Applications of Magnetostrictive Sensors for Guided Wave Screening of Heat Exchanger Tubing



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Southwest Research Institute

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BIO

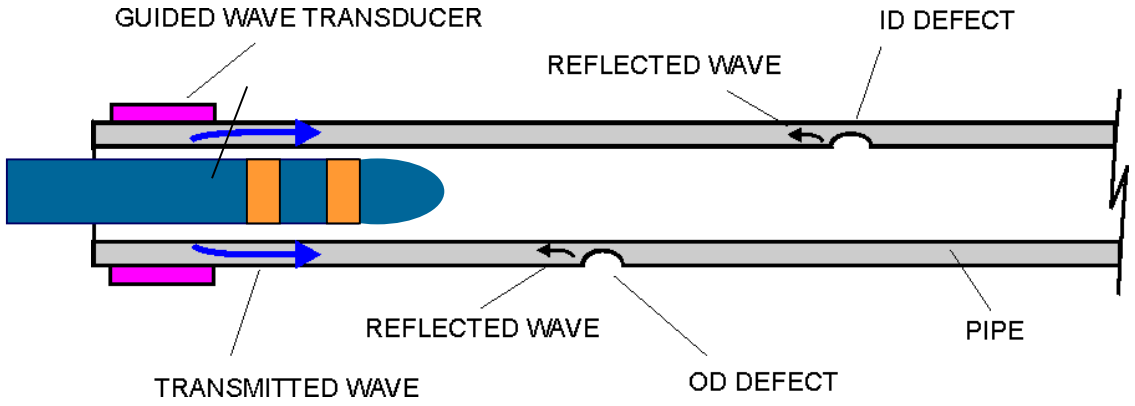
- Sergey Vinogradov, Ph.D. in Mechanical Engineering
- Staff Engineer at Southwest Research Institute, Structural Engineering Department
- 32 Years in NDE, last 22 years developing guided wave testing methods based on Magnetostrictive Transduction
- Pioneered high power Magnetostrictive Transducers (MsT)
- Earned 32 patents, including 12 patents in the USA
- Level III Trainer in Magnetostrictive Guided Wave Testing Method
- Recipient of 2018 ASNT Research Recognition for Innovation Award

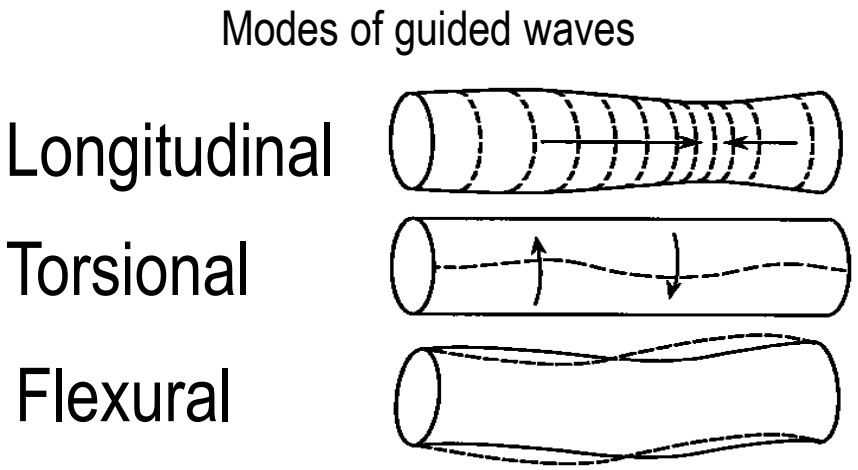
Agenda

- Concept of Guided Wave Testing
- Selection of Guided Wave Mode for Heat Exchanger Tubing
- Magnetostrictive Sensors Physics
- EMAT Probes for Carbon Steel
  - Application Examples
- MsT Probes
  - Dry Coupled MsTs With Bladder
  - EMAT MsTs for Duplex® and SeaCure® Tubing
  - EMAT MsTs with Natural Focusing Function
  - Application Examples
- Summary

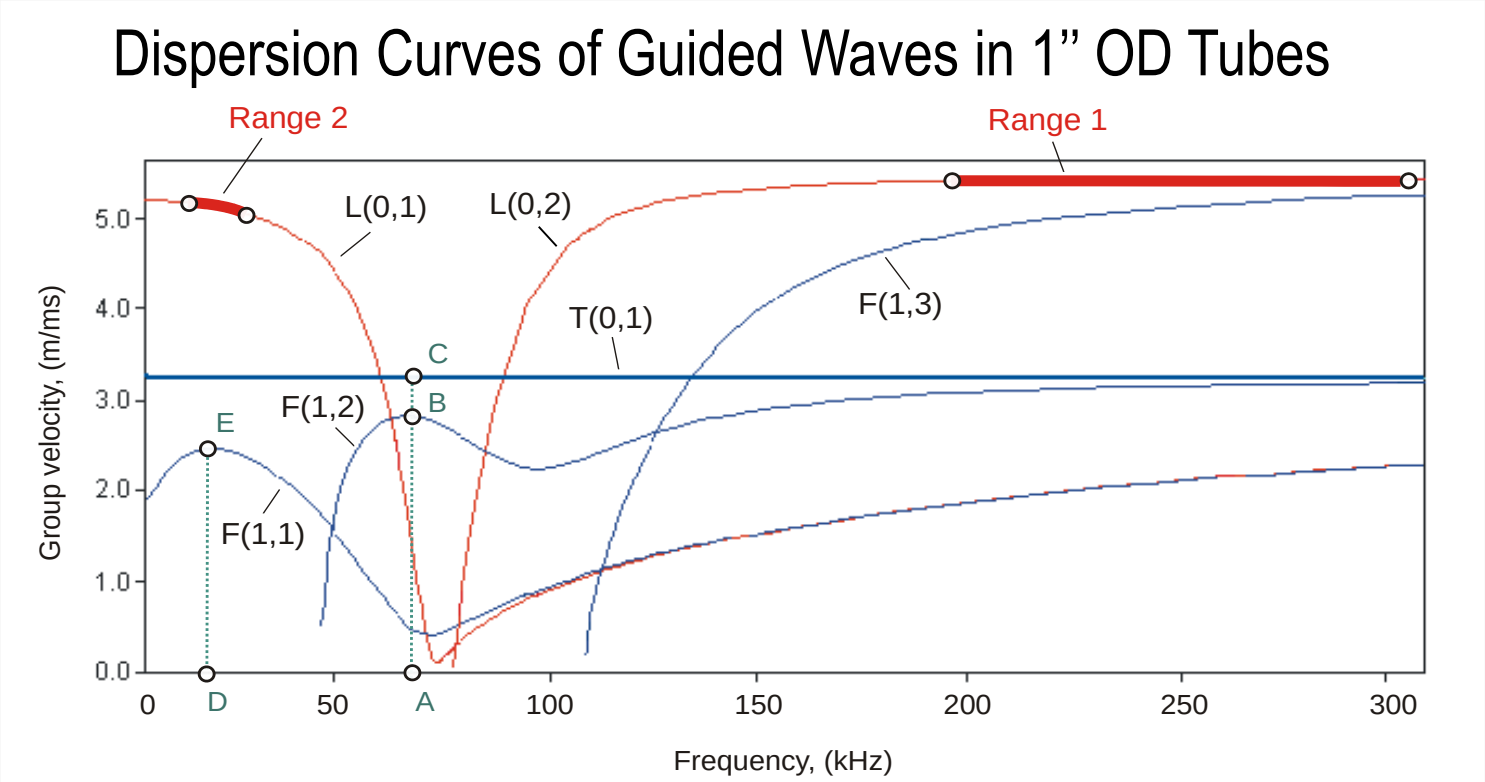
Guided Wave Testing Method

- The concept of rapid screening of heat exchanger tubing using guided wave testing has utilized the capability of guided waves to travel long distances (up to 100 feet) in the components essentially without attenuation
- The guided wave is generated in the tube wall by inserting a probe into the tube from one end approximately 30 cm to 60 cm
- Guided waves generated by the probe are mechanically or electromagnetically coupled to the tube wall





