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ROTATING PERMANENT MAGNET EXCITER FOR PIPELINE INSPECTION

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New inspection methodology

- A new method for the internal inspection of pipelines
- Eddy current based , but NOT local or remote field eddy currents
- Builds on the advances in permanent magnet technology

Acknowledgment

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and

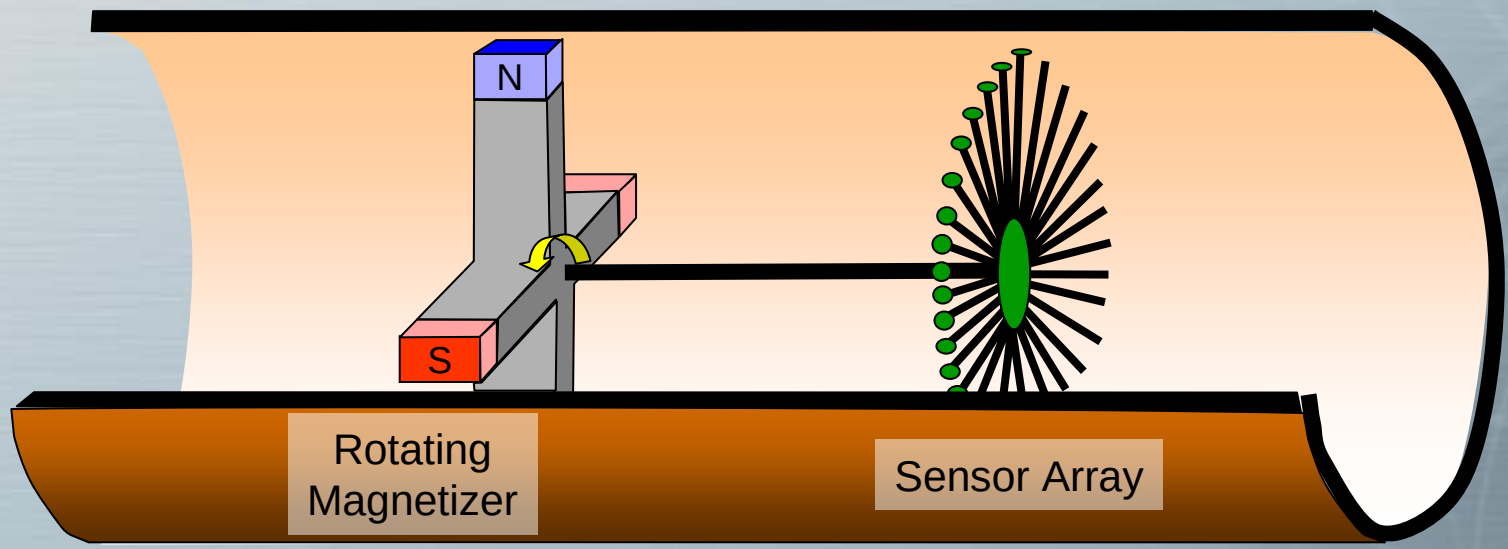
- Pipeline Research Council International (PRCI) Contract No. PR-003-03155

Outline

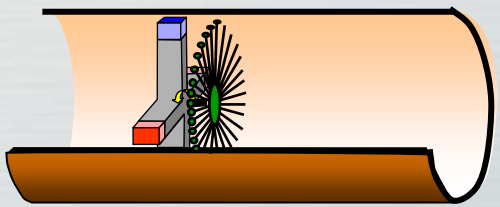
- Concept of Operation
- Magnetic Finite Element Modeling
- Prototype Implementation
- Theory of Operation
- Detection of Metal Loss Corrosion
- Electronic Improvments
- Application to Unpiggable Pipelines
- Summary

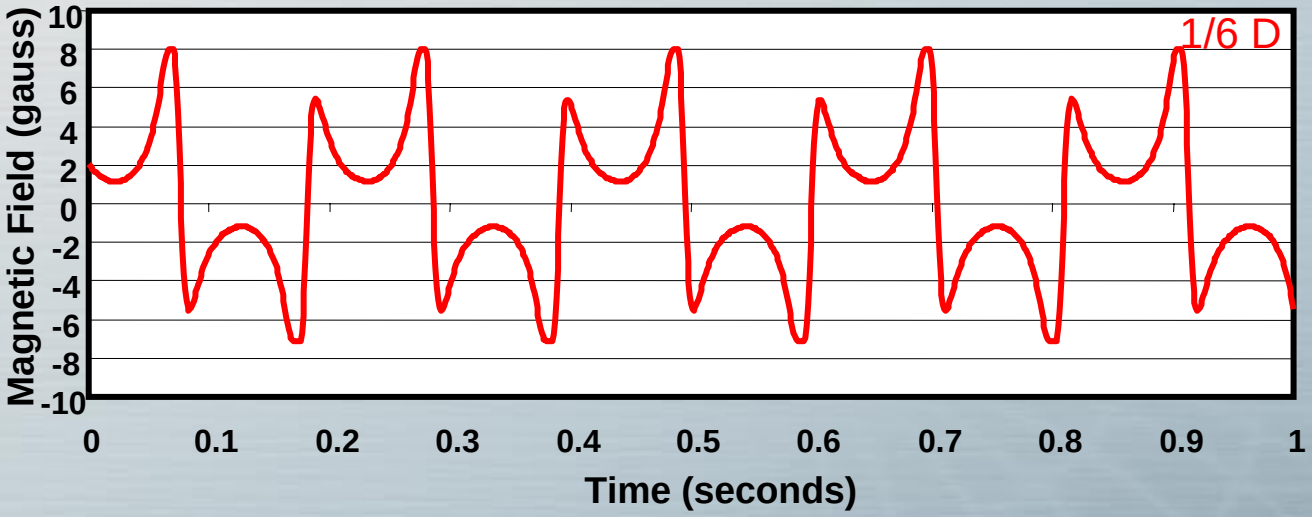
Concept of Operation

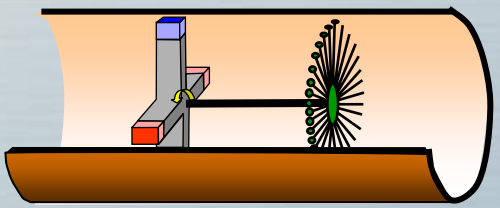
- Permanent magnets spin in a pipe
- Currents induced in the pipe wall
- Sensors measures magnetic field at the pipe surface

