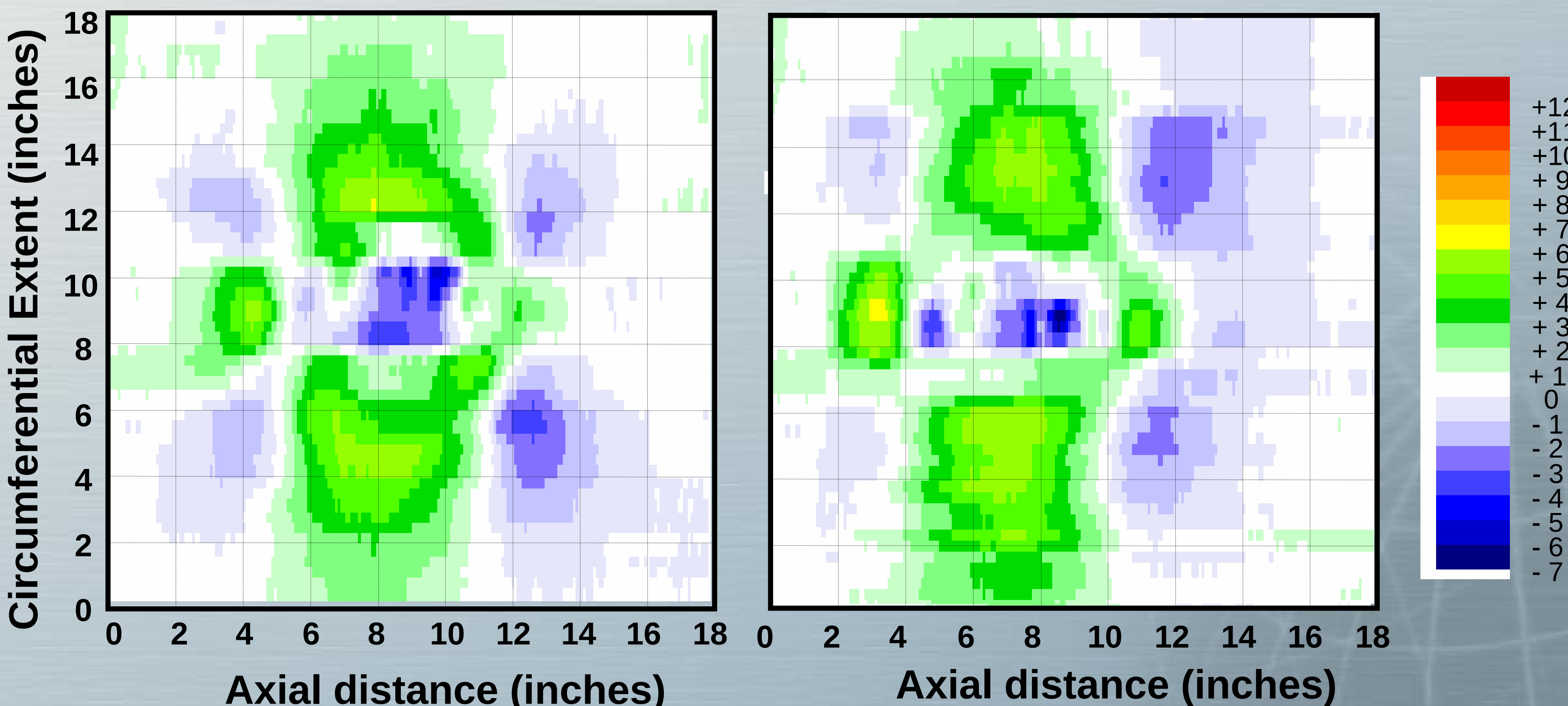


High

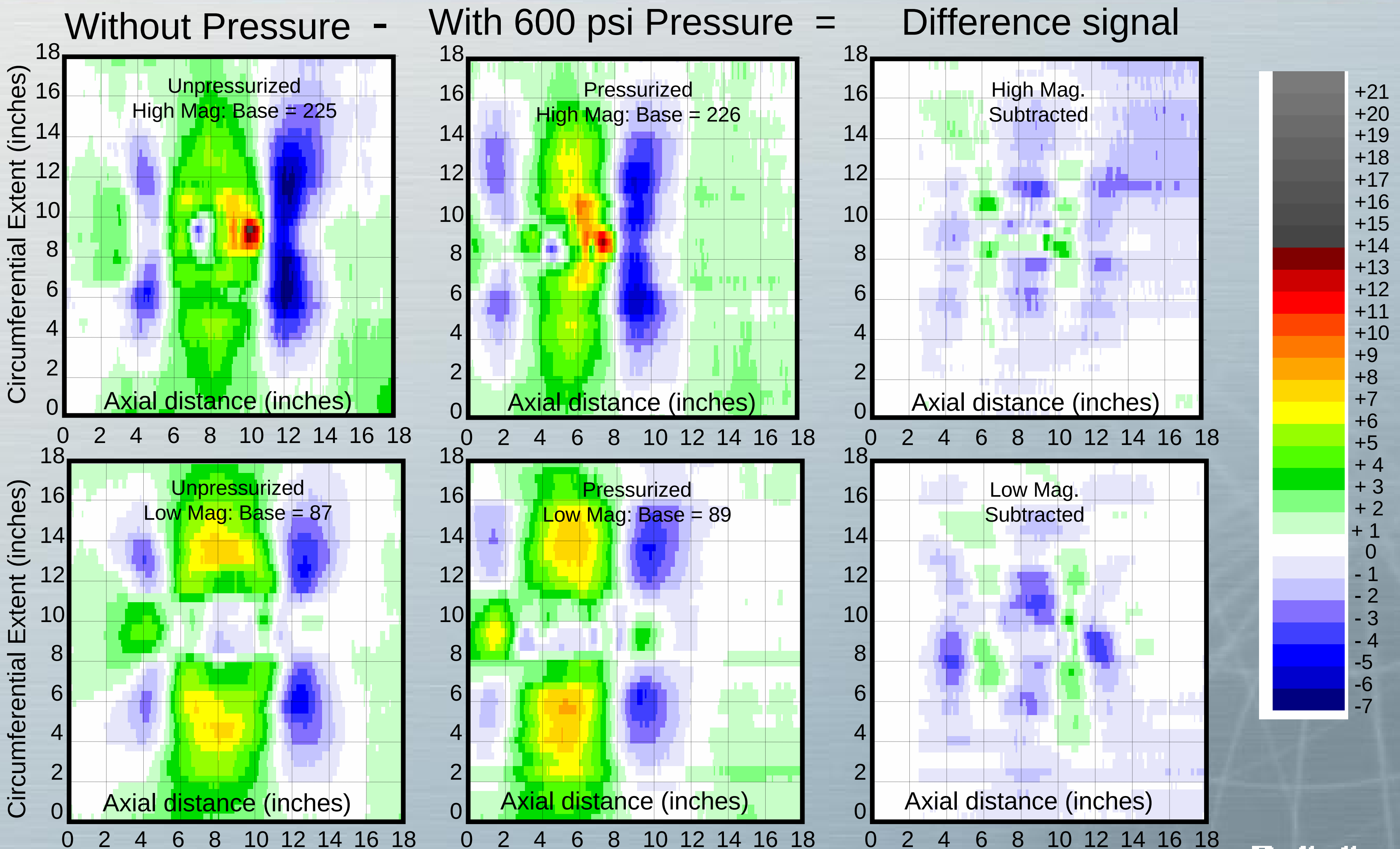


Pressure effects: Decoupled signal

Without Pressure | **With 600 psi Pressure**



Pressure effects: Subtracting high and low magnetization signals



Milestone 5 Summary: Data Analysis

- Decoupling analysis revealed the dent, gouge and rerounded signals
  - New dual magnetizer tool performed as well or better than two magnetizer approach used on previous projects
  - Velocity Effects were not significant at speeds less that 5 mph
  - Pressure effects were minimal for pressures up to 50% SMYS
  - Mechanical anomalies extracted in noisy pipe material
  - Mechanical Damage made with a Track Hoe resembles defects made with green machine

Milestone 6: Reporting

Mechanical Damage Inspection

Using MFL Technology

Summary

- Two magnetization levels are better than one
  – Detection: exposes anomalies hidden by the natural magnetic variation of some materials “Pipe Noise”
  – Characterization: Processing can reliably show areas of
    - Cold working
    - Residual stresses
- Dual magnetization tools can be designed to work on pipelines
  – Two different configurations give nearly identical results

Report Review

- The final report was reviewed by members of the the Pipeline Research Council International (PRCI) in February and March 2005
  - Technical questions addressed
  - No substantial problems
- A paper on the magnetizer design was peer reviewed and accepted for publication in the ASME Journal of Pressure Vessel Technology, Prof. Sam Zamrik of Penn State Editor. This is slated for a Special Edition on pipeline inspection in Summer 2005, compiled by Prof. Joe Rose of Penn State.

Intellectual Property Considerations

- A patent application on the three pole magnetizer and articulated magnet bar was filed in October 2004. The reference number is 44,301

- The dual magnetization concept and the decoupling procedure were developed under DOT OPS contracts. No patent applications were filed and these are now in the public domain.

Conclusion

- This research shows that there is added value in using dual magnetization techniques to inspect for mechanical damage in pipelines.
- In addition, this research demonstrates that a single inspection tool can be developed that records signals from both high and low magnetic fields with only a moderate increase in inspection tool costs.
- The next step for this technology is pigging vendor implementation and assessment on operating pipelines.