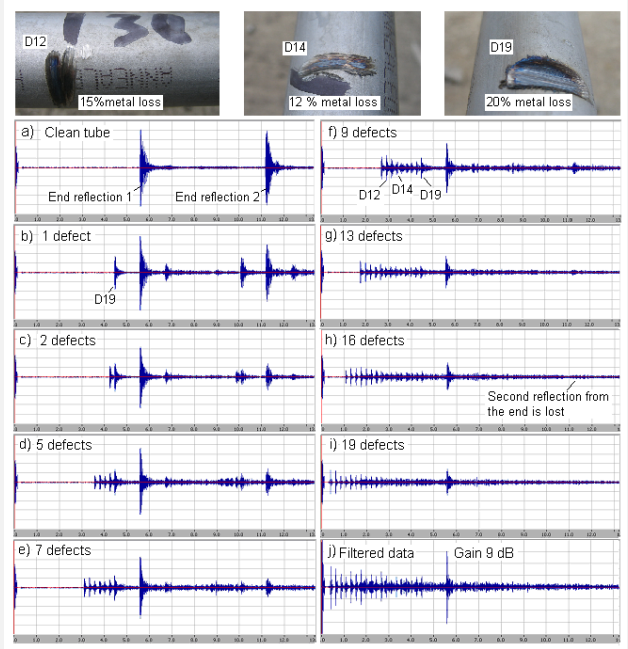
Selection of Guided Wave Mode



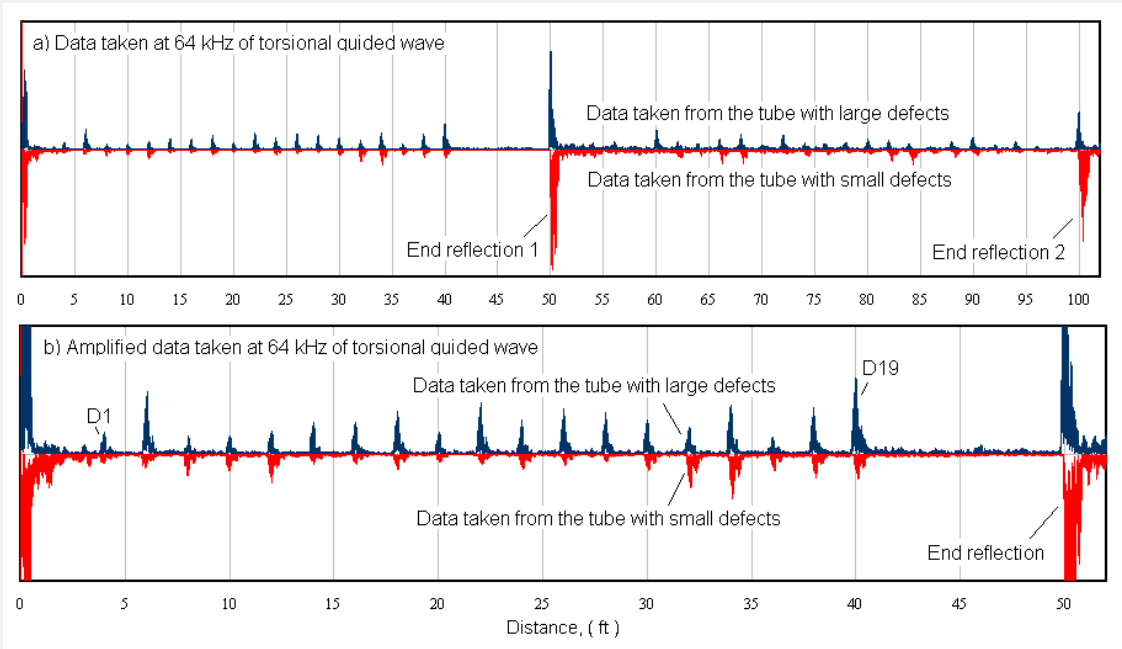
- Based on guided waves dispersion characteristics, a fundamental T(0,1) mode as well as L(0,1) and L(0,2) could be used for guided wave screening of heat exchanger tubes
- Utilization of flexural F(1,2) modes was also found to be beneficial for applications when guided wave focusing function is required

Selection of Guided Wave Mode: Experimental Justification

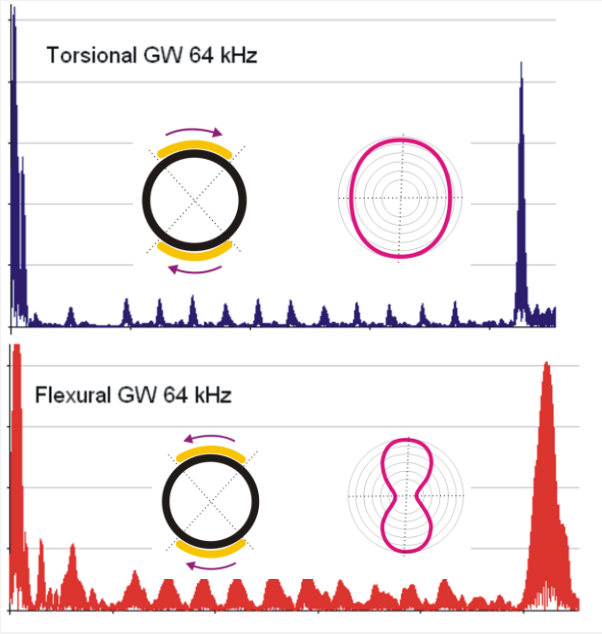
A tube with 19 defects up to 20% CSA
L (0,2) mode results



