Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Liquid Level Measurement Technique using Ultrasonic Waveguide Sensor

Young-Sang Joo, Jae-Han Lee
Korea Atomic Energy Research Institute, Yuseong P.O. Box 105, Daejeon, ysjoo@kaeri.re.kr

1. Introduction

The conventional liquid level measurement techniques make use of a pressure and flotation. The first technique is based on the measurement of a hydrostatic pressure. The second technique is based on the buoyant force by using a floating device. These techniques are not always satisfactory. The pressure measurement method has an insufficient accuracy. The flotation method is comparatively complex and involves moving parts. An ultrasonic wave can be applied to the liquid level measurement. Most ultrasonic level gauges are based on the sound reflection phenomena. The ultrasonic techniques depend on the sound speed and they are sensitive to the temperature, pressure and a liquid surface disturbance. Most ultrasonic sensors have a limitation in a high temperature and radiation condition. Recently, a new ultrasonic waveguide sensor was developed for an under-sodium viewing and inspection in sodium fast reactor [1, 2]. This waveguide sensor can be applied to the liquid level measurement. A new liquid level measurement technique by using ultrasonic waveguides is proposed for an application in the hostile environment of a high temperature and radiation.

2. Ultrasonic Waveguide Sensor

2.1 Lamb Wave Propagation in Plate

Ultrasonic wave is propagated in a solid elastic plate of a finite thickness by a special type of guided wave, the Lamb wave. Lamb waves are two-dimensional elastic waves that correspond to the coupled longitudinal and transverse motions in a plate. Lamb waves exist in the form of resonant modes where a combination of the frequency and phase velocity correspond to the standing waves in the thickness direction. There are many modes of Lamb waves. In symmetric modes, the motion is symmetric about the mid-plane of the plate, whereas in anti-symmetric modes the motion is anti-symmetric. Lamb waves are described by the Rayleigh-Lamb characteristic equation [3]. The theoretical Lamb wave dispersion curves can be obtained from the characteristic equations, as shown in Figure 1.

2.2 Leaky Lamb Wave

It is necessary to choose the special mode for each application purpose. The particle motion of the Lamb waves is elliptical, with components in the direction of wave propagation and normal to the plate surface. The normal component of a Lamb wave in the plate creates a local disturbance within a liquid, thus the acoustic energy is lost to the liquid. In the waveguide sensor application, the zero-order anti-symmetric A_0 mode has been utilized for a single mode generation and an effective radiation capability. The phase velocity of the A_0 mode is always less than the shear velocity, and consequently a single mode is generated in the waveguide plate. The A_0 mode has a significant particle displacement perpendicular to the plate due to the flexural mode. The energy will then be leaked out from the plate contacting the liquid.

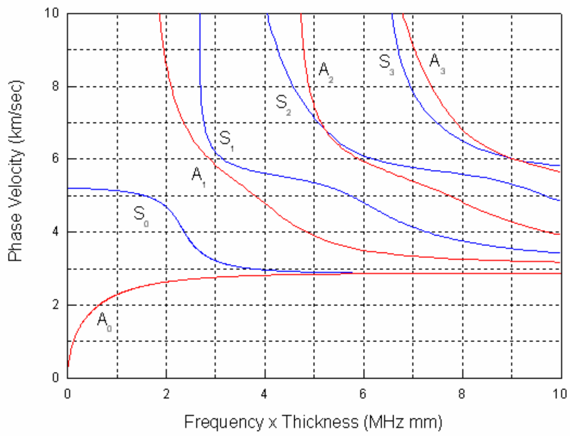

Figure 1. Dispersion curves of Lamb waves.

2.3 Waveguide Sensor

Waveguide sensor consists of an ultrasonic sensor, a wedge and a thin strip plate with multiple slits, as shown Fig. 2. The wedge is clamped to the top of the waveguide. The A_0-mode Lamb wave is generated in a plate by an excitation from the transducer where the compression wave is impinging at an angle within the wedge. The generated Lamb wave at the top of the plate propagates downwards towards the radiating surface side contacting a liquid. When a waveguide sensor is submerged in a liquid, the waves create the leaky compression wave within the liquid by a mode conversion. So, the reflection signals from the discontinuities of the plate on contacting the liquid disappear.

