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AN EMAT-BASED APPROACH TO LOCATING AND SIZING DEFECTS IN LARGE WELDED STEEL PLATE STRUCTURES

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ABSTRACT

Large steel structures are widely used throughout the industrial sector. The particular case being addressed here relates to the location and sizing of relatively large defects within very large, frequently abraded or corroded, steel structures. Such structures exist worldwide in many industrial sectors. As a case in point, consider a steel tank 20 m in diameter and 10 m high that is fabricated from a large number of welded steel plates, probably of varying thickness (say, from 12 to 24 mm) and frequently having a steel floor [1]. The specific inspection task discussed here addresses the walls of such a tank but it is extendable to the floor.

Keywords: EMATs, Lorentz Force, ultrasonics

1. INTRODUCTION

Material defects may be volumetric (such as corrosion pits or larger areas of varying amounts of wall loss) or crack-like (defects of this type may be encountered in the welds used to fabricate such large structures or in areas of localized stresses where phenomena such as thermal cycling may be the driving force for local crack growth). Although general overall corrosion can exist in some structures, the specific task being addressed here is where the defects are generally sparsely distributed throughout the large volume of material in such a tank/structure. The challenge is to develop an inspection protocol that has sufficiently high detection sensitivity while permitting high inspection speed so that the large surface area and material volume may be inspected at minimum cost and in a reasonable time. Several different approaches to addressing these inspection tasks have been investigated in the active area of inspection R&D [2], [3], [4].

2. MATERIALS AND METHODS

For a previous project, an EMAT-based defect detection system was designed to detect the presence of both volumetric and planar or crack-like defects in steel strips up to 350 mm in width and 10 mm in thickness, including defects at the plate edges/boundaries. This EMAT measurement system operates with a PRF of up to 300 Hz for tone burst (TB) guided wave measurements up to 500 kHz (at the maximum rated inspection speed of 1 meter/sec, this corresponds to generating, receiving and processing the information from one guided wave pulse every 3.3 mm of plate travel). Inspection of these steel strips is carried out just prior to the strips being rolled and welded to form a pipe; the EMAT system is fixed with respect to the steel strip as it passes through the EMAT system prior to the plate being welded to form a pipe. Reference material defects of 6 mm diameter flat bottom pits having various depths over 25% of the nominal wall and 0.5 mm wide saw cuts having a range of orientations, made with a 75-mm diameter blade and having a maximum depth of 10% of the nominal wall all generate a system response having a signal-to-noise ratio (SNR) in excess of 3. Slower inspection speed may result in an improved SNR.

3. RESULTS AND DISCUSSION

Based on this experience, we have designed approaches to defect detection in thicker plates. These approaches are based on the use of a variety of guided waves and guided wave modes (such as Lamb and SH) generated by Lorentz force EMATs (LF-EMATs). In some cases, the sequential, essentially simultaneous generation of multiple different wave modes and types has been deployed. LF-EMATs are chosen because their sensitivity is relatively independent of the material magnetic properties and no special surface coatings or other conditions are required. Generation and reception sensitivity are not sensitive to the presence of a surface oxide mechanical cold-working of the surface material. This means that, when designed appropriately, they may be used on a wide variety of metals of varying permeability and conductivity and over a wide temperature range [5].

Using experience gained from performing measurements on thinner plates, for this preliminary set of measurements, we have adapted one of our existing SH mode LF-EMAT transmitting and receiving systems to the task of detecting artificial defects at various locations in a 0.5-inch thick ASTM A570 construction steel plate 4-feet wide and 8-feet long. This LF-EMAT is not optimal for a plate of this thickness; it was designed for a

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different inspection task and is used here to demonstrate a general capability related to the specific real-world inspection task mentioned above. A more optimal EMAT is being built.

There are at least two quite different approaches to designing an inspection system, EMAT-based or otherwise, for a large structure: (i) perform detection and sizing in one operation or (ii) first detect and then later, in a subsequent set of scans, return to the detected anomalies for their further quantification. The most time-efficient approach probably depends on the number of defects/material anomalies that are present in the structure and the degree of quantification that can be achieved during the "first pass" inspection (the quantification of harmless, small defects is generally not cost-effective). The approach discussed below is one of several that could be implemented. However, this approach and the results obtained serve to define some general guidelines to developing a final inspection scenario. Other approaches to defect detection, including interpretation of measurements, are discussed in the literature [6], [7], [8].

