THE USE OF MAGNETOSTRICTIVE EMAT TRANSDUCERS ON OXIDE SCALED BOILER TUBES

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Abstract: The utilization of magnetostrictive Electromagnetic Acoustic Transducers (EMATs) has dramatically decreased inspection time for carbon steel boiler tubes coated with high temperature oxide scale. Conventional ultrasonic thickness gaging with piezoceramic transducers is commonly used to determine remaining wall thickness of pipes and tubes in corrosive and erosive environments. Pipes such as boiler tubes can develop coatings of oxide scale. Traditionally, this scale has been removed in order to couple conventional ultrasound into the part. Magnetostrictive EMATs utilize this scale to generate ultrasound in a test piece. Other advantages of the magnetostrictive EMATs over conventional ultrasonic transducers are that they can be used at a small distance or slight skew from the scaled surface, and do not require use of liquid couplant. Because the EMAT utilizes the magnetostrictive principle, it can be used with a range of ultrasonic pulser receivers. The theory behind the magnetostrictive EMAT transducer will be presented, with an emphasis on practical examples.

Introduction: The term EMAT stands for Electro-Magnetic Acoustic Transducer. This type of transducer uses a combination of static and dynamic magnetic fields to convert electrical energy into acoustic energy.

There are two contributions from an EMAT transducer that affect the amplitude of the ultrasonic signal. Within the NDT industry the most commonly utilized contribution is the Lorentz Force, and this will be referred to as the Lorentz EMAT within the body of this paper. The Lorentz EMAT can produce ultrasonic signals in bare metal. The lesser-known contribution from an EMAT transducer utilizes the magnetostrictive force and will be referred to as the magnetostrictive EMAT within the body of this paper. The magnetostrictive EMAT can produce ultrasonic signals under a specific condition, the presence of magnetic conductive materials.

The practical example that will be examined within this paper involves the presence of the high temperature oxide scale that is commonly found on the external walls of boiler tubes. The high temperatures found inside steam boilers, in excess of 500°C or 1000°F, can cause the steam and flue gas constituents to react with steel to form a brittle iron oxide called magnetite on the inside and outside surfaces of steel boiler tubing.

Figure 1 illustrates the performance range of each contribution. The magnetic field required for the Lorentz EMAT to vibrate clean metal must be of high strength, and the result of powerful magnets and high power output instruments. The magnetic field required by the magnetostrictive EMAT to vibrate the high temperature oxide scale is significantly lower strength than that required by the Lorentz EMAT. Figure 1 illustrates the difference in signal amplitude of the magnetostrictive EMAT and Lorentz EMAT at the same lower strength magnetic field level. At lower level magnetic fields, the magnetostrictive contribution has a greater amplitude output.

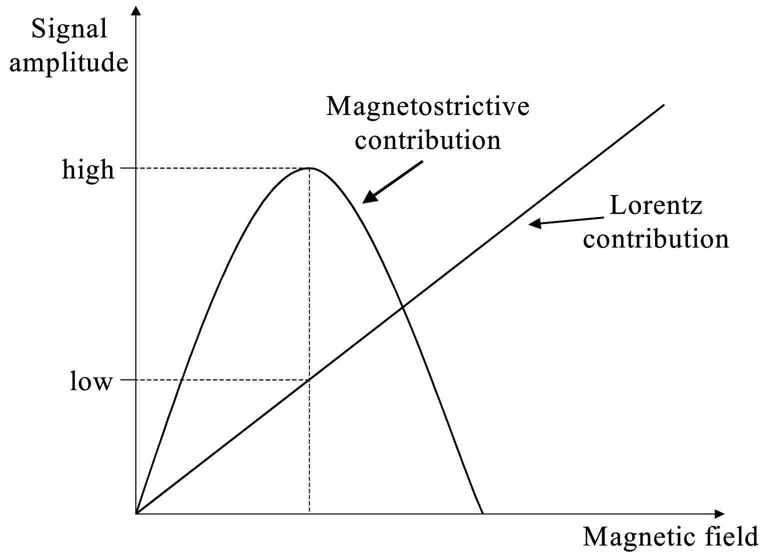

Figure 1 – magnetostrictive and Lorentz contributions

This paper will concentrate on a normal incidence shear wave magnetostrictive EMAT transducer. A common design of this type of transducer includes a permanent magnet, a wear face, a flat coil, and an electrical connection. This is shown in the cross sectional diagram in Figure 2.

