Long-range Guided Wave Inspection of Delayed Neutron Tubes used in Heavy Water Reactors by a Magnetostrictive Transducer

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1. Introduction

Delayed neutron (DN) tubes in the pressurized heavy water reactors (PHWRs) are susceptible to a possible leakage during operation because of fretting wear. Their geometrical complexity and inaccessibility due to a high radiation field, however, renders it difficult to inspect them by a conventional ultrasonic method. A long-range guided ultrasonic inspection, thus, will be only an option to be applied during a overhaul period.

In this paper, a magnetostrictive transducer was used for generating and detecting the guided waves for the DN tubes. This study, for the first time, investigated the applicability of a long-rang guided ultrasonic method to the detection of artificial notches even in the presence of various foreign objects.

2. Experimental methods and results

The assessment of guided wave propagation in tubes is extremely complicated than in plate. However, using a computer program developed by KAERI [1,2], the phase velocity and group velocity of the dispersion curves were determined for the DN tubes (OD = 9.5 mm thickness = 1.24 mm), as shown in Figs. 1 and 2. The ultrasonic vibration modes termed L(0,n), T(0,n), F(m,n) in Figs. 1 and 2 are referred to the longitudinal, torsional, and flexural modes, respectively. The fist index ‘m’ indicates the order of harmonic variation of displacement and stresses around the circumference and the second index ‘n’ is a counter variable. It was found that the T(0,1) mode (red color) had non-dispersive characteristics, which is a requirement for a long range inspection.

Guided waves propagate the whole cross-section of structure therefore, any surface(inner-side or outer-side and beneath) defect can detect. A Blue dotted line ,in Figs.1 and 2, is frequency of used our experiment. The Low-frequency guided waves have low wave attenuation(at 100kHz, typically no more than approximately 0.33 dB/m in bare pipe and approximately 1 dB/m in bare plate; plate has a higher wave attenuation because of the beam spreading that is absent in pipe) and, therefore , can propagate a long distance along the structure.

Consequently, a 100-persent volumetric inspection of a long segment of structure can be quickly and economically achieved by using the low-frequency guided waves.

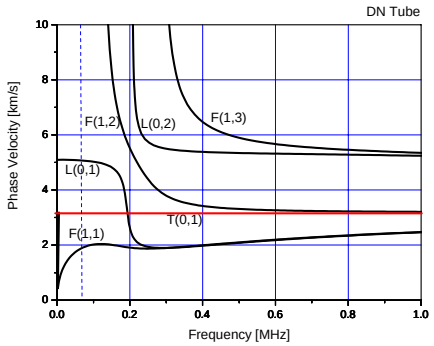

Fig.1. Phase velocity dispersion curve for the DN tube.

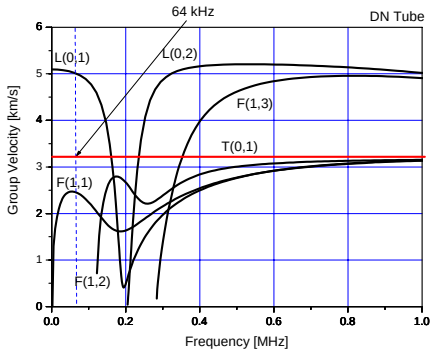

Fig. 2 Group velocity dispersion curve for the DN tube .

A torsional guided wave (T(0,1) mode) was generated in the tube with a thin Ni-strip (0.1mm thick, 10mm width) bonded to the tube that had been subjected to a magnetic bias along the circumferential direction. In contrast, the longitudinal guided wave (L(0,1) mode) are generated in the tube with a Ni-strip bonded to the tube that has been subjected to a magnetic bias along the axial direction.

Typical guided wave signals obtained from a DN tube (3 m long, 9.5 mm outer diameter, and 1.24 mm thick) are shown in Fig. 3 for the case of torsional guided wave and Fig. 4 for the case of longitudinal guided wave. An artificial notch with the depth of 5 mm and width of 3 mm is fabricated at the 2 m location and a pad with the length of 100 mm at the 1 m location from the magnetostrictive sensor.

Although the pad is attached in front of the notch, the notch signal is clearly seen and it can be shown that a good detectability of the notch.

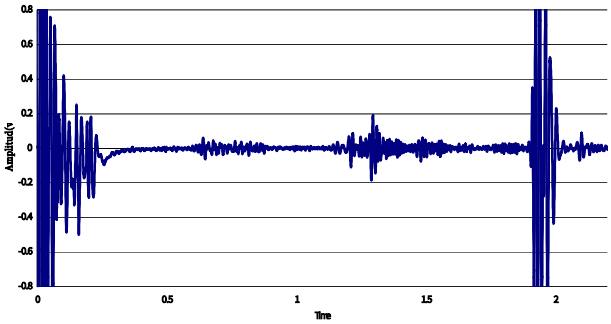

Fig.3 A torsional guided wave signal obtained from the 3 m long DN tube (A 100mm long pad at 1 m and an artificial notch were at 2m from the sensor. T(0,1) mode, frequency = 64 kHz).

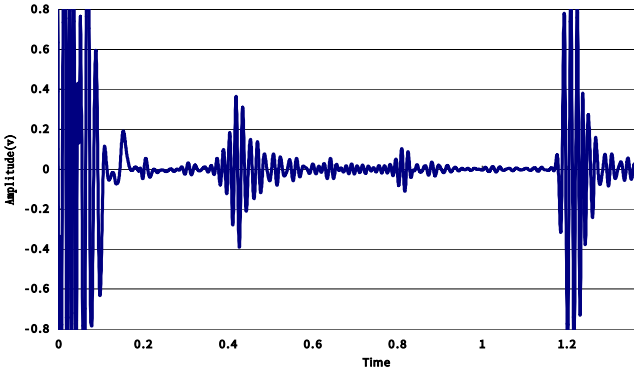

Fig.4 A longitudinal guided wave signal obtained from the 3 m long DN tube (a 100mm long pad at 1 m and an artificial notch were at 2m from the sensor, L(0,1) mode, frequency = 64 kHz).

3. Conclusion

The magnetostrictve guided wave method is used for the generation and detection of the guided waves in the DN tube. Both the torsional (T(0,1) mode) and the longitudinal (L(0,1) mode) guided ultrasonic waves were useful for the long-range inspection of small bore tube. It can be shown that a good detectability of the notch in the DN tube, even though several obstacles are attached in front of the notch.

REFERENCES

[1] Y. M. Cheong, D. H. Lee, S. S. Kim and H. K. Jung, "Analysis of circumferential guided wave for axial crack detection in a feeder pipe", 11th APCNDT, Jeju island, Korea, (2003) .

[2] Y. M. Cheong, D. H. Lee and H. K. Jung, "Ultrasonic guided wave parameters for detection of axial cracks in feeder pipes of PHWR nuclear power plants", Ultrasonics, Vol. 42, pp.883-888 (2004).