An Apparatus and Method for a Hemispherical Thickness Measurement using Magnetostrictive Ultrasonic Wave

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1. Introduction

In order to identify the phenomena associated with the nuclear accident, the demonstration experiments conducted by the Korea Atomic Energy Research Institute are classified into the In-vessel phenomenon (TMI accident) and the Ex-vessel phenomenon (Fukushima accident)[1].

Melt through is defined as the melt-down in the process of relocation of the melt when the cooling water in contact with the fuel rod in the reactor leaks and the fuel rod is exposed to air[2].

To analysis for those phenomena this technique need to an apparatus and method for measuring the thickness of an experimental hemisphere in a chamber in real time when the base material of the hemisphere exposed to a high temperature is gradually eroded[3-4]

In this paper, a hemispherical thickness measuring apparatus and method using a magnetostrictive ultrasonic wave that can accurately measure the hemispherical thickness change in real time as the reliability of the ultrasonic wave is secured.

2. Apparatus and Method

The ultra-high temperature & thickness measurement (ultrasonic response analysis) system is based upon the variation in the speed of propagation of a torsional wave in a material whose torsional modulus varies as functions of temperature & distance[5].

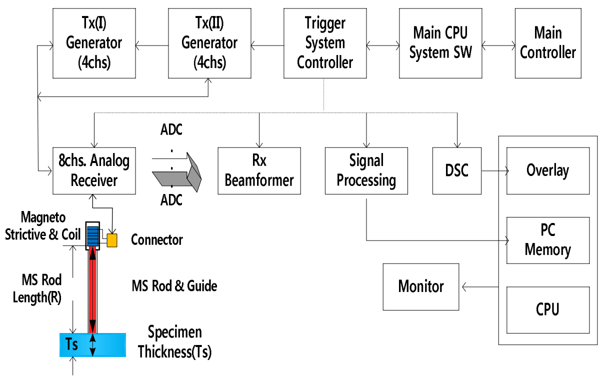


Fig. 1. The ultra-high temperature & thickness ultrasonic response analysis system

In that case, a generator system for producing a torsional wave is coupled through an acoustic waveguide to a sensor element which has a torsional modulus varied with temperature and distance functions. A discontinuity in the sensor causes a portion of the torsional wave while the remainder traverses the first notch point and then is reflected at a second end point. This time delay between the first and second pulse is calculated thus as a measuring equation (1), (2) of the temperature and distance(thickness). Fig. 1 shows the ultra-high temperature & thickness ultrasonic response analysis system.

2.1 Ultrasonic Velocity vs Temperature vs Distance(thickness)

Ultrasonic velocity is a function of young's modules which are decreased with increased temperature. Thus ultrasonic velocity is decreased with increased temperature equation (Eq. 1). Ultrasonic delay is increased with increased temperature of the material accordingly.

$$\upsilon = \oint (E/\rho)1/2,\ E = \oint (1/T),\ \upsilon = \oint (1/T) \quad (1)$$

where υ is ultrasonic velocity, E is Young's modulus, T is temperature.

The acoustic velocity in a solid is given by v=(D/Tf), in which D is a distance(1/2 thickness) and Tf is the flying time in a solid.

$$\upsilon = D/Tf = 1/2\ Thickness/Tf \quad (2)$$

2.2 Magnetostrictive Ultrasonic Transducer

Sensor design considerations include : material composition (thoriated tungsten), structure (polycrystall-ing), mode(extensional), shape(rod), supports, dis-continuities(notches), joint(EB weld). Above 2000℃ the choice of sensor materials is limited. Rhenium and thoriated tungsten have been successfully used.

It is to solve the above-mentioned high temperature problems, this transducer for a detection system which comprises a rod having a high melting point and fixed to a lower end of a hemisphere.

Table 1 Sensor design parameters

Sensor material	W-2% ThO2, 1mm diameter
Sensor section lengths	Sensor length : 500mm & Hemisphere T: 30mm
Coating	ThO2
Sheath material	W-26%Re
Outer diameter	2.0mm
Inner diameter	1.2mm

Table 1 is sensor design parameters and operating conditions for the experiments.

