Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

Mode Selection for Axial Flaw Detection in Steam Generator Tube Using Ultrasonic Guided Wave

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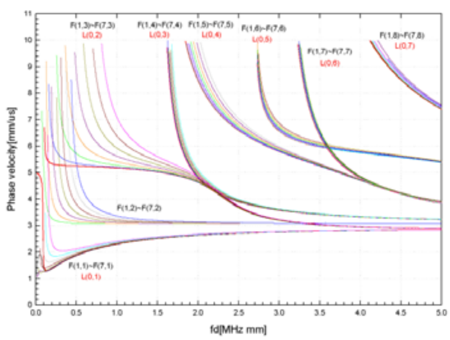
1. Introduction

The eddy current testing method is mainly used to inspect steam generator tube during in-service inspection period. But the general problem of assessing the structural integrity of the steam generator tube using eddy current inspection is rather complex due to the presence of noise and interference signal under various conditions. However, ultrasonic testing as a nondestructive testing tool has become quite popular and effective for the flaw detection and material characterization. Currently, ultrasonic guided wave is emerging technique in power industry because of its various merits. But most of previous studies are focused on detection of circumferential oriented flaws. In this study, the steam generator tube of nuclear power plant was selected to detect axially oriented flaws and investigate guided wave mode identification. The longitudinal wave mode is generated using piezoelectric transducer frequency from 0.5 MHz, 1.0 MHz, 2.25MHz and 5MHz. Dispersion based STFT algorithm is used as mode identification tool.

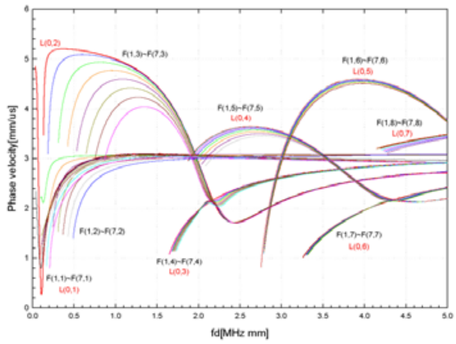
2. Dispersion Curve and Methods

2.1 Dispersion Curve

The most different physical property of guided wave compared to conventional ultrasonic wave is dispersive characteristic which is varying velocity with frequency and material thickness. Therefore, in order to generate exact wave mode and analyze received signal, we have to know the dispersion curve for inspected components. The dispersion curve presents various mode types depend on thickness and frequency. Fig. 1 shows the phase velocity dispersion curve and group dispersion curve for the steam generator tube of Korean standard nuclear power plant.



(a) phase velocity



(b) group velocity

Fig. 1 Dispersion curve for steam generator tube

The horizontal axis denotes the $f \cdot d$ value, where f is frequency and d is thickness, and vertical axis denotes velocity.

2.3 System and Specimen

A high power pulser(RITEC RAM 5000) was used for the generation of ultrasound and the RF signals were acquired using NI-PXI system with sampling frequency of 100MHz. In order to generate specific wave mode, variable acrylic angle wedge was used for angle incident. The applied frequencies are 0.5MHz, 1.0MHz, 2.25MHz and 5MHz. The transducer was connected to variable angle acrylic wedge to generate specific wave mode. The transducer and wedge assembly contact to the outside of steam generator tube. The longitudinal wave mode is used in this study.

The specimen material used in this study is Inconel 600 steam generator tube measuring 1800mm in length, 16.916mm in diameter and 1.09mm in thickness. Artificial defects with different depth were inserted at 1500mm position. All flaws are outside connected EDM notches. Fig. 2 shows the steam generator tube used in this study.

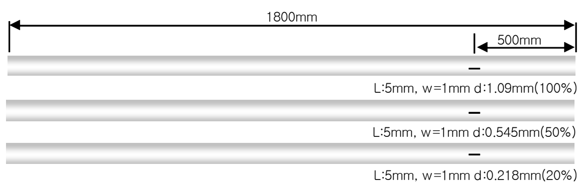


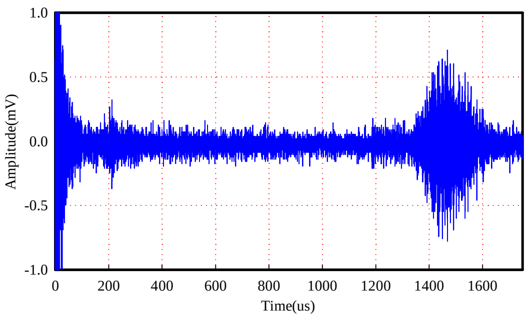
Fig. 2 The steam generator tube with axial cracks

