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Weld Inspection with EMAT Using Guided Waves

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Abstract
In the last decade, Electro Magnetic Acoustic Technology (EMAT) technology has come of age with tremendous success in many applications. The following paper provides information of EMAT technology used for the inspection of thin welds in automated environments.

Because of its efficiency in generating guided waves without couplant or contacting the part, EMAT is an ideal choice for volumetric inspection of welds in high-volume, automated environments.

Keywords: EMAT, weld inspection, guided waves, dry inspection

1. Comparison of Inspection Methods

The most common non-destructive testing solutions for weld inspection include vision, eddy current, magnetic flux leakage, radiographic, and ultrasonic techniques.

Automated vision systems inspect both the contour and the surface of the weld looking for deviations from a pre-programmed standard. Their resolution and software capabilities have kept pace with the increase in computing power, however they are strictly for surface inspection and the camera requires direct access to the weld line. Another important disadvantage in production environments is the possible misinterpretation of surface blemishes that do not affect the structural quality of the weld as defects, causing the rejection of valid parts. Rugged environments, with fumes and debris from operations also pose a challenge, affecting the readings vision systems provide.

Eddy current (EC) systems use electromagnetism to provide surface and a limited level of sub-surface inspection (a few thousands of an inch). EC is often used in conjunction with other techniques due to its difficulty detecting some critical defects and its inability to penetrate the test material.

Magnetic flux leakage magnetizes the test object and uses small flux sensors to scan the surface. This method is able to inspect deeper into the material, but it is highly inaccurate in characterizing both the size and the shape of the defect, and is limited to thin materials.

Radiographic or X-ray inspection is used to find sub-surface flaws and can penetrate deeply in almost any material. The slow speed and potential radiation hazards limits its use. The results in most cases require operator interpretation and it is seldom used in automated environments.

Ultrasonic testing (UT) uses high frequency sound waves to perform the examination and is the fastest growing nondestructive testing technique for weld inspection. Since the sound can be directed precisely, this technique is used for both surface and internal inspections.

The most common approaches for weld inspection using ultrasound are reflection and attenuation. With reflection a transmitter sends ultrasound towards the weld and a receiver "listens" to any reflections or "bounces" from voids or inclusions in the weld. With the attenuation technique, a transmitter and receiver are located straddling the weld. The amount of sound that can travel across the weld can help determine its quality since a good weld (good bonding) will attenuate less sound than a bad one. The latter is best suited for determining bonding of welds as in lap welds.

2. Conventional Ultrasonic Testing (UT)

In addition to the ability to provide volumetric inspection, UT has many advantages over other methods that make it especially well suited for weld inspection:

- Capable of detecting the most common weld defects (porosity, pinholes, lack of fusion, lack of penetration, concavity, mismatch, and internal cracking)
- Accuracy and sensitivity for the detection of small defects
- Capable of inspecting welds without direct access to the weld itself
- Safe for both the process and operators
- Fast inspection at production speeds
- Easy interpretation of results

The most common method of generating ultrasound waves uses piezoelectric transducers. Piezoelectric crystals generate the sound in the transducer, which is subsequently transferred into the material. Because high frequency ultrasound does not travel easily through air, the transducer needs to be coupled to the part by means of a liquid (couplant).

The use of couplant and the nature of the technique pose important limitations;

- Difficult to automate
- Unable to inspect at high temperatures
- Sensitive to surface conditions such as roughness and contamination (dirt, oxide, oil)
- Unable to inspect certain materials that require special wave modes (i.e. Shear Horizontal)

Maintaining the coupling between the transducer and the test material is essential for valid results. At high speeds or high temperatures couplant can evaporate, boil off, or fail to maintain integrity. Application of couplant can also be impractical in automated testing, or the couplant itself can complicate the inspection.

3. The EMAT Solution

For years manufacturers and customers have designed sophisticated couplant delivery systems and immersion tanks to permit ultrasonic inspection using piezoelectric transducers in industrial environments, making inspection cumbersome and expensive. In other cases, ultrasonic inspection with conventional piezoelectric transducers is simply impractical or impossible.

