Surface & Thin-Volumetric Inspections with EMAT
Table of Contents

- Traditional Inspection Options
- Introduction to EMAT
  - Theory
  - Characteristics
- Guided Waves and EMAT
  - Introduction to Guided Waves
  - EMAT Advantages for Surface and Thin-Volumetric Inspections
- Surface Wave Automated Applications
  - Tubes and Round and Square Billets
  - Plates, Ingots, Slabs
- Thin-Volumetric Automated Applications
  - Steel Strip
  - Laminated Strip
- Manual Applications
- Innerspec Technologies, Inc.
Traditional Inspection Options
# Traditional Inspection Options

<table>
<thead>
<tr>
<th>Visual Testing (VT)</th>
<th>Penetrant Testing (PT)</th>
<th>Magnetic Particle Testing (MP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A human or machine-vision system looks for visible defects</td>
<td>The surface of the part is coated with a penetrant in which a visible or fluorescent dye is dissolved or suspended. The dye penetrates in the cracks by capillary action</td>
<td>A magnetized part is impregnated with magnetic particles that cluster at the edges of surface cracks oriented in the opposite direction of the magnetization</td>
</tr>
</tbody>
</table>

- Very sensitive to visible blemishes in all orientations
- Cannot detect tight and sub-surface cracks
- Requires direct access to the area inspected
- Very sensitive to surface finish, changes in coloration and lighting conditions
- Good alternative for bad surface conditions and complicated geometries (e.g. weld overlays)
- Detects cracks in all orientations
- Manual and time consuming
- Insensitive to sub-surface cracks
- Subject to human error
- Contaminates the part and produces waste
- Good alternative for bad surface conditions and complicated geometries
- Permits automating part of the process (magnetization and impregnation). Detection requires visual inspection
- Only possible for ferromagnetic materials
- Low sensitivity to sub-surface defects
- Contaminates the part and produces waste
Traditional Inspection Options

<table>
<thead>
<tr>
<th>Eddy Current (EC)</th>
<th>Infrared Testing (IRT)</th>
<th>Ultrasonic Testing (UT)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Eddy Current" /></td>
<td><img src="image2.png" alt="Infrared Testing" /></td>
<td><img src="image3.png" alt="Ultrasonic Testing" /></td>
</tr>
</tbody>
</table>

A coil induces circular flows of electricity (eddy currents) on a conductive material. Flaws disrupt the flow, and the same coil or an adjacent one detect voltage and phase changes.

- Highly sensitive to surface and near-surface cracks
- Requires direct access to the area inspected and full-coverage arrays or scanning to inspect the area of interest
- Cannot detect flaws such as laminations that lie parallel to the probe coil winding
- Difficulty detecting long defects (only beginning and end are detected)
- Very sensitive to surface finish, roughness, material chemistry and magnetism

The part is subjected to an increase in temperature and inspected with infrared cameras. Surface defects will provide a different thermal profile.

- Highly sensitive to surface cracks in any orientation. No sensitivity to sub-surface defects
- Requires direct access to the area inspected and full-coverage
- Production systems require pre-wetting of the part and cannot inspect hot materials
- Very sensitive to environmental conditions

An ultrasonic surface or guided wave is propagated in the material. Flaws oriented perpendicular to the direction of sound will reflect sound back which is detected by the system.

- Highly sensitive to surface and sub-surface defects (cracks and laminations)
- Does not require direct access; a single transducer can cover a large area
- Can penetrate up to 12mm using surface and lamb waves
- It can detect non-perpendicular defects using an attenuation technique
- Conventional piezoelectric requires liquid couplant which contaminates the part, and can attenuate the signal or create spurious reflections
Introduction to EMAT
While Piezoelectric UT uses a crystal to generate the ultrasound, an Electro Magnetic Acoustic Transducer (EMAT) generates the sound in the part inspected.
EMAT can be used on most metals and geometries for all the standard UT applications

<table>
<thead>
<tr>
<th>Type of Inspection</th>
<th>Material</th>
<th>Geometries</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Flaw Detection</td>
<td>• Electrical Conductors</td>
<td>• Discrete and Continuous Geometries</td>
</tr>
<tr>
<td>• Points (1D)</td>
<td>• Ferrous: Carbon Steel, Stainless Steel, Nickel, Cobalt</td>
<td>• Plates (thin and thick)</td>
</tr>
<tr>
<td>• Seams (2D)</td>
<td>• Non-Ferrous: Aluminum, Copper, Brass, Uranium and most other metals</td>
<td>• Cylinders, Rods</td>
</tr>
<tr>
<td>• Surfaces (2D)</td>
<td></td>
<td>• Tubes (round, square or others)</td>
</tr>
<tr>
<td>• Volumes (3D)</td>
<td></td>
<td>• Structural Elements</td>
</tr>
<tr>
<td>• Thickness &amp; Distances</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Material Properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Stress/Anisotropy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Nodularity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• R-Value</td>
<td></td>
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</tr>
</tbody>
</table>
EMAT enjoys all the benefits of UT plus other particular advantages

**Ultrasonic Technique**
- Volumetric Inspection
- One-Side Access
- Meets UT Standards
- Safe

**Ultrasonics is Generated in the Part Inspected**

- **Dry Inspection** (no couplant)
  - Easy to Automate and Integrate in Production
  - No Couplant Induced Errors
  - High Inspection Speeds (up to 60 m/s)
  - Capable of High and Sub-Zero Temperatures

- **Insensitive to Surface Conditions**
  - Capable of Inspecting Rough, Dirty (Oily/Wet), Oxidized or Uneven Surfaces

- **Easier Probe Deployment**
  - No Signal Variations from Probe to Probe
  - Small Changes in Probe Angle do not Affect Results (e.g. part curvature)

