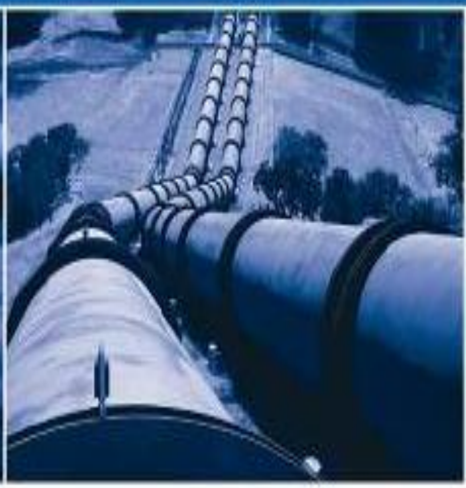
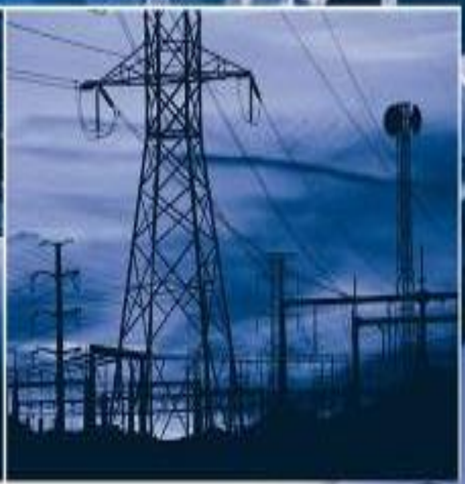
MRUT Overview





Wall-loss due to corrosion and erosion is the main problem in pipelines and storage vessels

- Corrosion and environmental erosion are the main causes of failure in underground and above ground pipelines, and tank vessels. The cost of these failures is over 10 billion dollars per year just in the US

- Corrosion affects all types of tanks and pipelines, but corrosion level is dependent on the materials held/transported, the metallurgy of the vessel/pipeline, the environment, and the type of layout and protection used

- Underground pipelines comprise the majority of long-distance transportation. Even though the inspection requirements are increasing, most underground pipelines are not inspected

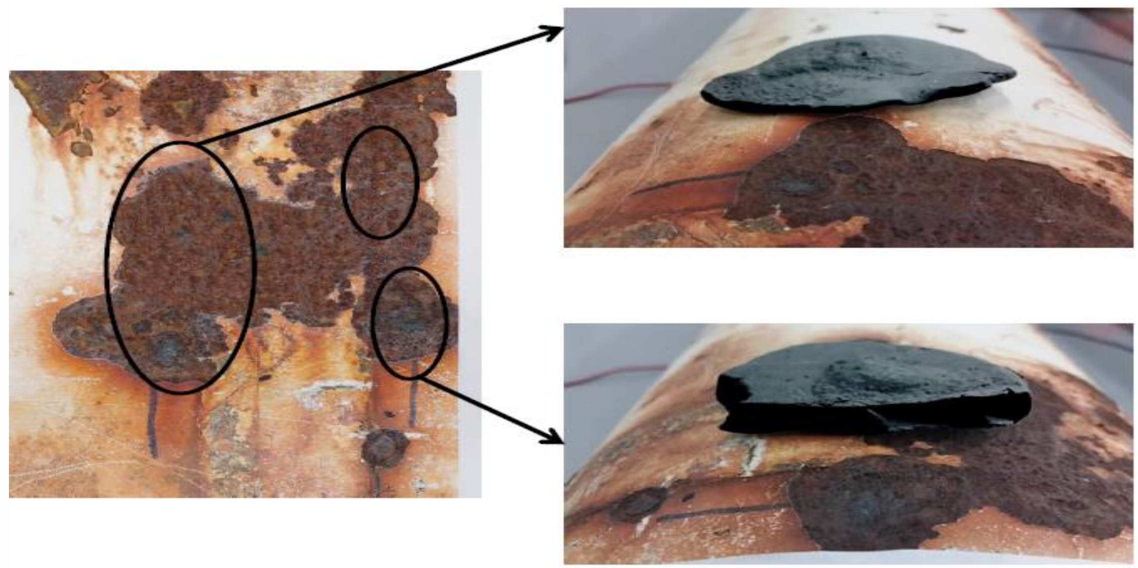
- Above ground pipelines are mostly used in short distance transportation for process piping, oil and gas terminals, barges, bridges and aerial crossings

- Above ground piping and storage vessels have more stringent inspection requirements due to the increased safety hazard associated with their operation

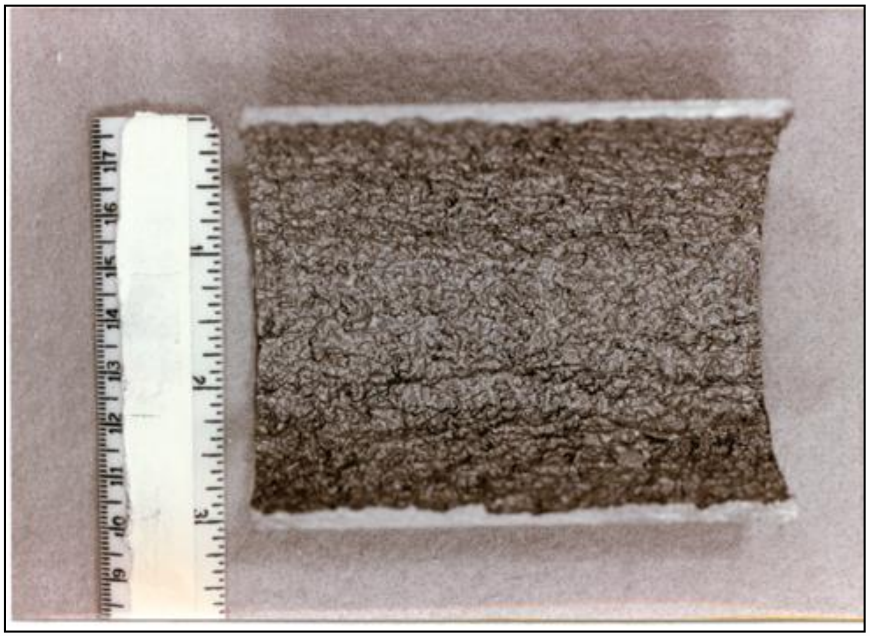
Corrosion in pipelines are classified by common types

Corrosion Types:

- Generalized Corrosion
- Pitting Corrosion
- Galvanic Corrosion
- Microbiologically Influenced Corrosion (MIC)

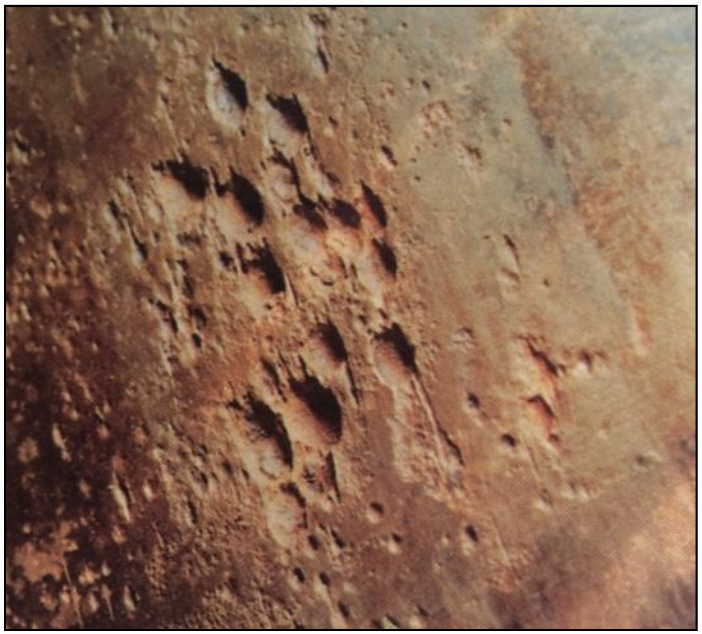


General corrosion is irregular metal loss over a broad area.



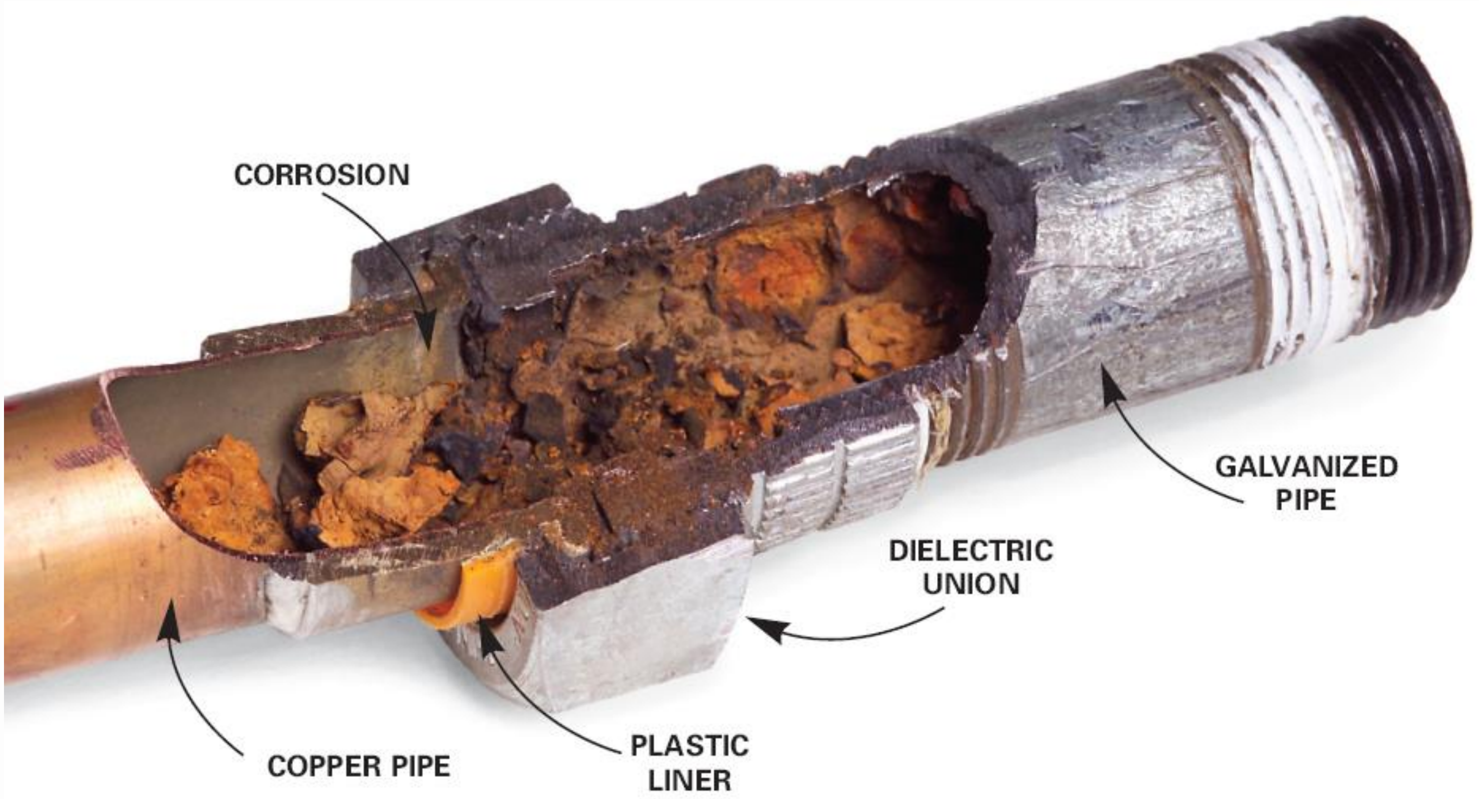
This type of corrosion is often caused by insufficient CP or a disbonded coating with soil or water ingress. This may occur internally and/or externally.