It is another object of this system to provide a hemispherical thickness measuring apparatus and method using the ultrasonic waves in which rod is cooled by an air-cooled heat exchange that means to block heat applied to the rod, and then the rod can be cooled through air ventilation.

2.3 Section View of Sensors and Measuring Apparatus

In case of performing the Ex-vessel phenomenon experiment, there is an advantage to measure for the erosion rate inside the hemispherical base material at high temperature. Fig. 2 is a schematic cross-sectional view of the ultrasonic wave transmitting system at the hemispherical thickness measuring apparatus.

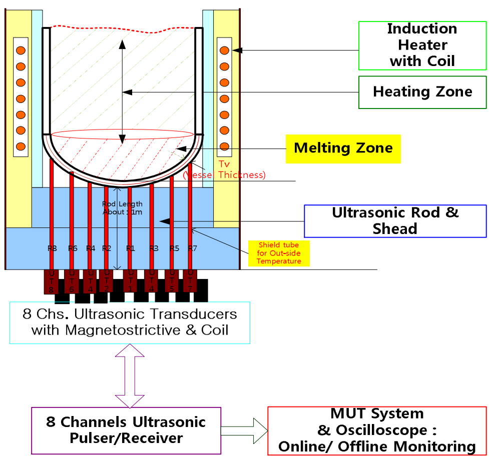


Fig. 2. A schematic sectional view of a hemispherical thickness measuring apparatus

2.4 Ultrasonic Wave Reflection Patters

For the wave propagation in physics, a plane wave is a constant-frequency wave, and the wave fronts (surfaces of constant phase) are infinite parallel planes of constant amplitude to the phase velocity vector. A case of when a plan wave is transmitted into medium I, medium II, and medium III with a distance (L: thickness), each respectively having impedance. Fig. 3 is the modes of wave the transmission and reflection in the triple-medium. Fig. 4 is a graph patterns of the reflection signals for the distance(L: Thickness) according to the radius of curvature by the hemispherical.

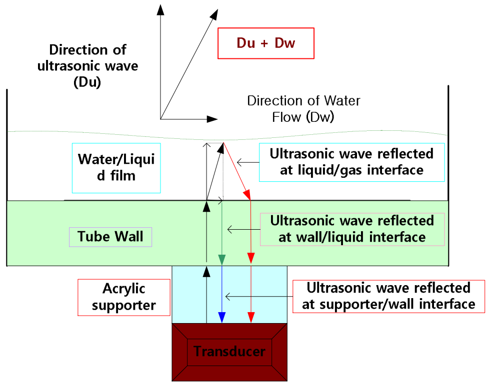


Fig. 3. Mode of wave transmission and reflection in the triple-medium

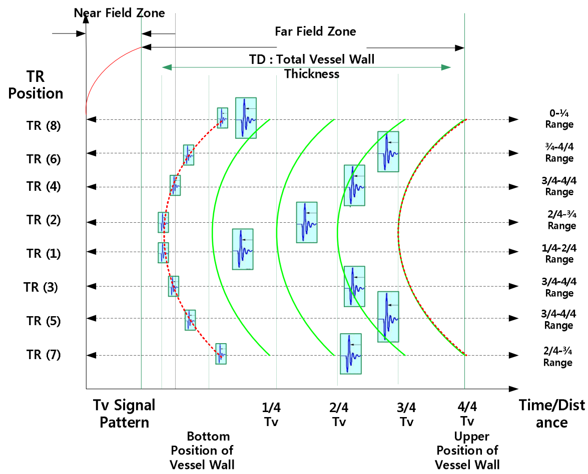
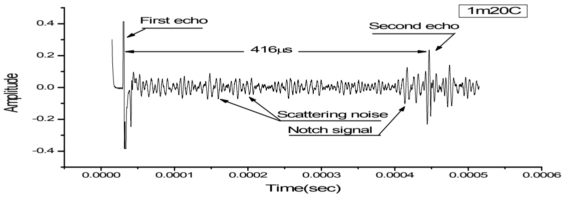