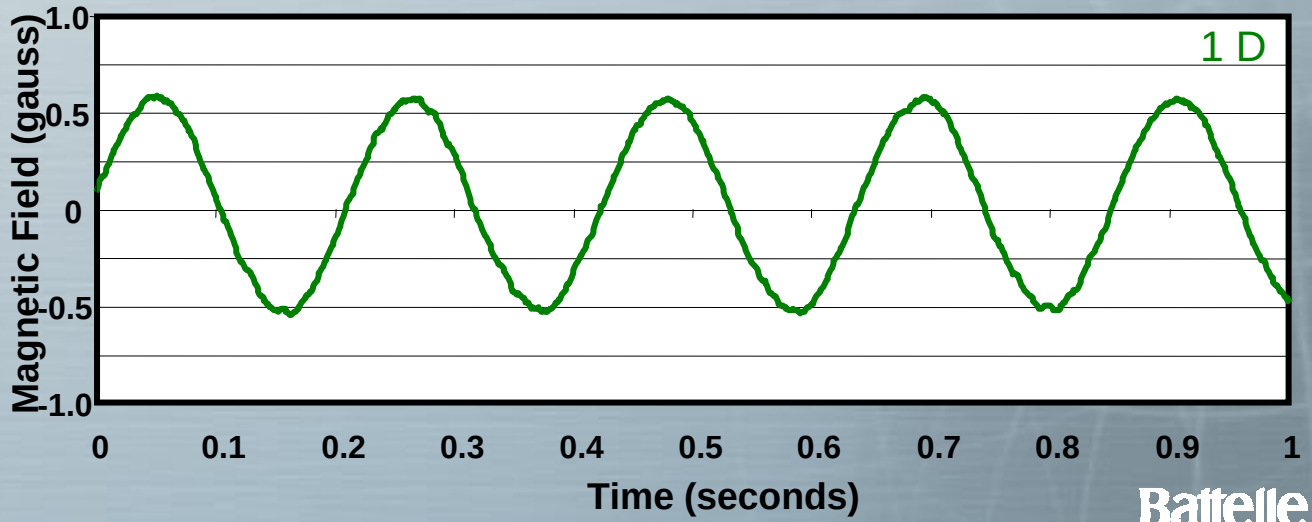


Magnetic fields detected in pipe









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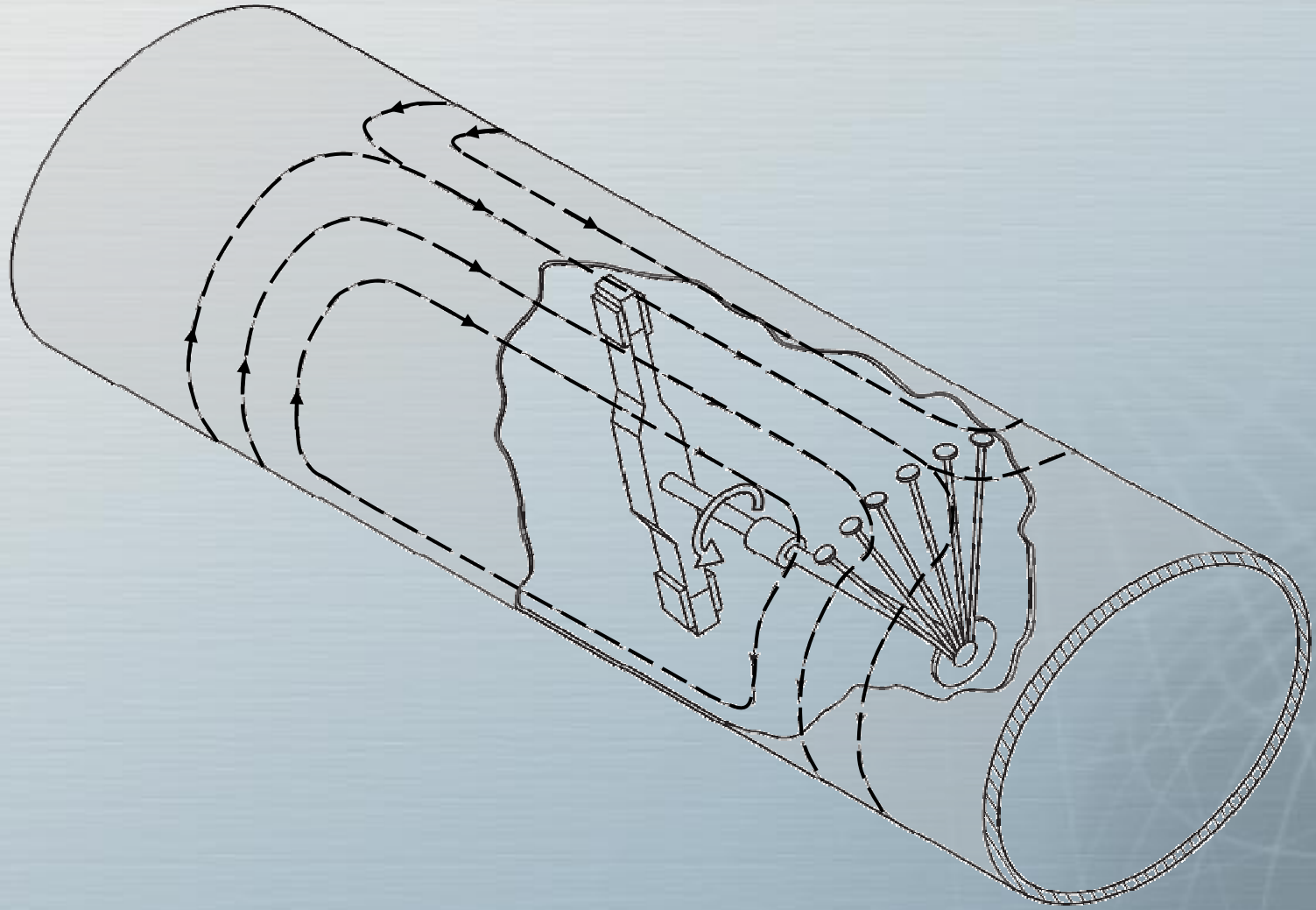
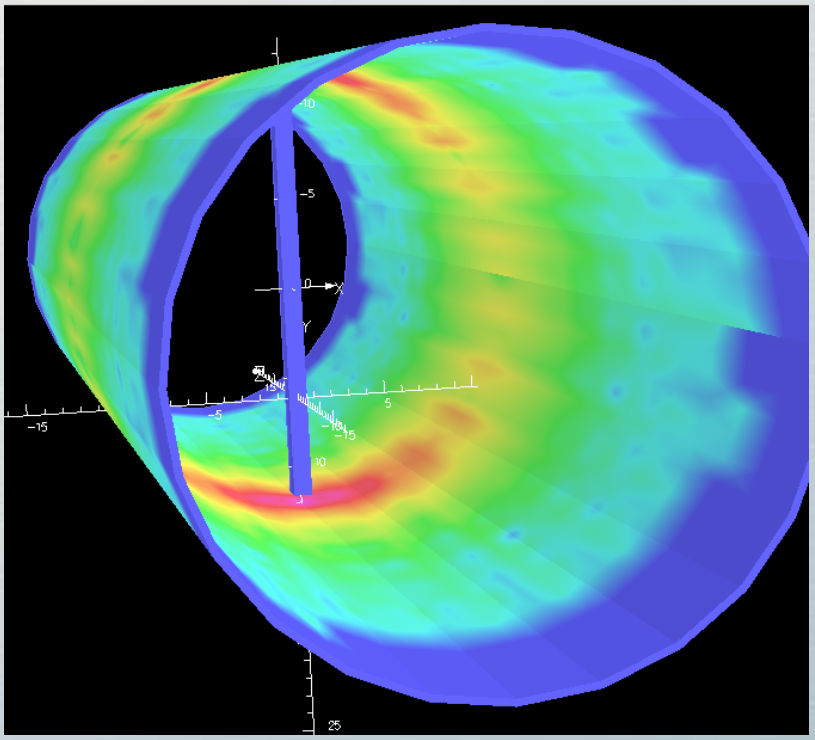
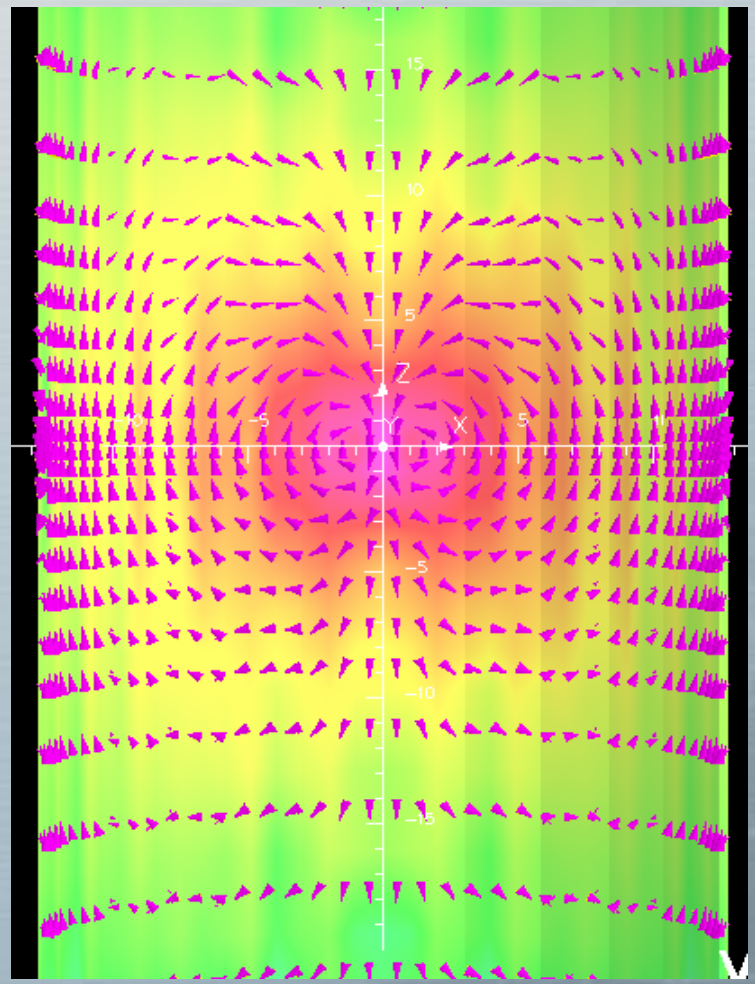
Current flow in the pipe



Magnetic finite element modeling



Log_{10} of the current density



Current flow

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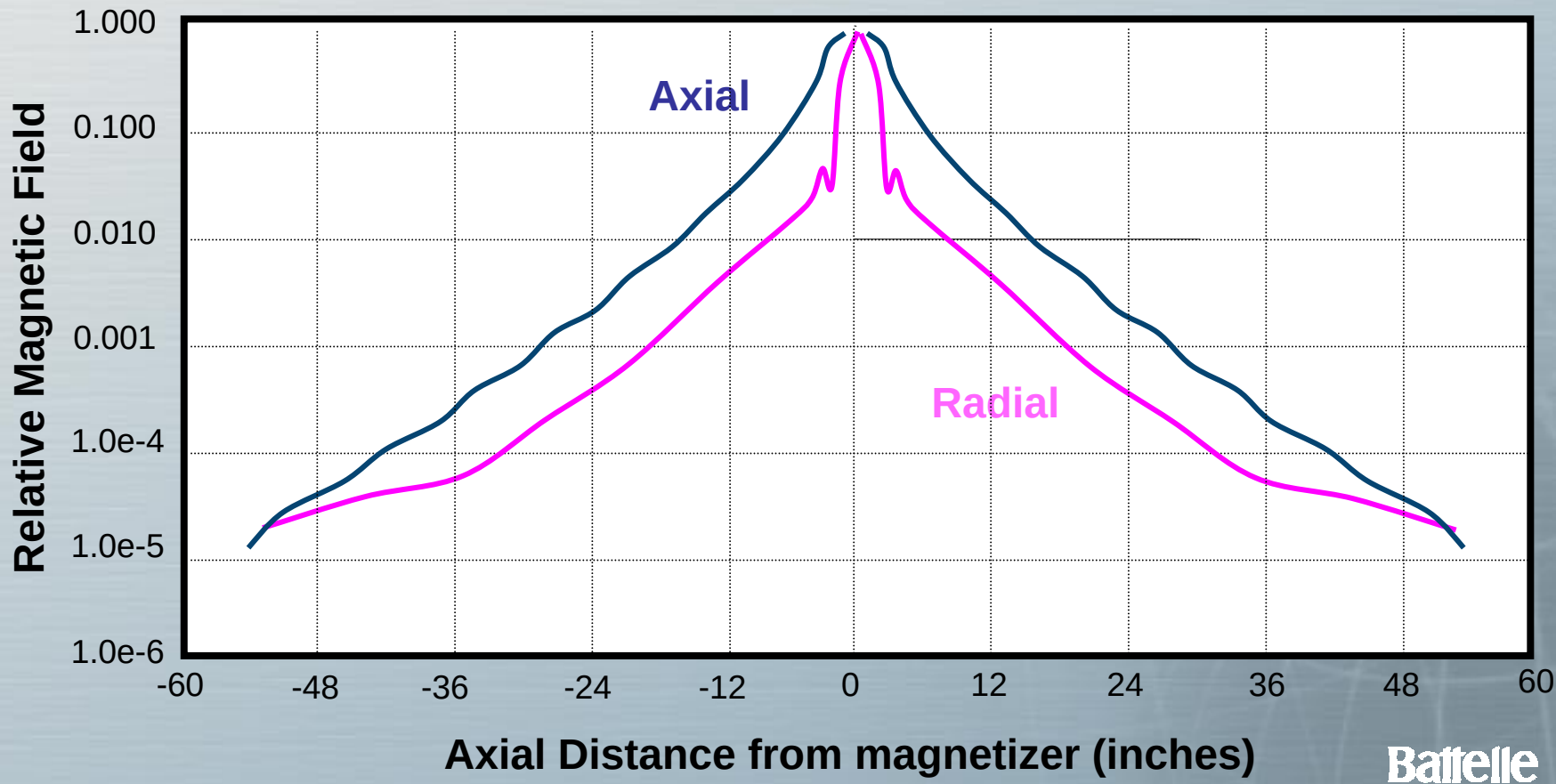
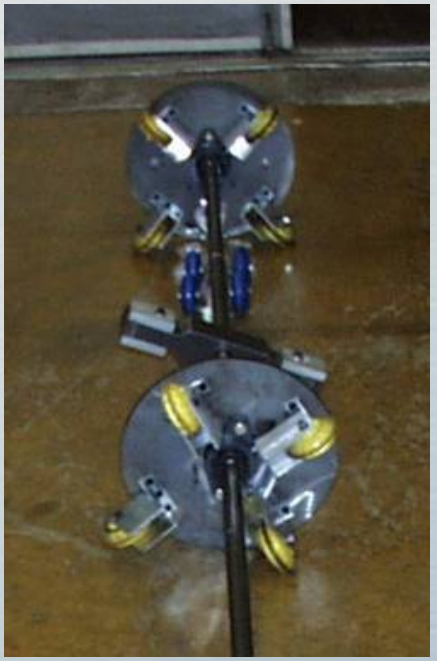
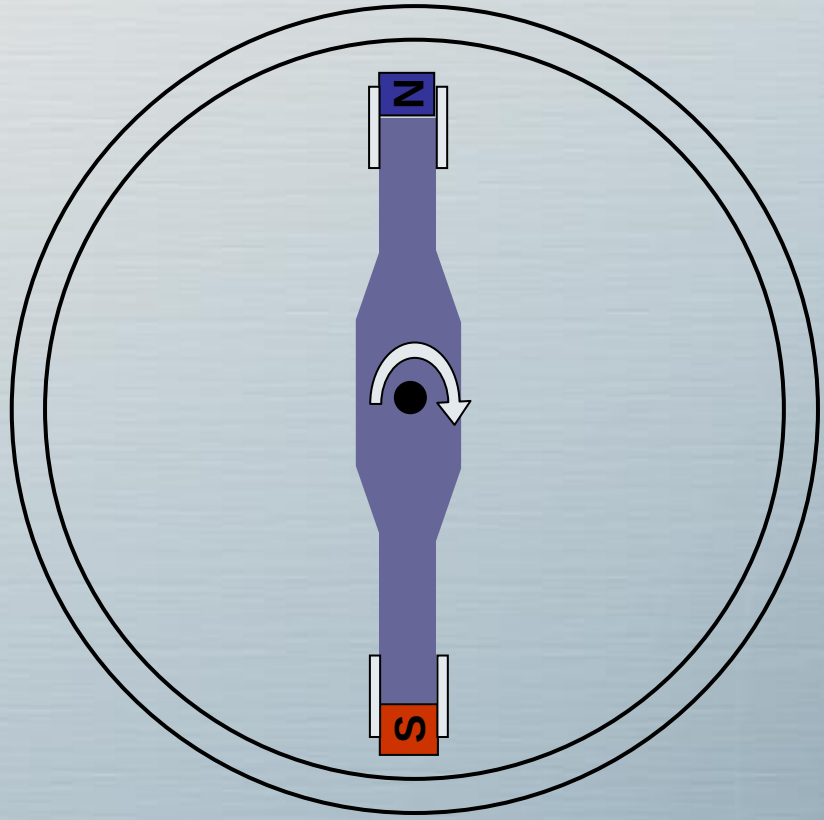
Magnetic field strength

