Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Reactor Coolant Temperature Measurement using Ultrasonic Technology

JaeCheon Jung[a]*, YongSun Seo[b], and Nicholas Bechue[b]
[a] *KEPCO International Nuclear graduate School, 658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan*
[b] *Krohne Messtechnik GmbH, Ludwig-Krohne-Str. 547058 Duisburg, Germany*
Corresponding author: jcjung@kings.ac.kr

1. Introduction

In NPP, the primary piping temperature is detected by four redundant RTDs (Resistance Temperature Detectors) installed 90 degrees apart on the RCS (Reactor Coolant System) piping circumferentially. Such outputs however, if applied to I&C systems would not give balanced results. The discrepancy can be explained by either thermal stratification or improper arrangement of thermo-wells and RTDs. This phenomenon has become more pronounced in the hot-leg piping than in the cold-leg. Normally, the temperature difference among channels is in the range of 1°F in Korean nuclear power Plants. Consequently, a more accurate pipe average temperate measurement technique is required. Ultrasonic methods can be used to measure average temperatures with relatively higher accuracy than RTDs because the sound wave propagation in the RCS pipe is proportional to the average temperature around pipe area.

2. Methods and Results

New RCS temperature measurement system using ultrasonic technology is proposed in this work. This method offers a countermeasure against thermal stratification effect on hot-leg piping with relatively low uncertainty; this has been an unresolved issue in NPPs. Ultrasonic method is based on the thermal dependence on speed of the propagation of sound into the coolant. Since the time-of-flight into the coolant is varied by the coolant density, this density can be converted to the temperature profile of the pipe area.

2.1 Ultrasound Measurement Principle

Ultrasonic thermometry is based on the thermal dependence of the speed of sound in materials. [2] The acoustic velocity can alternatively be expressed with Hook's Law as,

$$C = (E / \rho)^{1/2} \qquad (1)$$

where, E = bulk modulus elasticity (Pa, psi) ρ = density (kg/m3, lb/ft³)

This equation is valid for liquids, solids and gases. Sound travels faster through media with higher elasticity and/or lower density.

The ultrasonic wave which propagates the diametric path L of RCS Hot-leg pipe has sound speed *C*. The ultrasonic sound pulse that is transverse to the sensors P_u and P_d can be denoted by Equation (2).

$$Co = C \pm V\cos\theta \qquad (2)$$

The time of flight of the sound can be obtained by tuL and tdL respectively. Then the transit time Δt between two sensors is represented by Equation (3).

$$\Delta t = tuL - tdL = \frac{2L - V\cos\theta}{C^2 - V^2\cos^2\theta} \qquad (3)$$

Where, tdL = time to downstream (Pu → Pd) tdL = time to upstream (Pd ← Pu)

The correlation of ultrasound speed and temperature is shown in Figure 1,

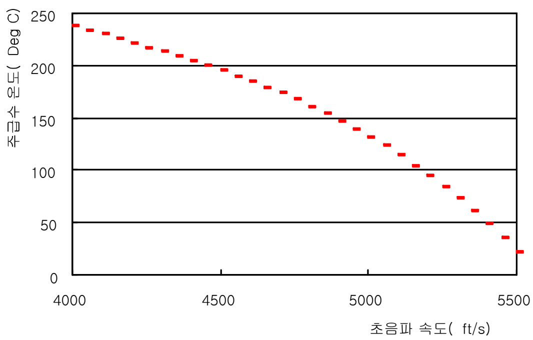

Figure 1. Correlation between ultrasound speed (m/s) and temperature (℃)

Unlike RTDs which measure temperature at a single point, ultrasound measures the integral of the temperature. RTD measure temperature as heat moves into the sensor, which ideally is positioned at the surface or a location within a material, thus the temperature being measured can only respond as fast as the thermal mass of the RTD. Ultrasonic thermometry responds at the speed of sound through an object.

