A Delay Time Measurement of ULTRAS (Ultra-high Temperature Ultrasonic Response Analysis System) for a High Temperature Experiment

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1. Introduction

The temperature measurement of very high temperature core melt is of importance in a high temperature as the molten pool experiment in which gap formation between core melt and the reactor lower head, and the effect of the gap on thermal behavior are to be measured. The existing temperature measurement techniques have some problems, which the thermocouple, one of the contact methods, is restricted to under 2000℃, and the infrared thermometry, one of the non-contact methods, is unable to measure an internal temperature and very sensitive to the interference from reacted gases. In order to solve these problems, the delay time technique of ultrasonic wavelets due to high temperature has two sorts of stage. As a first stage, a delay time measurement of ULTRAS (Ultra-high Temperature Ultrasonic Response Analysis System) is suggested. As a second stage, a molten material temperature was measured up to 2300℃. Also, the optimization design of the UTS (ultrasonic temperature sensor) with persistence at the high temperature was suggested in this paper. And the utilization of the theory suggested in this paper and the efficiency of the developed system are performed by special equipments and some experiments supported by KRISS (Korea Research Institute of Standard and Science).

2. Principle & Design for an UTS

The acoustic velocity in a solid is given by $v=(M/\rho)^{1/2}$, in which M is a modulus and ρ is the density of the solid. The acoustic velocity can be used as a measure of temperature. For solids, the both shear and compressive waves can be transmitted, and either shear or compressive waves can be used for temperature measurements. In practice, extensional (compressive) waves in a small diameter metal wire have generally been employed, of which velocity v results to $(E/\rho)^{1/2}$, where E is Young's modulus [2]. The sound pressure reflection coefficient R, and the acoustic impedance Z_1 and Z_2 of adjacent media 1 and 2 are correlated to $R=(Z_1 - Z_2)/(Z_1 + Z_2)$. For the extensional waves, impedance Z_e equals ρ and A, where A is the cross section area of the rod.

A magnetostrictive transducer, attached to one end of the sensor, injects short extension wave sound pulses. Figure 1 shows an ultrasonic thermometer using the pulse echo method. The sensor wire has one or more discontinuities near its hot end. The sound pulse is partially reflected at these discontinuities, and at the end of the wire. The exciting transducer converts the echoes to electrical pulses. The time between these echoes is measured. There is no fundamental relation between sound velocity and temperature. The ultrasonic thermometer must be calibrated by comparison e.g. with an optical pyrometer. We can get such a calibration curve for a sensor of thoriated tungsten. It appears that an ultrasonic thermometer is more sensitive at higher temperatures above 2000℃. Even there, however, the slope is only about 0.9ns/K/cm. Consequently, the echo times must be measured with great precision. A single sensor can comprise more than one measuring section, and provides information on the axial temperature profile from a single measurement. The indicated temperature corresponds to an average over the section length, rather than to the temperature at a specific point. Fig.1 shows an ultrasonic thermometer using the pulse-echo method.

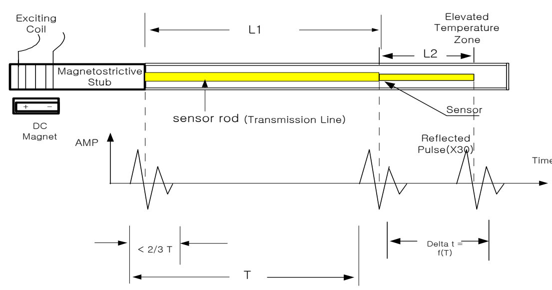

Fig. 1. Ultrasonic Thermometer using the Pulse-Echo Method

2.1 Sensor and Sheath Fabrication

Sensor design considerations include: material composition (thoriated tungsten), structure (polycrystall-ing), mode(extensional), shape(rod), supports, dis-continuities(notches), and joint(EB weld). Above 2000℃ the choice of sensor materials is limited. Rhenium and thoriated tungsten have been successfully used. In this experiment, sensors which have two notches at 50 and 80mm from the end of the thoriated tungsten rod are fabricated. The notches were fabricated by an electric beam and of which the diameter is 1mm, and length is 500 and 1000 mm. The dimensions of the sheath are 1.2mm in inner diameter, 1.4mm in outer diameter, and 150 and 300mm in length. This has generally been accomplished with a protective sheath of a tungsten-rhenium alloy. However, there is a strong tendency for the sheath and the sensor to contact the weld above 1800 ℃, resulting in the same type of acoustic interference that the sheath was meant to prevent.