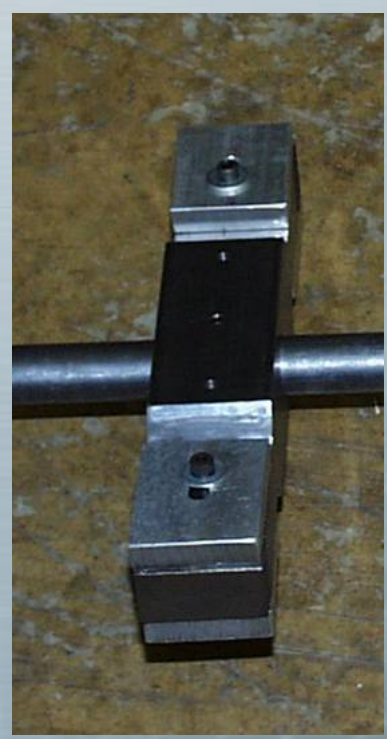
- Pipe Diameter is 12 inches
- Two poles



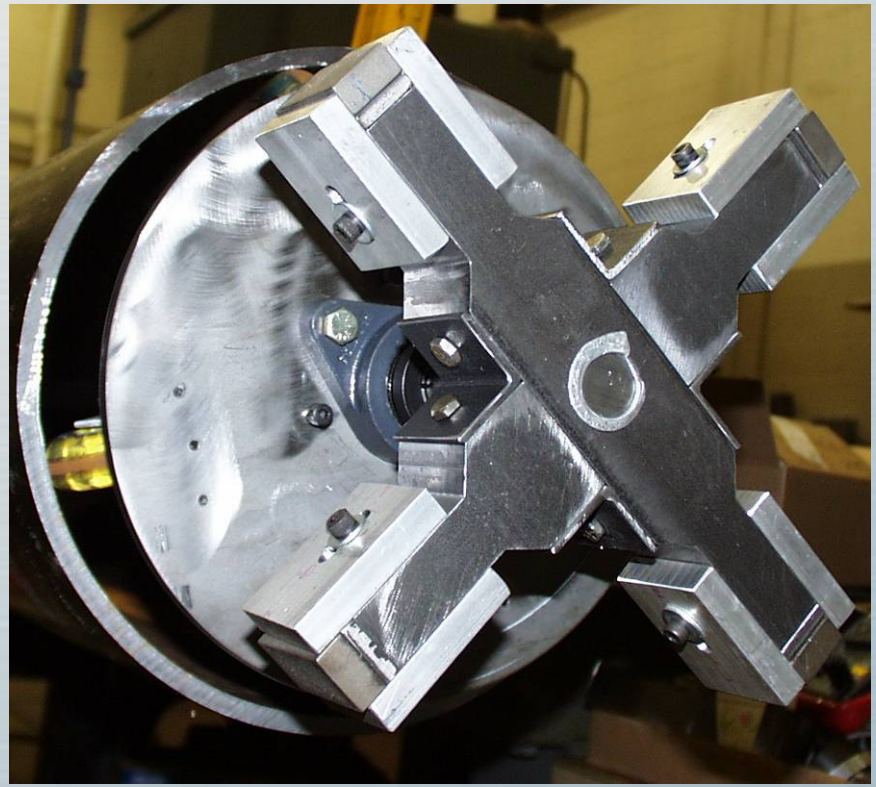
Prototyping – 2 pole system

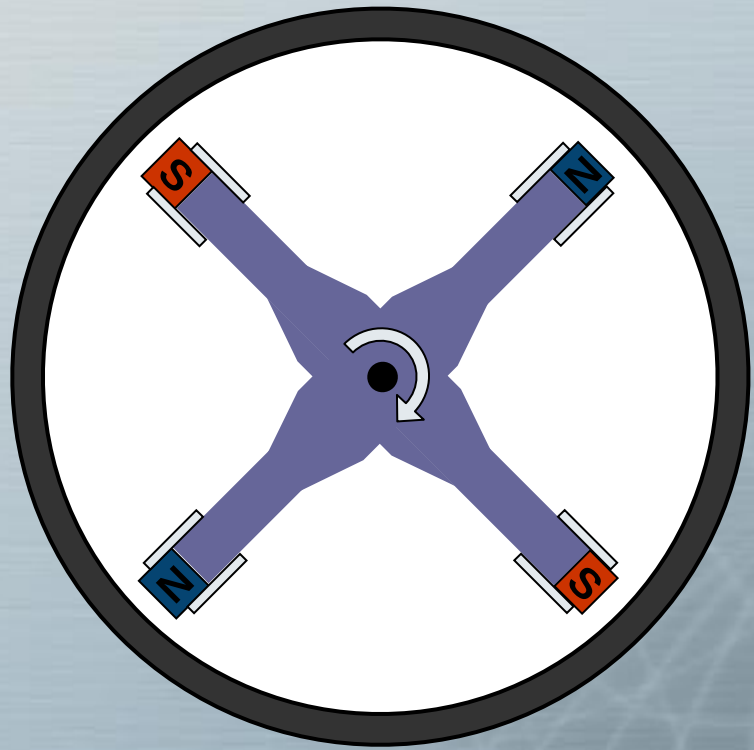






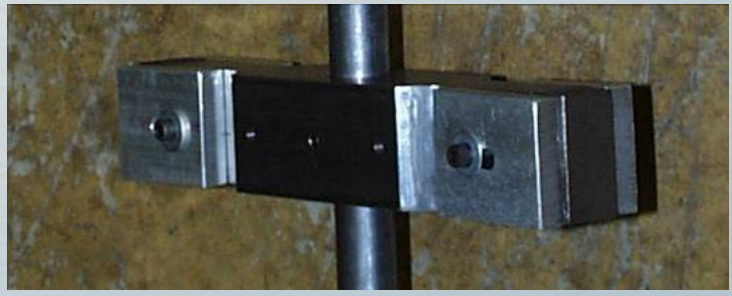
Prototyping – 4 pole system

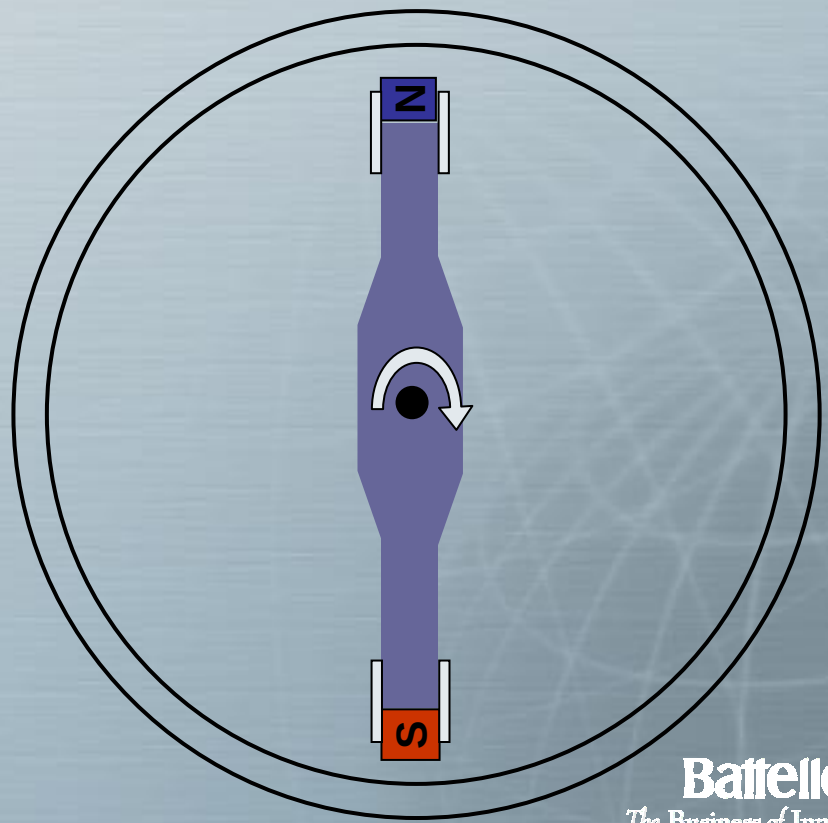




Prototype System Specs

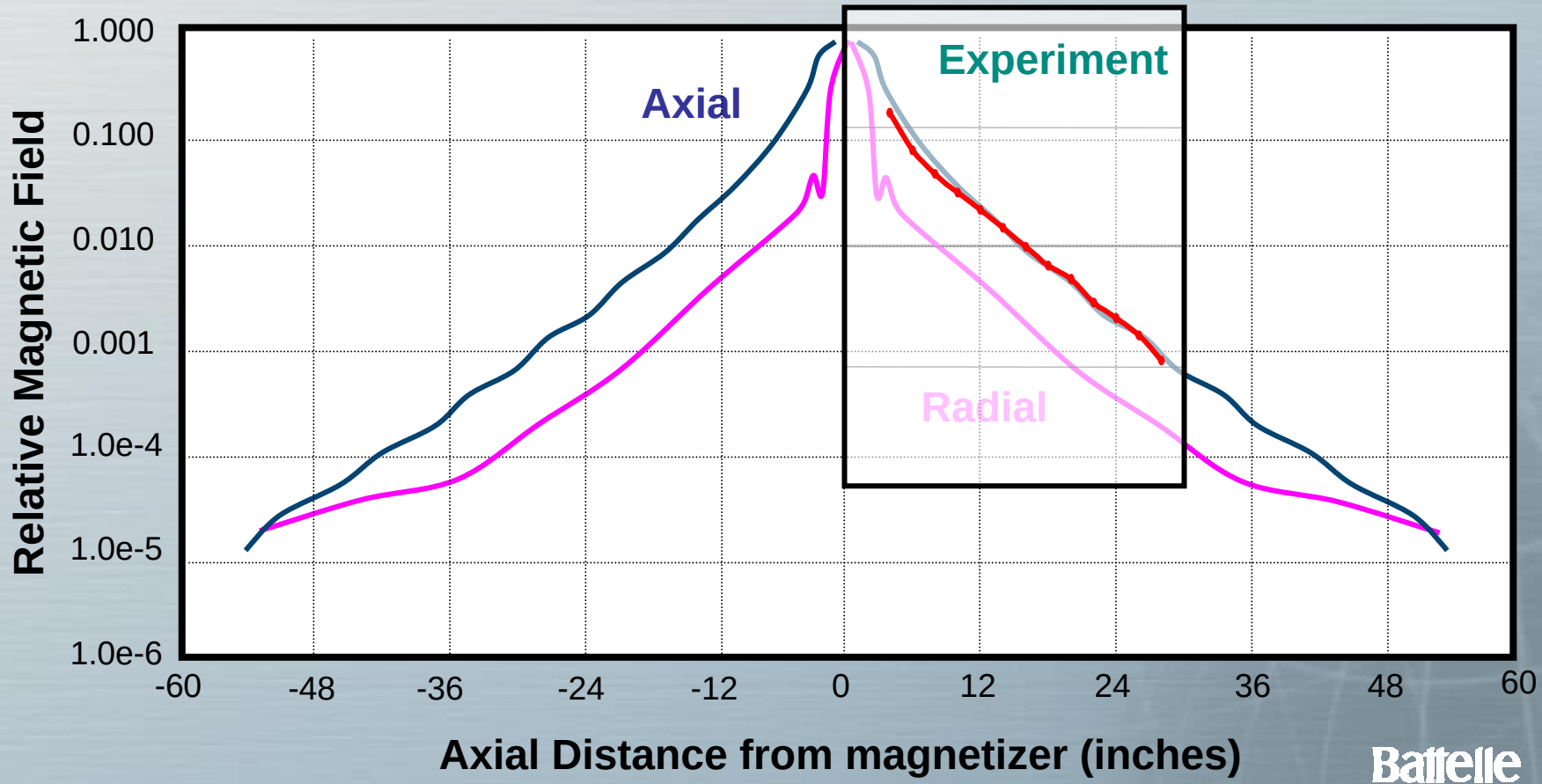
- 12 inch diameter pipe
- Magnetizer BAR
  - Diameter ~½ gap
  - Magnet 1” X 2” NdFeB 38
  - Even number of poles 2
- Rotation
  - 2 magnets
  - 300rpm x 1pair/60sec = 5 Hertz
- Sensors
  - Hall effect sensors
    - Gain 50x
    - Better low frequency response than coils
  - Axial and Radial





