Transactions of the Korean Nuclear Society Autumn Meeting
Jeju, Korea, October 21-22, 2010

Transducer Design of Electromagnetic Flow Meter Used at Sodium Thermal Hydraulic Test Facilities in KAERI

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1. Introduction

The KAERI (Korea Atomic Energy Research Institute) will perform a test for thermal hydraulic simulation with the STELLA-1 for Component Performance Test Sodium Loop in the year 2012 and in the next stage it will test the STELLA-2 for Sodium Thermal-hydraulic Experimental Facility[1]. The STELLA-2 consists of the reactor vessel with a core of electric heaters, four IHXs, two PHTS pumps, two DHXs, two AHXs, and auxiliary systems as the sodium purification system and gas supply system, and also the STELLA-1 for testing to use components in the STELLA-2 consists with the AHX component, the DHX, scaled IHX, and the PHTS pump. Of course, all components are scaled. In these sodium test facilities several kinds of flow measurements exists.

In this paper, the design of the electromagnetic flow meter used in these systems is introduced to be able to measure the range of 0.5 cm/sec to 80 cm/sec. This electromagnetic transducer will be applied to measure the flow rate between the DHX and the AHX, but also to be able to measure the sodium flow rate at the outlet of the PHTS pump.

2. Design requirements

It is necessary to measure the sodium flow rate in the natural circulation loop of the facility in different temperature conditions during experimental investigations. According to the performance specification, sodium temperature can vary in the range of 150~600ºC, and velocity of sodium flowing is in the range of 0.5~80cm/s, which is required in the sodium thermal hydraulic test facility.

3. Design features of the transducer

Applying the given requirements, let us briefly consider some features of the transducers of local liquid metal velocity with local magnetic field generated by a permanent, cylindrical magnet magnetized in the cylinder diameter line. Such transducer design is shown in Fig.1. Solid lines are field lines around the magnet. If supposed that the magnet dimension along the transducer axis is much greater than the magnet diameter, the transducer output voltage is defined by formula as Eq.1.

$$U = -4B_m R_0^2 \frac{2R_0}{a}\int_R^\infty W(r)\frac{dr}{r^3}, \qquad \text{Eq.1}$$

Where, R_o = magnet radius; R = transducer radius; B_m = maximal value of magnetic induction on the magnet surface, $a = (1 + R_o^2/R^2) + (\sigma_W/\sigma_f)\cdot(1 - R_o^2/R^2)$, σ_w and σ_f = conductance of wall and fluid, correspondingly.

At $W(r) = const = W_o$, the formula of Eq.1 gives

$$U = -4W_0 B_m R_0 \frac{R_0^2/R^2}{a}, \qquad \text{Eq.2}$$

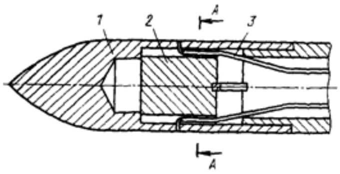
If the top limit of integration in the formula of Eq.1 is limited by value *r*, the voltage induced is defined by formula

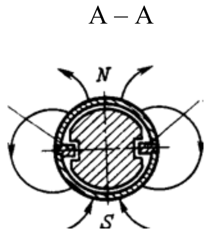
$$U_r = -4W_0 B_m R_0 \frac{R_0^2/R^2}{a}\left(1 - \frac{R^2}{r^2}\right), \qquad \text{Eq.3}$$

It is not difficult to make sure that at $r\ /R = 4.5$ the difference between voltages calculated by formula of Eq. 3 and Eq. 2 is less than 5%. Thus, it can be considered with the probability of 95% that the transducer output signal corresponds to velocity in the nearest area, whose diameter is equal to the transducer diameter multiplied by 4.5.

In real constructions of the transducers, transducer signal corresponds to velocity in less dimension area. This area can be defined if the real distribution of magnetic field is measured, approximated by proper function, which then can be used for substitution in Eq.1.

Also, the real transducers need experimental calibration because their output signal depends on both conductance of the medium measured (sodium) and pipe material (stainless steel). The conductance of these substances depends on temperature. Magnetic induction depends on temperature, as well. Besides, precise measurement of the magnetic induction in the area near small dimension magnets is practically impossible. Therefore, creation of a facility for calibration of transducers and development of the calibration technique is required as well.