Pitting corrosion is the presence of metal loss in isolated pits, which can be sharp-sided and deep



This type of corrosion is generally due to localized coating damage or ineffective CP. It may also be caused by MIC, isolated exposure to moisture, and certain types of CP faults.

Galvanic corrosion (also called bimetallic corrosion) is an electrochemical process in which one metal corrodes preferentially to another when both metals are in electrical contact, in the presence of an electrolyte



Microbiologically influenced corrosion (MIC) is corrosion that occurs or is accelerated by the presence of bacterial colonies on the pipe wall.

These bacteria do not consume the pipe material, but rather create an electrochemical environment that makes the localized pipe anodic, thus inducing corrosion and metal loss. This generally leads to pitting corrosion and can occur on the OD or ID.

Other sources/types of corrosion in pipelines

- Damage and Corrosion
- Erosion Corrosion
- Stray Current Corrosion
- Weld Area Corrosion
- Condensation and Corrosion
- Pooling and Corrosion
- Grooving and Corrosion
- Drip and Crevice Corrosion

Other pipeline defects which can cause failures

Pipeline Defects:

- Gouges and Dents
- Buckling
- Ruptures and Tearing
- Erosion
- Hydrogen Induced Cracking (HIC)
- Stress Corrosion Cracking (SCC)
- Weld Defects
- Coating Defects
- Manufacturing Defects

There are a number of tools designed to inspect for corrosion, with special emphasis on above-ground pipelines and storage tanks

Location of Pipeline/Vessel	Use	Problem	Cause	Inspection Tools
Underground	• Long Distance Transportation	• ID Corrosion • SCC	• Sedimentation	• PIG (MFL, UT or EMAT). Limited to piggable pipes • LRUT (very limited)
		• OD Corrosion	• Moisture entrapment due to failure of protective layer	
Above-Ground	• Short Distance Transportation • Process Piping • Oil terminals • Barges • Bridges and aerial crossings	• ID Corrosion • SCC	• Sedimentation • Erosion or cracking due to liquid speed and pressure	• Laser • AUT • LRUT • LFET • MFL • EMAT UT
		• OD Corrosion	• Moisture entrapment under supports and in air-to-soil interfaces • Weather wear	

The MRUT (Medium Range UT) permits fast scanning of pipelines and storage tanks using guided waves

Characteristics:

- Detects cracks, pits and corrosion on pipes and tanks
- Axial scan provides circumferential, volumetric inspection of pipelines (including under supports) at fast inspection speeds (150mm/s)
- Circumferential scan permits inspection of supports and soil interfaces up to 3m deep
- In tank configuration, the system scans up to 1m per pass
- Custom scanners adapts to all configurations and can inspect in any orientation (horizontal, up, down or sideways)

The MRUT has unique advantages for the in-service inspection industry

MRUT Advantages:

- Inspection near supports, flanges, branches, and other structures is possible
- Much better circumferential and axial resolution than LRUT
- Much smaller dead zone than LRUT
- Inspection of nearly any pipe size is possible with the correct probe
- The MRUT technique can allow for the inspection of pipeline sections that would otherwise be very difficult or expensive to access for other inspection techniques

Comparison of the most common inspection alternatives for corrosion screening

Technique	Effectiveness	Conclusion
Laser	• Provides accurate surface measurement of OD erosion when pipe is exposed	• Simple and limited alternative for visible OD erosion
Automated UT (AUT)	• Users X-Y scanner and normal beam probe/s to provide very accurate wall thickness measurement • The probe/s need to have direct access to the area of pipe/tank inspection	• Very slow inspection, time consuming and expensive • Unable to inspect under pipe supports and air-to-soil interface • Good technique in smaller sections with know problems
Long Range ultrasonic (LRUT)	• Users two rings of transducers to send sound along the pipe. It can cover up to 50 m from one location • Sensitivity is low (low frequency) and the results are hard to interpret because of the long distance covered. • It does not need direct access to the area of the pipe inspected	• Provides fast screening of long stretches of pipe • Range drops dramatically when the pipe is buried • Difficult to use in areas where many variables are present • Low sensitivity and difficult interpretation limit its validity • Used normally when no other method is possible (e.g. buried, un-piggable pipes)

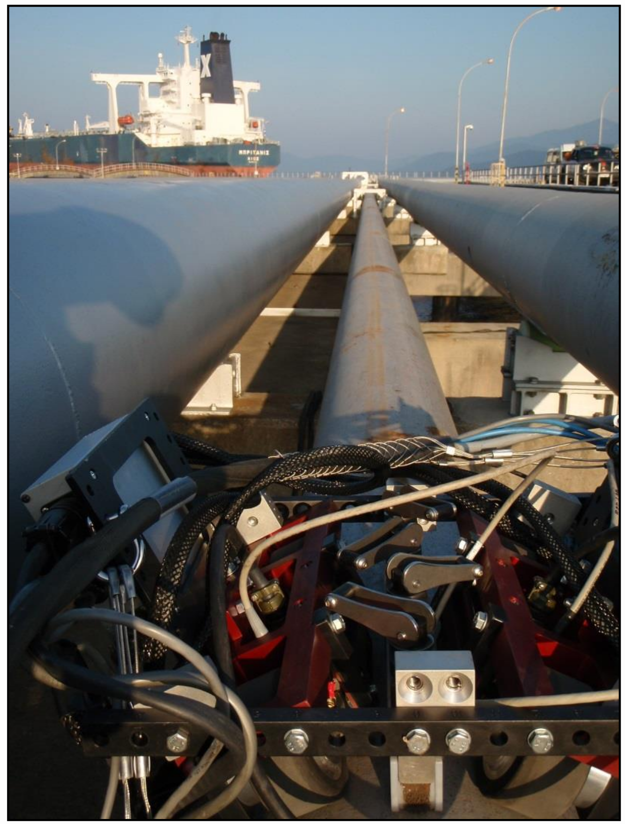
Comparison of the most common inspection alternatives for corrosion screening

Technique	Effectiveness	Conclusion
LFET	• Low Frequency Electromagnetic Technique detects corrosion and wall loss on bare pipe and lightly coated pipes • Provides better resolution then LRUT and Less than AUT at fast linear speeds • It required direct access to the area inspected	• Effective for pipe inspection of long stretches of exposed pipe • Not applicable for under-pipe supports and air-to soil interfaces • Relatively difficult to field with up to 32 sensors for a 10” pipe
temate® MRUT	• Electro magnetic Acoustic Transducer technique detects corrosion and wall loss on bare pipe, lightly coated pipes and tanks. • Material can be ferrous and non-ferrous • Provides better resolution than LRUT and less then AUT at fast linear speeds • Symmetric and Asymmetric modes provide focus on different section within the pipe wall as needed • It does not require direct access to the area inspected	• Effective for pipe inspection of long stretches of exposed pipe • Capable of inspecting under pipe supports and air to soil interfaces (1.8 m into the non-accessible area) • Uses only 2 sensors with up to 75m sensor to equipment distance

The MRUT is available in either hand-held or automated configuration

MRUT Automated:

- Sensor Assembly
- Remote Box
- Innerspec PowerBox 2
- Innerspec PowerBox MP
- Data Acquisition with Software
- Cable Bundle



The MRUT is available in either hand-held or automated configuration

MRUT Hand-Held Axial :

- Innerspec PowerBox H
- Signal Conditioning Box
- Sensor Assembly
- Cables

MRUT Hand-Held Circumferential :

- Innerspec PowerBox H
- Signal Conditioning Box
- Sensor Assembly
- Cables

MRUT Guided Waves

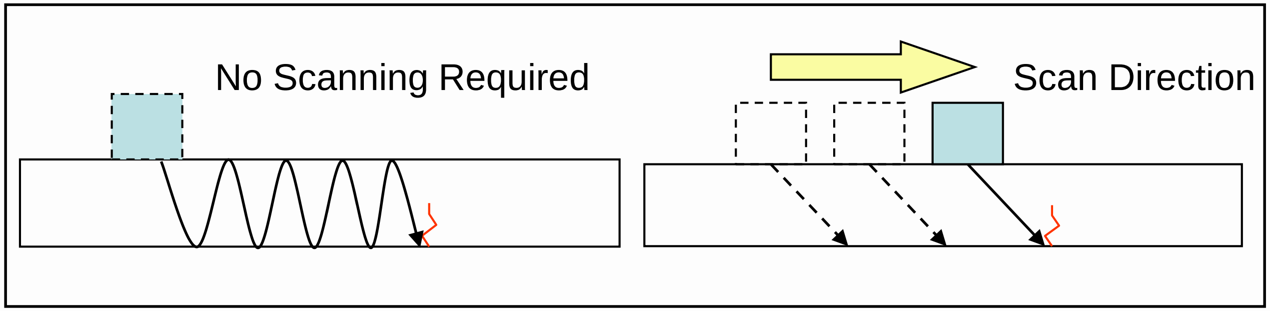
Ultrasonic Waves can be classified as Bulk or Guided Waves

- **Bulk Waves**
  - Wavelength of the waves is small compared to dimensions of the objects under inspection
  - Does not require a material boundary to propagate
  - Longitudinal, Shear- Velocity primarily function of material properties
- **Guided Waves**
  - Requires interaction of one or more material boundaries to propagate
  - Wavelength is typically in the order of the wall thickness or larger
  - Surface wave (Rayleigh waves) – Propagate along a surface, velocity primarily function of material properties
  - Shear horizontal waves (SH-Waves) – Propagate along a waveguide, velocity primarily function of material properties, frequency and thickness
  - Lamb waves – Propagate along a wave guide, velocity primarily function of material properties, frequency and thickness

Inspection with Guided Waves Vs. Bulk Waves

Characteristics:

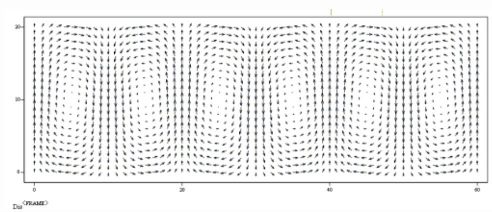
- Guided Waves fill up the entire volume of material and do not require scanning in the beam direction.
- The wave follows the curvature of the pipe making possible the complete inspection of the circumference from one location
- Bulk Waves require the scanning of the entire pipe surface with the probe for flaw detection.



The temate® MRUT-A uses Guided (Symmetric and Asymmetric) Lamb Wave Modes for inspection.