Compare: Modeling and experiment

- Pipe Diameter is 12 inches
- Two poles



Theory

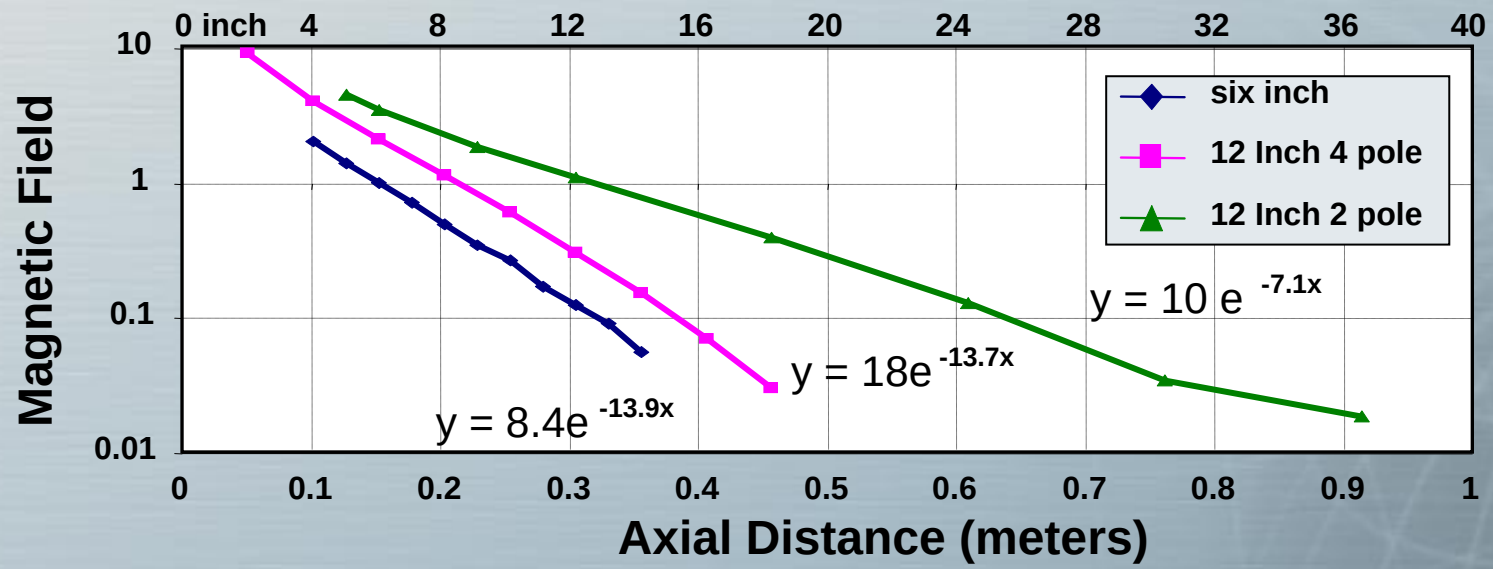
A first principles approximation, the peak magnetic field B_{pk} at the sensor is:

$$B_{pk}(z) \propto \underbrace{\frac{\beta}{n}\left(\frac{r}{\delta}\right)^2 M_0}_{\text{Amplitude}} \underbrace{e^{-\left(\frac{n}{r}\right)Z}}_{\text{Decay}}$$

- Z is the distance from the magnets along the pipe
- r is radius
- n is the number of pole pairs
- δ is the classical skin depth
- β is a coupling factor that includes liftoff (between 0 and 1)
- M_0 is magnetic energy in magnet piece

Compare: Theory and experiment

	Diameter		Number of poles	Pole Pairs / Radius	
	inches	meters		calculated	experiment
12 inch 2 pole	12	0.305	2	**6.6**	**7.1**
12 inch 4 pole	12	0.305	4	**13.1**	**13.7**
6 inch	6	0.152	2	**13.1**	**13.9**



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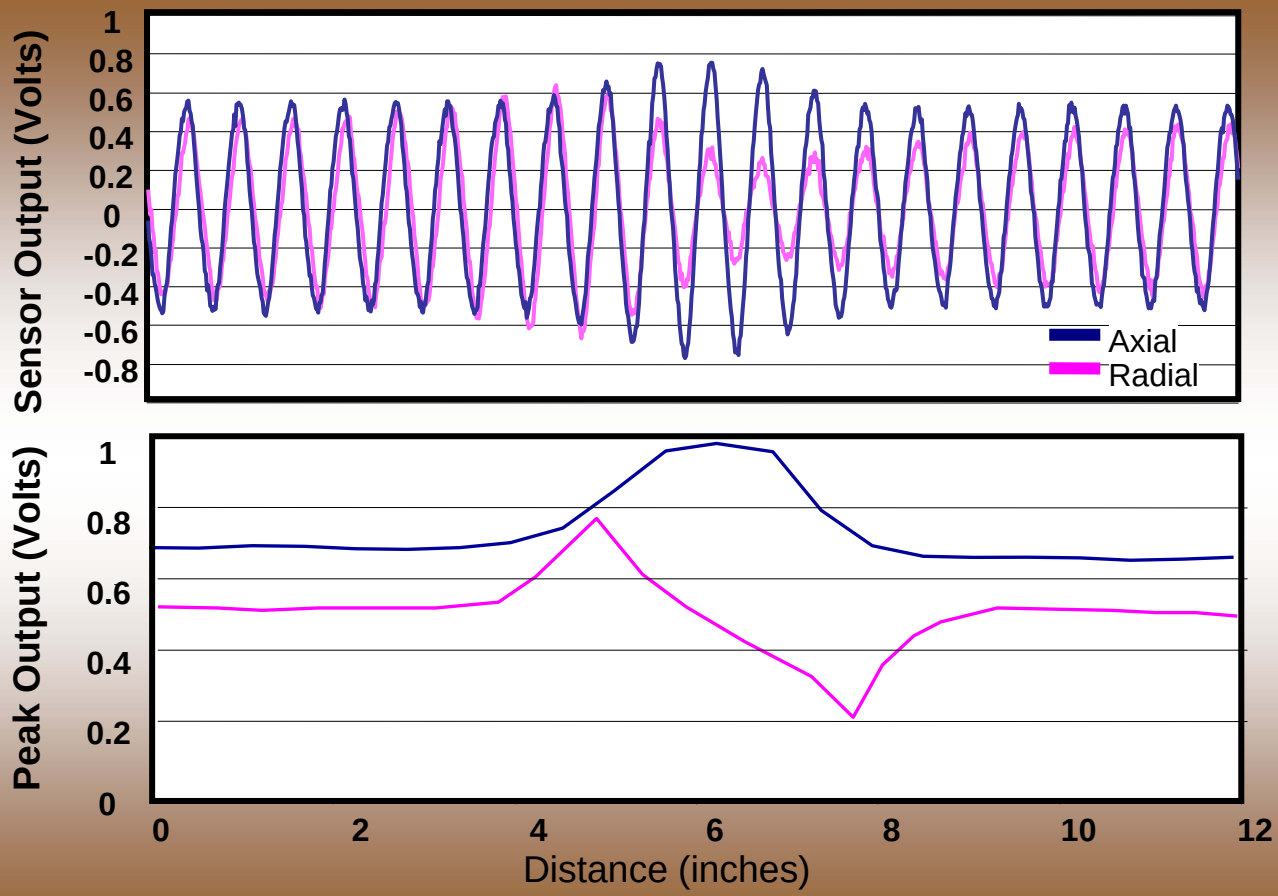
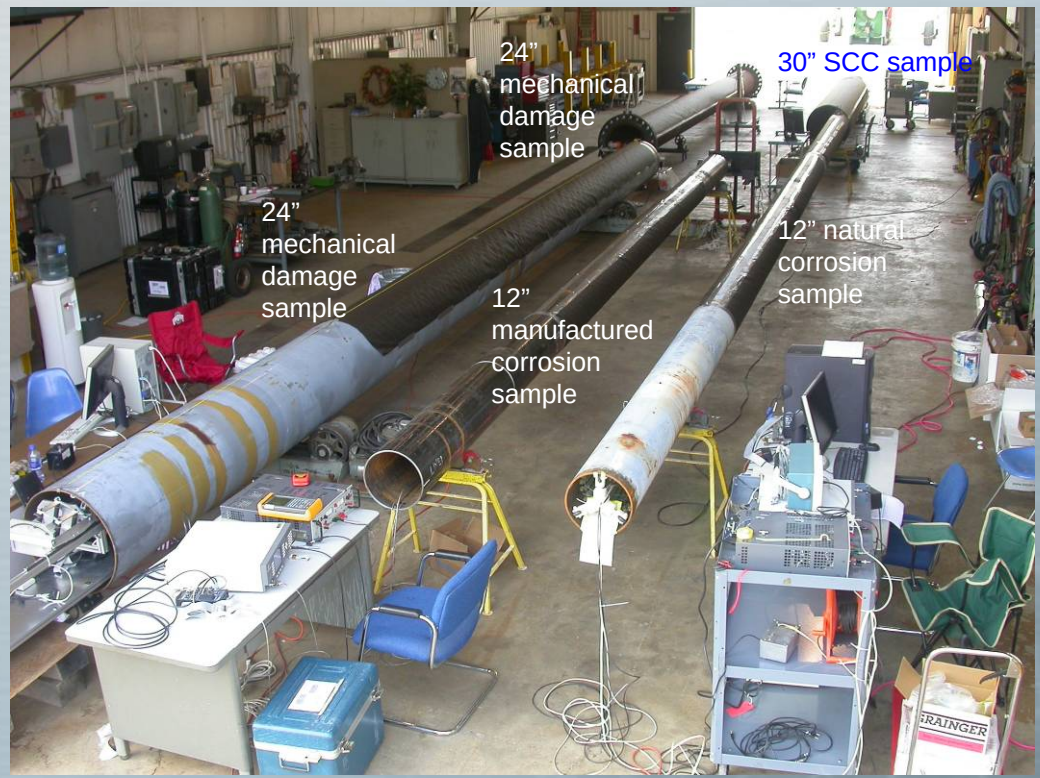
Typical metal loss signal



NETL/DOT Benchmark Tests at Battelle's Pipeline Simulation Facility

- September 2004
- 12 inch diameter pipe
- 0.375 wall thickness
- ERW and seamless