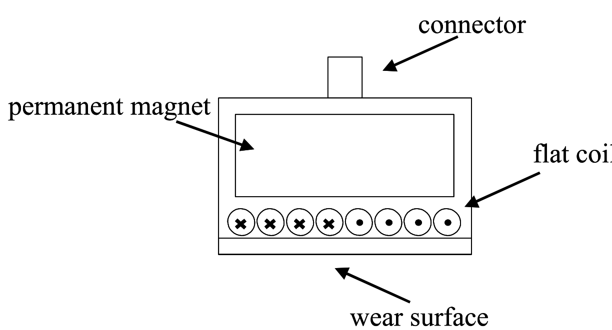

Figure 2 – cross section of typical EMAT

This design of magnetostrictive EMAT propagates normal incident shear waves into the part through high temperature oxide scale. It does this through the combination of static and dynamic magnetic fields produced from the permanent magnet and current induced coil, respectively, as shown in Figure 3. The scale is aligned along the static magnetic field B_s generated by the permanent magnet. The dynamic magnetic field B_d is induced from the current that runs through the flat coil. B_d causes the scale surface to be pulled radially outward and inward as the transducer is pulsed with an alternating electrical current. The dynamic magnetic field B_d pulses the scale, which in turn produces a normal incident ultrasonic shear wave within the pipe.

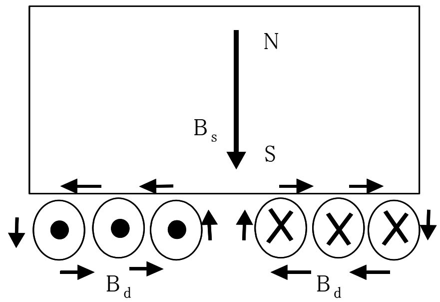

Figure 3 – method of sound wave generation

Results: Tests performed with a variety of scaled boiler tube samples, the Panametrics-NDT EMAT transducer E110-SB, a Panametrics-NDT Model 37DL PLUS Corrosion Gage, and a Panametrics-NDT EPOCH 4 Flaw Detector indicate that the minimum thickness that can be measured under ideal test conditions is 1.27mm or 0.050". Under more general industrial conditions, the minimum thickness is considered to be approximately 2mm or 0.080". The maximum thickness specification for the E110-SB is 125mm or 5", but in practical applications, boiler tube wall thickness will not reach this thickness. The temperature limitations of the Panametrics-NDT E110-SB are 0°C to 60°C or 32°F to 140°F in continuous contact, and up to 80°C or 176°F in intermittent contact. The measurement accuracy has been determined to be +/- 0.25mm or +/- 0.010".

Since the scale on a pipe can vary in thickness, the EMAT transducer does not produce a set center frequency. Instead, this frequency varies as scale thickness varies. The typical center frequency of the E110-SB is 5MHz but could range from 2 to 8MHz depending on the scale thickness.

A typical EMAT waveform is shown in Figure 4, representing a shear wave wall thickness measurement of a 4 mm boiler tube with a Model 37DL PLUS gage.

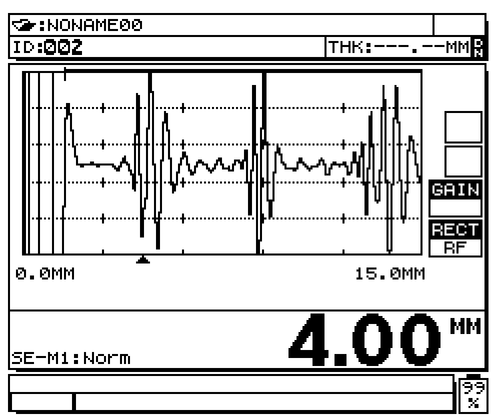

Figure 4 – typical EMAT waveform

For comparison, Figure 5 shows the waveform obtained from the same pipe sample using a conventional dual element 5 MHz piezoceramic transducer that generates a longitudinal wave.