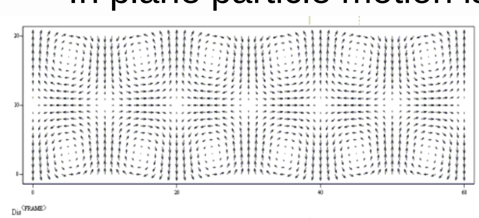
Characteristics:

- Wave propagates in a plate, tube or other thin structure
- Particle motion polarized perpendicular to the plane of plate
- Lamb wave velocity based primarily on wave mode, thickness of component, frequency of sound wave and material
- Dispersion Curves are necessary to determine phase and group velocity



Symmetric lamb mode

- Particle motion is symmetric relative to the middle of plate
- In plane particle motion is more dominant



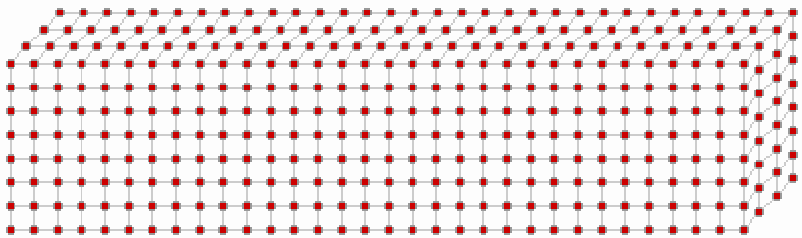
Asymmetric lamb mode

- Particle motion is asymmetric relative to the middle of plate
- Out of plane particle motion is more dominant

The temate® MRUT-C uses Guided Shear Horizontal (SH) Wave Modes for inspection.

Characteristics:

- Wave propagates in a plate, tube or other thin structure
- Particle motion is perpendicular to wave direction on a horizontal plane
- Multiple modes in a given thickness of material. But, the first order SH0 mode is independent of thickness variations with a constant
- SH waves tend to be less ‘leaky’ into surrounding surfaces



Shear Horizontal

- Particle motion is symmetric relative to the middle of plate
- In plane particle motion is more dominant

MRUT-A

The MRUT-A provides corrosion detection scanning results at speeds up to 150mm/s.

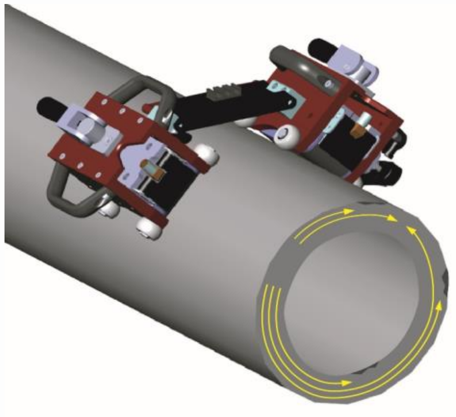
The MRUT-A equipment requires 4 items in addition to the PowerBox H instrument

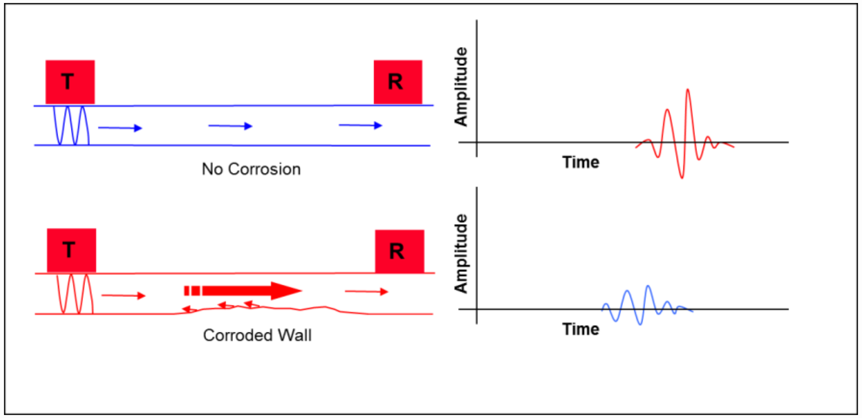
1. MRUT-A Scanners
2. Foam
3. Coils
4. T/R Cables
5. Encoder Cable

The attenuation technique is used for corrosion mapping (Pitch-Catch Method)

Axial Scanning:

- The Sensor travels axially straddling the OD of the pipe
- Transmitter sends waves around the pipe in both directions
- Corroded walls causes Time-Of-Flight shifts and decreases amplitude
- Time-Of-Flight shifts are caused by velocity changes when traveling through the thinner portion of the pipe
- Decreases in amplitude are caused by energy loss reflected from corroded areas
- 360º Scan of pipe with speed of approximately 150mm per second

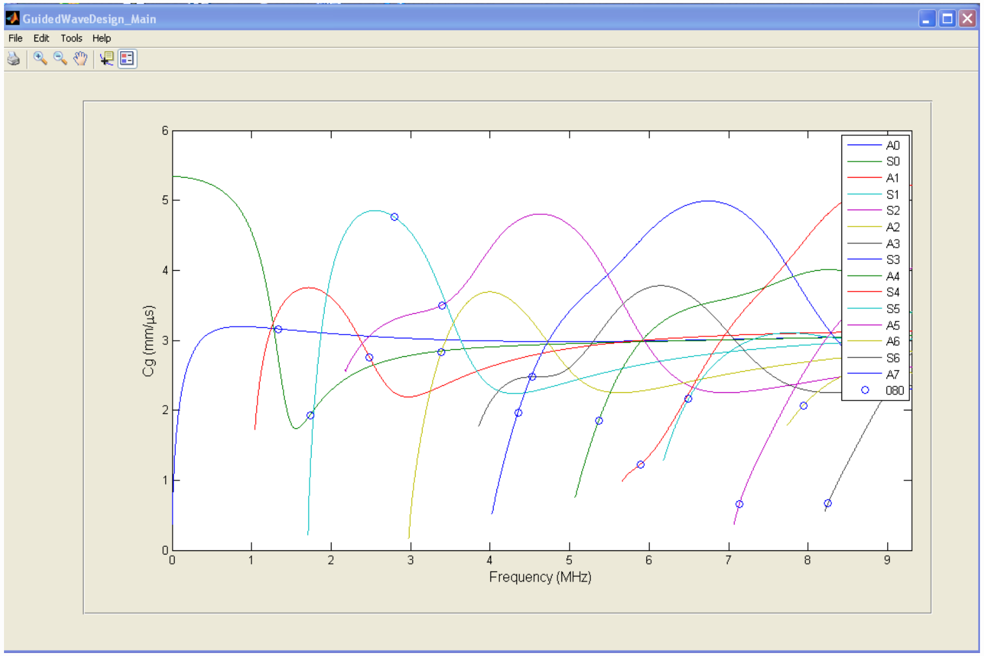




Selecting the proper lamb wave mode is critical to successful inspections

The behavior of the wave depends on the selected point of excitation due to possible dispersion and multi mode excitation:

- Sharp signals with high amplitude and narrow shape (less spread) are desired for better resolution
- The different frequency components that conforms the wave package may have different velocities resulting in the spread or elongation of the package after its propagation
- Due to the excitation bandwidth multiple modes can be excited at the same time
- Multi-mode excitation is not desired because the signal analysis becomes more complicated due to mode interferences



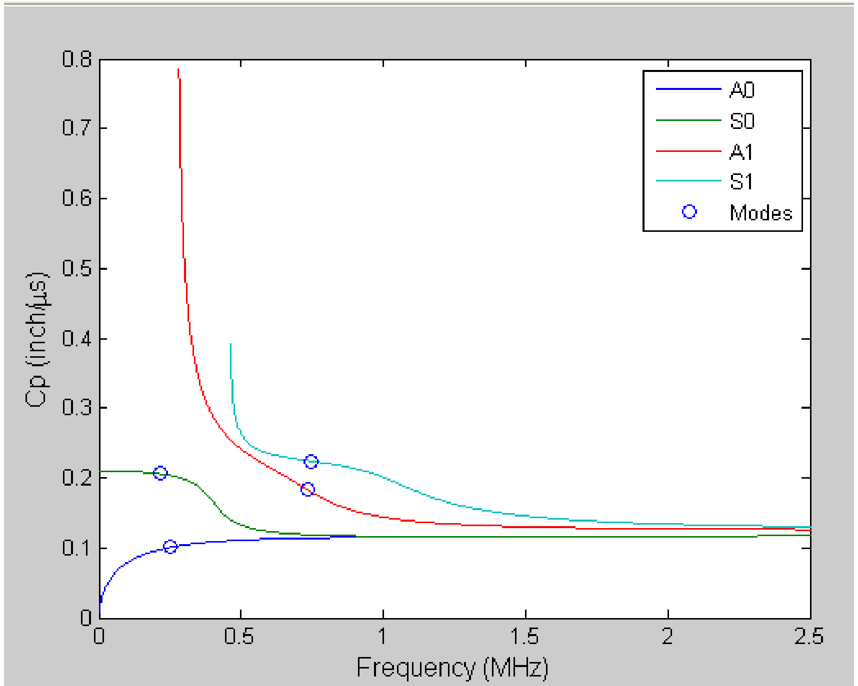
There are advantages and disadvantages of different modes

Mode	Advantages	Disadvantages
A0	- Strong excitability - Strong signal amplitude - Easy interpretation	- Due to strong out of plane particle motion strong reflections from welds - Due to strong out of plane particle good coupling with liquids and wrappings causing signal attenuation
S1	- Weak out of plane particle motion prevents coupling with liquids - Ideal for inspecting liquid filled tubes - Ideal for inspecting pipes with welded supports and joints	- Less excitable then A0 mode - Signal not as strong as A0 mode - Complicated signal analysis

The dispersion curves show the types of wave modes that can be excited in a given structure

Dispersion Curves:

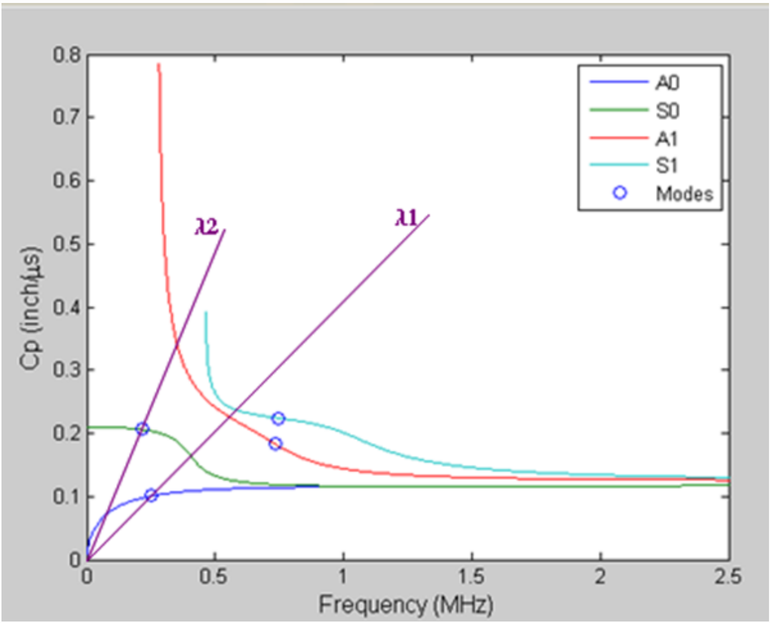
- Each curved line represents a wave mode
- Each point on the curve can be used for inspection
- The behavior and results will vary with each mode and point/frequency
- Appropriate mode and point/frequency selection is key for optimal results
- Dispersion curve plots change with material and thickness (Note: Curve shown only valid for thickness of 0.1" in steel)