3. Results

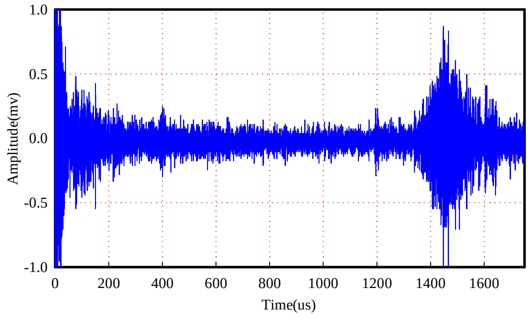
In order to detect axially oriented flaws, longitudinal guided wave is generated at the 1500mm away from artificial flaw of steam generator tube. The excitation frequency is selected to 0.5MHz, 1.0MHz, 2.25MHz and 5.0MHz. When the transducer frequency is 0.5MHz, the $f \cdot d$ value is 0.545. Propagation modes are selected from the dispersion curve at $f \cdot d$ of 0.545 value and incident angle is calculated by Snell's law. Nine selected mode are generated at the specific incident angle using variable angle wedge but there is no specific indication near the embedded flaw region for every mode. The end of tube signal can be observed from received signal.

Guided wave is generated by 1.0MHz transducer at the same transducer position. In this case, $f \cdot d$ value is 1.09. Selected wave modes from the dispersion curve and incident angle are generated using 1.0MHz transducer at specific incident angle. But the experimental result is same as the 0.5MHz transducer experiment result.

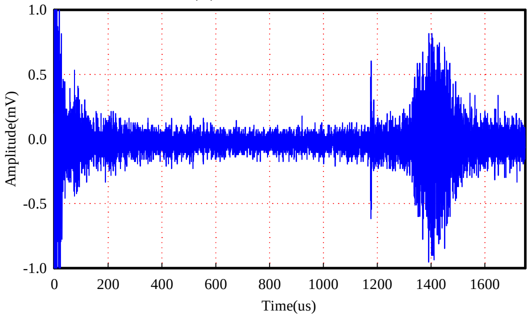
In case of the transducer frequency is 2.25MHz, the $f \cdot d$ value is 2.45. At the $f \cdot d$ value is 2.45, a family of wave has many circumferential order(n= 1, 2, 3…) and phased velocity of same family of wave is converge into specific velocity from the dispersion curve. Because of this reason, the incident angle of same wave family at $f \cdot d$ is 2.45 has same phase velocity. For example, L(0,1) and F(1,1)~F(1,7) have about 2.69km/s phase velocity. So the incident angle is about 61° from the Snell's law. From the dispersion curve in Fig.1, we can select five main wave families at the 2.45 $f \cdot d$ value. Phase velocity of those five wave family converge between 2.7 and 4.0km/s. Therefore, we select L(0,1), L(0,2) L(0,3), L(0,4) and F(1,2) wave modes at representative modes. The L(0,1) mode can detect 20% depth axial flaws including 50% and 100%. Fig. 3 shows the received signals from the artificial flaws depth of 20%, 50% and 100% at L(0,1) mode. The flaw indication can be observe at 1200 μs time scale.



(a) 20% axial flaw



(b) 50% axial flaw



(c) 100% axial flaw

Fig. 3 Received signals from axial flaws of steam generator tube

The 5.0MHz transducer used to generate guided wave at the same transducer position. In this case, $f \cdot d$ value is 5.45. The selected wave modes from the dispersion curve are L(0,n) and F(m, n), where m=1~7 and n=1~8. Even thought there were many selectable wave modes, experimental result shows that axial flaw on steam generator tube could not detected for all selected wave modes.

3. Conclusions

In this study, various guided wave modes are selected and generated to detect axial flaw of steam generator tube. Consequently, we propose the following results.

1. The dispersion curves of guided wave for steam generator tube were calculated. Guided wave modes are selected and generated from the calculated dispersion curves with frequency variation.
2. Axial flaws depth from 20% to 100% were detected in steam generator tube at 2.25MHz transducer L(0,1) mode.

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