Corrosion detection under pipe supports using EMAT Medium Range Guided Waves

Victor GARCIA [1], Carlos BOYERO [1], Jesus Antonio JIMENEZ GARRIDO [1]
[1] Innerspec Technologies Europe, S.L., Alcala de Henares (Madrid), Spain
Contact e-mail: europe@innerspec.com

Abstract. Corrosion detection under pipe supports is a recurrent problem in petrochemical and other process industries, with limited inspection alternatives due to the lack of immediate access to the corroded area. Long-Range UT (LRUT) has been used for years to inspect inaccessible areas but the large blind zone, limited resolution, and complex interpretation makes it difficult to field for this application. EMAT-generated Medium-Range UT (MRUT) addresses these limitations and provides a robust and proven solution to the problem. EMAT is a non-contact technique that can generate guided waves without couplant or pressure, and permits scanning the part with a single tranducer on parts without surface preparation. Using a single Shear Horizontal and Lamb wave transducer, EMAT MRUT provides excellent near field resolution (no blind zone) and it can detect defects ten times smaller than LRUT. EMAT MRUT is easy to field, and requires limited training. Innerspec Technologies will present the MRUT technique with special focus on practical examples of their experience in the field.

1. Introduction

Wall-loss detection in pipes is one of the most common inspections due to the evident danger for some industries. In some cases, the areas to be inspected are not accessible, such as corrosion under pipe supports and buried areas, main zones in which the corrosion is located.

The NDT options are limited in these situations. Recent methods based on ultrasonic time-of-flight analysis have delivered positive outcomes, although they have still not proven to be valid for their use in the field. Long Range UT guided waves (LRUT) at low frequencies (≈ 50 kHz) are capable of detecting defects at distances up to 50-100 m, but there is a large dead zone of around 3 meters, they cannot be used at high temperatures and their performance with welded supports is very poor.

Medium Range guided waves (MRUT) use higher frequencies (0,1 – 1,5 MHz) that make them more sensitive in terms of defect detection. MRUT guided waves can be either Lamb or Shear Horizontal (SH), being the first type frequently used for pipe and tank inspection, even when there are inaccessible areas such as under supports or semi-buried zones. However, Lamb guided waves can be affected by the presence of external factors such as liquids, coatings or welds.

SH guided waves do not show mode conversion and the main wave mode SH_0 is not dispersive, which make these waves be less affected by the presence of welds in their path, proving to be a suitable technique for the inspection of areas under supports.

2. Comparison between piezoelectric transducers and EMAT for ultrasound generation

The use of the ultrasonic technique is very common in the inspection world with proved reliability. The process that is most employed to generate the ultrasonic signal is to use piezoelectric transducers which, even when they are highly efficient and versatile, need to be coupled to the part to be inspected either with high pressure, forcing to perform a static inspection, or through a liquid medium that limits the positioning and the inspection speed and it might cause some interferences with the wave propagation.

EMAT is an ultrasonic technique that generates the sound within the part to be inspected instead of doing it in the probe itself. An EMAT transducer induces ultrasonic waves in the part with two different magnetic fields. A relatively high frequency field (RF field) generated by coils interacts with a static or low frequency field generated by magnets, creating a Lorentz force in a similar way to an electric motor [1]. This perturbation is the cause of generation of the elastic wave.

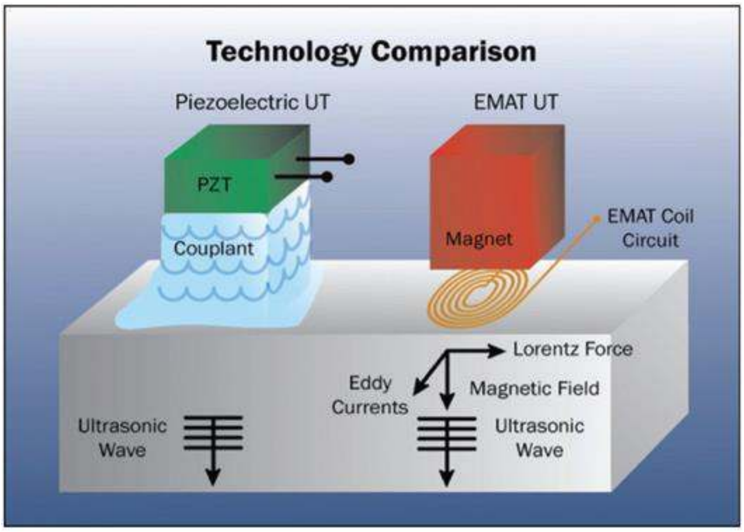

Fig 1. Technology comparison between piezoelectric UT and EMAT

In a reciprocal process, the interaction of elastic waves in the presence of a magnetic field induces currents in the receiving EMAT coil circuit. In ferromagnetic materials, magnetostriction also induces additional forces that increase the signal to levels that could not be reached only by the Lorentz effect. Several types of waves can be generated combining different magnets and coils.