3. Experiments

An experimental facility was setup for a verification of the liquid level measurement of the waveguide sensor. We demonstrated the principle of an operation of the ultrasonic waveguide sensor by using a leaky Lamb wave. The experimental hardware consists of a waveguide sensor assembly, a ultrasonic pulser receiver, a Lecroy oscilloscope and a computer. The ultrasonic pulser receiver sends out burst signals and it receives the A_0 Lamb wave.

The waveguide is a 1 mm thick, 15mm wide and 1000 mm long stainless steel plate with multiple slits. The 3.5 MHz transducer is excited by a short pulse. Figure 2 shows the strip waveguide sensor and the ultrasonic signals reflected from the discontinuities in the waveguides. When the waveguide strip plate is submerged under the liquid level, the reflection signals from the end and slits of the plate are discriminated by a mode conversion process. Liquid level can be measured by a discrimination of the reflected signals of the slits with a periodic interval in the plate.

4. Conclusion

A new ultrasonic technique for the measurement of a liquid level was developed, based on the waveguide sensor technology. The ultrasonic guided wave propagation has been characterized by an analysis of dispersion curve of a stainless steel plate. The zero-order antisymmetric A_0 leaky Lamb wave is selected for the optimal mode for the liquid level measurement by using the waveguide sensor. The A_0 Lamb wave propagates down a strip plate towards the liquid surface, where the reflection signals from the end and slits of the strip plate under the liquid level are discriminated by a mode conversion process. This technique can be useful for the liquid level measurement of a vessel in a hostile environment, such as a sodium level measurement in the sodium fast reactors.

ACKNOWLEDGEMENT

This study was supported by the Korean Ministry of Science and Technology through its National Nuclear Technology Program.

REFERENCES

[1] Y.S. Joo and J.H. Lee, "Development of Ultrasonic Waveguide Sensor for Under-Sodium Viewing in Liquid Metal Reactor," J. of Korean Society for Nondestructive Testing , Vol. 26, No. 1, pp. 18-24, 2006.

[2] Y.S. Joo, S.H. Kim and J.H. Lee, "Ultrasonic Waveguide C-Scanning for Under-Sodium Viewing of LMR," Proceeding of Spring Conference of Korean Nuclear Society, 2004.

[3] J.L. Rose, *Ultrasonic Waves in Solid Media*, Cambridge University Press, 1999.

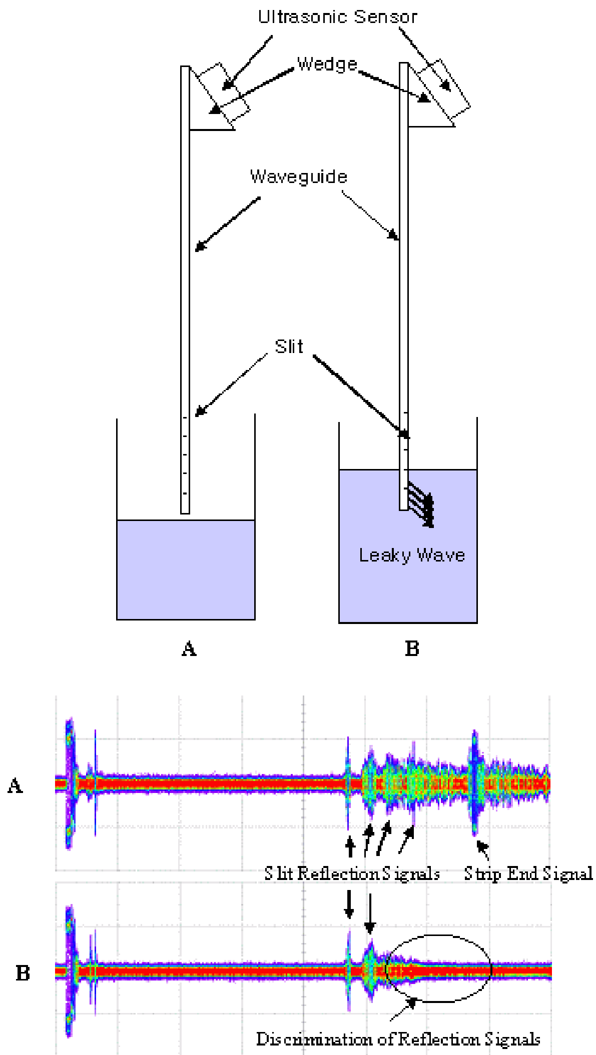

Figure 2. Ultrasonic waveguide sensor and periodic reflection signals from the discontinuities: Non-dipping condition (A) and dipping condition (B).