A tube with 19 defects up to 20% CSA
T(0,1) mode results

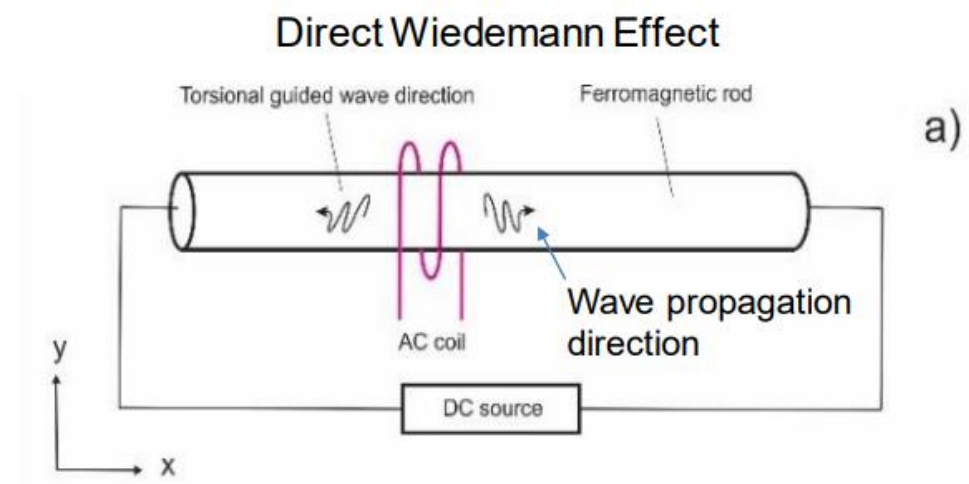


A tube with 11 defects up to 20% CSA:
T(0,1) mode response versus F (1,2) mode



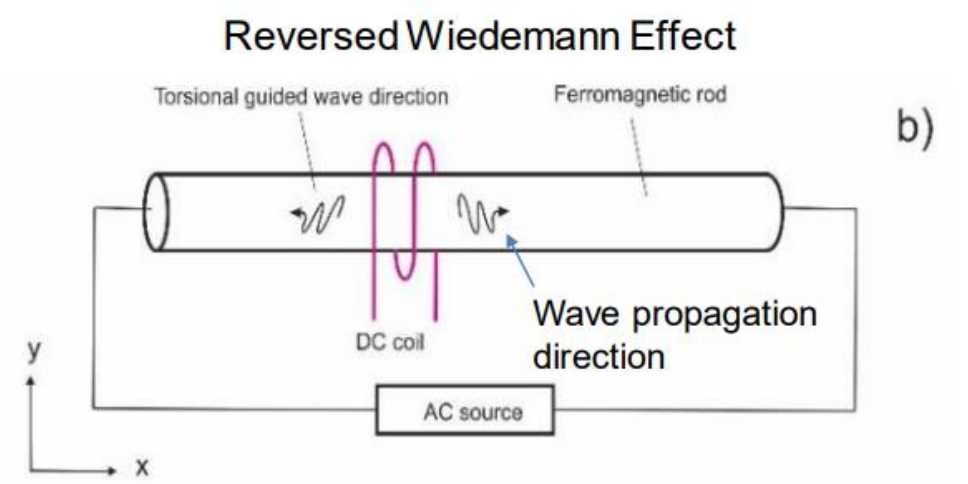
- Tests conducted on 1'' OD and 50 feet long SeaCure® tube with 19 artificial anomalies with up to 20% CSA wall loss
- Test indicated that longitudinal L(0,2) mode guided wave has essentially higher attenuation (compared with T(0,1) mode) due to higher rate of energy scattering when multiple anomalies are presented
- Field tests also indicated that L(0,2) mode at 100 kHz and higher attenuated rather quickly in the presence of ID/OD deposits
- Due to these reasons, T(0,1) mode was selected for heat exchanger tube inspection
- Flexural (F1,2) mode is used in cases when the circumferential extent of anomaly needs to be evaluated
  - The probe head in this case is rotated with fixed increment to provide a circumferential B-scan image

Magnetostrictive Sensors Physics: Wiedemann Effect



Mutual orientation of torsional wave and magnetic fields under direct Wiedemann effect

	Permanent magnetic bias direction	Time-varying magnetic field direction
Direction of Torsional wave propagation	Perpendicular	Parallel

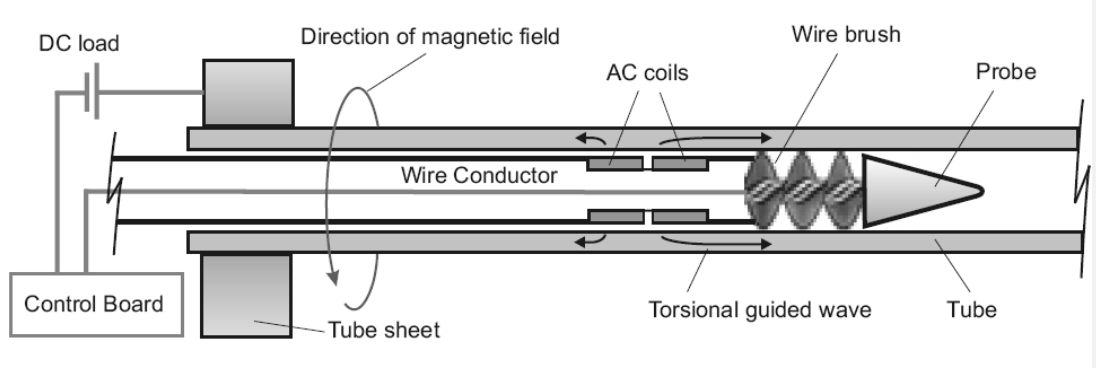


Mutual orientation of torsional wave and magnetic fields under reversed Wiedemann effect

	Permanent magnetic bias direction	Time-varying magnetic field direction
Direction of Torsional wave propagation	Parallel	Perpendicular

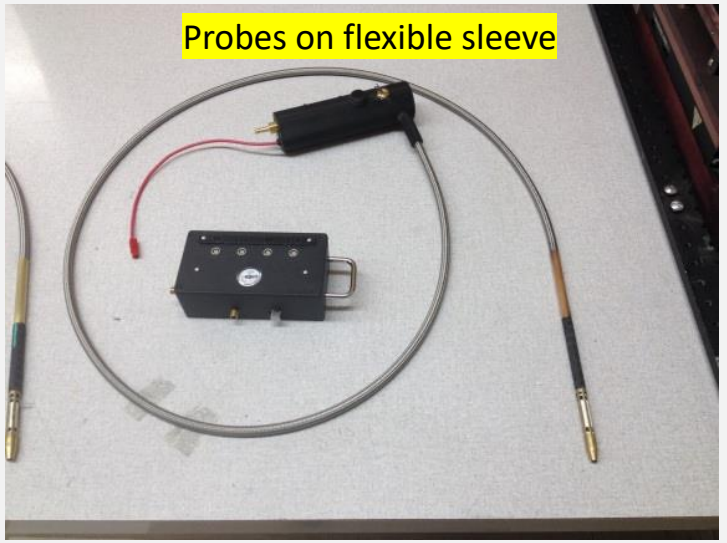
- Selection of transduction method is based on transduction efficiency and ability to generate pure torsional T(0,1) mode
- Direct Wiedemann effect was found to be more efficient in carbon steel tubes
- Reversed Wiedemann effect is more efficient in soft ferromagnetic alloys (SeaCure®, Duplex®)
  - It is also effectively utilized in dry coupled magnetostrictive transducers (MsTs) using FeCo strip as a core material

EMAT MsS Probe For Carbon Steel Tubes



- The probe utilizes the Wiedemann effect for electromagnetic generation of torsional guided waves
- No mechanical coupling to the tube is needed
- A low voltage DC current loop is used for introducing the circumferential magnetization into the tube.
- Only first 12 inches of tube need to be cleaned for data acquisition
- The presence of Fe oxides on tube ID improves signal strength
- 32 – 128 kHz frequency range
- 9 – 25 mm tube ID