Because the sound is generated in the part inspected instead of the transducer, EMAT is a non-contact technique that has the following advantages compared to piezoelectric transducers:

- Dry inspection. EMAT does not require any couplant gel for transmitting the sound, which makes this technique very useful for inspections at low and high temperatures.

- Impervious to surface conditions. EMAT is capable of inspecting through coatings and it is not affected by oxides, dust or roughness.
- Easy probe deployment. Snell's law is not applicable, therefore the probe angle does not affect the direction of propagation. The use of wedges and couplant gel is not necessary.
- Capability of generating SH modes. EMAT is the most practical and effective technique for generating shear waves with horizontal polarization without making use of pressure or low density couplants.
- Mode selection. The antenna-type construction of EMAT coils combined with a multi-cycle excitation provide a high precision in the frequency domain. It also allows for selecting accurately the wave of interest, which becomes essential when generating and interpreting guided waves [2].

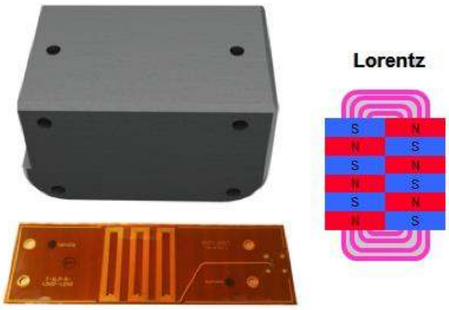

Fig 2. Configuration of coil and magnet used for generating shear horizontal guided waves

3. Guided waves

EMAT technology offers several options in terms of ultrasonic wave selection, including guided waves. The advanced knowledge of these waves and latest improvements in technology have promoted the use of guided waves in different applications that require a volumetric inspection.

Unlike angled beam waves, guided waves are propagated along a part parallel to its surface. The most common types of guided waves are Lamb and Shear Horizontal (SH), which fill up the whole volume of the part, and surface waves (Rayleigh), which follow the shape of the inspected specimen. Among the geometries that can be inspected with guided waves are bars, pipes, plates and rails.

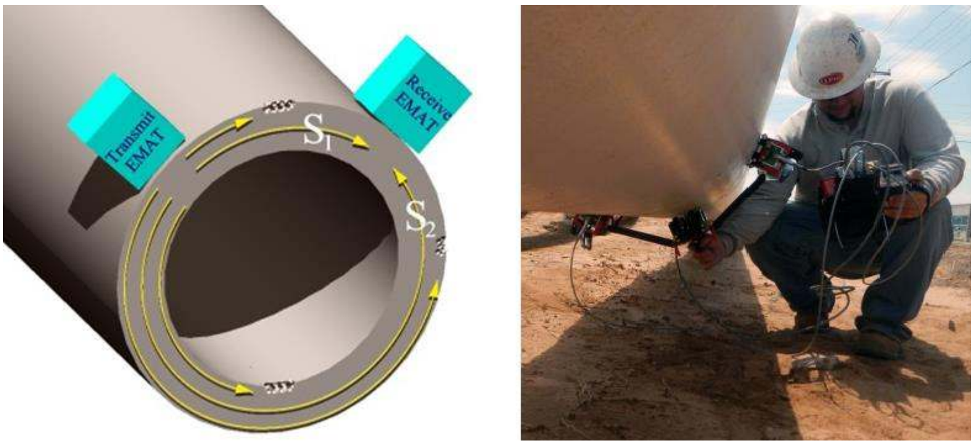

Fig 3. Configuration for axial inspection in a pipe with MRUT guided waves

Rayleigh and Lamb waves make use of an elliptical pattern with both horizontal and vertical particle displacement. However, while surface waves have most of their energy focused on the superficial region with the same penetration depth as their wavelength, Lamb modes allow for penetrating several wavelengths to perform a volumetric inspection [3]. Both types of waves are capable of travelling long distances. However, due to their vertical particle displacement they can be affected by the presence of liquids or coatings on the borders of the specimen under inspection. Rayleigh and Lamb waves are frequently used both for the inspection of products during the manufacturing process and for in-service applications.

