Applications of Linear Scanning Magnetostrictive Transducers (MST) for Finding Hard-to-Detect Anomalies in Structural Components

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Abstract: Guided wave testing is now a widely accepted method for detection of structural damage in many different types of components, from pipelines to pressure vessels to tanks. Torsional wave modes (T modes) in pipes and shear horizontal (SH) mode guided waves in plates are good candidates for finding areas with generalized corrosion, due to the absence of fluid coupling effects and their lack of dispersion. However, from our field test experience, certain types of defects are difficult to detect with conventional T mode or SH mode guided wave probes. Gradual wall thinning is one such type of defect; another is crack-like defects in or close to welds or penetrations in the pipe. Recently, Southwest Research Institute (SwRI) has developed a new sensor configuration and scanning system that overcomes these limitations. We have recently developed a linear scanning magnetostrictive transducer (MST) probe system, in which a FeCo strip wound with radio frequency (RF) coils is attached to the structure under test with shear wave couplant, and a moving permanent magnet driven by a motor is used to excite SH guided waves at predefined positions along this strip. The probe is designed to operate over a wide frequency range (20 – 500 kHz) and can be used to generate dispersive shear wave mode (SH1) in addition to the nondispersive SH0 mode. The use of different modes with the sensor at multiple positions allows detection of a range of defect types. In this paper, the performance of linear scanning MsTs is presented, including experimental evaluation of detection of gradual wall thinning patches of different depths and locations on a steel pipe and plate mockups. Another set of experiments evaluates detection of notches in seam welds. Indications from real-time B-scan and SAFT (synthetic aperture focusing technique) processing will be presented.

Keywords: Guided waves, Magnetostrictive probe, gradual wall loss, shear horizontal guided waves, crack-like anomalies
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APPLICATIONS OF LINEAR SCANNING MAGNETOSTRICTIVE TRANSUDCERS (MSTs) FOR FINDING HARD TO DETECT ANOMALIES IN STRUCTURAL COMPONENTS

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Introduction

- Gradual wall thinning and crack-like defects in or close to welds represent a serious challenge for detection using conventional guided wave testing.

- When these types of defects develop in areas hidden by pipe supports or wall penetrations, detection is impossible with conventional ultrasonic testing.

- This is the reason why development of short and medium range guided wave testing methods is a high priority for many industrial applications.

- The objective of the present research is to experimentally investigate the detection and quantification capability of the linear scanning MsT probe on gradual wall thinning and for detection of notches in seam welds.
Magnetostrictive Transducers for Transverse Vibrations

- Shear horizontal (SH) ultrasonic guided waves is a promising tool for fast screening of pipework for corrosion due to the ability to travel relatively long distances with low dispersion.
- One established approach to excite such waves in pipes is through a soft ferromagnetic ribbon material with a magnetic bias field perpendicular to the wave propagation direction.
- An alternative magnetostrictive transducer (MsT) design invented in 2008 uses a magnetic bias field parallel to the wave propagation direction.
- Compared to the previous designs, MsTs have the advantages of higher transduction efficiency due to better control over time varying and static magnetic fields.
Linear Scan MsT Transducer

- The linear scanning MsT probe utilizes a FeCo strip of a predefined length wound with RF coils and attached to the structure under test using a shear wave couplant.
- A permanent magnet driven by a step motor is used to excite SH guided waves at predefined positions along the strip.
- Manual manipulation of the probe is minimized, allowing significantly increased axial resolution and testing speeds.
- Scan data from various aperture sizes can be obtained with minimal effort by using magnets of different lengths.
- The ferromagnetic ribbon is encapsulated into a low-profile flexible casing.
Detection of Gradual Wall Loss on Mockup

- Initial experiments were conducted using a steel pipe of 406 mm OD and 10 mm wall thickness.
- The linear scanning MsT probe was installed at the pipe top. The guided wave propagation direction is labelled with an arrow.
- The permanent magnet used to generate SH guided waves has a length of 127 mm and a width of 12.5 mm. The scan increment was 12.5 mm.
- Five “V” shaped 38 mm wide gradual wall thinning patches with maximum depths of 10%, 18%, 28%, 36%, and 50% through wall were introduced by electrical discharge machining (EDM).
Gradual Wall Loss Detection Results

- Two excitation signals were applied to generate pure SH0 and combined SH0/SH1 guided wave modes, respectively.
- The first set of data was collected at 150 kHz; no indications were found.
- Results of the test at 250 kHz indicated that 50%, 36%, and 28% wall thinning patches are detectible.
- After applying SAFT, the 18% patch is marginally detectible and the 10% patch was not detected.
Detection of Gradual Wall Loss in Storage Tank Walls

- The linear scan MsT probe was evaluated for detection of generalized corrosion in a storage tank with extended internal surface corrosion.
- Probe was positioned on top of two areas of interest – welded pipe support and known corrosion spot with measured wall loss up to 36%.
- At 100 kHz, a few SH0 mode indications were observed relevant to the welded support and to deepest anomaly.
- At 150 kHz, multiple SH1 mode indications could be observed in both areas of interest.
- The presence of multiple SH1 mode indications provided more realistic information about the defect morphology.
Detection of Crack-Like Defects in or Close to Welds

- Welds typically have cross-section changes that cause some of the guided wave energy to be returned to the probe.
- If a crack-like defect is in the weld, any indications produced by the crack will be merged into the weld reflection.
- One way to detect short anomalies in welds is to transmit the guided wave at an angle of 20 – 30° to the weld normal.
- In this case, the guided wave energy returned from the weld will not be reflected to the probe, per Shell’s law.
- On the other hand, anomalies with lengths less than a wavelength will act like a point reflectors and will return some energy to the probe.
Conclusions

• A linear scanning probe based on rigid and flexible MsT technology was demonstrated for detection of gradual wall thinning and crack-like defects in welds.

• The SH1 mode can be used for gradual wall thinning for short range applications, such as screening of pipe or tank supports using circumferential or axial path guided waves. SH1 mode dispersion might limit its use over long ranges.

• Detection of crack-type defects hidden in seam welds was demonstrated using an angle beam. The physical flexibility of the linear scan MsT probe lets it be adapted to different surface geometries to obtain desired beam angles.

• Future work will include use of two linear scan MsT probes in pitch catch mode to allow utilization of full matrix capture (FMC) and total focusing method (TFM) algorithms.