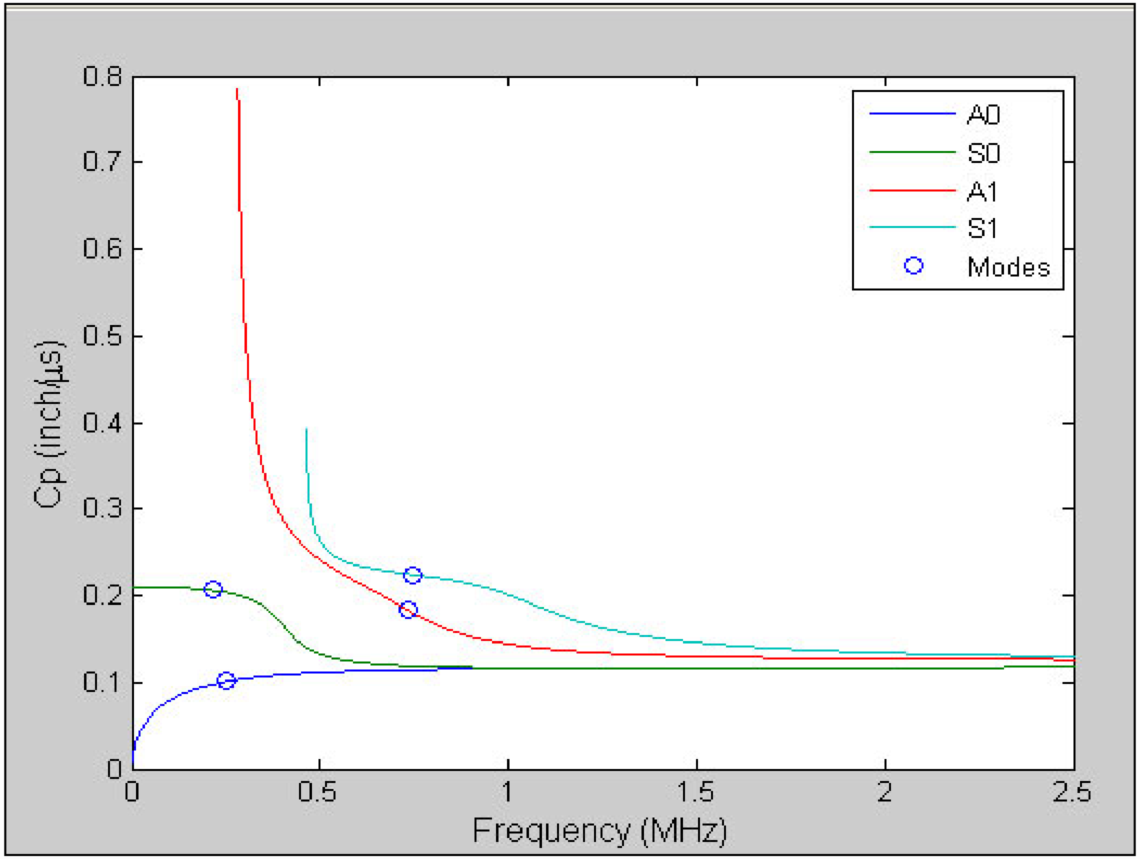
The dispersion curves show the types of wave modes that can be excited in a given structure

Example:

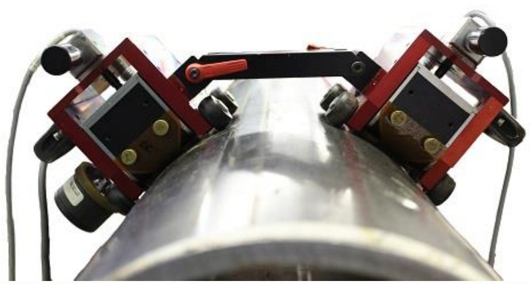
- EMAT probe with wavelength λ1 or wavelength λ2 operating at 250 kHz can generate two wave modes, with phase velocities of 0.1 in/us (A0) and 0.2 in/us (S0) respectfully
- Phase Velocity Dispersion Curves are used mostly for the design and selection of EMAT coils

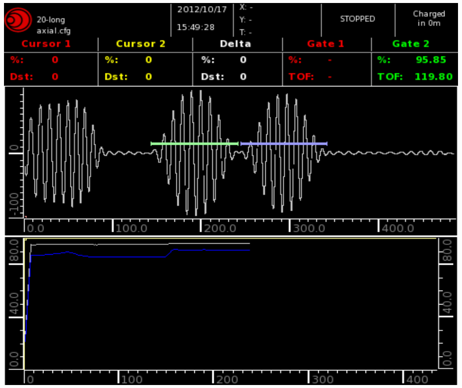


Different coils can excite different wave modes with different frequencies and phase velocities

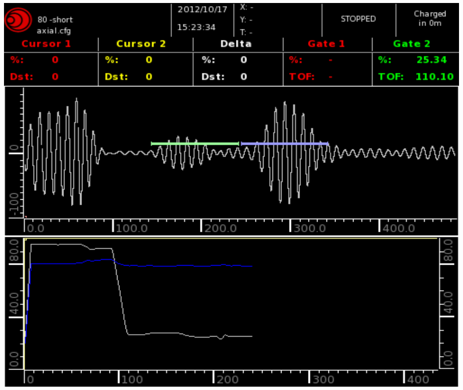


Attenuation is easily identified by observing the signals in the short and long path