Shear waves are composed by particles whose displacement is perpendicular to the direction of wave propagation, with different polarization depending on the generation mechanism. Piezoelectric transducers are based on the refraction of the longitudinal energy to generate shear vertical waves, which are polarized at 90 degrees from the input angle. Making use of high-pressure couplants or electromagnetic induction (EMAT) it is possible to generate Shear Horizontal (SH) waves whose propagation is parallel to the input surface. As guided waves, SH modes are, in some cases, the best option to inspect pipes and other parts where liquids, flanges or coatings might be the cause of attenuations of other ultrasonic waves.

3.1 Equations of guided waves

Although angles beam waves and guided waves are fundamentally different, both types are governed by the same differential equations [4]. Mathematically the main difference between them is that, for angled beam waves, there are no boundary conditions that the proposed solution must comply. However, guided waves must satisfy both differential equations and boundary conditions.

For Rayleigh and Lamb waves the frequency equations for symmetric modes are:

$$\frac{\tan(qh)}{\tan(ph)} = -\frac{4k^2pq}{(q^2-k^2)^2} \tag{1}$$

For asymmetric modes:

$$\frac{\tan(qh)}{\tan(ph)} = -\frac{(q^2-k^2)^2}{4k^2pq} \tag{2}$$

p and q values are obtained by:

$$p^2 = \left(\frac{\omega}{c_L}\right)^2 - k^2 \quad \text{and} \quad q^2 = \left(\frac{\omega}{c_T}\right)^2 - k^2 \qquad (3), (4)$$

Where k is:

$$\omega/C_p \tag{5}$$

Phase velocity C_P can be obtained from equations for shear waves, where d = 2h and ω = 2πf. The result is:

$$C_p(fd) = \pm 2C_T \left\{ \frac{fd}{\sqrt{4(fd)^2 - n^2 C_T^2}} \right\} \quad (6)$$

When n=0 (symmetric mode SH0) then $C_P=C_T$, a less dispersive wave than shear wave C_T. The rest of SH modes (n≠ 0) are dispersive.

4. Under support inspection with EMAT. Case study.

To find a reliable NDT method for corrosion detection under supports without physically lifting or removing them is still a pending issue. Several types of compensation pads and supports are in use in the field, some of them welded to the pipes, this fact makes the inspection be especially difficult due to the negative effects caused by the welds on the results obtained by different techniques.

EMAT Medium Range guided waves are presented as a solution for this type of inspections. As described in section 3, one of the main differences between Lamb and SH guided waves is the displacement of the particle. While Lamb guided waves have both vertical and horizontal components, SH guided waves are only displaced on the horizontal plane. For this reason, SH waves are less affected by external factors including liquids, coatings or welds.

Since non-welded supports do not cause severe signal attenuations, it is possible to inspect these regions with Lamb guided waves. However, in welded supports or compensation pads, ultrasonic energy attenuations and leakings into the support make this type of guided waves be inappropriate for this application. For these cases SH guided waves are presented as the most reliable solution, as the effects of welds and other external factors are eliminated.
To prove this theory, different tests were performed utilizing SH probes with permanent magnets on a 7 mm thick painted pipe containing 8 welded 300 mm squared patches. Under these compensation pads there were natural corrosion defects of different known degrees of severity, one of them covering a flawless area. [5]

The inspection was performed utilizing SH probes with permanent magnets making use of pitch-catch configuration with a frequency of 500 kHz, positioning the transmitter and receiver probes at each side of the welded patches at different spots. With this configuration, the transmitter induces Shear Horizontal guided waves that travel to the receiver probe located at the other side of the compensation pad. This probe measures the intensity of the received ultrasonic waves. If discontinuities are present under the pad, the amount of ultrasonic waves reaching the receiver will be reduced, with an existing relationship between the signal amplitude drop and the severity of the defects.

Fig 4. Transmitter and receiver probes located at both sides of a compensation pad

To check the effect that welds cause in the ultrasonic waves, two defect-free areas were inspected, being one of them under a welded patch. In the bare area, the transmitter and receiver probes were located at 300 mm one from each other. Once positioned, the ultrasonic inspection parameters were modified to obtain a signal amplitude level at the receiver in the range of 70-90% of full scale, avoiding signal saturation. For the second area under study, the probes were placed at both sides of the welded compensation pad making use of the same ultrasonic parameters than the first case. The amplitude level of the signal measured by the receiver was 70-90% of full scale.