- **Unique Wave Modes**
  - Capable of Generating Horizontally Polarized Shear Wave Energy
  - Guided Waves (Especially Advantageous for Weld Inspection)

**Challenges**
- More Power Required
- Lower Signal-to-Noise
- Larger Sensors
Guided Waves and EMAT
Waves that propagate constrained by boundaries are usually referred to as Guided Waves

Guided Waves:

- What can be a waveguide?
  - A surface
  - A plate,
  - A rod, tube, pipe
  - Rail or other structure

- In ultrasound, the practical range of guided waves can vary from centimetres to tens of meters
Surface waves are very well suited for detecting small surface and near-surface defects and cover large areas

Surface waves:
- Surface waves (a.k.a. Rayleigh waves) travel the surface of a solid material penetrating to a depth of one wavelength
- Combine both a longitudinal and transverse motion to create an elliptic orbit motion
- Normally used for detecting defects 0-5mm from the surface
- Sensitive to defects approx. 1/10th of a wavelength
- Can detect defects far away from the source. Typical applications cover 10-1500mm ahead of the transducer
Lamb and Shear Horizontal (SH) waves can penetrate and detect defects anywhere within the boundaries of the material.

**Lamb & SH Waves:**

- **Lamb Waves**
  - Like surface waves, Lamb waves combine a vertical and a transverse motion to create an elliptical wave.
  - Symmetric and asymmetric modes can be used to increase sensitivity to different types of defects.

- **Shear Waves**
  - Perpendicular to the wave direction on horizontal plane ("non-leaky")
  - Only available with EMAT for practical purposes.

- Can detect defects from a few cm to meters away from the transducer.
Using Guided Waves, EMATs have significant advantages over conventional UT for thin weld inspection, especially for automated environments.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>EMAT UT</th>
<th>Piezoelectric UT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permits inspection of &lt;6mm Thick Materials</td>
<td>Yes</td>
<td>Limited</td>
</tr>
<tr>
<td>Dry (No couplant)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Impervious to surface contamination</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Speed</td>
<td>+2 m/s</td>
<td>Couplant limited</td>
</tr>
<tr>
<td>Continuous Self-Calibration</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Consistency and Quality of Readings</td>
<td>Very High</td>
<td>Couplant and noise dependent</td>
</tr>
</tbody>
</table>
Surface Wave Applications
EMAT permits surface inspection of tubes and round and square billets at high temperatures, and at much lower cost than other automated techniques (EC, IRT)

Characteristics:

- Capable of detecting defects from 0 to 3mm on billets and tubes
- A combination of both attenuation and reflection techniques can detect all the longitudinal cracks, and most other defects (roughness, folding, etc.)
- Easy to install, simple to operate with very low maintenance and operating costs compared to other methods
For inspection of plates, ingots and slabs, EMAT replace vision systems at a fraction of the cost, and provides the ability to detect tight cracks

**Characteristics:**

- Capable of covering large surfaces with a few sensors and detect defects perpendicular to sensor orientation

- Installation for copper plates (picture) uses two sensors per side to detect surface and sub-surface cracks 25mm (L) x 0.25mm (H) on a 940mm wide plate

- Replaced machine vision system which couldn’t detect surface cracks at a fraction of the cost
Thin-Volumetric Applications
The temate® ST-SC(HR) is designed for full volumetric inspection of thin strip (<12mm) using guided waves

- Application I: Steel Coils
- In-line or off-line installation
- 100% full volumetric inspection
- Multi-channel system for different gage materials
- Detects internal defects at production speeds (over 400m/min)
- Custom designed for the each customer’s specific requirements
The dual sensor technique detects defects in the rolling direction using Guided Waves

**Characteristics:**

- Two sensors send plate waves from center to edges of strip
- Inspects strip up to 7mm, pickled and non-pickled
- Detects defects in the rolling direction as shallow as 0.1mm
- Minimum defect length detection of 7mm at maximum line speeds
- 100% volumetric inspection except for small band at the edge
- Cost efficient and reliable technique
Guided waves can be also be applied to laminated materials such as coin stock

demate® ST-LA(CS):

- Three-layer nickel/brass and copper laminated composite used for coin stock
- Detects delaminations in any of the layers
- Multi-channel system for different gage materials
- Detects internal defects at production speeds (over 400m/min)
- Custom designed for the each customer’s specific requirements
The sensors in this case are located on both edges

Characteristics:

- Two sensors send plate waves from the edges of the strip
- The system detects Time-Of-Flight variations and changes in amplitude from internal delamination
- Dual frequency guarantees that any defect size is detected
- Inspects 100% of material
- First cost-effective solution for this problem
Manual Applications
Hand-held instrumentation allow using the equipment in the field for a variety of applications

Applications:

- Surface Waves
  - Weld overlays
  - Rolls
  - Structural components

- Thin-Volumetric
  - Thin welds (<6mm)
  - Corrosion under supports
  - Corrosion in air-to-soil interfaces
  - Pipelines and tanks
Innerspec Technologies
Our Company

- US company located in Lynchburg VA with offices in Europe and China, and representatives and distributors throughout the world
- 56 patents for NDT applications and equipment
- First EMAT (NASA) in 1989. First commercial EMAT in 1994
- World leader in High-Power Ultrasound and EMAT with over 200 integrated systems installed in 25 countries, and the most complete line of standard equipment
- temate® and Rollmate® product lines
Why Innerspec Technologies?

- Off-line and in-line systems installed in industrial environments with millions of hours of inspection. Most (95%) are currently in operation 24/7
- R&D resources to tailor the technology to each particular application
- Experience in complete turnkey solutions for full automation or use by low-skilled operators
- Top references from world-class manufacturers

Assembly Area
Thank You
for your attention