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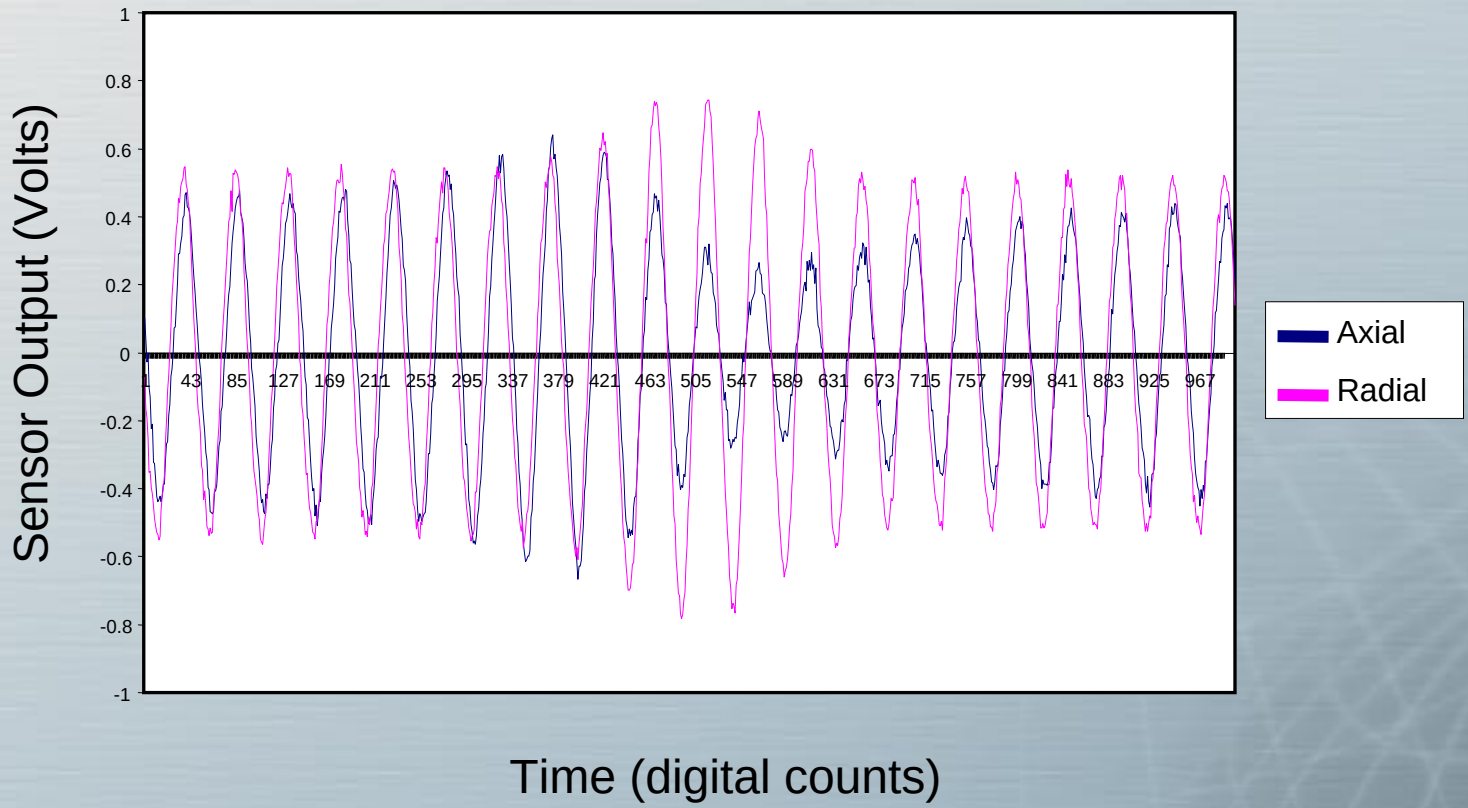
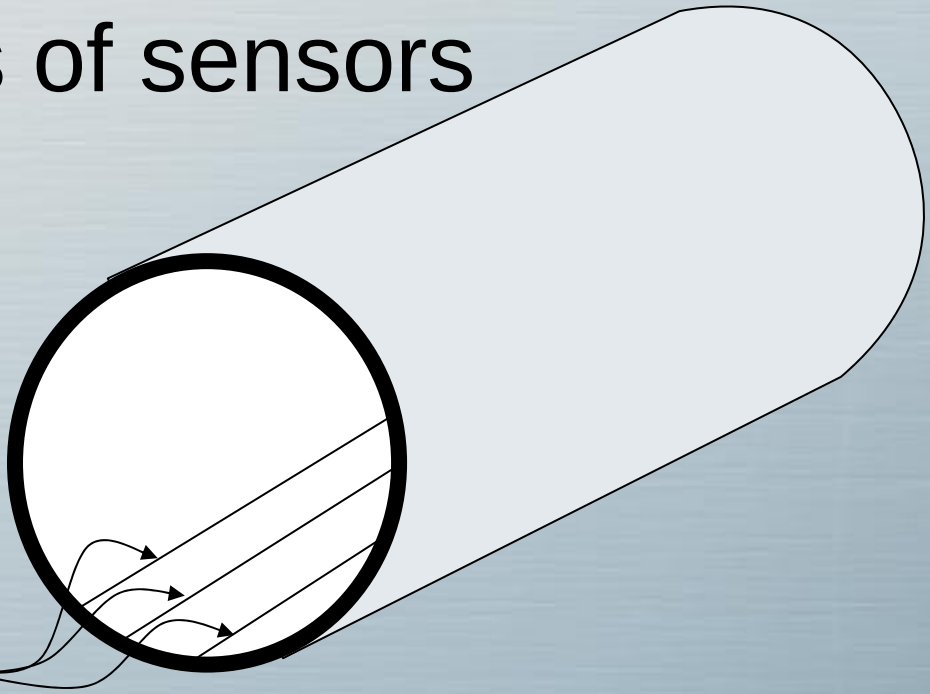
MC09 Signal



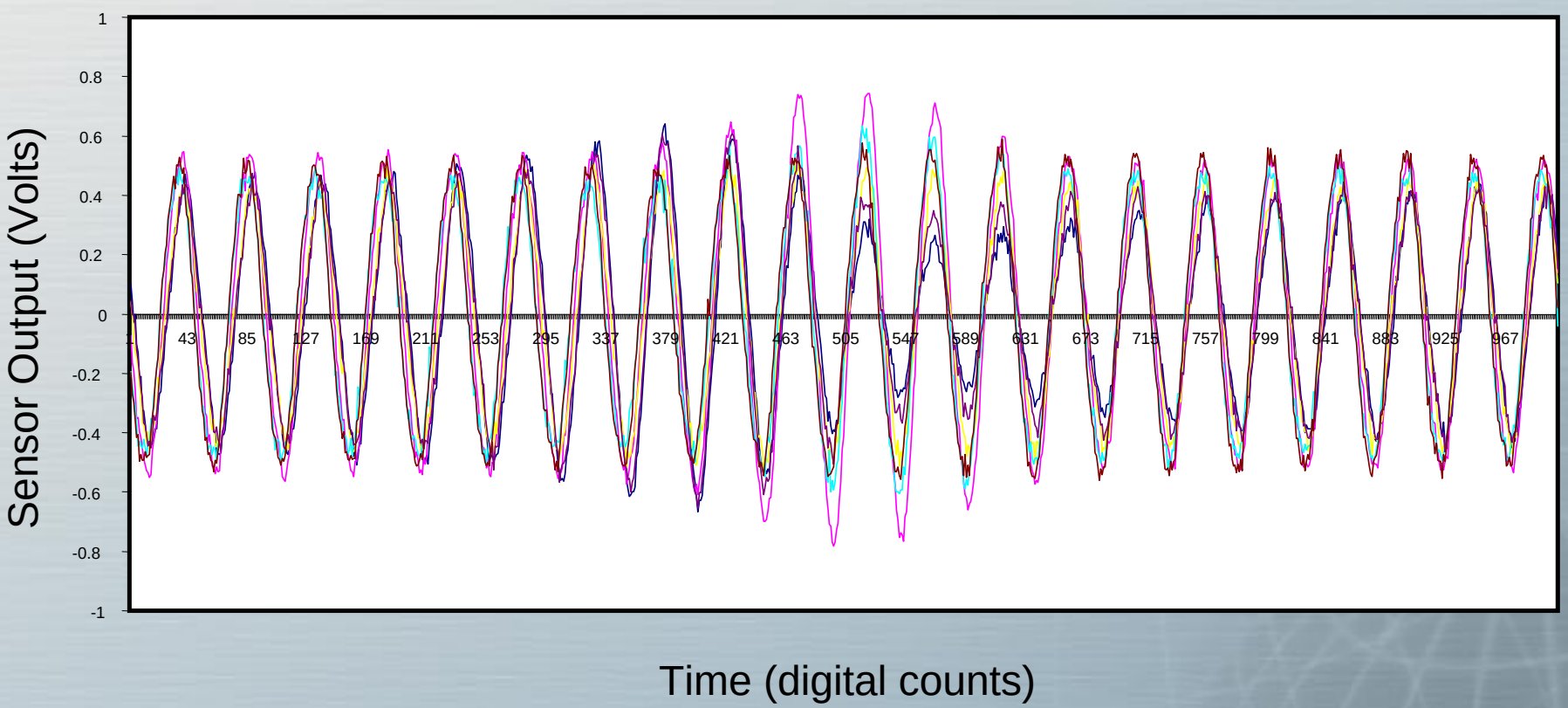
Sensor configuration

- Pairs of sensors measure the axial and radial magnetic field
- 3 pairs of sensors