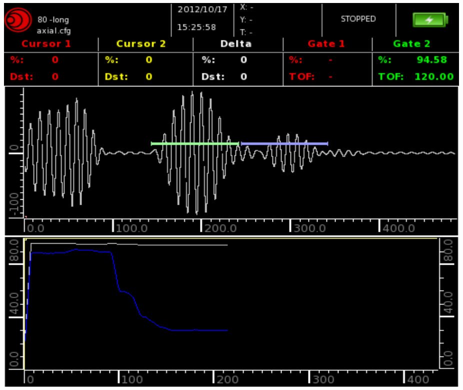




Clean area

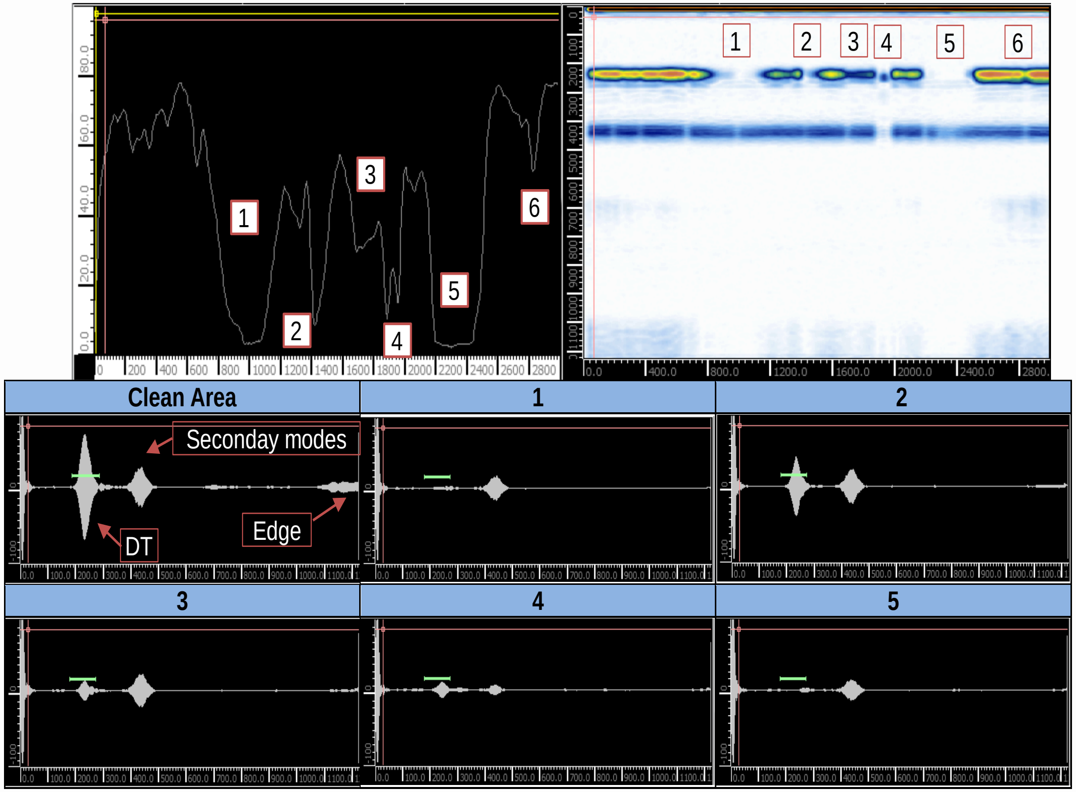


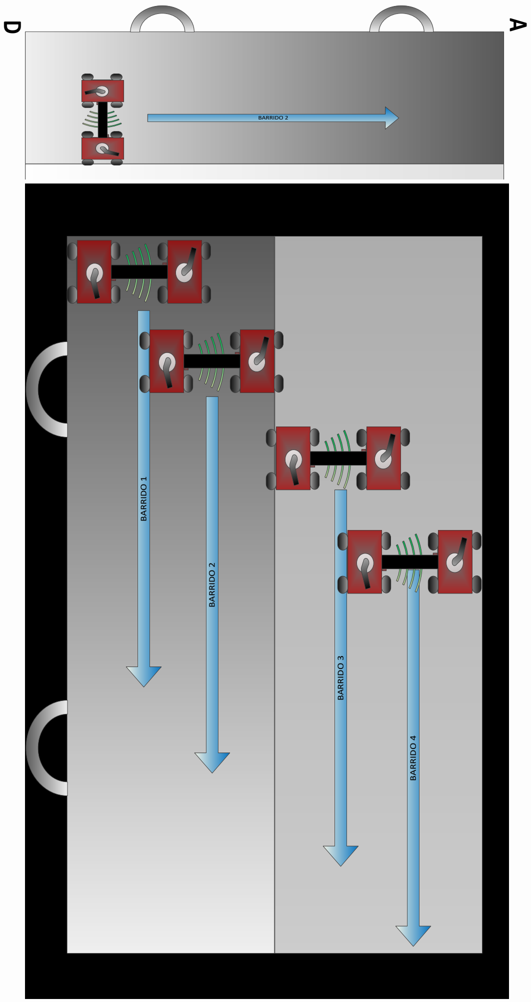
Short path attenuation



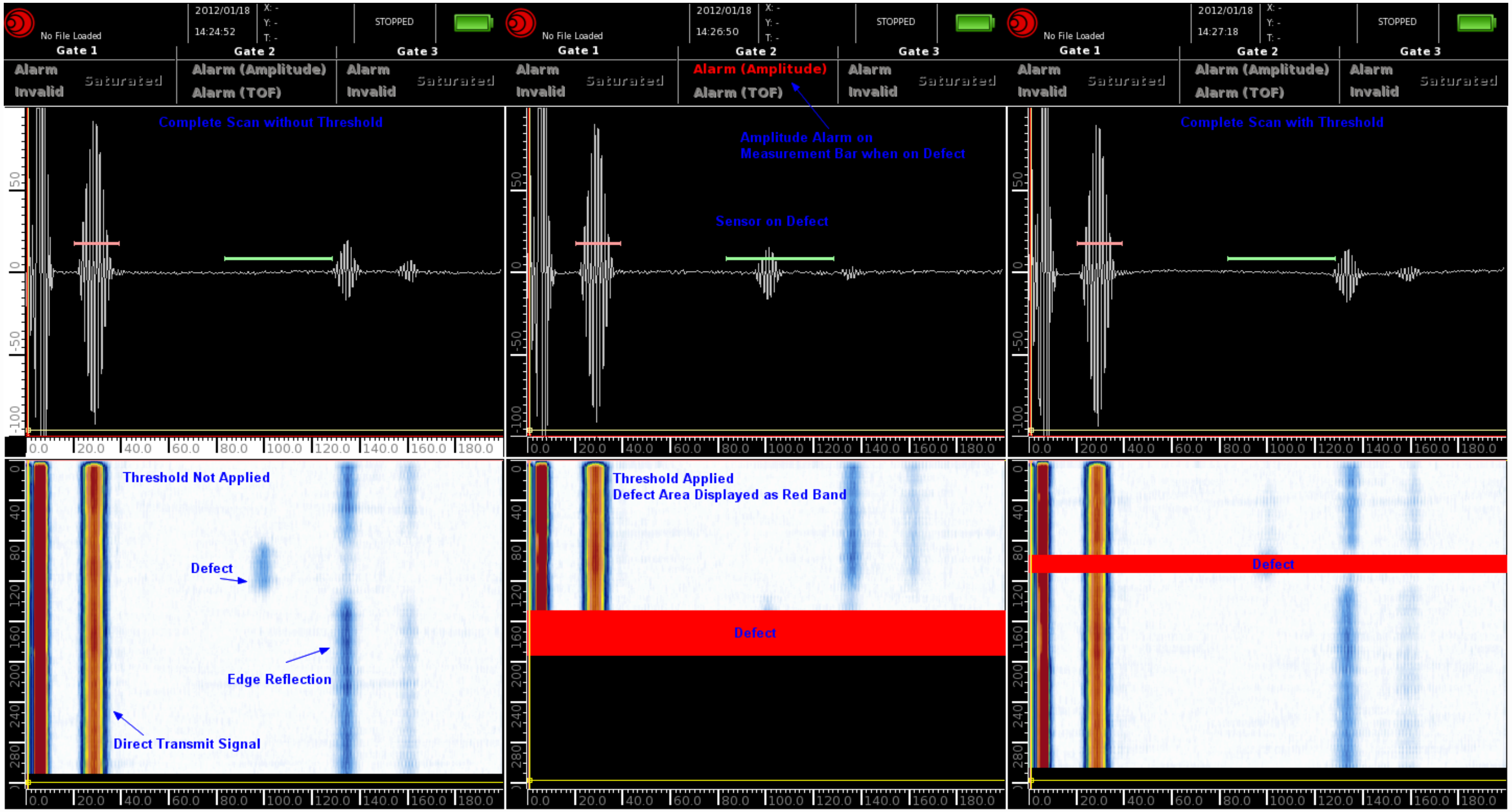
Long path attenuation

The MRUT–A scanner is ideal for pitch-catch inspection on flat surfaces

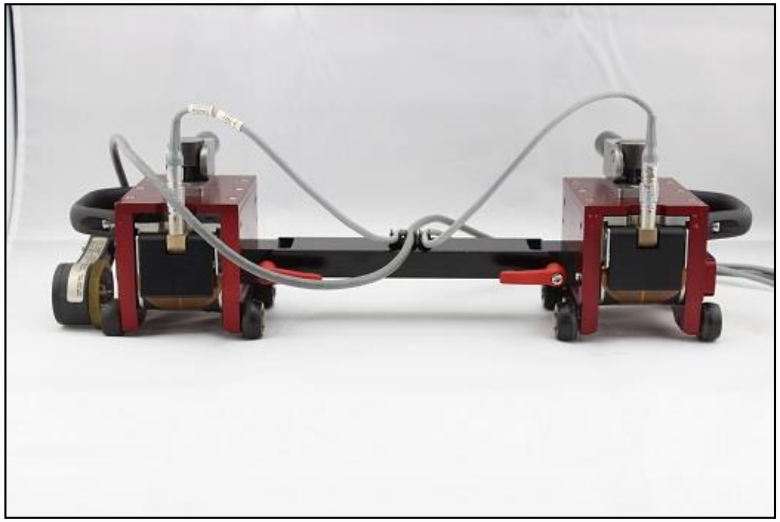


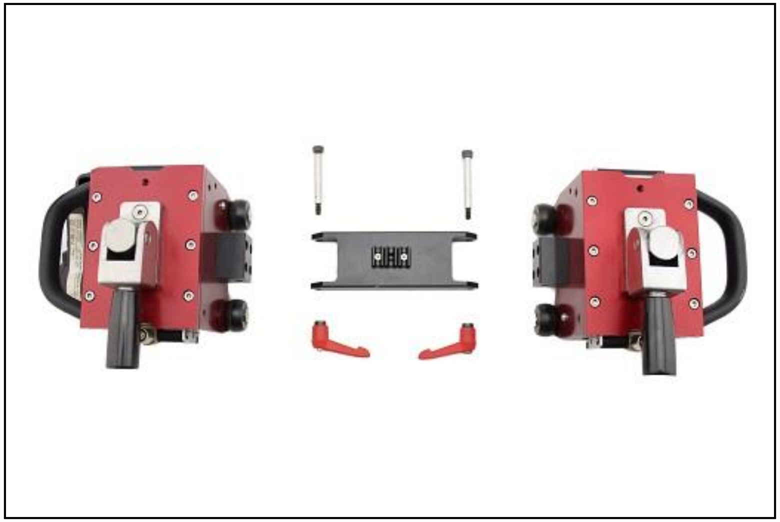


Preset thresholds can be set in correspondence with Gates to alert users of defects within the inspection area

