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PITTING CORROSION DETECTION IN THIN TUBES USING TORSIONAL GUIDED WAVE MODE T(0,1)

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ABSTRACT

The use of ultrasonic guided waves has been identified as a promising technology for continuous monitoring of pipe structures to detect defects of cross-sectional area ratio less than 5%. This paper presents an effective approach to use torsional guided wave mode T(0,1) in thin and small diameter stainless steel tubes for detecting small pitting defects using magnetostriction sensors. The phenomenon of scattering of the fundamental torsional mode T(0,1) from complex-shaped discontinuities in thin tubes is closely examined, and its excitation parameters are optimized to an extent using finite element (FE) simulations. From the numerical and experimental results, the optimized design for transmitting/receiving pure torsional modes in cylindrical waveguides at high frequencies in the range of 1MHz are investigated. The results show that the reflection coefficient of torsional guided wave mode T(0,1) is a stronger function of the through-thickness depth as well as the axial and circumferential extent of the notch. The finite element results are then compared with the experimental data. The sensitivity of the reflected signal from defects up to 2% of the cross-sectional area ratio was examined, and it was found that defects smaller than 2% of the cross-sectional area ratio were detectable.This work is of great interest to many process industries including semiconductor manufacturing industries.
Keywords: Guided waves, Pitting corrosion, Magnetostriction

Nomenclature

T(0,1)	Fundamental torsional guided wave mode
d	Depth of the pit
D	Diameter of the pit
E	Young’s modulus

1. INTRODUCTION

Corrosion is a major cause of component failure and therefore its detection and control is a key issue. Pitting is localized corrosion where the corrosion damage is localized which occurs in passive materials like stainless steel and nickel-chromium alloys. In this work the pit is defined by two parameters: the depth of the pit (d) and diameter of the pit (D). If the ratio (D/d) is lesser than 10 it is said to be localized corrosion [1].

Guided waves play an important role in defect detection and are employed in the various type of transducers including piezoelectric and magnetostrictive type. Because of its nondispersive nature the fundamental guided torsional wave plays a unique role in cylindrical waveguides [2]. Since it is nondispersive the shape of the wave remains undistorted during propagation and the exact times of events can be effectively identified. Among various transduction mechanisms, the torsional waves can be effectively generated without flexural and longitudinal modes by the magnetostrictive method utilizing a ferromagnetic patch bearing strong magnetostriction [3-5]. Because of this reason, a magnetostrictive method will be mainly considered to generate high-frequency torsional waves in this investigation.

2. Methodology

The aim of this work is to develop a transduction mechanism to find out pitting defects of a cross-sectional area ratio of less than 2% in thin tubes of small diameter. For this analysis a stainless steel tube (diameter=9.5mm, thickness=0.95mm, length=600mm, density=7950kg/m^3, E=192Gpa) was artificially cracked and inspected by the guided torsional waves. Its schematic is shown in Figure 6. The entire work is classified as two segments which are finite element modelling and experimental validation.The disperse plots are shown in Figure 1, for the mentioned specimen. An incident T(0,1) torsional guided wave mode around 1MHz is considered throughout this investigation. However mode conversion to the non-symmetric mode could occur at a non-axisymmetric feature. More on this in results and discussion. A finite element modelling study on the reflection coefficient behaviour from cracks of varying depth, circumferential and axial extent is presented. Finally an experimental procedure describing the efficient generation of torsional guided waves at high frequency is discussed and some numerical results are validated with that of experiments. The

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magnet orientation for providing stable static bias magnetic field and solenoid coil windings around a magnetostrictive patch of prescribed length play a key role in generating torsional guided waves in the cylindrical waveguide [4].