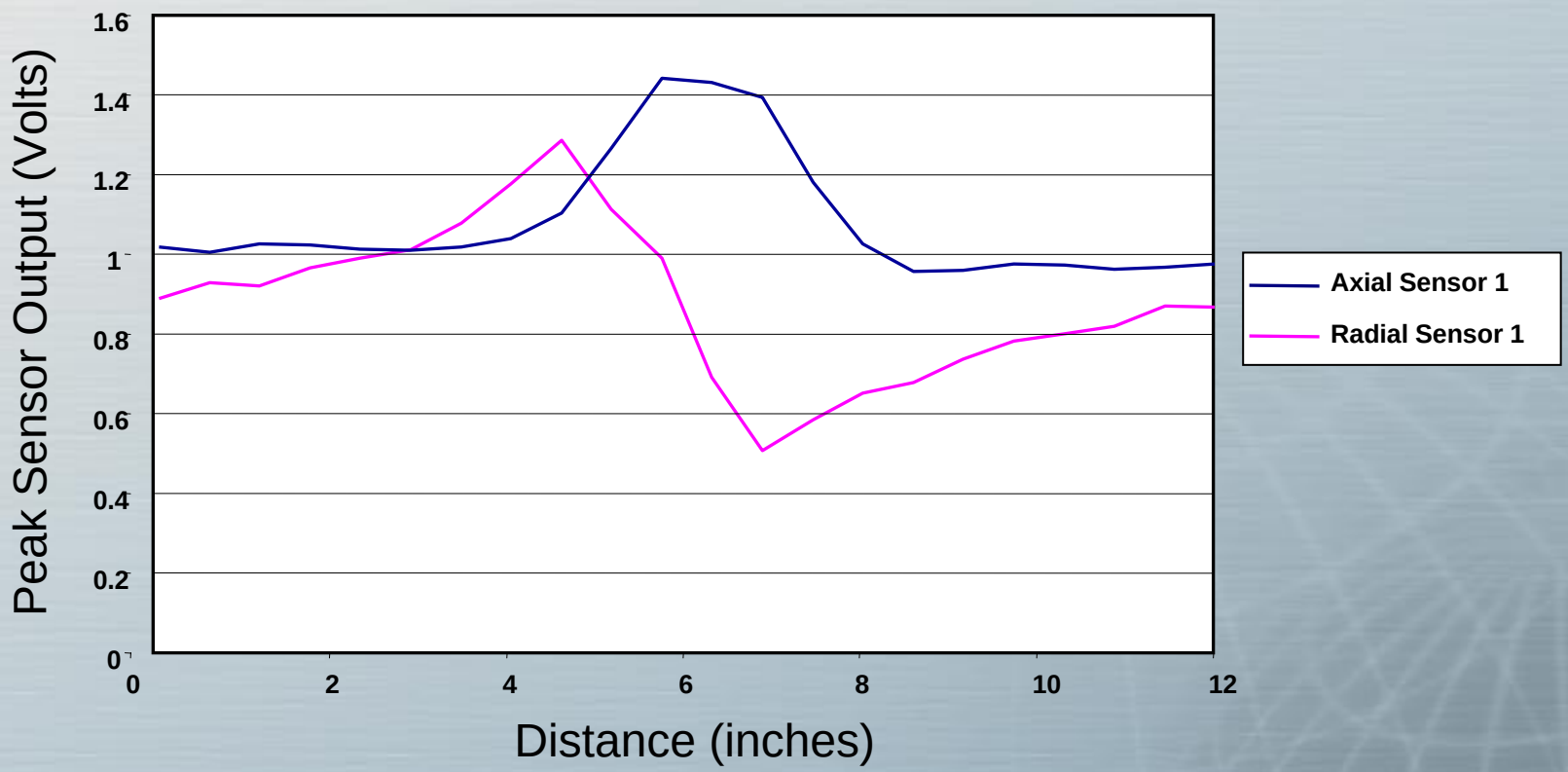


3 scan lines
with two sensors orientations per line
Note: Not all three sensor pair pass under defect, especially narrow ones.