In the light of the results obtained, it was proven that the welds had no effects in the propagation of the Shear Horizontal guided waves.

The rest of the compensation pads were inspected following the same procedure described above, registering a signal attenuation level related to wall-loss estimation.

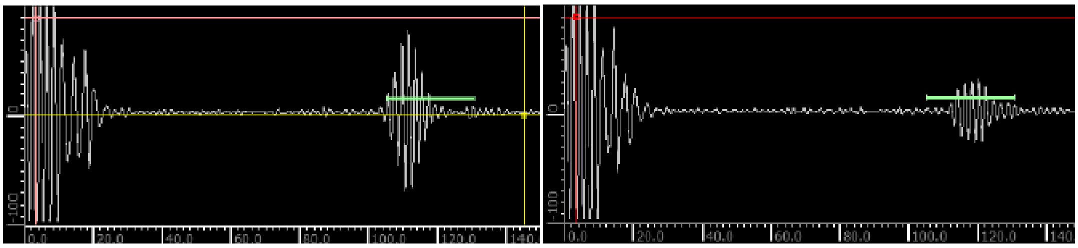

Fig 5. Oscilloscope image of a flawless area (left) and a defective zone (right)

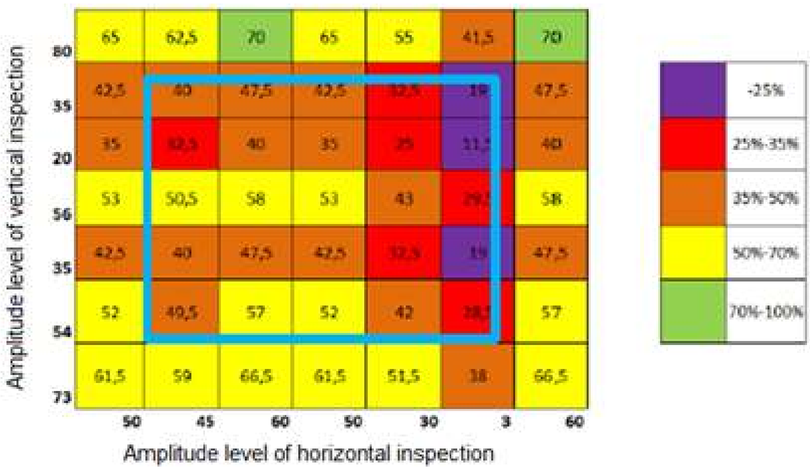

Fig 6. Severity estimation of wall loss under a compensation pad based on signal amplitude levels

After the tests, the estimation results were compared with the real wall-loss data of the areas covered by the compensation pads, which were acquired before welding the patches to the pipes, verifying a high correlation between the real wall-loss and the signal amplitude drops measured by the system.

Therefore, the benefits and limitations of the use of SH probes with permanent magnets are the following:

Benefits:

- SH guided waves are less affected by external factors than Lamb guided waves
- No mode conversion
- Easier results interpretation compared with other types of guided waves, due to the simple wave mode selection and the non-dispersive characteristic of SH_0 wave mode.

Limitations:

- Sensitivity to probe positioning and lift-off.
- Guided waves allow for an estimation of the severity of the area, but it is not possible to size the defects.

5. New magnetostrictive technique

After the encouraging results of the study performed by using SH probes with permanent magnets, it was proven that this type of ultrasonic wave is the best option to work when there are external factors that make the inspection not feasible by using Lamb guided waves, although the SH probes with permanent magnets present positioning limitations in the field.

To improve the capability to use SH guided waves and overcome the positioning limitations observed, a new patent-pending scanner and technique has been developed by Innerspec Technologies in cooperation with GuidedWave has now improved the capability to use Shear Horizontal (SH) guided waves. These magnetostrictive probes have been especially designed for the inspection under supports and semi-buried areas and they have been an important step forward in the guided waves technique. [6]

While SH probes with permanent magnets generate the ultrasound within the material by a combination between Lorentz and magnetostriction effects, these new sensors generate the ultrasound only by meanso of the magnetostriction effect in a more efficient manner, achieving a higher resolution and sensitivity.