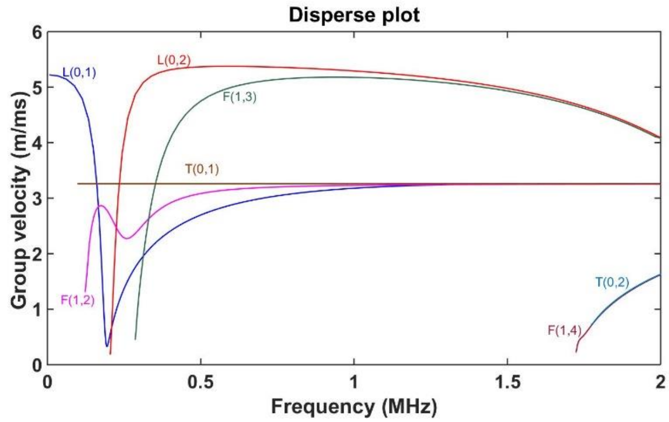

FIGURE 1: GROUP VELOCITY DISPERSION CURVES FOR L(0,1), L(0,2), T(0,1), T(0,2), F(1,2), F(1,3) AND F(1,4) FOR THE SS TUBE OF (ØD 9.5MM AND THICKNESS 0.95MM) AS A FUNCTION OF FREQUENCY.

3. RESULTS AND DISCUSSION

For an ultrasonic wave motion in a solid body a defect represents a scatterer and it can be detected and characterized by its effect on the incident pulse.

3.1 Finite Element modelling and results

The T(0,1) mode at 1MHz was excited and monitored.The excitation on a cross-section is shown in Figure 2 and is monitored on other cross section by adding circumferential displacements of all nodes at that location.

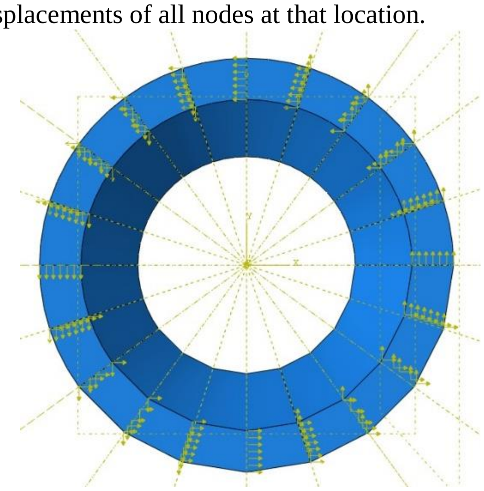

FIGURE 2: TORSIONAL EXCITATION ON THE CROSS-SECTION OF THE PIPE

The cylindrical holes(defects) which are less than 2% of the cross-sectional area ratio i,e of diameters 500μm,400μm and 300μm with various depths along the thickness were modelled, analysed and their reflection coefficients are plotted as shown in Figure 3. It can be observed from Figure 4, the trend of reflection coefficients increases with an increase in diameter and depth of the pit which is also illustrated in the form of a cross-sectional area ratio in Figure 5.

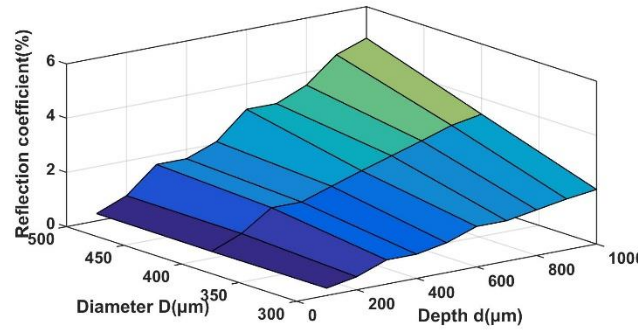

FIGURE 3: 3D-PLOT OF REFLECTION COEFFICIENTS AS A FUNCTION OF DIAMETER AND DEPTH.

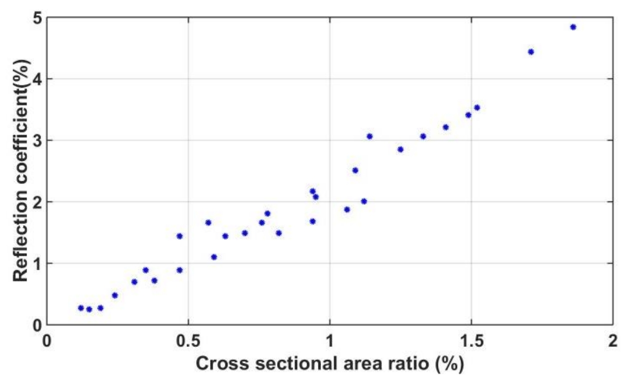

FIGURE 4: 2D-PLOT OF REFLECTION COEFFICIENTS AS A FUNCTION OF CROSS-SECTIONAL AREA RATIO.