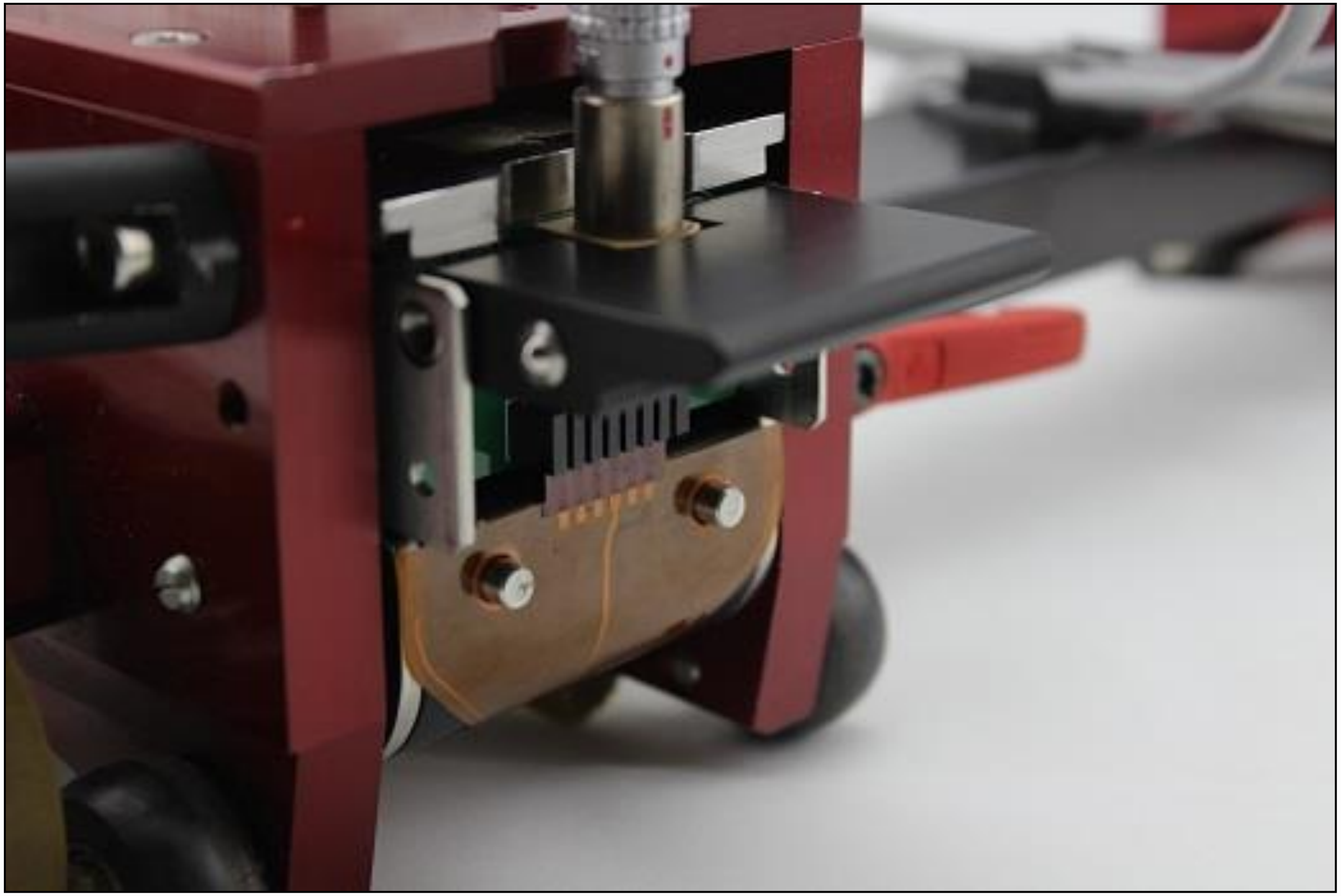


The MRUT-A Scanner assembly is designed to withstand harsh field environments

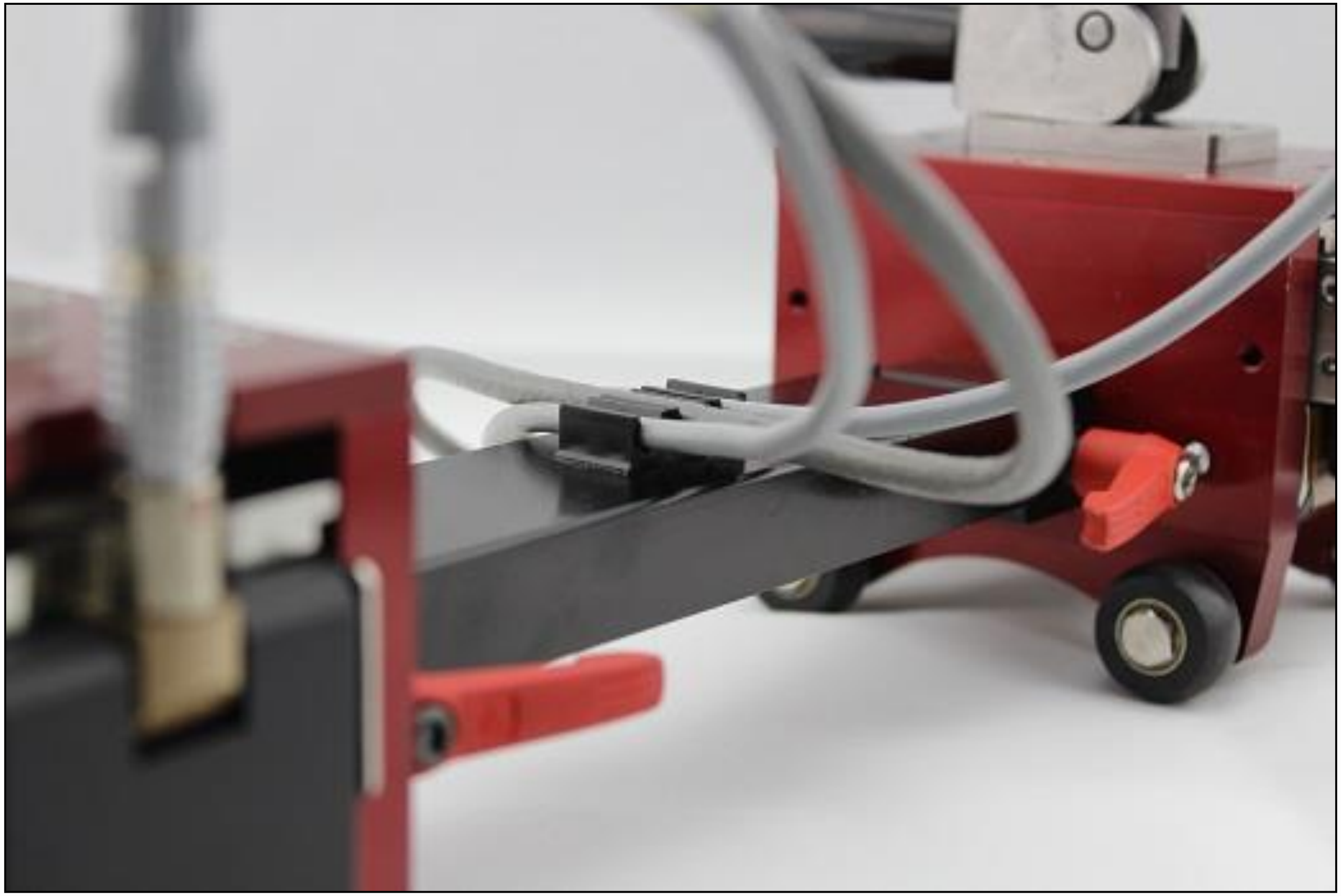




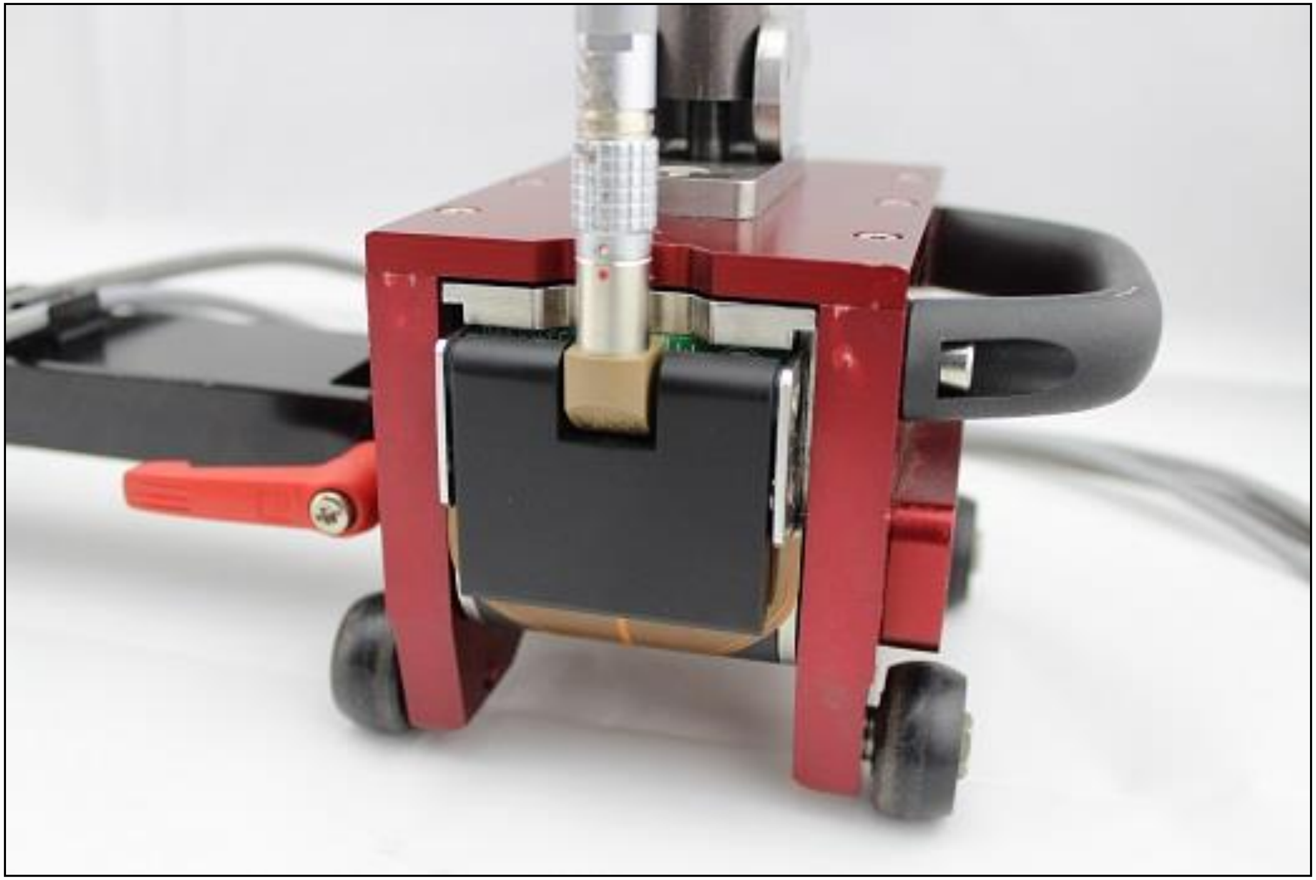
The scanner is designed for easy coil replacement



The cables can be attached to the arm to remove from scanning path



The wheels and magnets should be routinely cleaned for optimal performance and to remove loose particle buildup



MRUT-C

The MRUT-C provides high resolution results for corrosion detection up to 3m (118”) from the scanner.

The MRUT-C instrumentation requires five items in addition to the PowerBox H kit

1. MRUT-C Scanner
2. Magnetizer
3. Coil
4. T/R Cable
5. Encoder Cable

The MRUT-C is engineered for detection corrosion in areas previously difficult to inspect

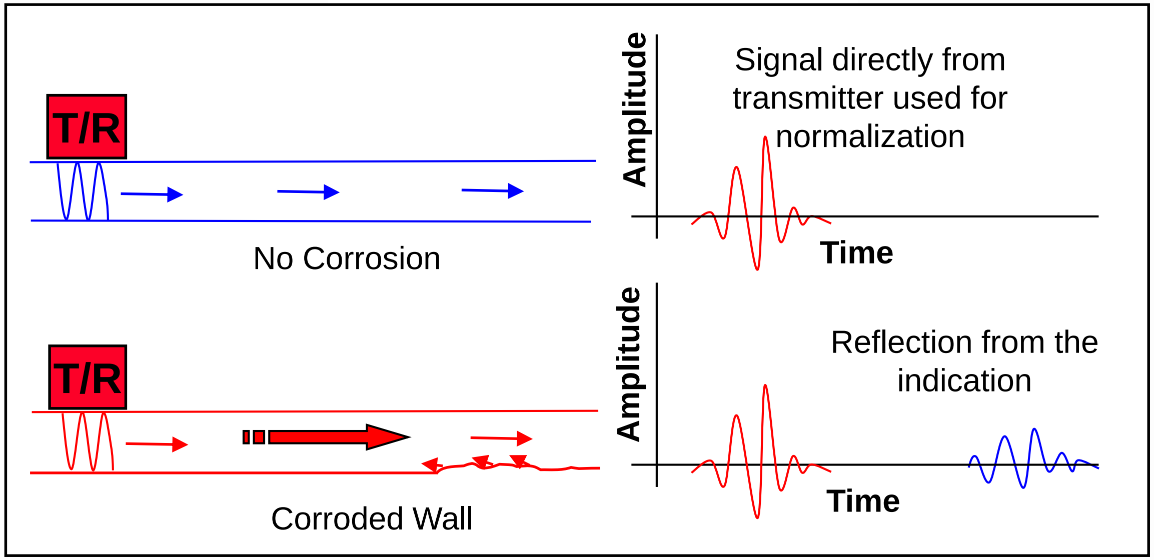
MRUT-C Applications:

- Corrosion under coatings
- Corrosion under insulation
- Corrosion under supports
- Corrosion near flanges, T's, branches, or other pipe features

The reflection technique is used for corrosion mapping (Pulse-Echo Method)

Circumferential Scanning:

- The Sensor travels circumferentially straddling the OD of the pipe
- The Sensor will detect reflections from defects along the material
- Indications are caused by energy being reflected from the defect back to the sensor.
- Results can be encoded and displayed with A, B, C, and Line scan options
- 360º Scan of pipe with speed of approximately 150mm per second

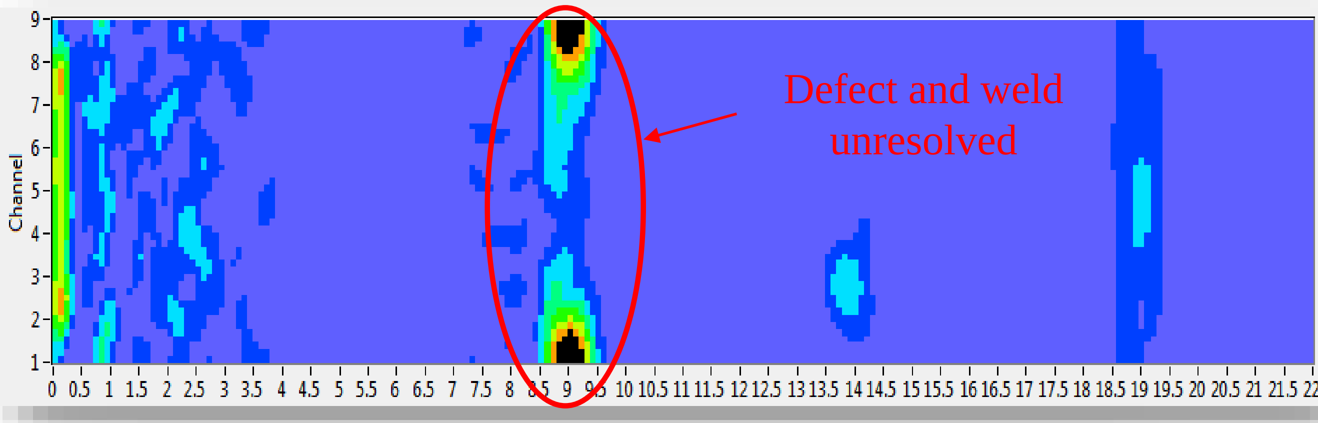


MRUT-C has unique advantages for In-service inspection

MRUT-C Advantages:

