# Experimental Investigation on a Radiation Beam Steering Function of a Plate Waveguide Sensor

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## 1. Introduction

Liquid sodium is used as the coolant in a Sodium Fast Reactor (SFR). As the liquid sodium is opaque to light, a conventional visual inspection can not be used for performing an in-service inspection of the internal structures under a sodium level. An ultrasonic wave should be applied for an under-sodium visual inspection of the reactor internals. Under-sodium ultrasonic sensors have been widely developed for a visual inspection of the reactor core and the internal components of SFR [1]-[3]. Immersion sensors and waveguide sensors have been applied to the under-sodium visualization. The immersion sensor has a precise imaging capability, but may have high temperature restrictions and an uncertain life. The waveguide sensor has the advantages of a long lifetime and stable application. Recently a new plate-type waveguide sensor has been developed for an under-sodium visual inspection [4,5]. And a new technique is presented which is capable of steering an ultrasonic beam of a waveguide sensor without a mechanical movement of the sensor assembly. The steering function of the ultrasonic radiation beam can be achieved by a frequency tuning method of the excitation pulse in the dispersive low frequency range of the $A_0$ plate wave [4]. In this study, experimental verifications of an ultrasonic radiation beam propagation of a plate waveguide sensor are performed.

## 2. Plate Waveguide Sensor and Radiation Beam Steering Function

Plate waveguide sensor consists of a thin strip plate, wedge and ultrasonic sensor, as shown Fig. 1. Lamb wave (or plate 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. The particle motion of Lamb wave is elliptical, with components in the direction of wave propagation and normal to the plate surface. The normal component of Lamb wave in the plate creates a local disturbance within a liquid, thus the acoustic energy is lost to the liquid. When a waveguide sensor is submerged in a liquid, the waves create the longitudinal wave within the liquid by the mode conversion. The longitudinal ultrasonic beam resulting from the mode conversion is emitted at an angle $\theta$ to the waveguide normal, given as:

$$Sin\ \theta(fd) = \frac{V_L}{C_p(fd)} \quad (1)$$

where $V_L$ is the longitudinal wave velocity in a liquid and $C_p$ is the phase velocity of the Lamb wave. Radiated longitudinal ultrasonic beam is reflected from the object in water. Reflection waves are received via the face of the impinging plate surface by the reciprocal mode-conversion process.

In the waveguide sensor application, the zero-order anti-symmetric $A_0$ mode has been utilized for the single mode generation and an effective radiation capability. Figure 2 shows the dispersion curves of the phase and the group velocity for the $A_0$ mode. In the dispersive region of the $A_0$ mode where the products of the frequency and the thickness of the plate (*fd*) are below 3.5 MHz·mm, the phase velocity depends on the frequency. In this region, a fine frequency tuning of the excitation pulse creates a change of the phase velocity. The beam radiation angle $\theta$ of a leaky wave can be changed by the phase velocity of the $A_0$ mode in accordance with Eq. (1).

## 3. Experimental Verification of Radiation Beam Steering

An experimental facility was setup for an experimental verification of the radiation beam profile and the steering of a plate waveguide sensor. Figure 3 shows the bock diagram of the experimental hardware setup. It consists of a X-Y-Z scanning system, a pulser/receiver (RITEC RAM-10000 system), a computer, a Lecroy oscilloscope and a waveguide sensor assembly. Winspect$^{TM}$ program was used for A,B,C-Scan imaging software. The waveguide is a 250 mm long stainless steel plate, 15mm wide and 1 mm thick. The 1 MHz and 3.5 MHz transducers are used. The transducers are excited by tone burst signals.

In the plate sensor which a 1MHz transducer is installed, the end section of the waveguide sensor is inclined to the same radiation angle so that the emerging beam is vertical. An image of the radiation beam profile is built up by the X-Y-Z mechanical scanning of the plate sensor over the target. The transverse C-scan image of radiation beam profile is shown in Fig. 4 (a). The beam profile characterization experiment of the plate sensor where a 3.5MHz transducer is installed was carried out for a verification of the radiation beam steering. Figure 4 (b) shows the transverse C-scan image of the beam profile test target. The angle of the main beam was clearly inclined according to the frequency of the transducer.

## 4. Conclusion

A new technique which is capable of steering an ultrasonic beam has been developed for an application to a plate waveguide sensor. The steering technique of a radiation beam can be achieved by an excitation frequency in the dispersive low frequency range of the $A_0$ Lamb wave. The ultrasonic beam steering function of the plate waveguide sensor was investigated by transverse C-scan experiments in water. The radiation beam steering function of the plate waveguide sensor was successfully verified by the transverse C-scan experiments for a radiation beam profile imaging.

## ACKNOWLEDGEMENT

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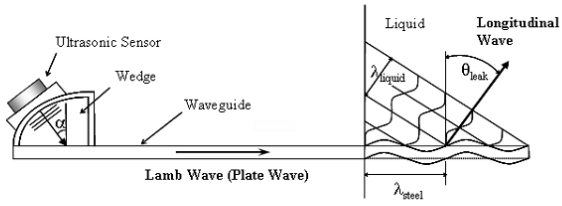



Figure 1. Waveguide sensor and leaky Lamb wave propagation

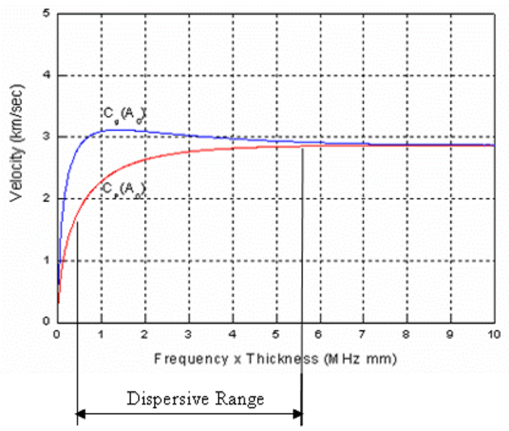



Figure 2. Dispersion curves of phase and group velocity for $A_0$ mode

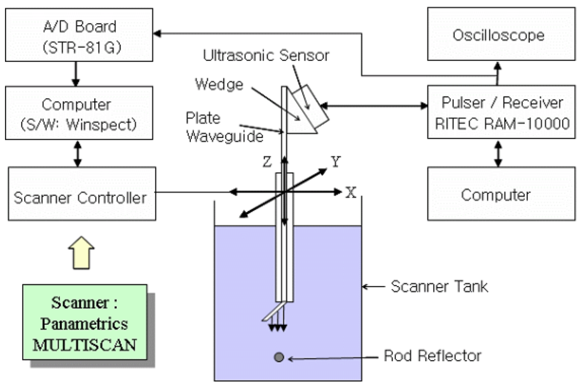
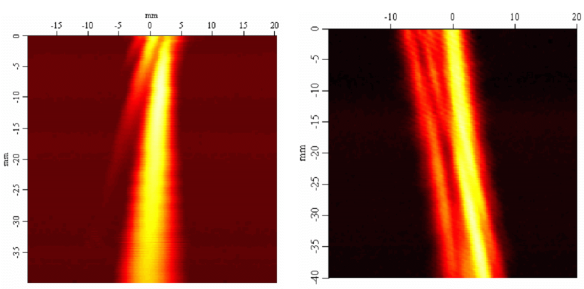



Figure 3. Experimental block diagram of transducer beam characterization



(a) 1MHz (b) 3.5 MHz

Figure 4. Transverse C-Scan beam profile images for the investigation of radiation beam steering of plate waveguide sensors