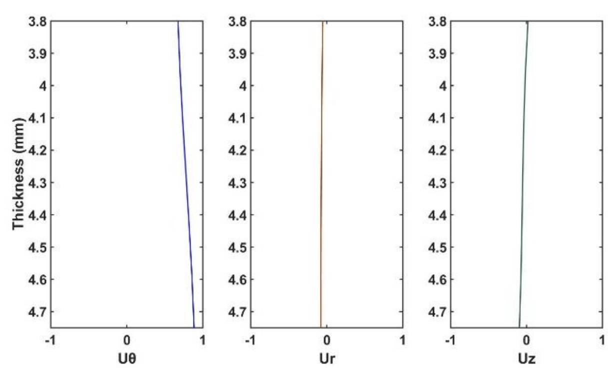

FIGURE 5: MODE SHAPES OF THE U_θ (TANGENTIAL), U_r (RADIAL) AND U_z(AXIAL) NORMALISED DISPLACEMENTS FOR A MODE CONVERTED REFLECTED PULSE FROM THE DEFECT.

3.2. Experimental results

The magnetostrictive patch transducer set up is shown in Figure 7. T(0,1) guided wave at 1MHz which is far less than the cut off frequency of T(0,2) is excited and received in the pitch-catch method. The measured signal for a particular case of defect diameter 500μm and through-hole depth of 950μm is shown in Figure 8. The velocity of T(0,1) mode is 3260m/s as shown in

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Figure 1.The first pulse arriving at 46μs represents the direct wave and the second pulse at 150μs represents the reflection from the left end. The pulse in between them at 90μs represents the mode converted reflected signal from the defect.

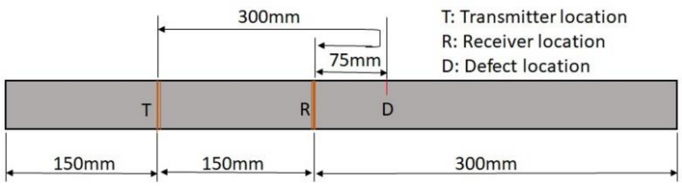

FIGURE 6: THE SCHEMATIC ARRANGEMENT OF THE TRANSDUCER FOR CRACK DETECTION BY TRANSMITTING TORSIONAL WAVE.

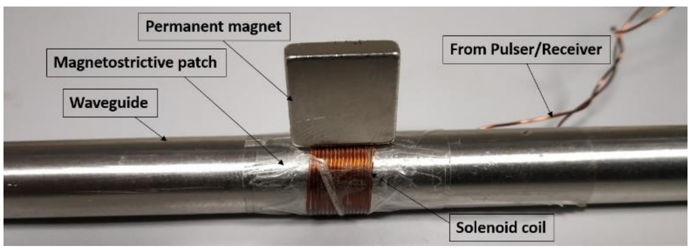

FIGURE 7: DESCRIPTION OF THE MAGNETOSTRICTIVE PATCH TRANSDUCER.

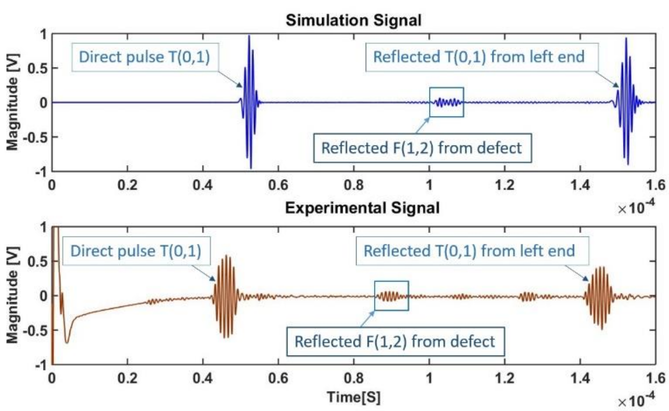

FIGURE 8: THE MEASURED SIGNAL FROM THE CRACK BY SIMULATION AND EXPERIMENTAL SETUP.