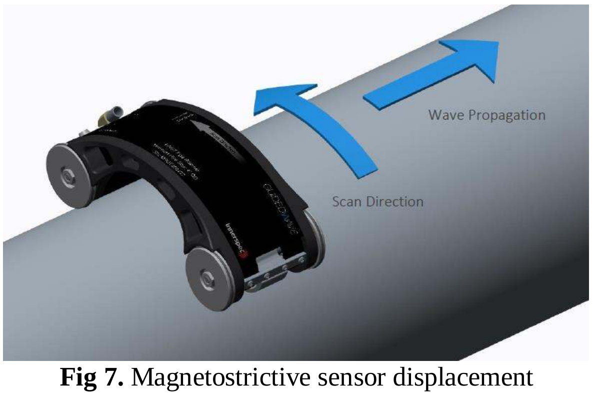

Fig 7. Magnetostrictive sensor displacement

To augment this effect it is necessary to utilize a magnetostrictive strip that must be adhered to the part under inspection either temporarily or permanently. This tape will be magnetized and the sensor will be displaced over it working in a pulse-echo configuration. Only removing the loose scale of the specimen is required to adhere the strip and it is possible to perform the inspection even with painted parts.

Fig 8. Circumferential scanning with magnetostrictive sensor

Innerspec's single-transducer magnetostrictive scanner has a dead zone of 10-15 cm which permits inspection in very close proximity to the area of interest. Moreover, by inspecting closer to the defects, the detection and resolution are at least ten times better or more than with LRUT. This method can complement LRUT providing greater detection and resolution on shorter lengths of pipe, or on restricted-access areas where the deployment of LRUT rings is not feasible. [6]

Moreover, the new design of these sensors includes the possibility of shooting guided waves only in one direction, avoiding reflections from the opposite inspection side that could result in wrong interpretations.

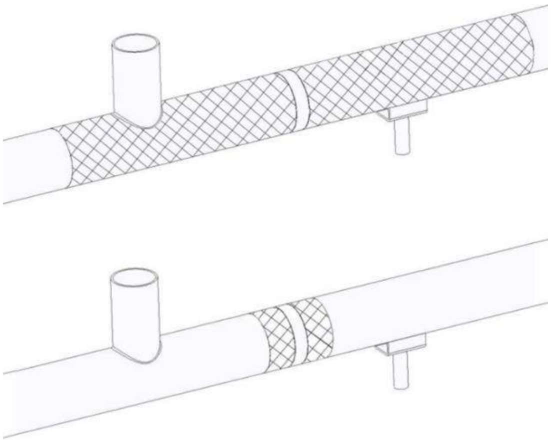

Fig 9. LRUT (up) and MRUT (down) dead zones comparison

To achieve a better detection, this development based on magnetostrictive sensors includes the implementation of a Synthetic Aperture Focusing Technique (SAFT) algorithm that processes data and improve considerably the resolution, making clearer the visualization of the discontinuities.

6. Conclusions

The NDT options for corrosion under pipe support inspection are currently limited. Medium range guided waves generated by EMAT are presented as a reliable solution for this inspection making use of Shear Horizontal guided waves, which have the following advantages:

- Less affected by external factors such as liquids, coatings or welds than Lamb guided waves
- No mode conversion
- Easier results interpretation
- Simple wave mode selection
- Non-dispersive characteristic of wave mode SH0.

The new magnetostrictive technique benefits from all the advantages mentioned above and resolves the limitations observed when using SH probes with permanent magnets, achieving a higher resolution and sensitivity in terms of defect detection.

The combination of the new magnetostrictive sensor for inspection under supports and inaccessible areas along with the MRUT scanner for pipes and tanks evaluation conforms the most complete solution with guided waves in the market.

References

[1] V. García, “Transductores acústicos electromagnéticos (EMAT). Los ultrasonidos sin acoplante. Aplicaciones y desarrollos” Revista AEND nº 62

[2] B. López, “Surface and Thin Volumetric Inspections with EMAT”

[3] B. Lopez, “Inspection Trends June 2004”

[4] J. Rose, “Ultrasonic Waves in Solid Media” páginas 101-245

[5] V. García, C. Boyero, “Inspeccón bajo soportes con ondas guiadas transversales horizontales generadas por EMAT”

[6] R. Sass, M. Kidd, “Detection of Defects and Corrosion Under Pipe Supports and Inaccessible Areas Using EMAT Medium Range UT Techniques”