EMAT or Electro Magnetic Acoustic Transducer technology was developed in the 70s as a non-contact, dry inspection alternative to piezoelectric transducers. Initially confined to laboratories and some high-end applications, it has experienced growing popularity with the advent of new materials and high-speed electronics.

3.1. EMAT Inspection Applications

An EMAT inspection platform can be adapted to most geometries and applications and works with most metals for all of the standard UT applications (Figure 1).

Type of Inspection	Material	Geometries
•Flaw Detection - Points (1D) - Seams (2D) - Surfaces (2D) - Volumes (3D) •Thickness & Distances •Material Properties - Hardness - Nodularity	•Electrical & Magnetic Conductors - Ferrous: Carbon Steel, Stainless Steel, Nickel, Cobalt - Non-ferrous: Aluminum, Copper, Brass, Uranium & most other metals	•Discrete & Continuous Geometries - Plates (thin & thick) - Cylinders, Rods, Tubes, (round, square or others) - Structural Elements

Figure 1. EMAT technology is applicable to various types of inspection, material and geometries.

EMAT UT differs from conventional ultrasonic methods in the way sound is generated in the part to be inspected. An EMAT, consisting of a magnet and a coil of wire, uses Lorentz forces and magnetostriction to generate an acoustic wave within the material itself. No couplant is required, making EMATs suitable for automated, high speed, and in-line inspection applications.

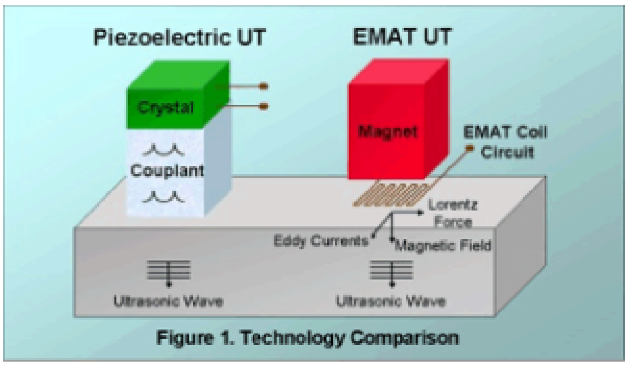

Figure 2. EMAT is couplant-free ultrasonic inspection technique.

An EMAT induces ultrasonic waves into a test object with two interacting magnetic fields (Figure 2). A relatively high frequency (RF) field generated by electrical coils interacts with a low frequency or static field generated by magnets to create the wave in the surface of the test material. Various types of waves can be generated using different RF coil designs and orientation to the low frequency field. EMATs are the only practical means for generating shear waves having a horizontal polarization (SH waves), which do not travel through low-density couplants.

3.2. EMAT Inspection for Welds Using Guided Waves

EMAT provides many advantages over conventional UT for weld inspection. The shear wave is most commonly used for ultrasonic weld inspection. Shear Vertical (SV) and Shear Horizontal (SH) both have particle vibrations perpendicular to the wave direction. Conventional ultrasonic inspectional utilizes the SV wave, with an angle of between 30° and 60° from the normal beam. Maintaining the position of the probe is critical to obtaining an accurate inspection. A limitation of SV waves in weld inspection is the inability to cover the full vertical volume of the material. At some points defects may even limit complete inspection.