2.2 Temperature Measurement Uncertainty

The measurement of temperature uncertainty using ultrasound is primarily based on the measurement of time of flight in the piping section as well as the instrument timing circuit accuracy. We focused on two major factors to improve the overall uncertainty namely, the inside diameter measurement of pipe diameter; spacing between transducers; and the density of fluid. To determine the uncertainty of spacing between transducers, an experiment was performed to obtain the maximum error of spacing due to misalignment of transmitting and receiving transducers. The temperature conversion uncertainty of Ultrasonic instruments is expressed in Equation (4).

$$\varepsilon_{temp} = \sqrt{\varepsilon_{tx}^2 + \varepsilon_{c0}^2 + \varepsilon_L^2} \quad (4)$$

Where, ε_L is the uncertainty of spacing between transducers and, ε_{c0} is the uncertainty of sound-speed to temperature conversion table

The uncertainty associated with the time delay uncertainty and the timing circuit uncertainty of Ultrasonic instrument denoted as Equation (5).

$$\varepsilon_{tx} = \sqrt{\varepsilon_{tdelay}^2 + \varepsilon_{tinst}^2} \quad (5)$$

The experiment performed using standard fluid system having uncertainty of±0.2% is used to find out the overall uncertainty of the new method and the results show a good agreement with the predicted calculations.

2.3 Temperature Measurement Application

Since there have historically been no statistics on how much deviation has been reported between RTD and Ultrasonic measurement for RCS measurement, the following results from Feedwater measurement are introduced in this work.

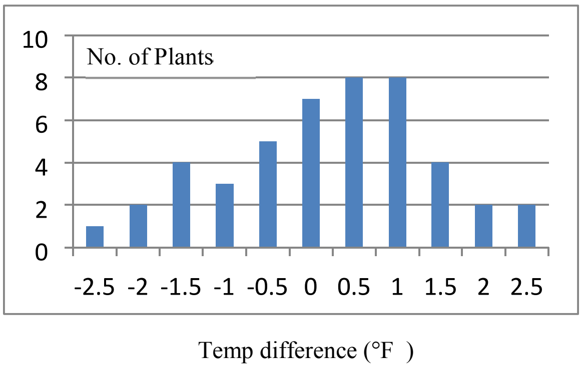

Fig. 2. Feedwater temperature comparison result between RTD reading and Ultrasound conversion [Caldon]

NPPs experiences shown in Figure 2 proves that there is a definite level of temperature measurements error. These results which come from 47 NPPs show a comparison of feedwater temperature readings between RTD and UFM. The temperature readings differ by up to 2.5°F.

Krohne UFM (Altometer-V) has been installed in OKG nuclear in Sweden. The data obtained by the Krohne instrument shows ±0.2˚F over the range of conditions in RCS, Therefore, around ±0.8˚F improvement can be expected at any condition excluding measurement error. This value may be larger if the error could be reduced by improving measurement precision and accuracy.

3. Conclusions

The inaccuracy of RCS temperature measurement worsens the safety margin for both DNBR and LPD. The possibility of this discrepancy has been reported with thermal stratification effect. Proposed RCS temperature measurement system based on ultrasonic technology offers a countermeasure to cope with thermal stratification effect on hot-leg piping that has been an unresolved issue in NPPs. By introducing ultrasonic technology, the average internal piping temperature can be measured with high accuracy. The inaccuracy can be decreased less than ±1˚F by this method.

Further study is needed to resolve the accuracy and uncertainty through the application of this method.

REFERENCES

[1] USNRC-ML072700849, CADON experience in nuclear feedwater flow measurement, 2005

[2] Lynnworth, L. C. in Ultrasonic Measurements for Process Control, Academic Press.

[3] J.C. Jung et al., "Estimation of the Flow Profile Correction Factor of a Transit-Time UFM for the Feedwater Flow Measurement in a NPP" IEEE TNS. Vol. 52, No. 3. 2011

[4] ABB-CE, "CrossFlow-Ultrasonic Flowmeter," [8]Frank M. White, "Viscous Fluid Flow," Mc-Graw Hill Inc., New York, 1974, pp. 484.

[5] RPC, "Comments on NRC Information Notice 9508(1)", Apr. 1995

[6] J. C. Jung et al., "Ultrasonic flow measurement system for NPP's by optimum flow rate calculation and uncertainty improvement" KNS, Fall, 2000.

[7] J. C. Jung et al., "Development of a multi-path UFM for the application to feedwater flow measurement in NPPs," KNS Spring, 2000.

[8] J. C. Jung et al., "Nonlinear correlation model for estimation of flow profile correction factor of UFM in nuclear power plants," ICAPP-2003, May 2003.

[9] H. A. Tasman, M. Campana, D Pel, J. Richter, Ultrasonic Thin Wire Thermometry for Nuclear Applications, Temperature—Its Measurement & Control in Science and Industry, AIP, pp 1191-1196, 1982