Fig. 4. A graph patterns of the reflection signals for the distance(L) according to the radius of curvature by the hemispherical

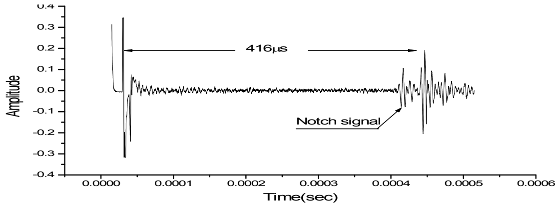
3. Experimental Conditions and Results

In this experiment, only the data of the time delay result according to the temperature was acquired because the condition of the thickness of the hemisphere (L: 30mm) was not changed. The adjustment value for the storage files before the measurement of the oscilloscope is set to 20.0 ns/ pt in the time axis range. The delay time of the ultrasonic signal according to temperature was calculated by the stored file data without the direct function of the oscilloscope. Fig. 5a shows the signal phase with low initial signal-to noise ratio that is original reflection patterns. In that case, it is difficult to catch the reflected thickness signal, so we applied a digital signal processing(DSP) technique to enhance the s/n ratio. Fig. 5b also shows the enhanced signal used by the DSP technique. The time delay-dependent temperature including the thickness of the hemisphere (L: 30mm) for each Fig. 6(a), Fig. 6(b), Fig.

6(c) was calculated about 0.62 μs, 0.74 μs, 0.76 μs time delay for the thickness respectively. Based on a estimated length 1000mm(L: thickness) as the reference data, the total time delay range could be calculated about 12.49 μs at 25℃.

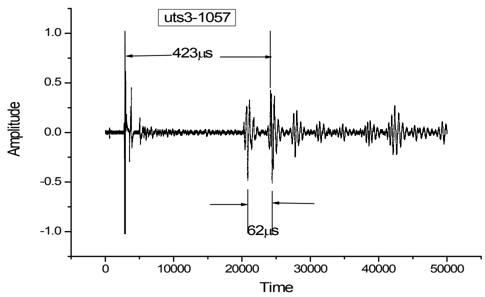


(a) Original signal

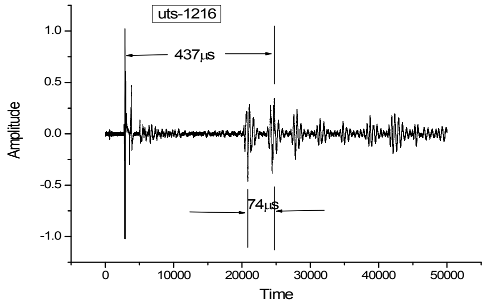


(b) Enhanced processed signal

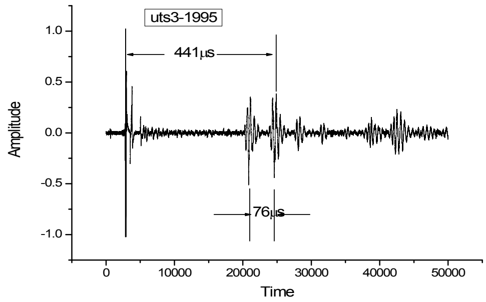
Fig. 5. Processed signal phase & low initial signal-to noise ratio at high temperature



(a) Time delay of hemisphere (Thickness: 30mm) at 1057 ℃



(b) Time delay of hemisphere (Thickness: 30mm) at 1216 ℃



(c) Time delay of hemisphere (Thickness: 30mm) at 1995 ℃

Fig. 6. The time delay-temperature for the thickness of the hemisphere

4. Conclusions

The present relates to a hemispherical thickness measuring apparatus and method for measuring in real time.

In the first experiment, the hemisphere delay time was measured when the temperature condition was changed under a constant hemisphere thickness. In this case, to improve the signal - to - noise ratio at high temperature inside the hemisphere, a new digital signal processing has been applied.

The thickness of the hemisphere will be measured at a later melting point as very high temperature range in future.

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