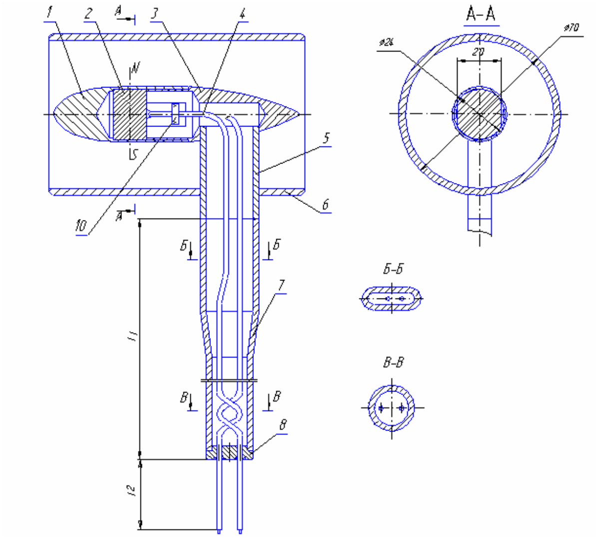
(1) case, (2) magnet, (3) electrodes

Fig. 1. Transducer with cylindrical magnet.

4. Results and Discussion

4.1 Design of low flow meter transducer

The transducer of sodium low flow rates design is presented in Fig. 2. The transducer is a pipe (6), in which a sensitive element of streamlined form is installed, and to be able to change the pipe diameter. The pipe diameter corresponds to diameter of the natural circulation loop of the sodium thermal hydraulic test facility as the STELLA-2. Maximal diameter of the sensitive element case is 24mm. The sensitive element case consists of two details: cowling (1) and stem (3). A nearly cylindrically shaped permanent magnet (2) fabricated of iron-nickel-cobalt alloy is located inside of the cowling. The number is tagged in Fig. 2.



(1) cowling, (2) magnet, (3) stem, (4) electrode (5) support, (6) pipe, (7) extender, (8) plug, (10) clincher

Fig. 2. Low flow meter transducer.

4.2 Calculated characteristics of the transducer

The same formula is used for calculated estimations of output signals of both the transducer of velocity and flow meter. But in this case, it is supposed that the transducer is installed in an unbounded liquid metal flow, and its signal is defined by formula of Eq. 2.

For the first type transducer (idealized transducer with infinitely long magnet) of 24mm in diameter this formula gives U = 2.82mV at the velocity of 80cm/s and 17.6μV at the velocity of 0.5cm/s. For the real transducer the signal value will be the previous values multiplied by 0.6, namely 1.79mV and 10μV.

Whereas the magnet field decreases rapidly enough when moving off from the transducer, its signal is defined by the velocity of liquid sodium near it. As noted above, if the magnetic field is defined by the formula of Eq. 1, the transducer output voltage is defined with a probability of 95% by velocity in the area of the flow, whose diameter is equal to the transducer diameter multiplied by 4.5. At real distribution of magnetic induction shown in Figure 6, this number decreases to 3.7. Thus, the second type transducer of 6mm in diameter will respond to the sodium velocity in the area of 22mm in diameter. The transducer output signal calculated by the formula of Eq. 2 is 0.187mV at sodium velocity of 80cm/s. The calculated values of the transducer output signal should not be considered as exact values. Their true values will be obtained during calibration.

5. Conclusion

The flow rate transducer should have a measurement uncertainty of ± 2.5%. As the signal of the transducers depends on their diameter, it is supposed to develop, manufacture, and test the velocity transducers of two diameters. The transducer of greater diameter will be used to measure the lowest velocities, and the transducer of smaller diameter will be usedto measure higher local velocities in more detail. Their measurement uncertainties should be found experimentally. Calibration will be carried out at four sodium temperature values: 150, 300, 450, and 600 ºC. Lifetime tests will be not supposed.

The developed transducer will be applied to measure the low flow rate between the DHX and the AHX. And this design methodology will be applied to design the flow rate at the outlet of the PHTS pump installed to the STELLA-1 and the STELLA-2. Also this technology is very applicable to any liquid metal processes.

ACNOWLEDGEMENT

This study was performed under the Mid and Long-term Nuclear R&D Program sponsored by the Ministry of Science and Technology (MOST) of Korea.

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[1] T.H. Lee, J.H Eoh, H.Y. Lee, J.H. Lee, T.J. Kim, J.Y. Jeong, S.K. Park, J.W. Han, Y.B. Lee, D.H. Hahn, "Scientific Design of Large Scale Sodium Thermal-Hydraulic Test Facility in KAERI", IAEA-CN-176/09-03, pp299-300, 7-11 December 2009.