The right nondestructive examination technique not only helps control the quality of the final product, but also provides valuable process control feedback to improve productivity, reduce cost, and increase the efficiency of the welding machine. This is especially important in high-volume, continuous processing lines where a few minutes of bad production can result in significant losses.

In the last decade, powerful ultrasonic electromagnetic acoustic transducer (EMAT) technology has come of age with tremendous success, becoming the technique of choice for many applications.

Comparison of Inspection Methods

The most common nondestructive examination solutions for weld inspection include visual, 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 preprogrammed 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 interface. 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 systems use electromagnetism to provide surface and a limited level of subsurface inspection (a few thousandths of an inch). Eddy current 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 shape of the defect, and is limited to thin materials.

Radiographic or X-ray inspection is used to find subsurface flaws and can penetrate deeply into almost any material. The slow speed and potential radiation hazards limit 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. It is the fastest growing nondestructive examination 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 toward 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 so they straddle the weld. The amount of sound that can travel across the weld can help determine its quality since a good weld (good fusion) will attenuate less sound than a bad one. The latter is best suited for determining joining of welds as in lap and mash seam welds.

Conventional Ultrasonic Testing

In addition to volumetric inspection, ultrasonic inspection 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, incomplete fusion, incomplete penetration, 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, and
- 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 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 the couplant can boil off or fail to maintain integrity. Applying a couplant can also be impractical in automated testing, or the couplant itself can complicate the inspection.

Introduction to EMATs

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.

Electromagnetic acoustic transducer (EMAT) technology was developed in the 1970s as a noncontact, 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.

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 — Fig. 1.

Ultrasonic testing with EMAT technology differs from conventional ultrasonic methods in the way sound is generated in the part to be inspected — Fig. 2. An EMAT, consisting of a magnet and a coil of wire, uses Lorentz forces and magnetostriiction 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.

An EMAT induces ultrasonic waves into a test object with two interacting magnetic fields. 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. The EMAT technology is the only practical means for generating shear waves having a horizontal polarization (SH waves), which do not travel through low-density couplants.

EMAT Inspection for Welds Using Guided Waves

The EMAT technology 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 — Fig. 3. Conventional ultrasonic inspection utilizes the SV wave, with an angle of between 30 and 60 degrees 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 their inability to cover the full vertical volume of the material. At some points defects may even limit complete inspection.

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 90 deg, 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 at 90 deg for weld inspection include the following:

- Shear horizontal waves fill the volume of the material independent of thickness enabling inspection of the entire weld,
No “rastering” motion or “phased array” of sensors is necessary for inspection resulting in space-efficient inspection equipment.
Separate transmitter and receiver permit normalization of the signal for self-calibration, guaranteeing maximum reliability, and
Less sensitivity to probe positioning during inspection contributes to ease of automation and integration into production.

Advantages of EMATs for Weld Inspection

Since EMATs generate sound in the part itself instead of in the probe, they have several advantages over conventional ultrasonic methods for automated weld inspection. The lack of couplant eliminates issues with consistency and quality of readings as well as speed of inspection associated with piezoelectric UT. The EMATs are also impervious to surface contamination and can be used on surfaces with dirt, oil, water, or rust. They can inspect on curved and uneven surfaces. The benefits of these characteristics have been demonstrated in the steel, automotive, nuclear, and petrochemical industries with EMAT inspection systems performing manual and automated in-line inspection in harsh industrial environments.

Innerspec Technologies has designed, manufactured, and installed EMAT systems that inspect thousands of welds per day in the most rigorous industrial environments. Existing EMAT inspection applications include

**Flash weld inspection in steel coils.** The EMAT system is integrated with the welding machine and inspects the weld, without additional cycle time, prior to moving through the pickle line and cold mill — Fig. 5.

**Laser weld inspection.** Off-line and in-line inspection systems inspecting flat panels such as tailor-welded blanks (see lead photo) and tubular transmission components.

**Girth weld inspection.** Welded tube and shaft inspection for automotive and oil industries.

**Lap weld inspection.** Mash seam welds.

Conclusion

Created as a noncontact, 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 of EMATs to use guided waves and the technology’s imperviousness to the conditions of the material make it the technique of choice for many automated applications where the speed, reliability, and quality of readings is paramount to the success of the inspection.