The T-EMAT that we used could, with varying efficiency that depended upon the frequency being used, generate the SH0 and SH1 modes in the 0.5-inch thick plate. Two receiver EMAT transducers (R-EMATs) were constructed: one with an active region of under a quarter wavelength in the wave propagation direction and about 20 mm perpendicular to the propagation direction and a second about two wavelengths in the wave propagation direction and about 50 mm wide. Each receiver has particular advantages related to sensitivity and spatial resolution. The transmitter EMAT transducer (T-EMAT) and R-EMATs will eventually be scanned over the 4 by 8-foot plate surface as either separate assemblies or with fixed relative positions (both separation distance and transducer orientations) one to the other.

To date, all measurements have used the larger R-EMAT and a T-EMAT current at selected frequencies and a 4-cycle TB. For the SH0 mode, a direct T-to-R SNR in excess of 20 (26-db) was obtained with a T-to-R separation distance of 30 cm and no temporal averaging and at a distance of 300 cm using 16 averages (this long travel distance required us to use a reflection from one end of the plate but the process of reflection does not substantially alter the signal amplitude). In order to minimize the interference of multiple plate internal reflected signals, a PRF of 30 Hz was used. Even in this case, plate edge reflected signals resulted in a rather large "dead" zone. Obviously, the dispersive SH1 mode suffered significantly greater signal loss; the direct SH1 mode signal at a T-R distance of 60 cm required 16 averages to achieve an SNR of 10 (20-db). So far, it has also proven a challenge to develop measurement conditions using the SH1 mode that did not involve substantial interference from direct and reflected SH0 modes propagating in the plate. Both transducer configuration and signal processing approaches are being pursued to enhance our ability to separate "useful" signals from the annoying geometrical reflections.

In order to assess one aspect of the defect detection sensitivity of this measurement system, a separate, smaller area 0.5-inch thick steel plate with a milled "slot" 25 mm long by 3 mm wide by 2.5 mm deep was used (at this stage, moving our EMAT system over the larger plate was very time consuming so the smaller plate was chosen for these initial capability demonstration measurements). With the T-EMAT about 50 cm from the "slot" and the R-EMAT placed between it and the "slot," a reflected SH1 signal having an SNR of about 6 (16-db) was received at the R-EMAT after 16 averages (which takes about 0.5 seconds). A smaller SH0 back-scattered signal was also received from this defect.

Using these results, we have designed and are building a T-R LF-EMAT system that is optimized for the short-range detection of "small" defects using the SH1 mode (within 100 cm on each side of the T-EMAT) and for the detection of larger defects at longer distances using the SH0 mode. Based upon measurements to date, we anticipate being able to classify artificial defects into three categories: (i) under a volume of about 0.2 to 0.5 cubic cm, (ii) between 0.5 and 3 cubic cm and (iii) larger using a single "pass" of the EMAT system over the plate (scanning the EMAT system once over each region of the test object). In addition, for the "larger" category, we anticipate being able to estimate the dimension perpendicular to the beam direction.

A variety of scanning scenarios are possible and at least two will be evaluated. First, a T-EMAT with R-EMATs on both sides (to take advantage of the bi-directional aspect of the current T-EMAT) with each R-EMAT in the range of 30 to 60 cm from the T. Overlapping scans will be used so that the inevitable dead zone around the T can be assessed. Additionally, scans will be made parallel to plate edges and at angles thereto. Second, a T-EMAT that can be rotated about an axis perpendicular to the plate and an R-EMAT array for the efficient assessment of a large plate area will be evaluated. In both cases, a variety of signal processing methods will be evaluated. Rotating the T-EMAT and moving the R-EMATs accordingly has the advantage of interrogating a defect multiple times from different angles (with the process repeating at different T-EMAT positions). Also, this can minimize the influence of weld/plate edge reflected and scattered signals which can cause significant problems by "masking" a "small" defect signal within a much larger reflected signal (the intrinsic attenuation of sub-MHz elastic waves in plates with "unloaded" surfaces is very low). Some of these approaches are applicable to the detection of weld defects using approaches such as scanning while straddling the weld (preferably scanning to minimize reflections from the geometrical features of the weld).

4. CONCLUSION

Preliminary measurements using LF-EMAT guided waves, specifically SH0 and SH1 modes, on a 4-feet by 8 feet, 0.5-inch thick plate yielded encouraging results with respect to the range of wave propagation and relatively small defect detection within a reasonable defect to R-EMAT separation distance. Larger defects will be detectable from longer distances. These results allow us to develop our scanning and defect detection strategy by strategically moving a rotating T-EMAT and an array of R-EMATS (relative to a fixed location of the T-EMAT) and along with the T-EMAT. Such a scanning strategy using our high speed LF-EMAT technology and not requiring any prior preparation of the test object are likely to be key contributors to a cost effective and efficient solution.

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