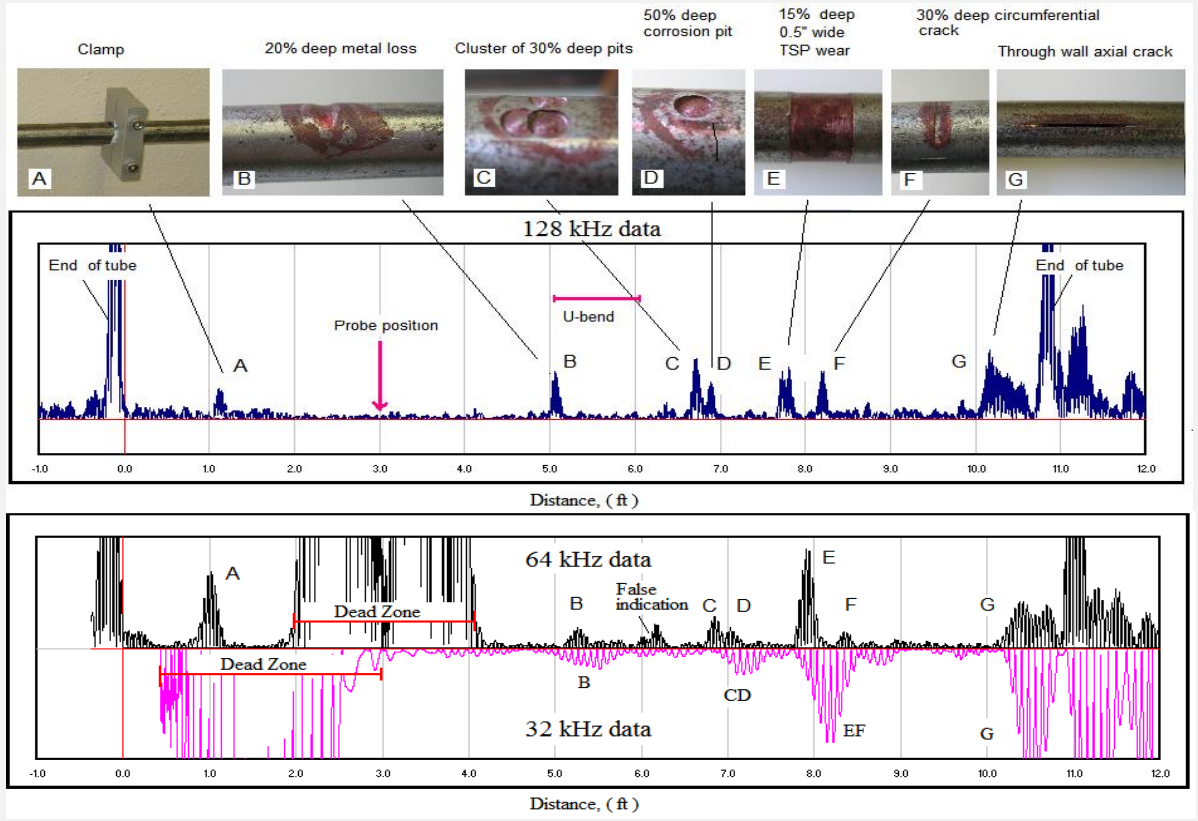




Tube condition that can be tolerated



Evaluation of T (0,1) mode in CS Tube with Anomalies at 128, 64 and 32 kHz



What was detected:

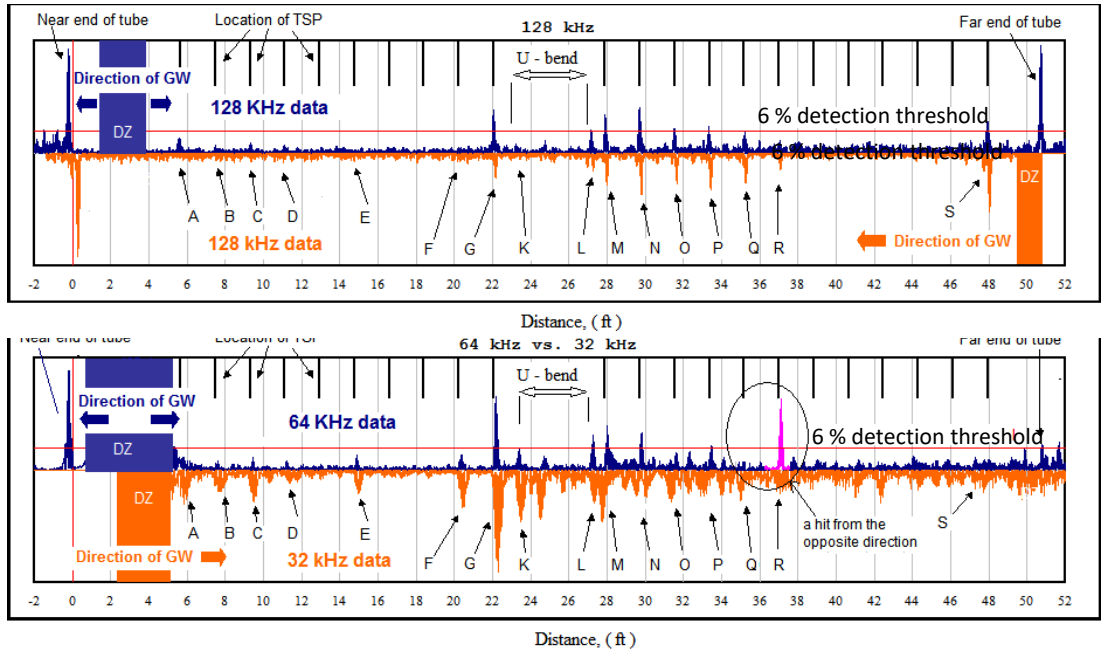
- Volumetric defects with 20% wall loss (-12 dB at 128 kHz versus -6 dB at 64 and 32 kHz)
- Cluster of pitting corrosion up to 30% deep (-12 dB at 128 kHz versus -6 dB at 64 and 32 kHz)
- Single corrosion pit 4 mm diameter 50% deep
- (-8 dB at 128 kHz versus -3 dB at 64)
- 15% deep tube support plate (TSP) wear (-12 dB at 128 kHz versus -18 dB at 64 and 32 kHz)
- Circumferential notch 30% deep (-12 dB at 128 kHz versus -4 dB at 64 kHz)
- Axial notch 1'' long through wall (-12 dB at 128 kHz versus -10 dB at 64 kHz and -24 dB at 32 kHz)
- Tube support clamp
- (-7 dB at 128 kHz versus -15 dB at 64 kHz)

Summary:

- All frequencies could detect introduced anomalies
- Lower frequencies have lower axial resolution resulting in merging of indications from defects located close to each other
- Higher frequencies performed much better under a clamp simulating a tube support, on single pitting and on circumferential notches

