Testing of Electromagnetic Flow Rate Transducer 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 STELLA-1 for Component Performance Test Sodium Loop in the year 2012 and subsequently it will test at STELLA-2 for Sodium Thermal-hydraulic Experimental Facility [1]. The STELLA-2 consists of the scaled reactor vessel with a core of electric heaters, four IHXs, two PHTS pumps, two DHXs, two AHXs. In the STELLA-2 several kinds of flow measurements exists.

In this paper, the electromagnetic flow meter as a prototype tested in the IPPE (in Russia), was manufactured as a prototype by a shop in the KAERI. This electromagnetic transducer will be used to measure the flow rate between the DHX and the AHX, and also 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 under 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, we analyze 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. If 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 [2].

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

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.

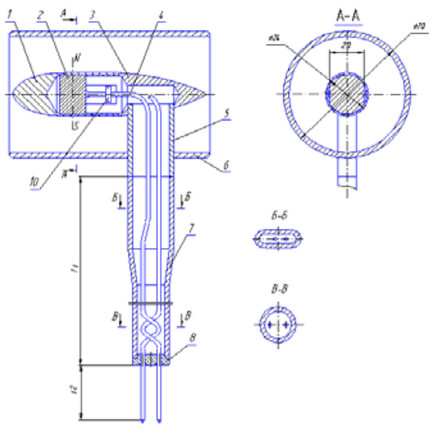
At $W(r) = const = W_o$, if the top limit of integration in the formula of Eq.1 is limited by value *r*, the voltage induced is defined by formula

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

In real transducer construction, transducer signal corresponds to velocity in smaller 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 as magnetic induction depends on temperature. Besides, because precise measurement of the magnetic induction in the area near small dimension magnets is difficult, calibration of transducers is required as well.

The transducer of sodium low flow rates design is presented in Fig. 1.



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

Fig. 1. Low flow rate transducer.

The transducer consists of two details: cowling (1) and stem (3). A nearly cylindrically shaped permanent magnet (2) of the ALNICO alloy is located inside of the cowling.

4. Results and Discussion

4.1 Test results of the transducer

First testing was performed at a calibration facility of the IPPE in Russia, and Fig. 2 is process flow sheet of the facility for transducer calibration of a calibration facility.

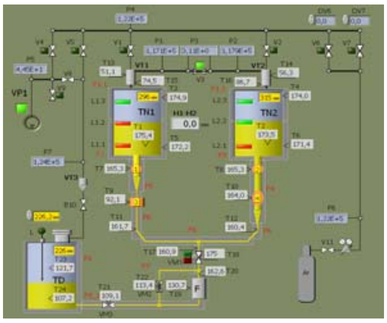


Fig. 2. Process flow sheet of the facility.

Calibration factor (*Kr*) of flow rate transducer having pipe inside diameter of 50mm as a function of temperature is as Fig. 3.

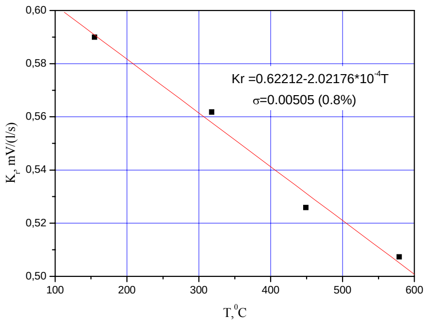


Fig. 3. Calibration factor (*Kr*) of low flow rate transducer as a function of temperature.

The results of uncertainty (δ_{Kr}) for the transducer of pipe inside diameter 50mm are as Table I.

Table I. Uncertainty (δ_{Kr}) of the transducer of pipe inside diameter 50mm.

Temp. (*T*, ºC)	Calibration factor(*Kr*)	Standard Deviation(σ)	Uncertainty (δ_{Kr}, %)
152	0.5820	$3.70x10^{-3}$	1.73
307	0.5616	$1.97x10^{-3}$	1.66
359	0.5503	$5.79x10^{-3}$	1.88
448	0.5442	$1.00x10^{-3}$	1.62
579	0.5073	$5.01x10^{-3}$	1.88

The uncertainty is defined by $\delta_{Kr_{D50}} = \sqrt{\delta_{RF}^{\ 2} + \delta_a^{\ 2}}$. In this case the uncertainty of reference flow meter is defined by $\delta_{RF} = \dfrac{0,654}{0.384 + 4.1 \cdot 10^{-5} \cdot T}$ within 150~600 ºC, and the uncertainty of reference flow meter is in the range of 1.68~1.6%. Thus, the uncertainty of low flow rate transducer is defined by $\delta_a = 0.95\sigma / Kr$.

The calculated values of the transducer output signal should not be considered as exact values. Their true values will be obtained during calibration.

4.2 Fabrication of transducer in KAERI

Fig. 4 shows the transducer fabricated in KAERI. This transducer was installed in the KAERI test facility for calibration of several kinds of sensors.

The transducer was fabricated with a magnet of ALNICO 9. The dimension of a previously designed size were applied.

Fig. 4. The fabricated transducer of low flow meter in KAERI.

5. Conclusion

The measurement uncertainty of flow rate transducer was within ± 1.9%. These measurement uncertainties were found experimentally. Calibration will be carried out at the range of 150 ºC to 600 ºC.

The developed transducer will be applied to measure the flow rate between the DHX and the AHX in STELLA-2. Also this technology is very applicable to any liquid metal processes in STELLA-2.

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