Since the reflection from the left end is from an axis-symmetric feature there is no possibility of mode conversion to asymmetric modes. But from the defect which is a non-axis symmetric feature there is a high probability of mode conversion and flexural modes are generated. From Figure 1, the flexural modes generated at 1MHz are F(1,2) and F(1,3). Among F(1,2) and F(1,3), the former has the highest probability since its tangential displacement is dominant as shown in Figure 5. For F(1,2): [$U_r < U_z < U_\theta$] and for F(1,3): [$U_r < U_\theta < U_z$]. Since the incident T(0,1) mode has tangential displacement it is likely to convert into a mode which has more tangential displacement compared to radial and axial [2]. So it is concluded that the mode converted signal from the defect is F(1,2) whose group velocity is 3230m/s. The proposed magnetostrictive transducer can suitably work at high-temperature conditions for monitoring pitting corrosion [7].

4. CONCLUSION

In this investigation an existing magnetostrictive transduction method was optimized in various parameters like magnetostrictive patch length, coil winding and magnet orientation to work at high frequencies around 1MHz to generate pure T(0,1) guided waves. This configuration is apparently useful for detecting cracks of cross-sectional area ratio less than 2% in thin tubes of small diameter.

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REFERENCES

[1] Carandente, Rosalba, and Peter Cawley, “The Effect of Complex Defect Profiles on the Reflection of the Fundamental Torsional Mode in Pipes.” *NDT and E International* Vol.46 No.1(2012):pp. 41–47. DOI. 10.1016/j.ndteint.2011.11.003.URL.https://doi.org/10.1016/j.ndteint.2011.11.003.

[2] Demma, Peter Cawley, Michael Lowe, and Roosenbrand, “The reflection of the fundamental torsional mode from cracks and notches in pipes,” *CISM Int. Cent. Mech. Sci. Courses Lect* Vol. 499 (2010): pp. 195–209.DOI: 10.1121/1.1582439.URL.https://link.springer.com/chapter/10.1007/978-3-211-78777-9_8.

[3] Kim, Yoon Young, and Young Eui Kwon, “Review of Magnetostrictive Patch Transducers and Applications in Ultrasonic Nondestructive Testing of Waveguides.” *Ultrasonics* Vol.62(2015):pp. 3–19. DOI.10.1016/j.ndteint.2011.11.003.URL.https://doi.org/10.

[4] Seung Hyun Cho, Hoe Woong Kim, and Yoon Young Kim, “Megahertz-range guided pure torsional wave transduction and experiments using a magnetostrictive transducer,” *IEEE Trans. Ultrason. Ferroelectr. Freq. Control* Vol. 57 No. 5 (2010): pp. 1225–1229. DOI. 10.1109/tuffc.2010/1535. URL. https://ieeexplore.ieee.org/document/5456272

[5] Kim, Yoon Young, Chan Il Park, Seung Hyun Cho, and Soon Woo Han. “Torsional Wave Experiments with a New Magnetostrictive Transducer Configuration.” *The Journal of the Acoustical Society of America* Vol. 117 No. 6 (2005): pp.3459–68.DOI. 10.1121/1.1904304. URL.https://doi.org/10.1121/1.1904304.

[6] Michael Lowe, David Alleyne, and Peter Cawley, “Defect detection in pipes using guided waves,” *Ultrasonics* Vol. 36 No.1–5(1998): pp. 147–154.DOI. 10.1121/1.1904304.URL. http://asa.scitation.org/doi/10.1121/1.1904304.

[7] Balasubramaniam,K., Mishra,TK.,2018, “Segmented strip design for a magnetostriction sensor (MsS) using amorphous material for long range inspection of defects and bends in pipes at high temperatures,” U.S. Patent 10,073,065B2.

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