Performance of 32, 64 and 128 kHz T-mode Guided Waves in Heat Exchanger





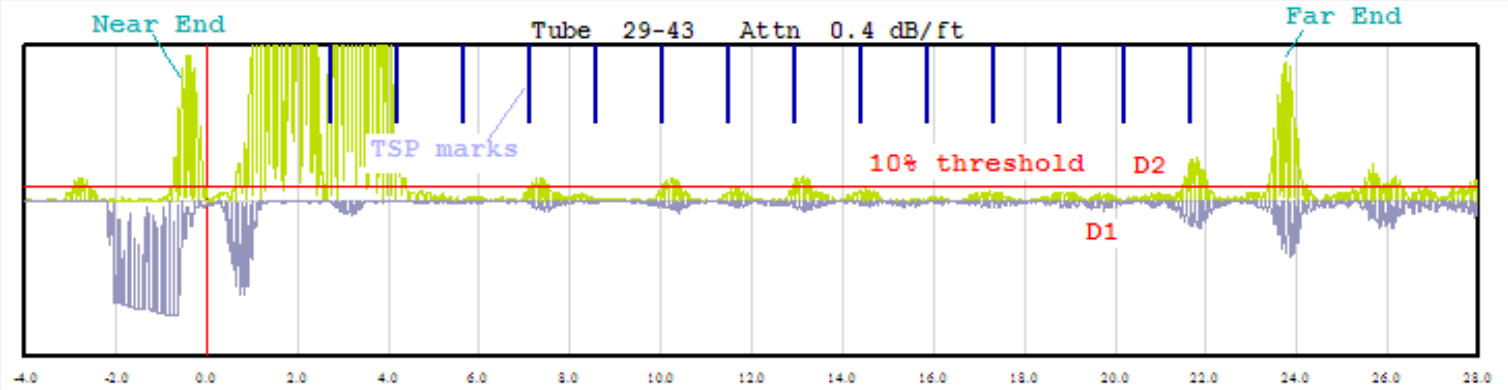
- Testing was conducted in 23 feet long heat exchanger with a U-bend (up to 53 feet total tube length)
- Guided Waves at 128 kHz performed the best in U-bends and in the areas after U-bends
- Multiple areas under TSPs were fully covered without any loss of the sensitivity
- Areas with tight TSP fits could be saturated with non-flaw related indications equivalent to 3-15% CSA
- The presence of flaws in such an areas can be recognized using the trend analysis or by applying a pattern recognition approach.

RFEC vs MSS: 32 kHz Torsional Guided Waves

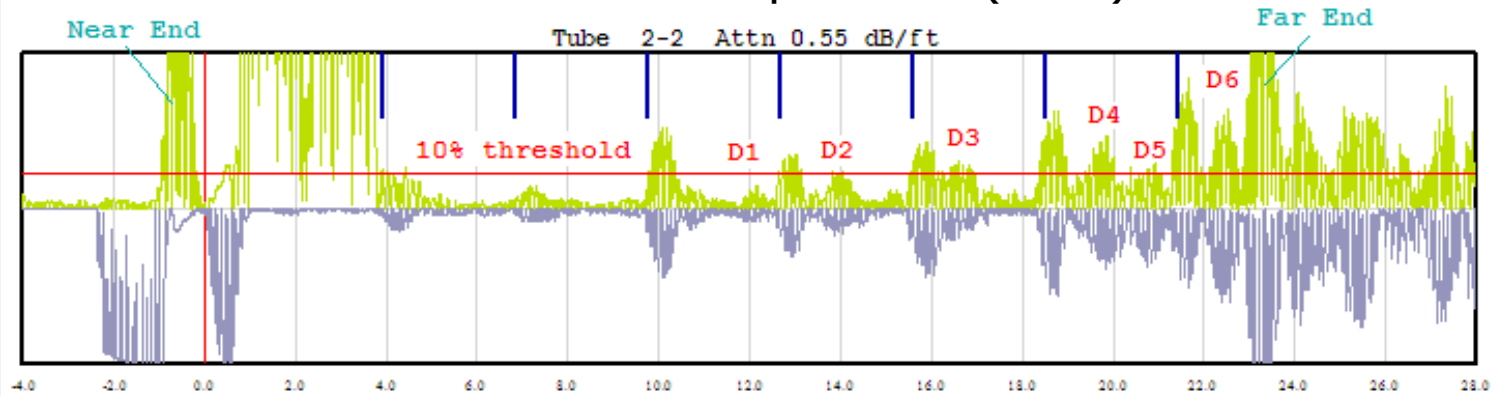




Tube defects up to 10% (RFEC)



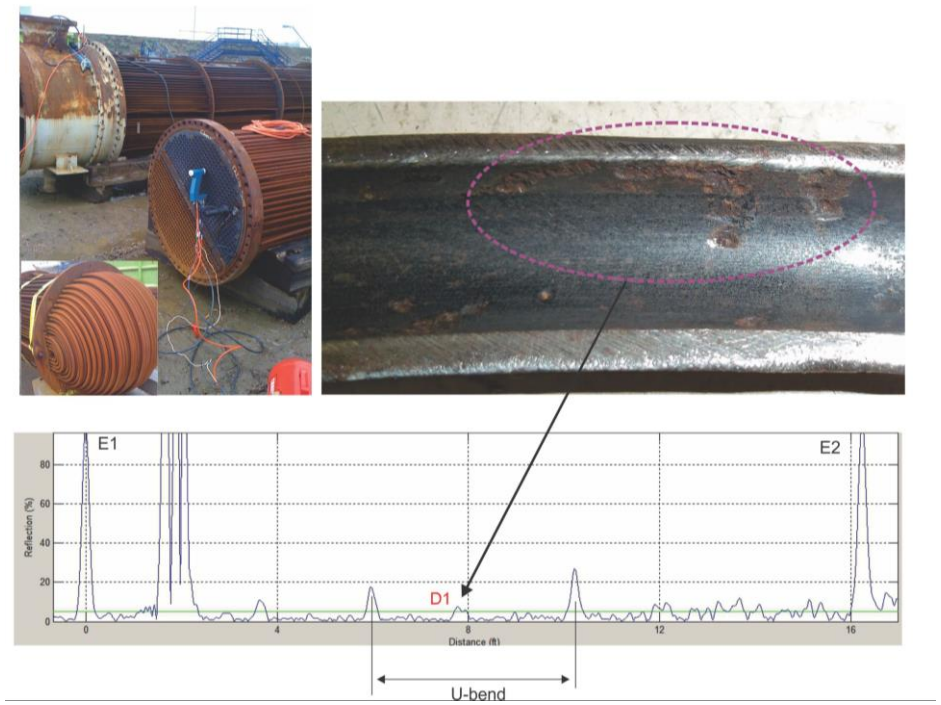
Tube defects up to 35% (RFEC)



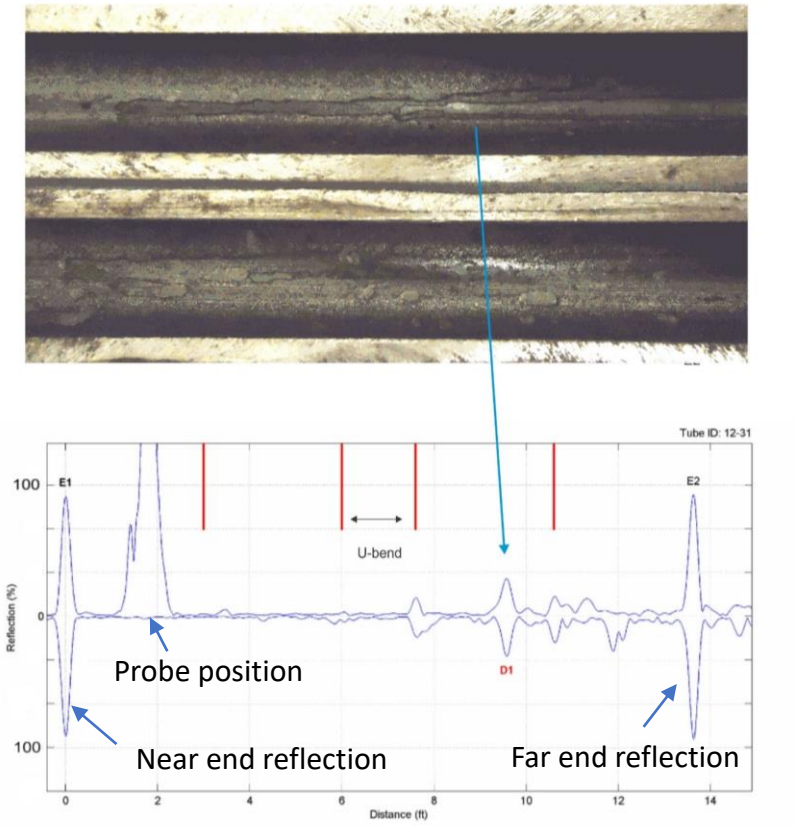
- Tubes at this condition could only support 32 kHz guided waves
- Comparison of MsS and RFEC reports indicated that there is a consistent correlation in ranking of anomalies