MC09 Signals for 3 Sensor Pairs

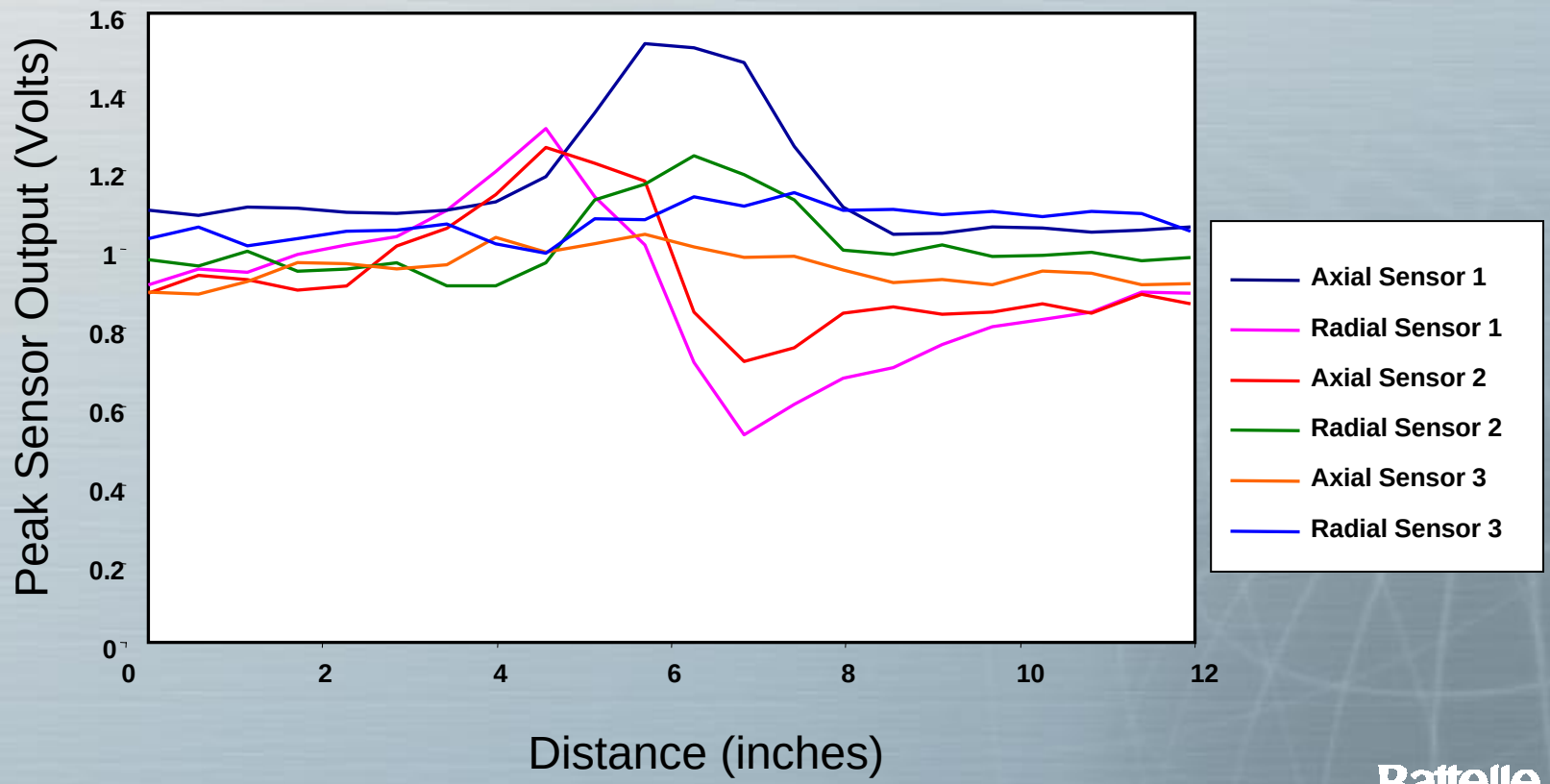


MC09 Deep Long



MC09 Synchronous Detection

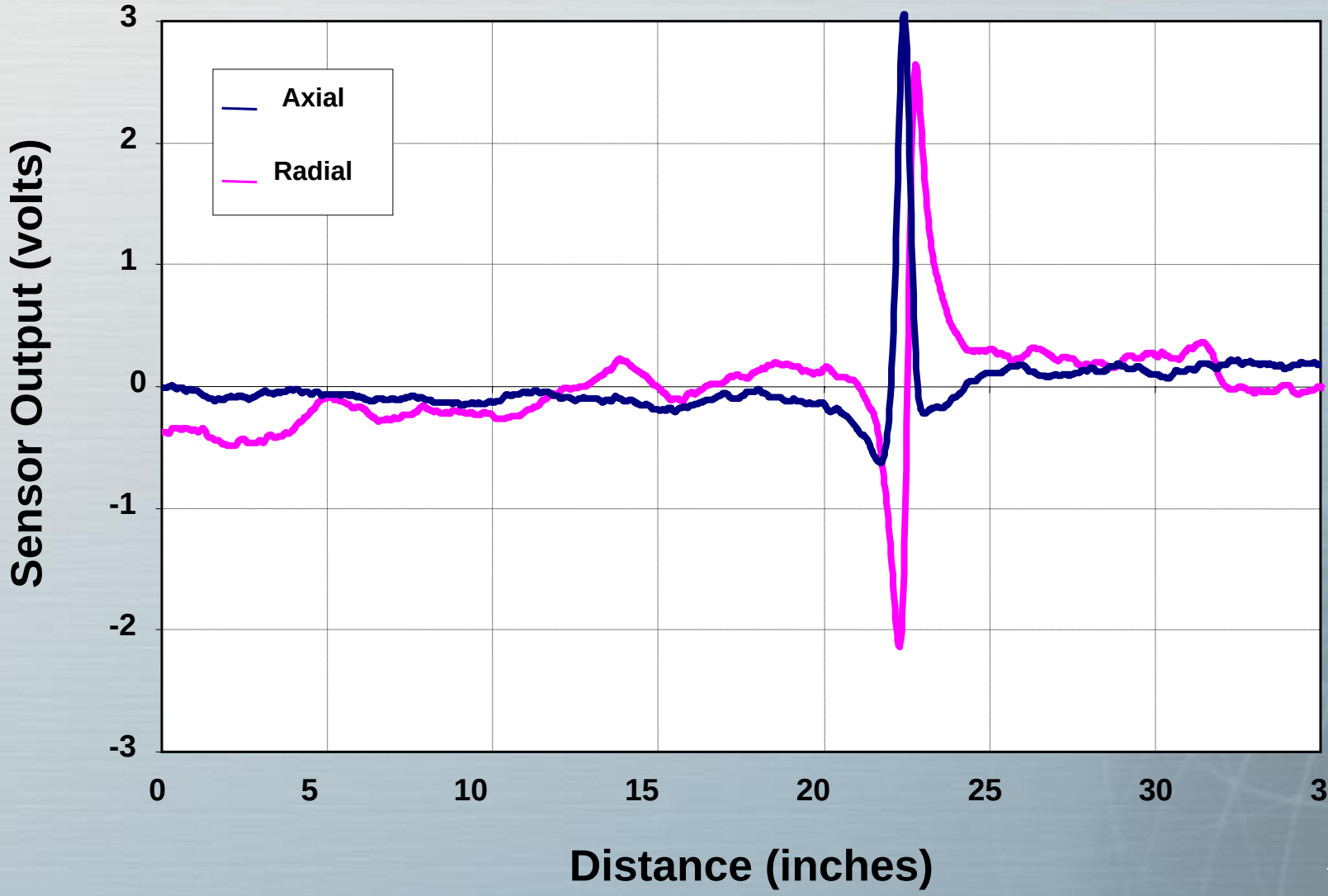
- Sensor Pairs 1 and 2 detect defect



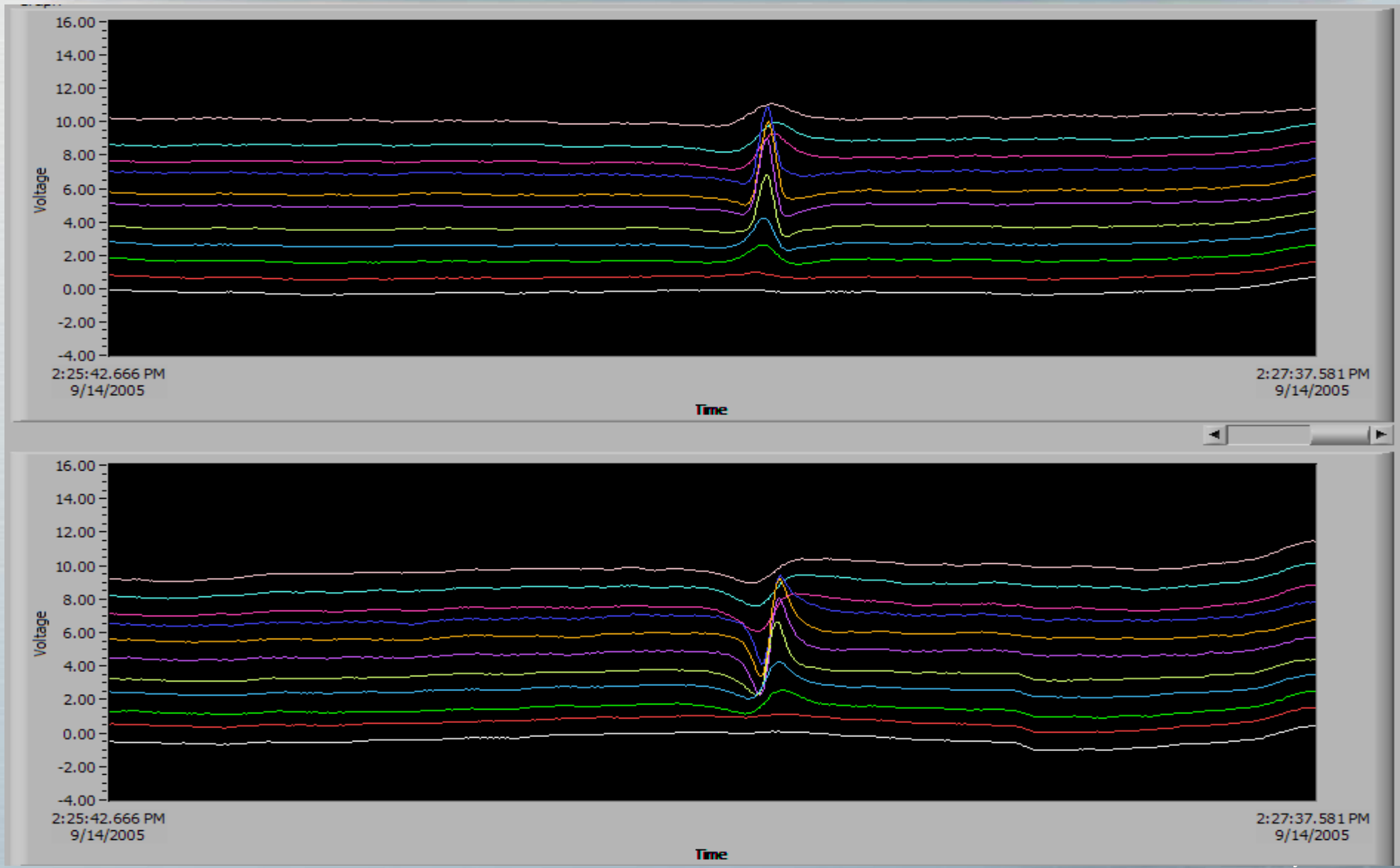
Electronics Improvements

- Digital lock-in amplifier
  - National Instruments PXI-4472B,8 Inputs, 24 BIT, .5HZ AC Cutoff Filter
- Currently implemented three for 24 Channels
  - One sync to rotating magnet
  - 22 channels for 11 sensor pairs (axial and radial
  - One spare
- Sensors
  - Hall effect sensors, currently using Honeywell SS495
  - Next generation higher sensitivity, programmable gain and offset sensors being examined
  - 9 volts at 50 milli amps

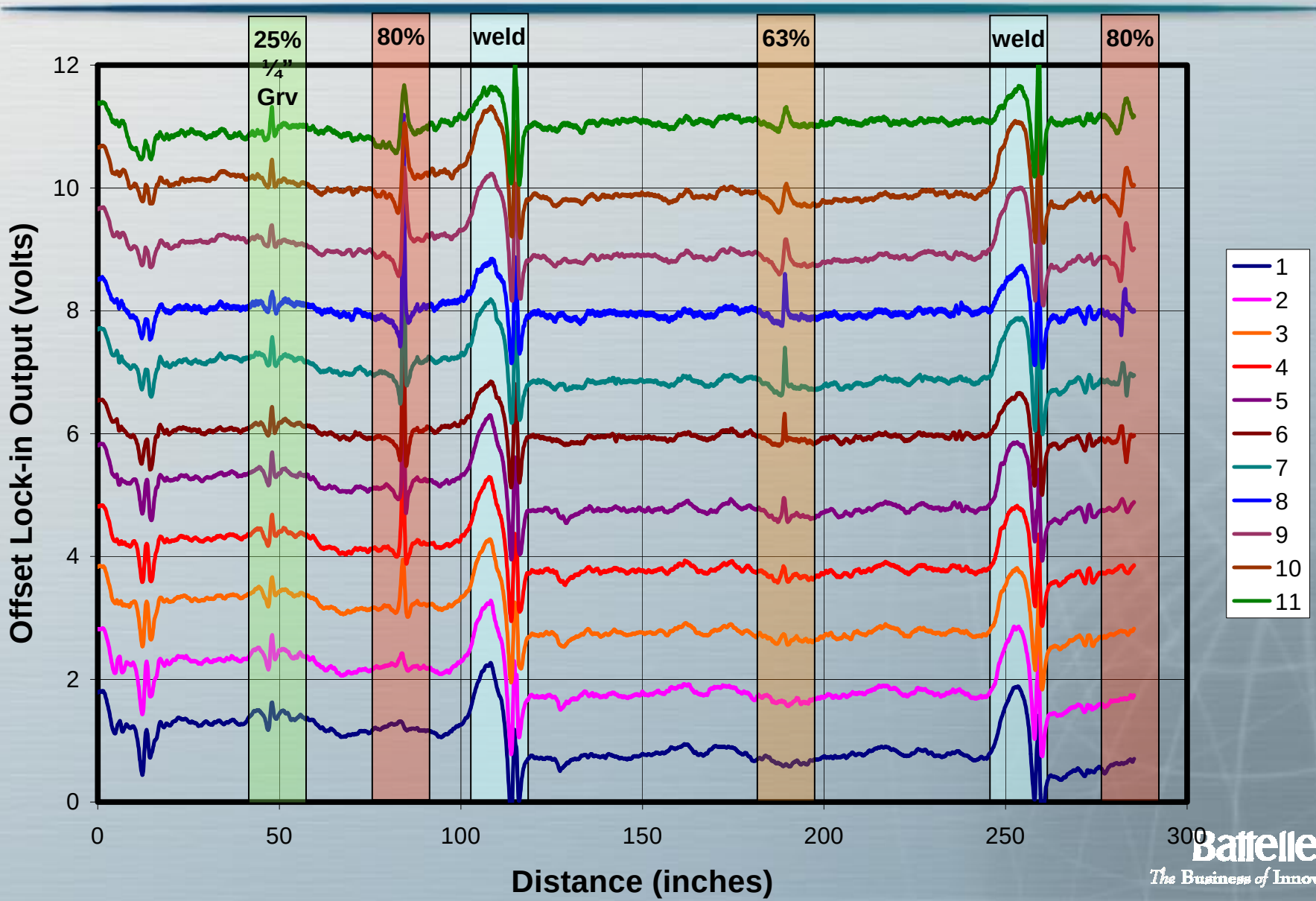
Result: Cleaner signals, faster data rates