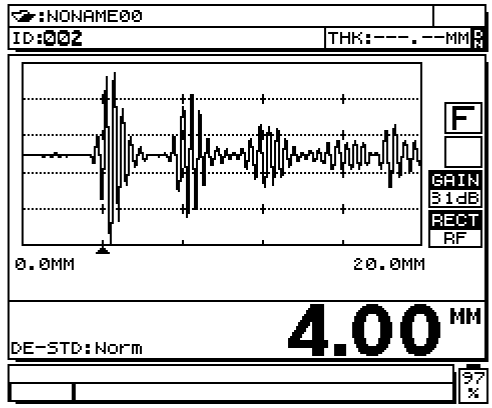

Figure 5 – typical piezoceramic transducer waveform

Discussion: It is extremely difficult to inspect boiler tubes coated in oxide scale using traditional ultrasonic methods. Due to the flaky nature of the scale, there are many air-scale-air interfaces through which it is difficult or impossible to send ultrasound. Inspection techniques under these conditions typically consist of either removing all of the scale on a given section of pipe, or removing scale in random areas to be spot-checked. The scale is difficult to remove, which makes both of these methods time consuming. Because of the time involved in scale removal, a 100% surface scan is rarely performed.

With the magnetostrictive EMAT, the scale is advantageous to the user. The scale acts as the active element of the magnetostrictive EMAT, since it is converting magnetic energy to acoustic energy. This eliminates the scale removal process altogether. The EMAT transducer presents additional advantages to the user. No couplant is required, which increases convenience and greatly decreases scanning time. The EMAT can produce a normal incidence shear wave without mode conversion. The normal incidence shear waves that are produced provide greater resolution than a longitudinal wave due to a shorter wavelength, and can thus measure down to a thinner minimum wall at a given frequency.

The magnetostrictive EMAT also can be used at a slight distance or at a skew from the part. Because the scale generates the sound energy, the sound is still propagated normal to the surface of the part even if the transducer is somewhat skewed. See Figure 6 for direction of sound propagation. This also means that one transducer can be used for multiple diameters of piping, since regardless of placement and contact area, the sound will still propagate normal to the tube diameter. This eliminates the need for multiple transducers for a range of boiler tube sizes.

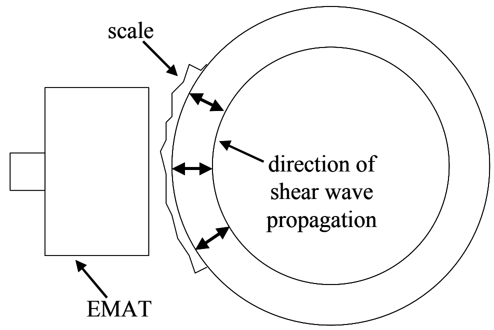

Figure 6 – direction of wave propagation

Consideration should also be given to the limitations of the magnetostrictive EMAT transducer. One of these limitations is the potential for magnetic saturation from the permanent magnet. Magnetic saturation of the oxide scale can result in a decrease in returned backwall signal amplitude. The magnetostrictive EMAT should have a mechanism that allows for variation in the lift-off from the part being inspected. This lift-off must be adjusted for optimal signal response during each calibration or setup.

Thickness measurements utilizing magnetostrictive EMAT transducer results are not as precise as those from a conventional piezoceramic transducer at a similar frequency, mainly due to the ringing characteristics of the EMAT and the variation in wave shape depending on oxide conditions. Because of this, the magnetostrictive EMAT is not intended to replace the piezoceramic transducer in boiler tube applications with high accuracy requirements. Instead, it should be utilized as a screening tool for scaled boiler tubes. Thanks to the ease of scanning, it will be possible to quickly locate general areas of wall thinning on a boiler tube. Potentially critical areas can then be inspected more precisely with a conventional dual element piezoceramic transducer. The magnetostrictive EMAT allows for a full surface coverage as opposed to the limited coverage area that is inspected with typical ultrasonic methods.

The EMAT transducer design has potential to be used at much higher temperatures than 80°C (176°F). Unlike piezoceramic transducers, whose temperature range is limited by the various heat expansion coefficients of the critically bonded components, the EMAT components can withstand a much larger temperature range. The critical temperature point is dependent upon the depoling temperature of the permanent magnet and the electrical component temperature specifications of the specific EMAT design.

Conclusions: It is possible to conclude that the magnetostrictive EMAT is a critical inspection tool for scaled boiler tubes. The EMAT saves inspection time because scale removal from boiler tubes is eliminated from the inspection process. Scanning time is also reduced since no couplant is required for the inspection. The EMAT is a versatile solution since it can be used to inspect a variety of pipe diameters with thickness down to 2mm or 0.080" with an accuracy of 0.25mm or 0.010". If additional precision is required, the EMAT can be used for full surface coverage to pinpoint areas of concern and further spot inspection with an ultrasonic transducer can be performed.

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