2.2 ULTRAS (Ultra-high Temperature Ultrasonic Response Analysis System)

The Panametrics high power pulser/receiver 5058 PR and a 500MHz sampling rate oscilloscope were used as the electronic devices needed to conduct the experiments. The test was tried to find a pulse shape with an adjustable current pulse capability above 1A in amplitude, a pulse width in the range of a 1 to 10μs pulse width and a pulse repetition frequency adjustable in the range of 50 to 500 Hz. Besides, to generate an ultrasonic signal was used a magnetostrictive material rod, REMENDUR, which is composed of 49%Fe, 49%Co, and balance Va and Mn and whose length is 25.4 mm. Initially, a charge cable pulser is used to produce a short duration, high amplitude current pulse in the pulse coil. After a time delay, the returned acoustical signals reflected from the sensor elements induce new electrical signals in the same pulse coil. These signals are run through a line driver amplifier for transmission to a remote signal processing console. Fig. 2 shows the ultrasonic thermometry electronics control block diagram.

Experiments to characterize the ultrasonic thermometry behavior were carried out in a furnace which provided temperatures up to 2200℃. To measure the delay time from a reflector using only one, transducer E5 was mounted on one end of the magnetostrictive rod, and connecting 5058, the PR to a transducer. The delay time was computed taking care to use the round trip distance on an oscilloscope. The sensor wires used were 2% thoriated tungsten, specified as straight rods by the manufacturer. Calibrations were performed on roughly 500 and 1000mm long sensor wires, EB welded to a 25.4mm long remendur section. Fig. 2. is delay time at a 1600℃ Temperature (Sensor length : 1000mm). Fig. 3. shows delay time at a 2200℃ Temperature (Sensor length : 500mm).

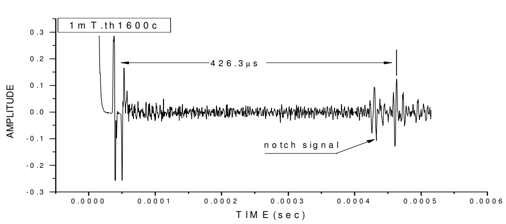

Fig. 2. Delay time at a 1600℃ Temperature (Sensor length : 1000mm)

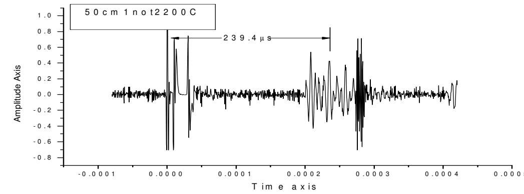

Fig. 3. Delay time at a 2200℃ Temperature (Sensor length : 500mm)

3. Conclusion

As demonstrated by the data shown, the ultrasonic thermometry technique has been very useful for determining the temperature profiles within the molten pool in core experiments. This technique could be used, since thermocouples are unsuccessful above 2000 ℃. Optical pyrometry was not applicable due to limited physical access to the experiments, as well as the opaque nature of the sample whose internal temperature was to be measured. Nevertheless, the considerable uncertainty and obvious inaccuracy observed in the early experiments demonstrates a need for additional work to obtain a reliable, accurate temperature monitor. It is believed that a combination of attention to unwanted reflections, especially at the pressure feed through and between the sensor and sheath, will be especially important. The pressure feed through can be eliminated by including the entire sensor assembly within the pressure vessel, or it can be moved sufficiently far from the end reflection to prevent overlap of the primary signal reflections. Sensor-sheath reflections can be minimized by utilizing a rotating sensor, as previously described. In the future, molten pool experiments will utilize sensors modified in these ways. The ultrasonic thermometry technique could be used in a variety of reactor safety experiments, especially those involving extremely high temperatures or requiring temperature gradient measurements.

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