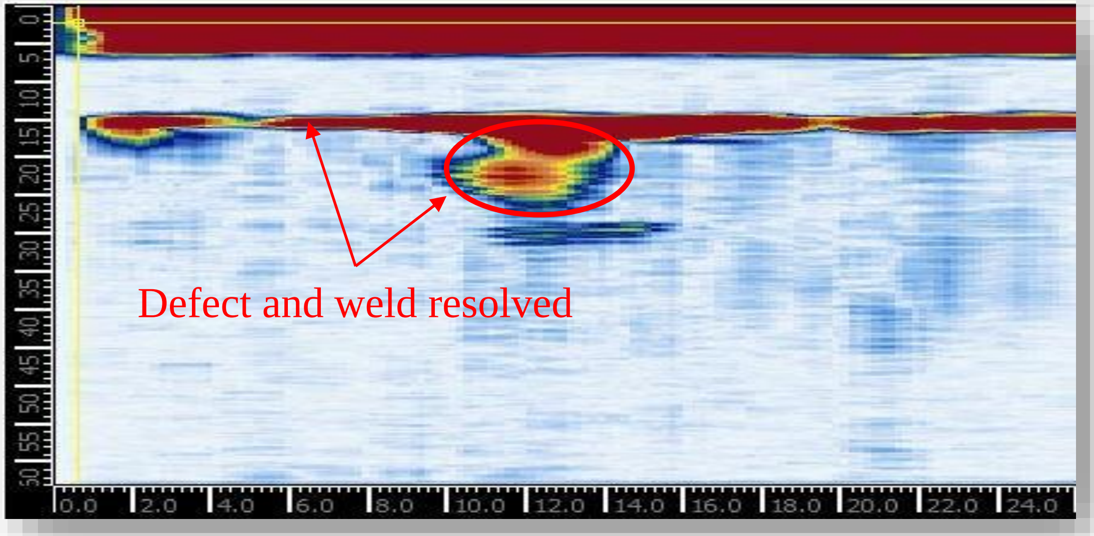
- Inspection beneath coatings, insulations, and inaccessible areas is possible
- Inspection near supports, flanges, branches, and other structures is possible
- Much better circumferential and axial resolution than GW LRUT
- Much smaller dead zone than GW LRUT
- Inspection of nearly any pipe size is possible with the correct probe
- The MRUT technique can greatly reduce the time and costs associated with pipeline integrity management
- The MRUT technique can allow for the inspection of pipeline sections that would otherwise be very difficult or expensive to access for other inspection techniques

MRUT-C provides higher resolution for circumferential scanning…



LRUT System

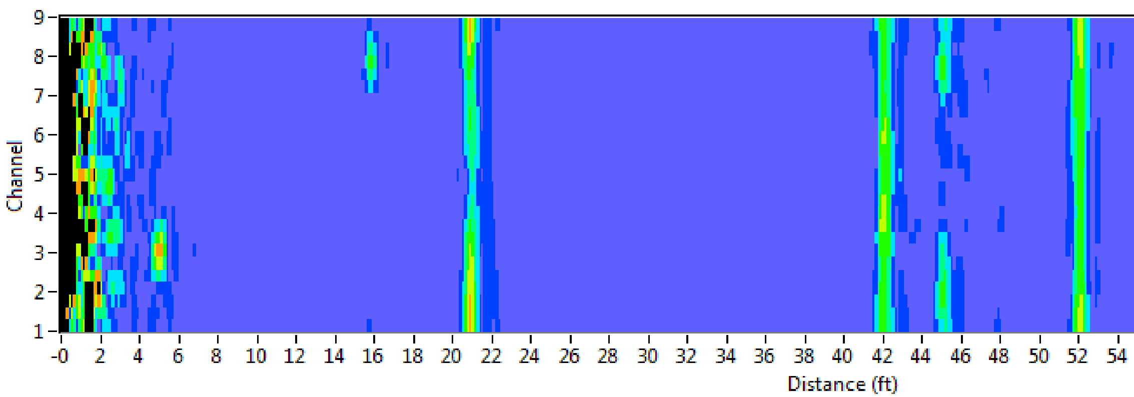
Axial resolution ≈ 4-12 cm



MRUT System

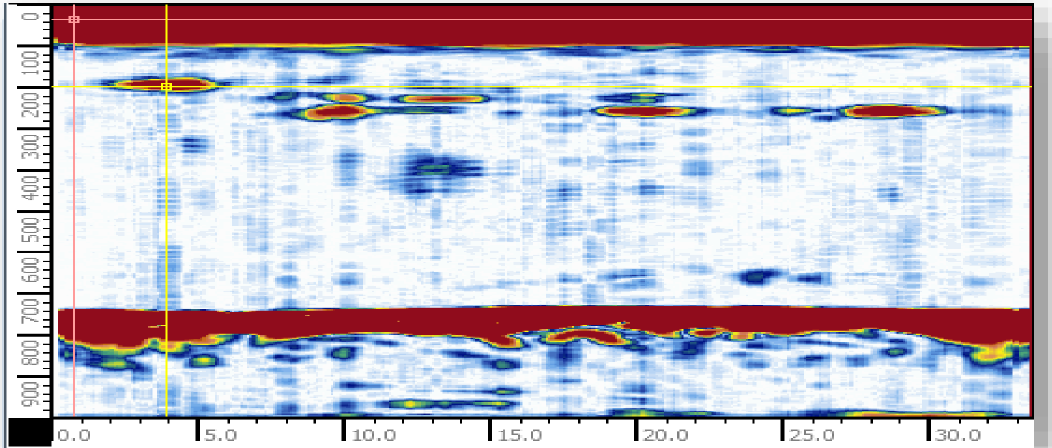
Axial resolution ≈ 1-3 cm

…and improved lateral resolution…



LRUT System

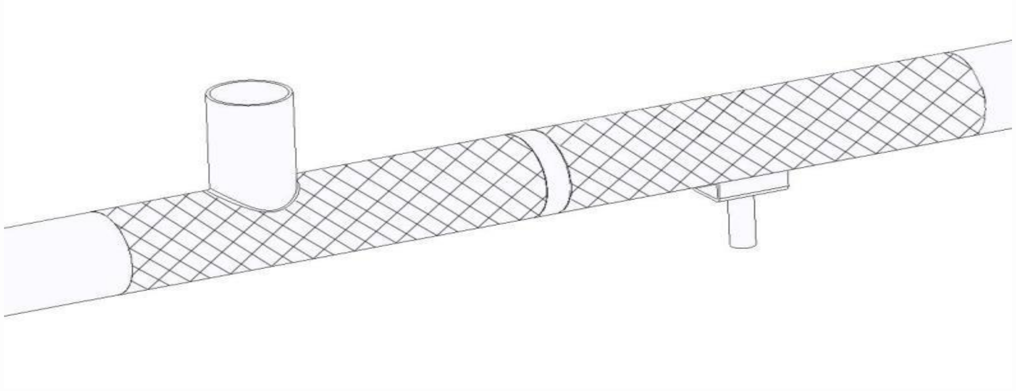
Lateral resolution ≈ 1/8th-1/16th pipe circumference



MRUT System

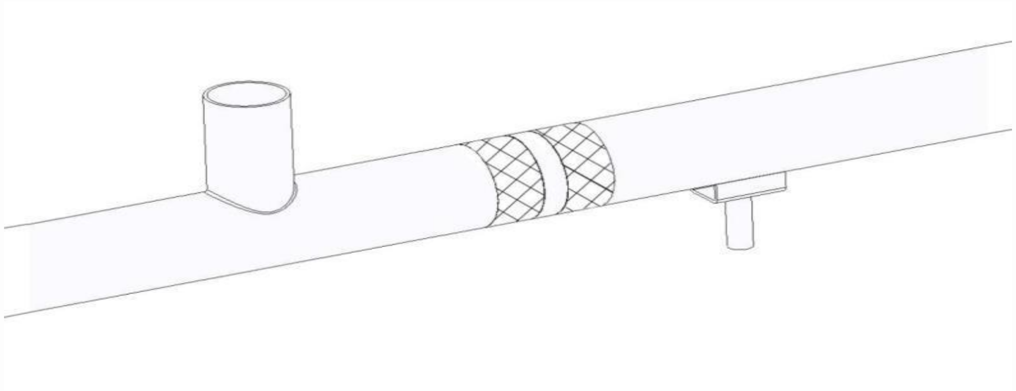
Lateral resolution ≈ 3-6 cm

…and shorter dead zone



LRUT System

Dead zone = 2-3m



MRUT System

Dead zone = 12cm or 5 inches

The MRUT-C strip material is created specifically for this unique application

Magnetostrictive Strip:

- The strip material used with the MRUT-C probe is highly magnetostrictive and must be well-attached to the pipe
- See the MRUT-C application sheet for full details
- The probe can be used to determine if the strip is properly bonded or not during the scan
- A magnet is used to magnetize the strip prior to scanning

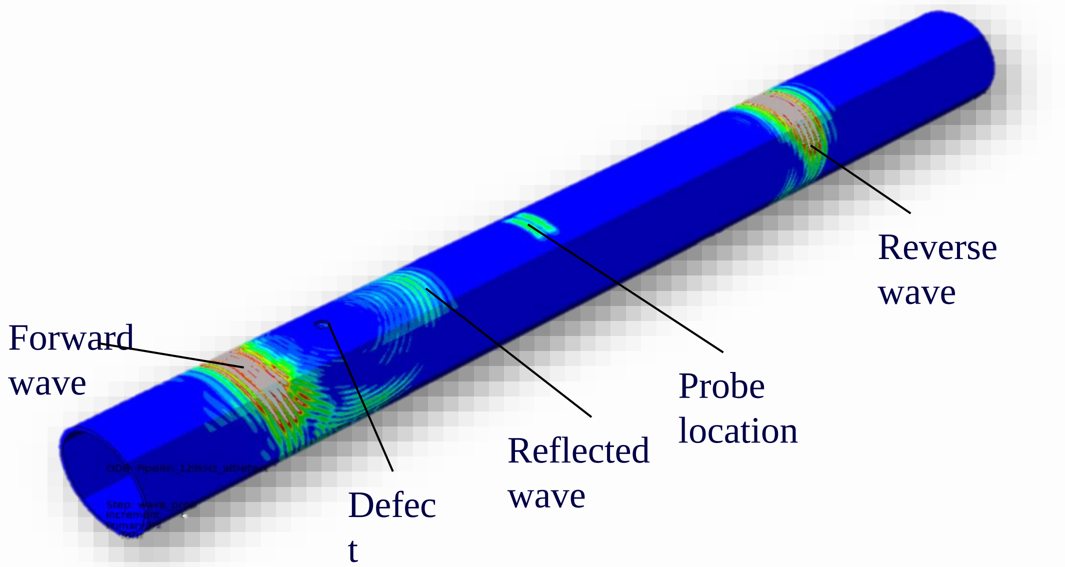
Strip

Magnet

The MRUT-C uses EMAT pulse-echo configuration

Pulse-Echo:

- Probe sends guided wave pulse down axis of pipe
- Any defects, welded supports, or other features reflect some energy
- The reflected energy travels back to the probe and is detected
- The software uses the velocity and arrival time of the wave to determine its distance from the probe
- The probe is moved and this process is repeated