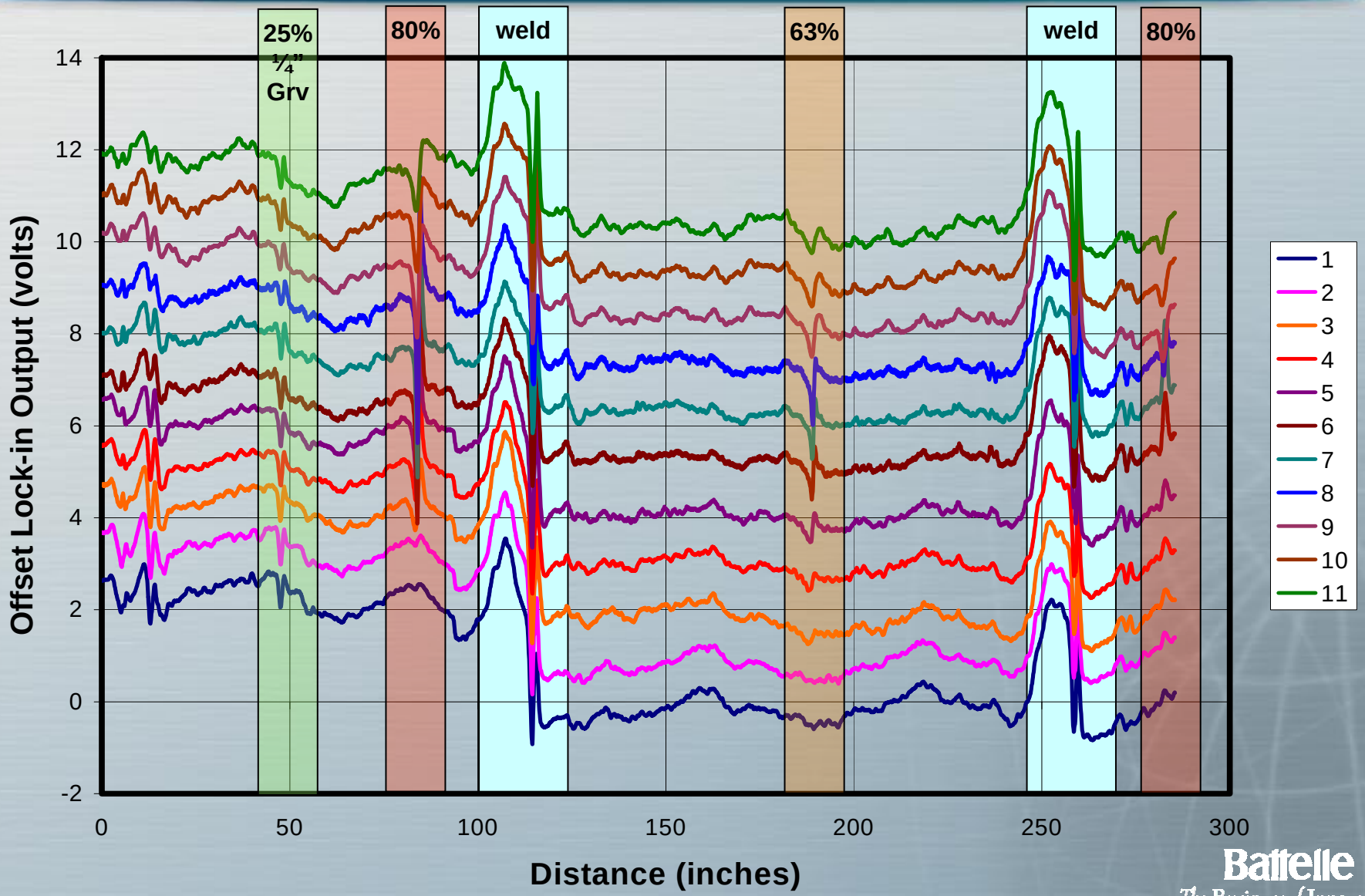
Real time data display



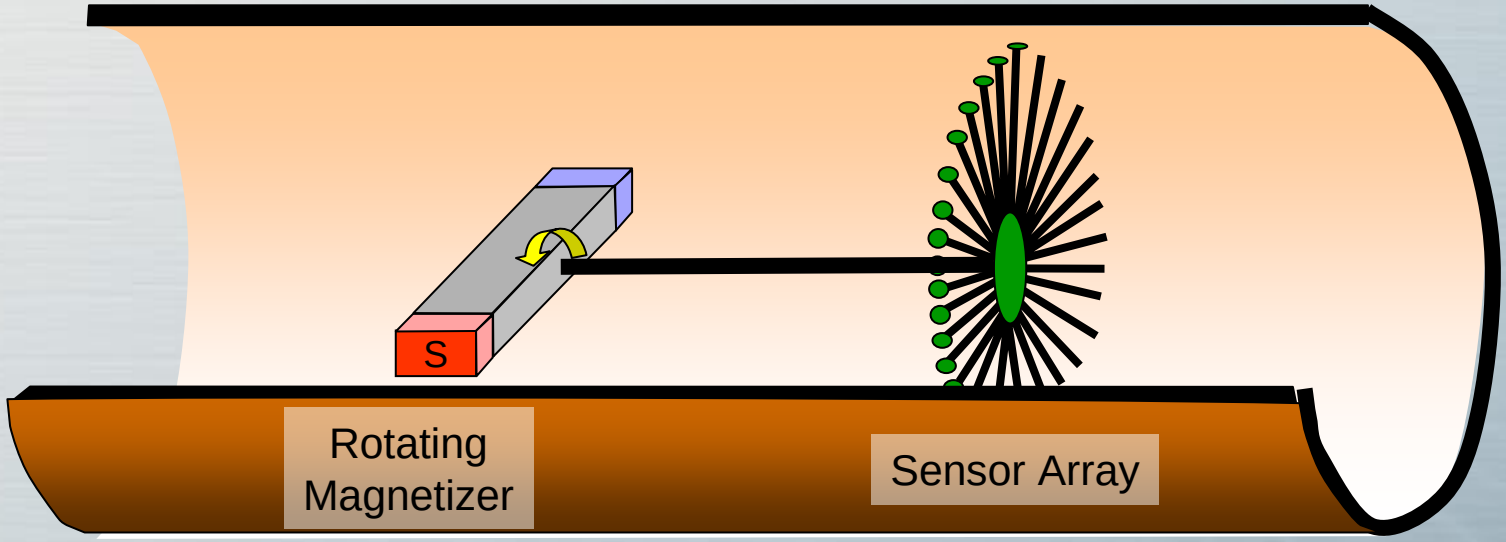
24 Feet of Axial Data



24 Feet of Radial Data



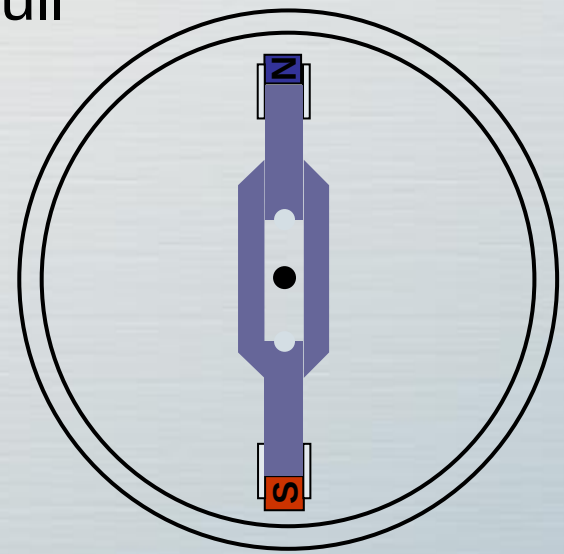
Application to Unpiggable Pipelines

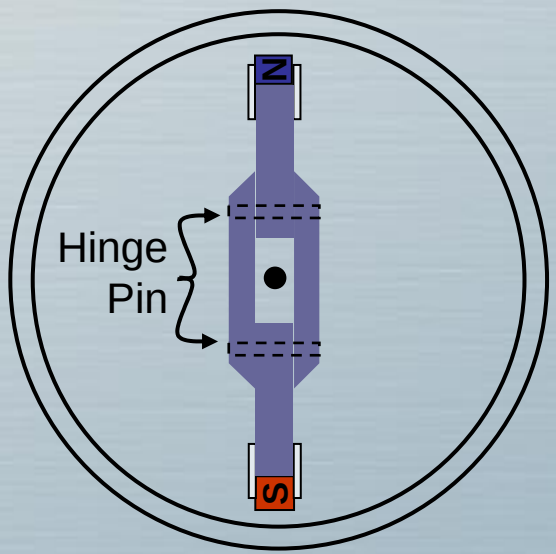


- The two pole configuration well suited for passing narrow pipeline restrictions such as plug valves.
- Magnetizer can be designed to shrink in magnetizing direction to 2/3 of pipe ID.
- Each sensor is small three terminal semiconductor. Sensors array easily collapsible.

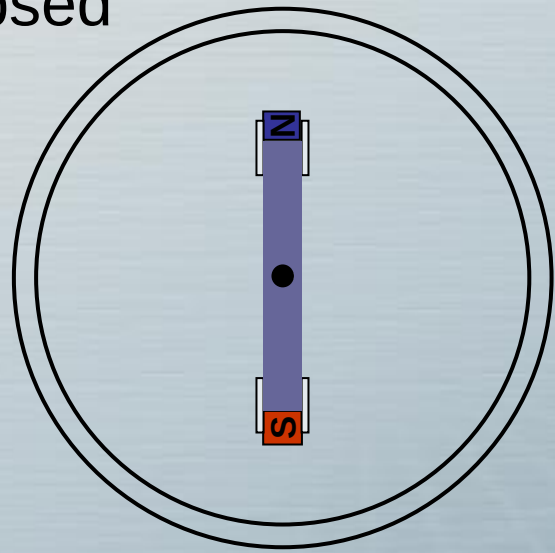
Telescoping and Hinged Magnetizer

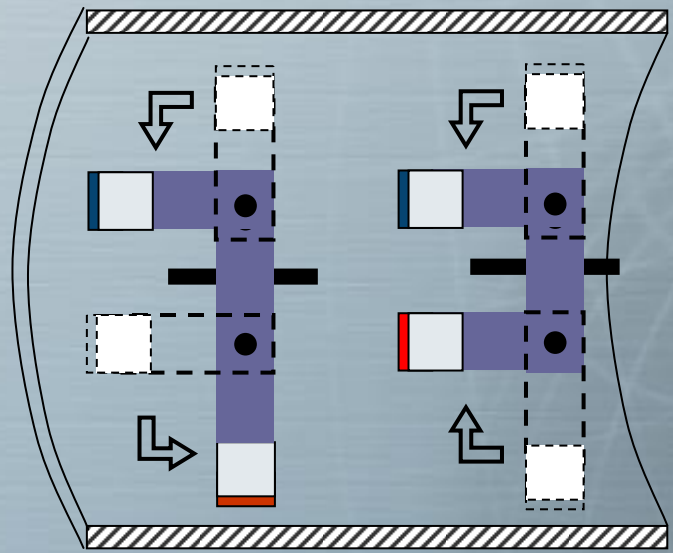
Full



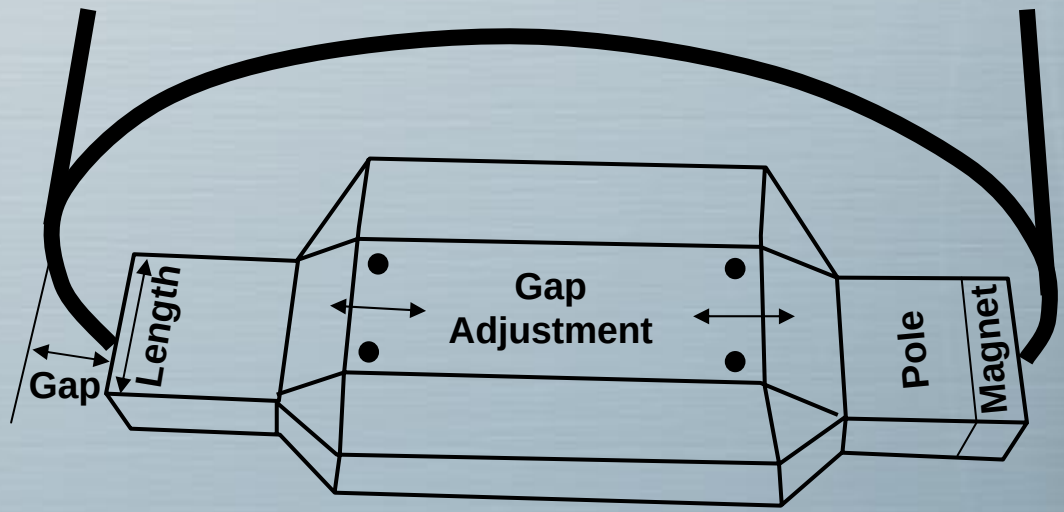


Collapsed

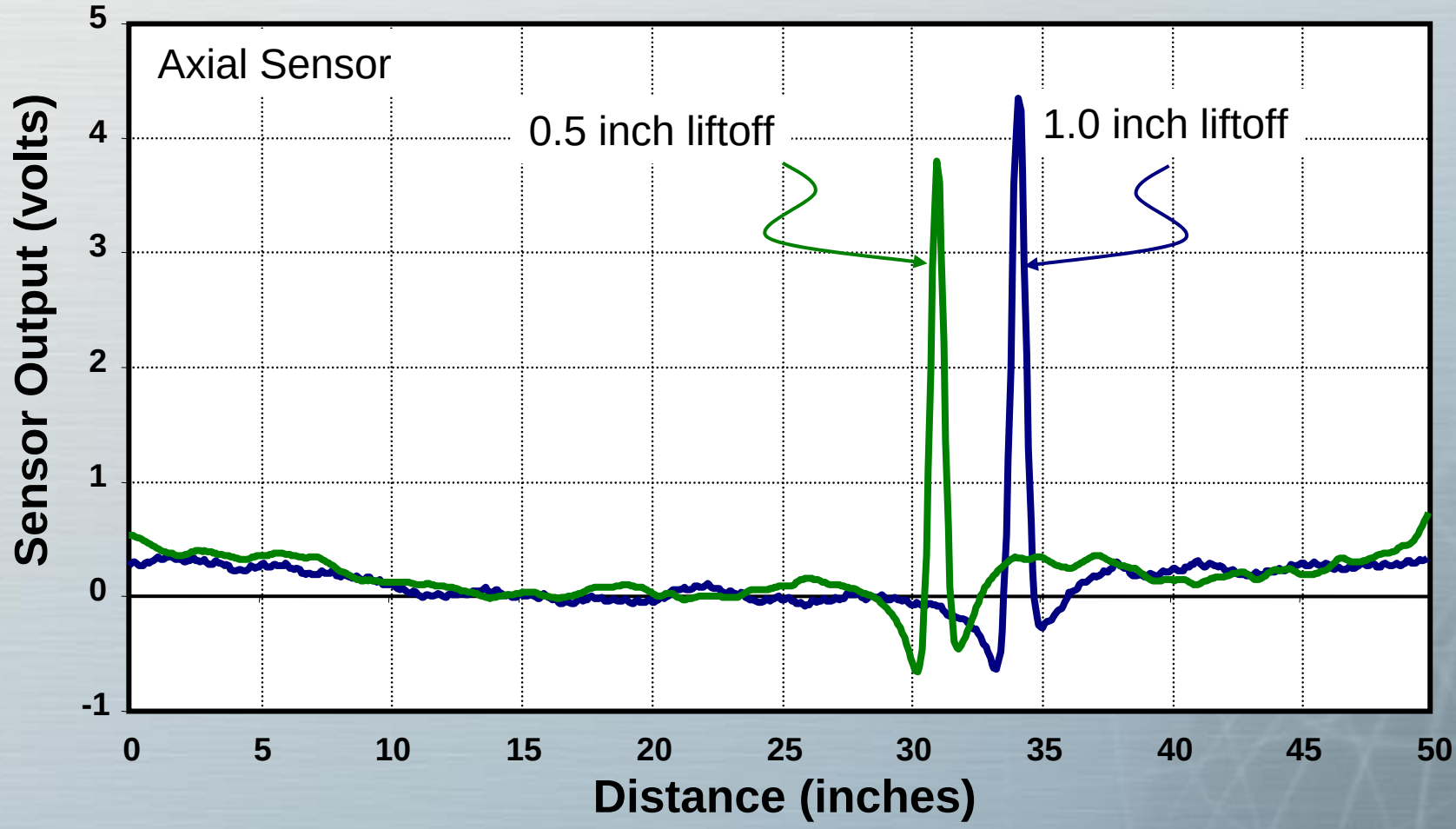




Examining Gap Distance



Gap Distance



Summary

- A new inspection method has been developed based on rotation of permanent magnets.
- Theory, modeling, and experiments show the existence of strong currents flowing in the circumferential direction.
- Pipeline anomalies disrupt the flow of the circumferential currents. The disruption can be detected using magnetic field sensors
- The sensors are positioned a pipe diameter away from the magnets. This differs from RFEC which needs 2 or more.
- Easily configured to pass obstructions such as plug valves.