Detection of Corrosion in U-Bends and Areas Past the U-Bends

Detection of generalized corrosion in U-bend



Detection of corrosion past U-bend

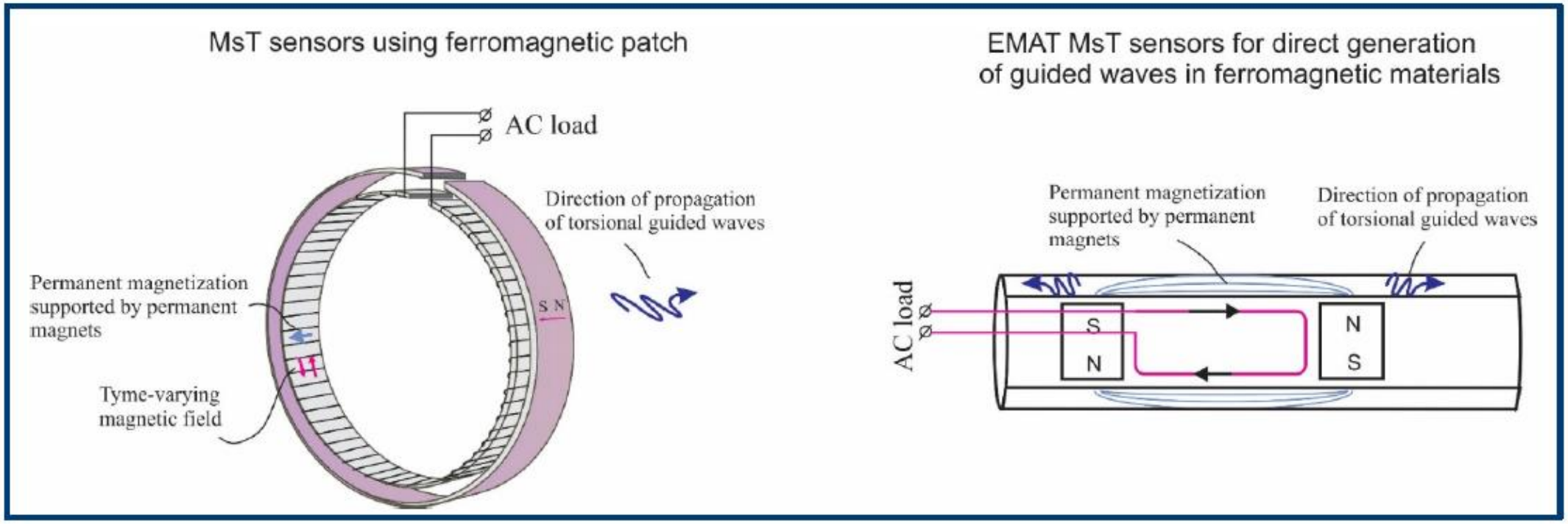


- Isolated anomalies typically produce stand-alone indications
- In case of minor generalized corrosion, the A-scan will have multiple indications
- Major corrosion typically stops propagation of guided waves and the end reflection would be missed

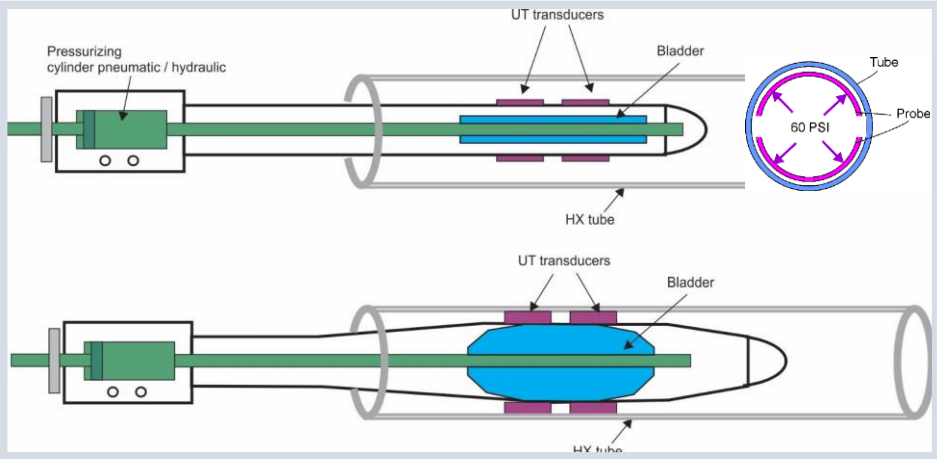
MsT Transducers

Magnetostrictive Transducers (MsT) were invented in 2008 as an alternative to direct Wiedemann effect sensor options with the following features:

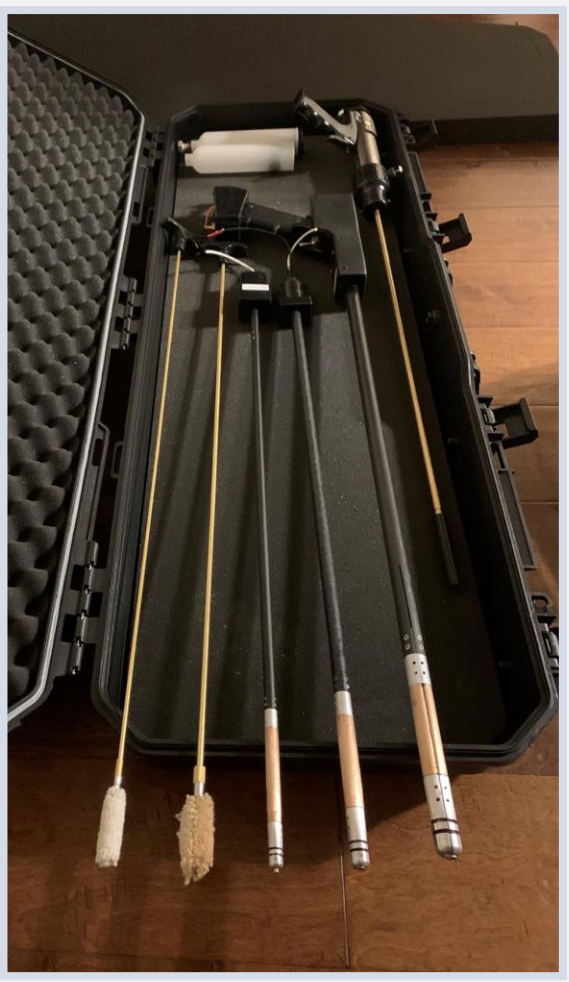
- Reversed the biasing and time-varying magnetic fields orientations
- Easier to use rare earth magnets for stronger and more consistent biases in small tubes
- Pure high amplitude torsional mode generation



