ELECTROMAGNETIC ACOUSTICAL TRANSDUCER (EMAT) INSPECTION OF STORAGE TANKS

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Abstract:
Tank floors of large storage tanks are regularly inspected for bottom side corrosion utilizing the magnetic flux exclusion (MFE) nondestructive testing technique. MFE is limited in the thickness of steel it may accurately inspect since the steel requires saturation by magnetic flux. As thickness increases, flux density decreases, and saturation is no longer achieved. For applications beyond approximately 1.016cm (.400"), time consuming automated ultrasonic inspection (AUT) or manual ultrasonic inspection (UT) is typically specified in lieu of MFE. A cost effective alternative was requested by clients to perform a qualitative survey of material beyond the thickness limitations of MFE. An ultrasonic test system utilizing EMATs was identified as a solution and qualified. For some applications, EMATs have proven to be cost effective qualitative inspection technique. It is especially well suited for thick plate in tanks, flat plate, bulkheads, piping, and pressure vessels.

Along the Trans-Alaska Pipeline System (TAPS) and at the Valdez Marine Terminal, annular rings in crude oil storage tanks exceed 2.032cm (.800") in thickness. This thickness is well beyond the limitation of MFE. EMATs with manual and/or automated UT follow-up was selected to perform the inspection. EMATs are ultrasonic transducers that create sound through the exploitation of Lorentz forces and the magnetostrictive effect. Avoiding the use of couplant, these non-contact transducers generate ultrasound within the atomic structure of the inspection medium.

Configured to perform a through-transmission technique, EMATs have been effectively fielded in multiple tanks and thick plate applications. EMATs have shown they are effective in detecting volumetric wall loss on thick annular plates, piping, corrosion detection under welded bulkhead stiffeners, and under structural members of tapered-bottom tanks. When correctly fielded with quantitative follow-up, EMAT technology is a cost-effective inspection technique when MFE is limited due to material thickness or UT is cost and/or time prohibitive.

Introduction: An EMAT does not introduce sound into a test material like a typical contact ultrasonic probe. A contact transducer generates sound when it is pulsed from the test instrument. A piezoelectric material vibrates at a given frequency, which converts the energy into a mechanical vibration. The waveform produced by the vibrating crystal propagates through a liquid couplant and then into the test medium. A liquid couplant is required, as ultrasound is highly attenuated by air.

EMATs do not require a liquid couplant as they operate on completely different physical principles. Instead of generating sound external to the test object and coupling through the surface, an EMAT generates ultrasound *within* the material by using the atomic structure of the material as its own sound generator. The two forces that allow this are Lorentz and magnetostrictive forces. The magnetostrictive effect is the primary generator of sound within a material if the material is ferritic, (iron bearing). Additionally, sound is generated to a lesser extent from Lorentz forces.[1]

Thick plate commonly found in large diameter storage tanks and pressure vessels can create project impediments due to the fact there are limited technologies capable of inspecting such a large area in a timely manner. Due to project time constraints, a cost effect method was required to inspect two 83 meter diameter crude oil storage tanks at the Valdez Marine Terminal at the terminus of the Trans Alaska Pipeline in Valdez, Alaska. An EMAT system configured for a through transmission technique was selected as a potential solution for qualitative screening. AUT follow-up was required on all indications.

Results: For two consecutive summers an EMAT test system has been fielded to perform qualitative tank floor evaluation. Tanks sizes have ranged from approximately twenty meters to more than eighty-three meters in diameter. The EMAT test system runs along the individual floor plates detecting bottom side corrosion. Using an EMAT system saved approximately 400 man hours per tank as compared to the previous method of manual and automated UT. EMATs have been successfully fielded on externally reinforced tapered-bottom tanks, bulk storage tanks, piping, flat plate, and various architectural structural members. The combination of EMAT as a qualitative evaluation tool with quantitative follow-up using ultrasonics has proved to be a rapid and accurate combination.

Discussion: Magnetostriction was first detected by James Joule in 1842. While experimenting, he noticed nickel (Ni.) elongated when placed in a magnetic field. A magnetostrictive material is one that transforms from one shape to another when subjected to a magnetic field. The reciprocal of the magnetostrictive effect is the Villari effect. Thus, magnetostriction is similar to the piezoelectric effect. A magnetostrictive material is capable of converting a magnetic field to mechanical vibrations, and converting mechanical vibrations into a magnetic field (electron movement).[2]

Within an unmagnetized magnetic material such as iron, the magnetic domains of individual grains are randomly oriented. As magnetic flux is introduced to the material, the domains begin to rotate and align themselves parallel with the magnetic field. The stress of the rotating poles results in an elongation of the material. As more flux is introduced, the internal stress increases. If the magnetic field is systematically applied and removed, the resulting stresses elongate and then return the material to its original static position. The repeated application and termination of a magnetic field causes a mechanical motion and creates a vibrational wave form within the material.[3]

Lorentz forces are more commonly referred to as electromagnetic forces. The physics behind Lorentz forces is the foundation that explains how electric motors, generators, and generally any electrically mechanized system moves and operates. Within a generator, a conductor is rotated through a magnetic field. The influence of the magnetic field causes electrons within the conductor to move in one direction. When a conductor starts to move, available electrons move from a stationary position down the conductor according to the right hand rule. For every action, there is an opposite and equal reaction. When an individual electron is forced out of its valence and moves in one direction, a force is exerted on the atomic structure of the conductor in the opposite direction. This causes a very minor distortion of the metallic lattice along the lines of several hundred parts per million. By subjecting the inspection material to the subsequent application and termination of current, sound is generated in the material.

Within an EMAT, a static magnetic field influences the eddy currents generated by a conducting coil near the surface of the test medium. An EMAT establishes a static magnetic field through the use of a permanent rare earth magnet or an electromagnet. An electrically conductive coil is placed along the bottom of the transducer housing. The eddy currents created by the coil when it is pulsed, interact with the static magnetic field in the material. A protective wear plate protects the coil from damage during use.

EMAT signals typically are displayed on a screen representing time vs. amplitude (time of flight). Multiple waveforms are visible on the time base line. The appropriate waveform for the inspection to be conducted is identified. Frequency is adjusted to isolate one wave form package from other waveforms as much as possible.[4] Corrosion is detected based upon the time a signal travels a known fixed distance between two transducers (ΔT). Within a plate of uniform thickness, velocity is constant. If corrosion exists in the area between the T_x and R_x transducers, the wave front must compress and distort to propagate around the corrosion pattern. This decreases the time for the wave to reach the receiving transducer. The decrease in time correlates to the presence of corrosion. Additionally, corrosion or discontinuities may cause a loss of amplitude (ΔA). These two factors are used to access the condition of the tank floor. Similar to

MFE, the technician visually determines if top-side corrosion is present. If topside corrosion is not present, the technician will mark the surface between the two transducers as an area of interest. Follow-up quantitative analysis is then performed with manual and/or automated ultrasonics.

Conclusions: Utilizing EMATs configured for through transmission has proven to be an effective qualitative inspection technique to detect volumetric wall loss on steel plate. EMATs have shown that they may be fielded to perform qualitative assessments on plate thicknesses that exceed capabilities of MFE test systems. A quantitative inspection technique, usually manual or automated ultrasonics, is used to further evaluate any anomalies detected with the EMAT system. The combination of EMAT inspection and quantitative follow-up for corrosion detection has shown it is an effective tool for many tank and flat-plate applications.

References:

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