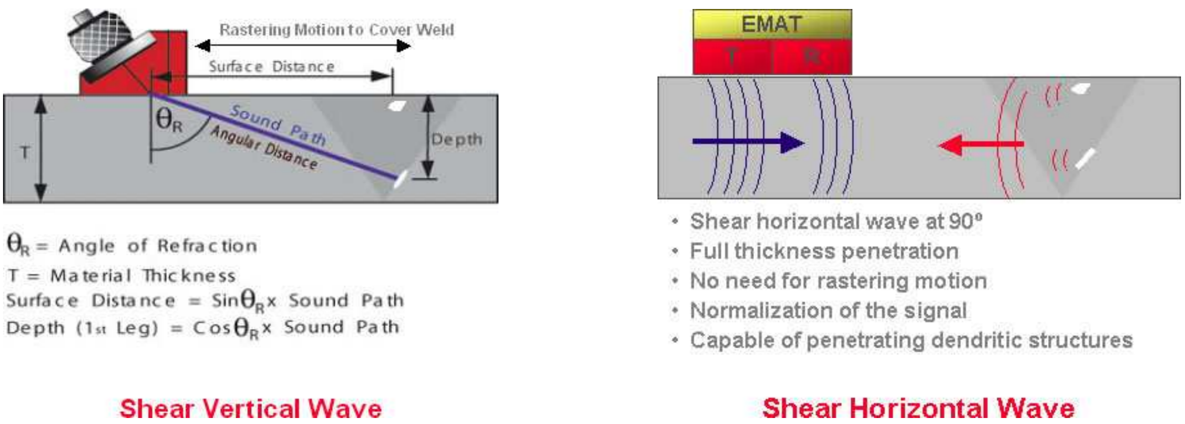

Figure 3. Comparision SV and SH waves

On the other hand, Shear Horizontal energy can be extremely useful for weld inspection in two ways.

1. Shear Horizontal waves do not mode convert (change direction, speed and motion) when striking surfaces that are parallel to the direction of polarization. This is especially relevant when examining austenitic welds and materials with dendritic grain structures (e.g. certain stainless steels).
2. At 90º Shear Horizontal energy becomes a guided wave that fills up the full volume of the material and permits inspection of the full cross-section of the weld. The advantages of using SH waves for weld inspection include:
    a. SH waves fill the volume of the material independent of thickness enabling inspection of the entire weld
    b. No “rastering” motion or “phased array” of sensors is necessary for inspection resulting in space efficient inspection equipment
    c. Separate transmitter and receiver permits normalization of the signal guaranteeing maximum reliability
    d. Less sensitivity to probe positioning during inspection contributes to ease of automation and integration into production.

3.3. Existing Applications

Guided wave EMAT systems have already been successfully introduced in a number of weld inspection applications:

- Flash-butt weld inspection in steel coils. The **temate® Si-CJ** system is integrated with the welder and inspects the weld, without additional cycle time, prior to moving through the pickle line and cold mill.
- Tailor Welded Blank inspection. Used primarily in the automotive industry, Tailor Welded Blanks are flat panels with different characteristics (chemistry, thickness) that are welded together prior to stamping. The **temate® Si-WB** inspection system is currently the industry standard for inspection of TWB all over the world.
- Mash Weld (RSEW-MS) inspection. Mash Welders (lap welders) are commonly used in galvanizing, annealing and other finishing processes. The **temate® Si-MWC** is integrated in the welder to perform post-weld inspection immediately after welding.
- Laser Lap Weld inspection. The **temate® Si-LL** is used to inspect laser lap welds that are used in the automotive industry to join the roof and side panels of cars.
- Longitudinal ERW in tubes. ERW tubes can have very thick walls and small diameters, which make them especially difficult to inspect at fast speeds in automated environments. The **temate® Si-WT** is designed for this application.
- Other butt-welds. Thin materials are routinely welded in tubes (e.g. girth welds) and plates to meet specific codes, or to avoid costly failures in the field. The **temate® Si-BW** is a generic instrument designed to inspect any type of butt-welds.

4. Conclusion

Created as a non-contact, dry alternative to piezoelectric transducers, Ultrasonic EMAT systems are no longer limited to laboratories and high-end applications and are now widely used in industrial environments.

The ability to easily generate guided waves, its imperviousness to the conditions of the material, and its propensity to be integrated in production, have made EMAT the technique-of-choice for automated inspection of thin welds in industrial environments where the speed, reliability and ease-of-use is paramount to the success of the inspection.