MsT HX Probes With Bladders





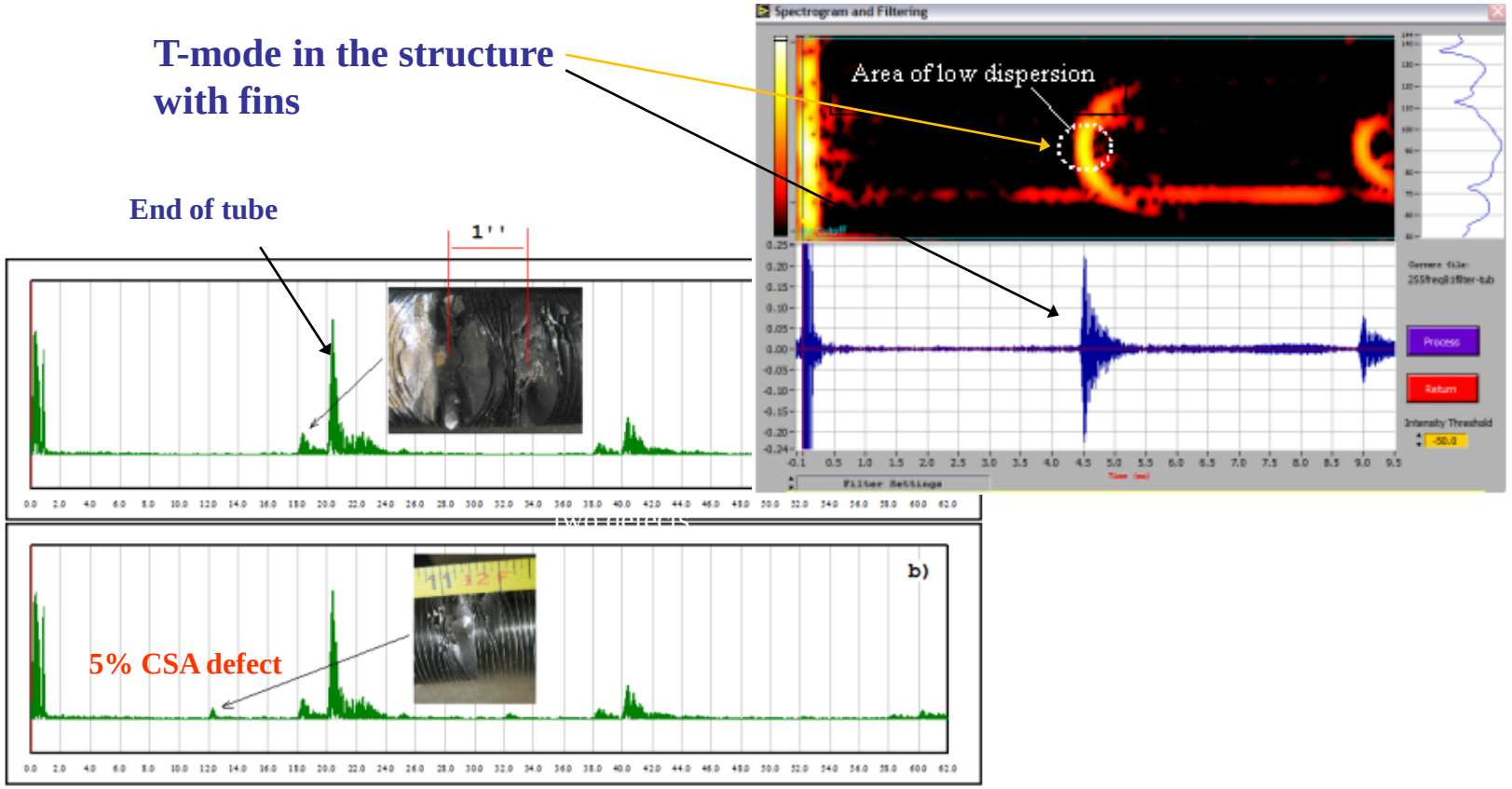


- Applicable to any tube materials (ferromagnetic or non-ferromagnetic)
- Utilize FeCo strip and two half shell MsT probes for generation of transversal vibrations
- Covers up to 80% of the tube circumference resulting in higher sensitivity
- Can be coupled to the tube by dry contact
- If the surface condition is not smooth, then shear wave couplant can be used for better acoustic coupling
  - Shear wave couplant removal tool is provided with the package
- Will fit to 11 to 60 mm tube ID
- Frequency range: 30 – 250 kHz

Detection of Artificial Anomalies in Finned Tube With Embedded Fins

MsT probe with a bladder and shear wave couplant was used





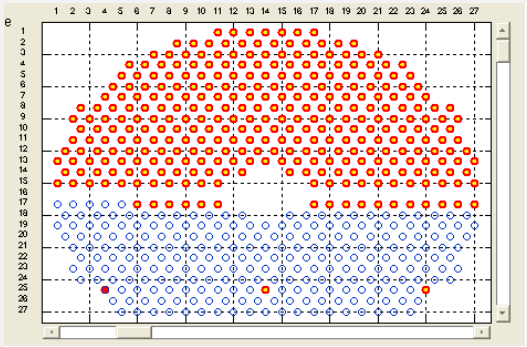
- Finned tubes can be tested using ID or OD coupled probes
- Only selected frequencies will propagate in finned tubes with low dispersion rate (90 kHz in the tube shown on a slide)

Guided Wave Screening of Oil Lube Cooler

Guided waves screening of 5/8” OD Super-Ferritic SeaCure® tubing was conducted at Nuclear Power Plant (Project was supported by EPRI)

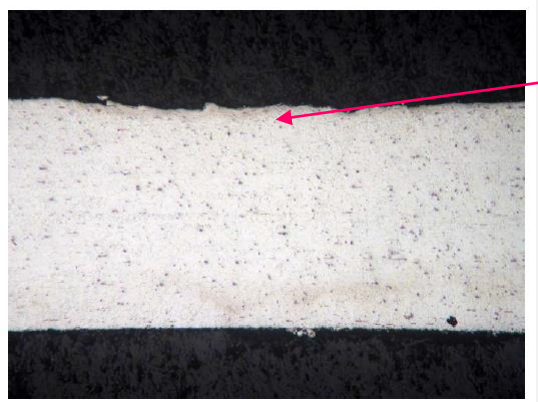
- 100 kHz torsional guided wave EMAT MsT probe was utilized for screening
- The highest accomplished speed of uninterrupted screening was approximately 3 tube/min
- 329 tubes total were inspected with 62 out of 329 tubes being inspected from both sides of the cooler for confirmation of the reading
- 308 tubes were found to be in good condition
- 21 tubes identified as having relevant indications including 4 tubes with relevant indications near the area of rolled expansion, indications near the tube support plate, and indications in the free span areas
- 4 of these tubes were pulled out for destructive testing and anomalies were confirmed in 3 tubes out of 4
- A false call was caused by an indication produced by a tube support plate