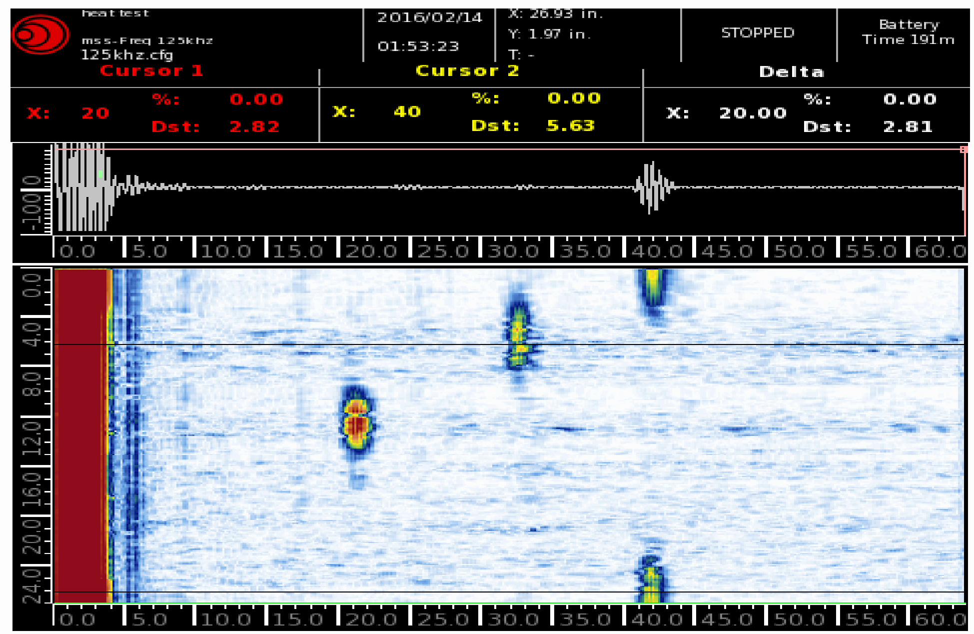
MRUT-C Software and Equipment Overview

Example : MRUT–C scanner in pulse-echo configuration for circumferential scan

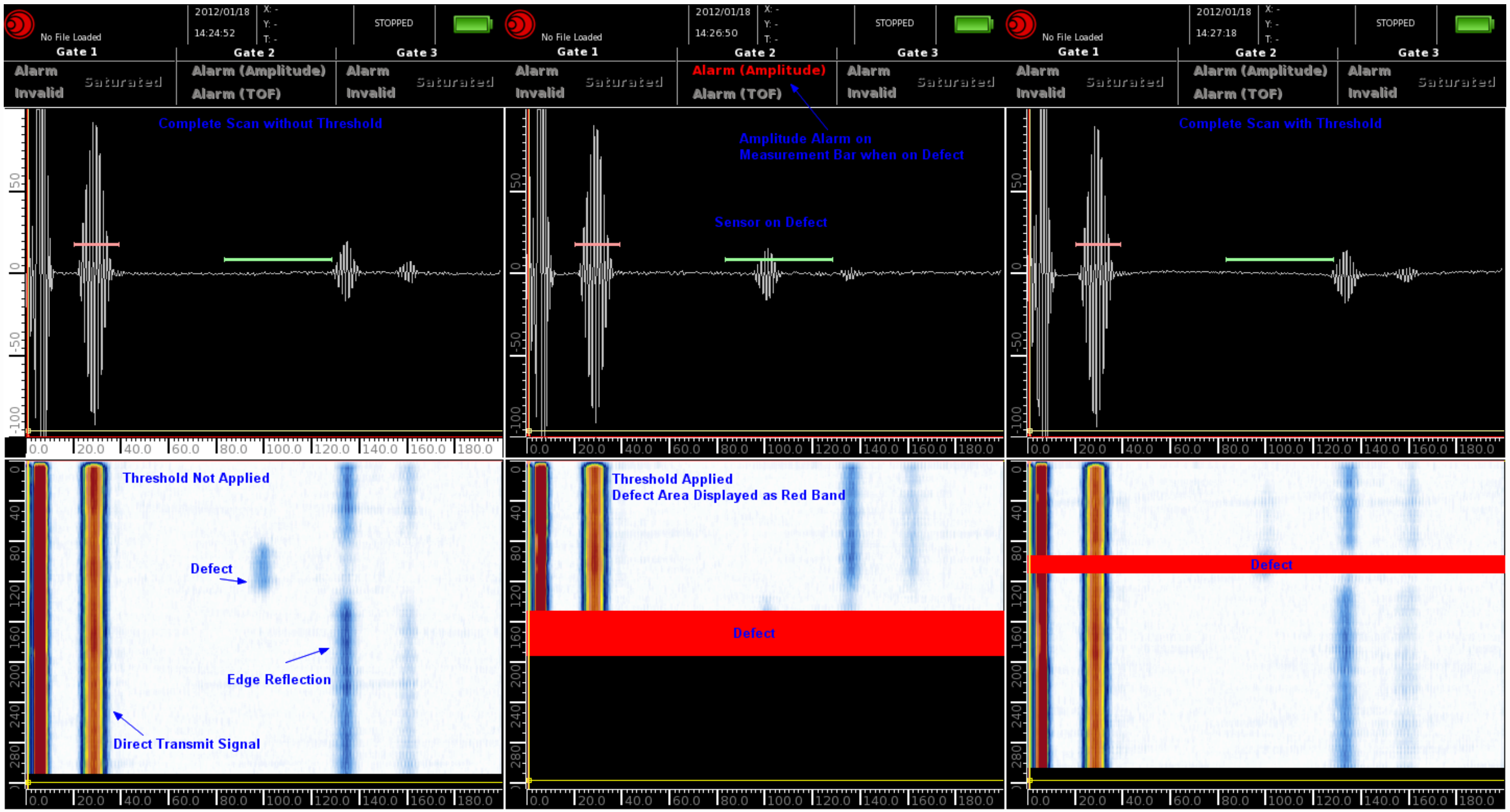
MRUT-C provides the operator with real-time information about the inspection

Circumferential Pipe Scanning (Reflection):

- Defect reflections are displayed when the sensor is operating in Pulse/Echo configuration
- The waveform and defects can be displayed on A-Scans, B-Scans, and strip charts
- Signal Reflection indicates a defect located in-line with the signal path



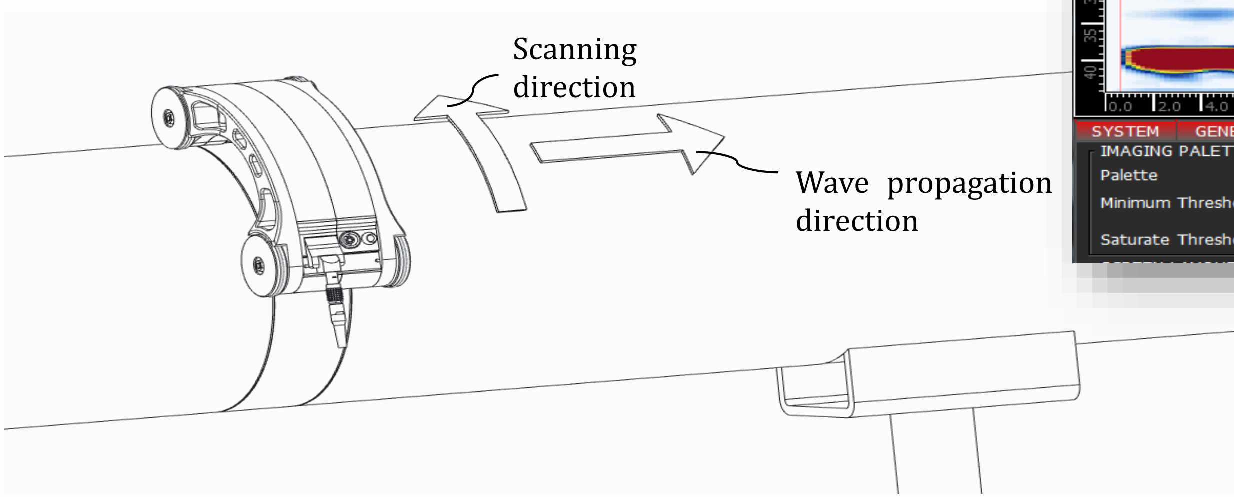
Preset thresholds can be set in correspondence with Gates to alert users of defects within the inspection area

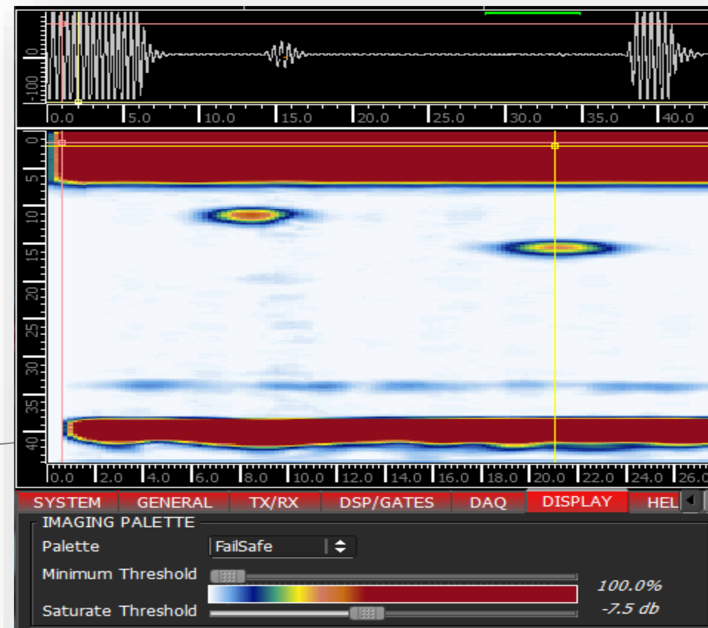


The MRUT-C Scanner uses EMAT for high resolution, repeatable results

MRUT-C Features:

- Magnetostrictive scanner
- Provides higher defect resolution than LRUT
- Inspects hidden or inaccessible regions
- Generates a simple 2D scan image

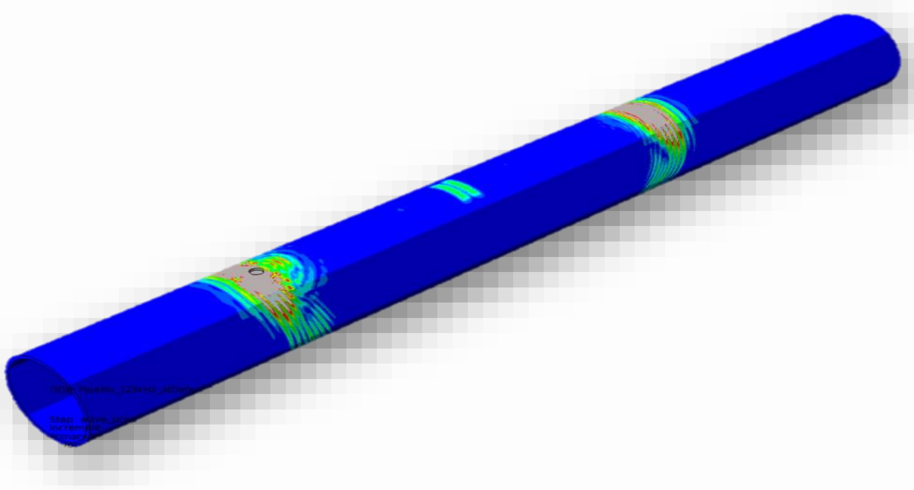




The encoder can be used to better locate defect areas on the circumference of the pipe

MRUT-C Encoder

- The encoder is the wheel attached to the side of the probe that allows the software to know the position of the probe around the pipe as it collects the data
- The encoder allows the probe to be moved forward or backward to collect data, which will be immediately displayed on the screen



The MRUT-C Scanner assembly is designed to withstand harsh field environments

The scanner is designed for easy coil replacement

The magnetizer conveniently fits into a pocket on the side