Testing of Local Velocity Transducer Used at Sodium Thermal Hydraulic Test Facilities

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1. Introduction

KAERI (Korea Atomic Energy Research Institute) will perform a test for a thermal hydraulic simulation with STELLA-1 for a Component Performance Test Sodium Loop in the year 2012, and subsequently it will construct for STELLA-2 for a Sodium Thermal-hydraulic Experimental Facility [1] in the year 2016. The STELLA-2 consists of a scaled reactor vessel with a core of electric heaters, four IHXs, two PHTS pumps, two DHXs, and two AHXs. In STELLA-2, several kinds of flow measurements exists.

In this paper, the local velocity transducer as a prototype tested in IPPE (in Russia), was manufactured as a prototype by a shop in KAERI. This local velocity transducer will be used to measure the flow rate in a pool.

2. Design requirements

It is necessary to measure the sodium flow rate in a pool through a thermal hydraulic simulation under different temperature conditions during experimental investigations. According to the performance specifications, sodium temperature can vary in the range of 150~600ºC, and the velocity of the sodium flow 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 a local liquid metal velocity with a 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.

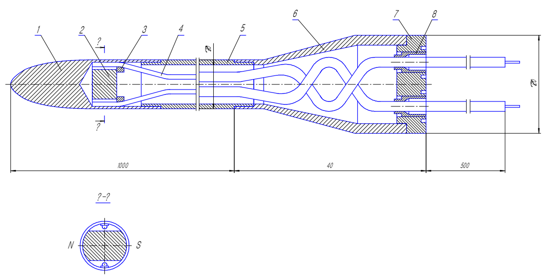
At $W(r) = const = W_o$, if the top limit of integration in Eq.1 is limited by value *r*, the voltage induced is defined by formula

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

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

Also, real transducers need an experimental calibration because their output signal depends on both the conductance of the medium measured (sodium) and pipe material (stainless steel). Because a precise measurement of the magnetic induction in the area near small dimension magnets is difficult, calibration of the transducers is required as well.

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



1-cowling, 2-magnet, 3-clincher, 4-electrode, 5-pipe, 6-adapter, 7-plug, 8-reducing bushing

Fig. 1. Schematic drawing of local velocity transducer.

The transducer consists of cowling (1) and a nearly cylindrically shaped permanent magnet (2), and this magnet of the ALNICO alloy is located inside of the cowling. As shown in Fig.2, the transducers were 10mm and 6mm in diameter.

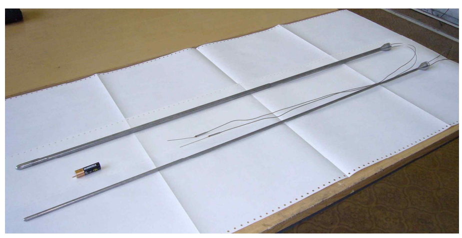


Fig. 2. Local velocity transducer.

4. Results and Discussion

4.1 Test results of the transducer

As with the electromagnetic flow rate transducer [3, 4], first testing was performed at a calibration facility of the IPPE in Russia, and Fig. 2 is a process flow sheet of the facility for a transducer calibration of a calibration facility.

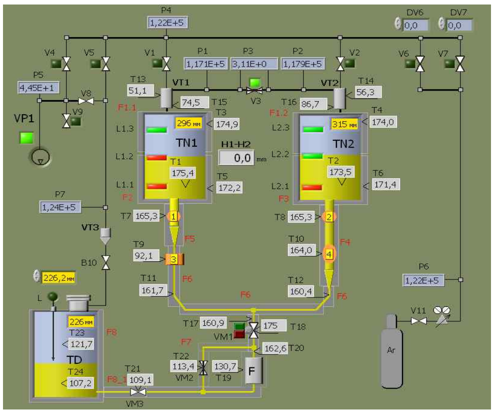


Fig. 2. Process flow sheet of the facility.

The results of uncertainty (δ_{Kr}) for the transducers are shown in Table 1 and Table 2.

Table 1. Uncertainty (δ_{Kr}) of the transducer of a pipe with 10mm diameter.

Temp. (T, ºC)	Calibration factor(Kr)	Standard Deviation(σ)	Uncertainty (δ_{Kr}, %)
157	-0.212	0.372x10^{-3}	1.7
290	-0.208	0.595x10^{-3}	1.7
456	-0.212	1.790x10^{-3}	2.3
531	-0.215	2.120x10^{-3}	2.5

Table 2. Uncertainty (δ_{Kr}) of the transducer of pipe for 6mm diameter.

Temp. (T, ºC)	Calibration factor(Kr)	Standard Deviation(σ)	Uncertainty (δ_{Kr}, %)
147	0.05430	0.26x10^{-3}	1.67
359	0.04753	0.58x10^{-3}	1.64
484	0.05306	1.4x10^{-3}	1.71
579	0.05520	2.7x10^{-3}	1.90

The uncertainty is defined by $\delta_{Kr_{D50}} = \sqrt{\delta_{RF}{}^2 + \delta_a{}^2}$. In this case the uncertainty of the 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 the reference flow meter is in the range of 1.67~2.5%. Thus, the uncertainty of a 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 Installation of transducer in KAERI

The transducer fabricated at KAERI and in IPPE was installed at the KAERI test facility for the calibration of several kinds of sensors.

5. Conclusion

The measurement uncertainty of the flow rate transducer was within ± 1.9% and ± 2.5%. These measurement uncertainties were found experimentally. Calibration will be carried out within the range of 150 ºC to 600 ºC.

The developed transducer will be applied in STELLA-2. Also this technology is very applicable to any liquid metal processes in STELLA-2.

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