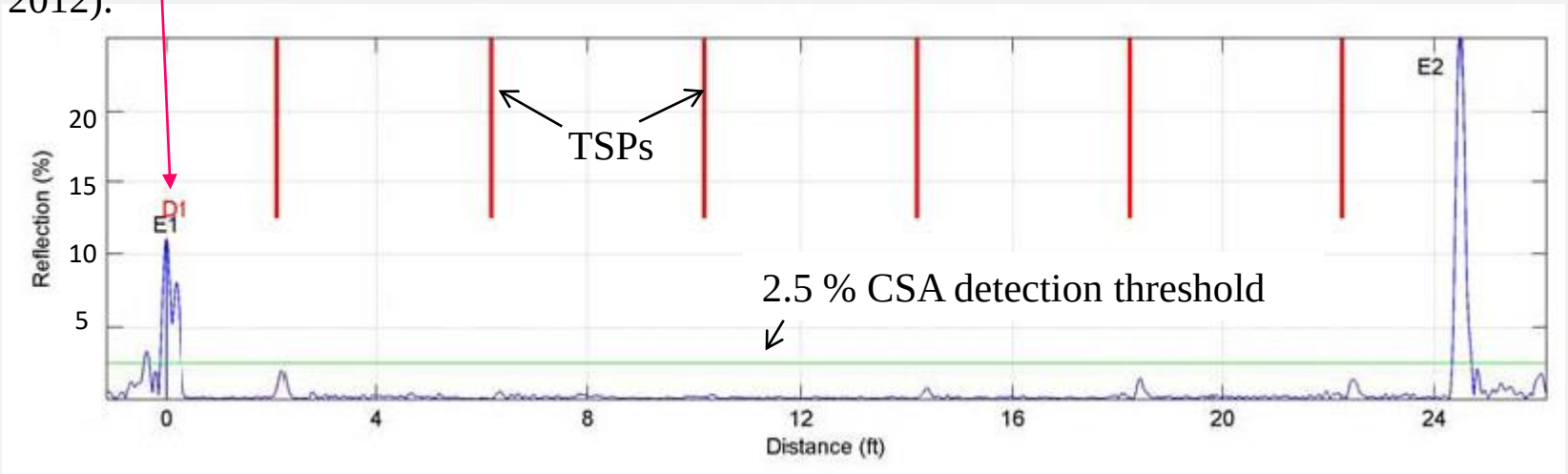


Guided Wave Screening of Oil Lube Cooler

- An example of anomaly found near the rolled expansion area is presented
- The anomaly was equivalent to 3% cross-section metal loss
- Some tubes had pronounced deposit but it did not undermine the test results

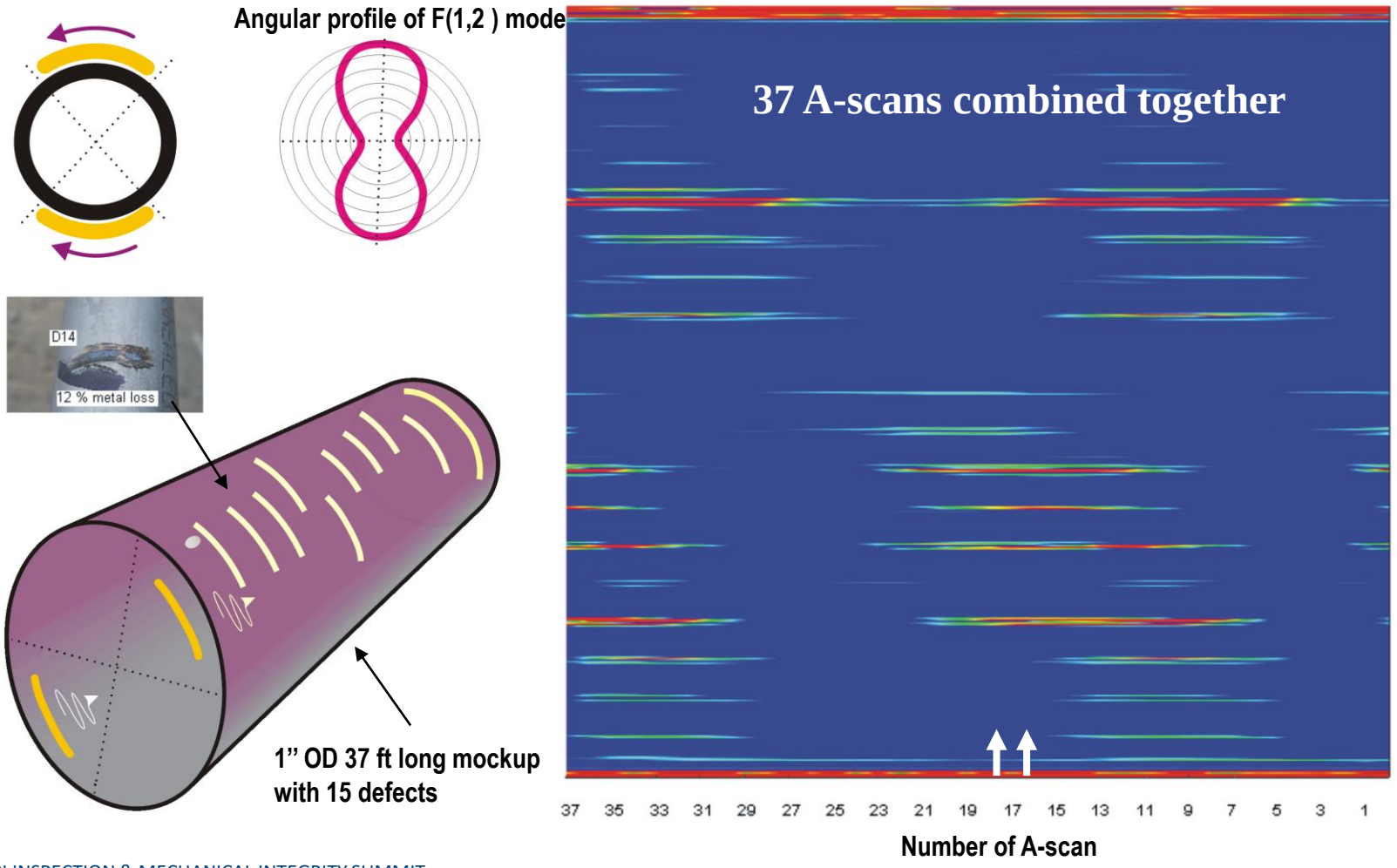


"Cross-sectioning reveals an elongated 0.001" to 0.0014" depression in the range of .055" – .060" long (50X acid etched). 494X magnification reveals plastic deformation typical of mechanical damage, OD of tube is at top.
(by Perry Holzman, "Comparison of Tube Pull Analysis Results to Guided Wave NDE Indications in SeaCure® Tubing", 12th EPRI BOP Symposium, Avon, CO. 2012).



EMAT MsTs with Natural Focusing Function

Natural Focusing in 1” OD Tubing (0 -360° Scan)



- Naturally focused flexural guided waves exhibited high capability in identifying both circumferential position and the circumferential extent of the anomalies in the whole body of the 37 ft long tube
- The feature can be effectively utilized for enhanced characterization of indications, including the indications produced by tube support plates and cracking in rolled expansion area

Summary

Guided wave screening of heat exchanger tubing is emerging technology with the following features:

Advantages:

- The method allows testing of tubes that can not be tested using other methods due to deposits
- Only one foot area of the tube needs to be cleaned for probe insertion
- Full Coverage of U-bends
- Coverage of areas under TSP
- Detection of anomalies near tube sheet
- High speed ~ 30 sec / tube

Disadvantages:

- Limited flaw depth sizing capability (ranking only)
- Inspection range depends on tube condition and some tube geometries might not support guided waves

Thank you!



Questions?

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