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Preliminary Modeling of Permanent Magnet Probe Flowmeter for Voltage Signal Estimation

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1. Introduction

Recently, Sodium Integral Effect Test Loop for Safety Simulation and Assessment (STELLA-1) was constructed to test the practical performance of key SFR sub-systems including Passive Decay Heat Removal Circuit (PDRC) system. To test and validate performance of the PDRC system, development of instrument measuring flow rate of high temperature sodium flow must take precedence. Thus, a proto-type permanent magnet probe flowmeter (PMPF), which is electromagnetic type, was manufactured by KAERI. An experimental study on performance analysis of the flowmeter has been performed. The study shows that sodium flow rate is linearly proportional to the induced voltage signal from the flowmeter under the turbulent flow condition. The experimental results support its availability in the PDRC system. But, the flowmeter should be able to measure sodium flow at low Reynolds number as well. That is because the PDRC system uses sodium natural convection for its operation. Thus, calibration of the flowmeter should be done at very low sodium flow rates. However, Von Weissenfluh et al. showed that the relationship between flow rate and measured voltage signal from the flowmeter may become non-linear at very low flow rates [1]. The non-linearity restricts the utilization of level sensor which provide reference flow rate in the calibration experiment.

The primary objective of this study is to predict the sodium flow rate range where the induced voltage signals are linearly proportional to flow rates by estimating the induced voltage signals against sodium flow rates for a wide range of flows numerically. A commercial code FLUENT is adopted for the analysis of flow field. And MAXWELL which is an electromagnetic analysis software using a finite volume method has been used to analyze the magnetic field generated by permanent magnet of the flowmeter. The induced voltage signals have been estimated by coupling the sodium flow field and the magnetic field using FLUENT MHD module.

2. Description of PMPF

Fig. 1 shows geometry of the developed flowmeter, called PMPF, and Fig. 2 shows a simplified measurement methodology of the PMPF. The PMPF mainly consists of ALNICO 8 permanent magnet, SUS304 sheath, two electrodes and pipe with diameter of 50mm. A pair of electrodes is attached to the sheath to detect the electrical potential arising from the interaction of the flow field with the magnetic field.

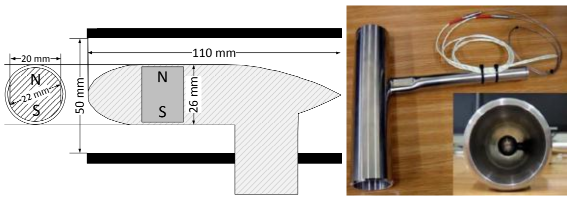

Fig. 1. Schematic of the PMPF and its picture

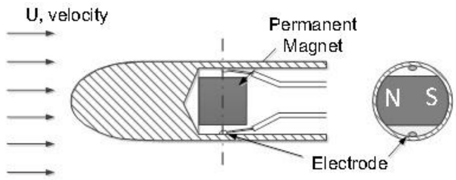

Fig. 2. Schematic of permanent magnet probe

3. Numerical Simulations

Overall simulation procedures are described in Fig. 3. MAXWELL software generates magnetic field data and FLUENT generate flow field data. The respective data are coupled in the FLUENT MHD module and resulting data to expect is the electrical potential distribution. More detailed explanation about the modeling work is addressed as follows.

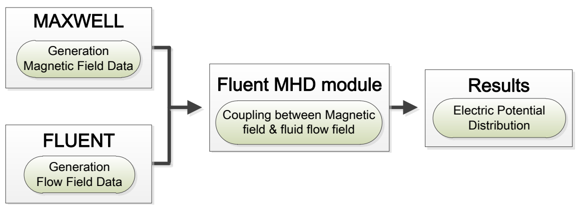

Fig. 3. Flow chart of the numerical simulations in this study

3.1 Magnetic field simulation

The magnetic field around the permanent magnet was simulated using MAXWELL as shown in Fig. 4. The magnetic and physical properties of the magnet were obtained from the relevant reference [2]. The simulated magnetic field data around the magnet were extracted at 1440 points and then, the extracted data have been used to make magnetic field data file of the required format to be imported to FLUENT MHD module.

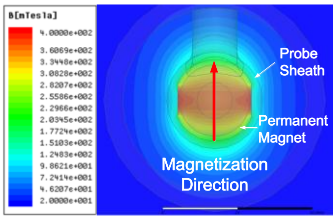

Fig. 4. Magnetic field plot in PMPF & pipe cross section

3.2 Flow field simulation

The 3D geometry of the flow field simulation is shown in Fig. 5. The length of the pipe is 1.2 meter. The geometry was meshed using ANSYS ICEM. The mesh contained 1,190,751 elements. After meshing, it was imported into FLUENT. Table 1 shows information about FLUENT solver setting used in the simulation.

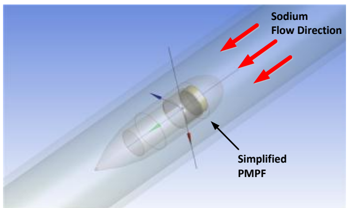

Fig. 5. 3D geometry of PMPF and pipe

Table 1. FLUENT solver setting

Turbulence model	Realizable k-epsilon
Inlet velocity [m/s]	Turbulent flow: 1, 0.5, 0.1, 0.03 Laminar flow: 0.01, 0.006, 0.003
Temperature [^{o}C]	250
Spatial Discretization	Second Order Upwind
Pressure-Velocity Coupling Scheme	Coupled

3.3 PMPF voltage signal estimation

Motion of liquid sodium perpendicular to magnetic field produced by permanent magnet (ALNICO 8) generates electromotive force (e.m.f.) in liquid sodium. The generation of e.m.f. indicates that electrical potential distribution is produced in liquid sodium flow. FLUENT MHD module enables us to analyze this interaction between motion of liquid sodium and magnetic field by solving numerically governing equations, magnetic induction equations or electric potential equations. In this study, electric potential equations are numerically solved to obtain electric potential distribution in liquid sodium. Contour of generated electric potential for sodium flowing at the flow rate of 1.96 lps is shown in Fig. 6. The unit of electric potential is V.

PMPF measures potential difference developed across the electrodes as a voltage signal. Generated electric potential difference versus inlet flow rate of sodium is presented in Fig. 7.

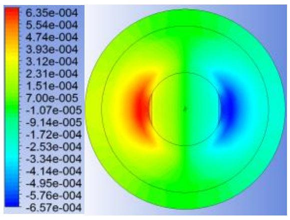

Fig. 6. Electric potential in Sodium

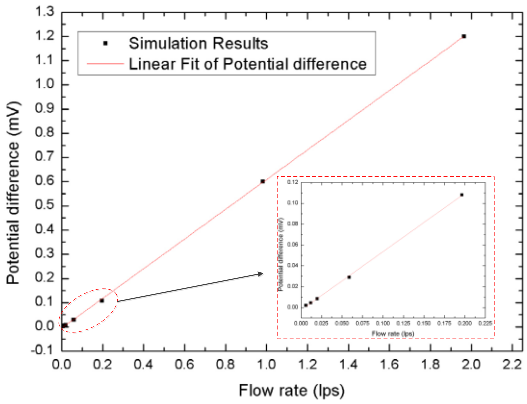

Fig. 7. Simulated electric potential versus sodium flow rate

As seen in Fig. 7, it is observed that the potential difference depends on flow rate fairly linearly in the flow rate range of 0.0059 to 1.96 lps. The calibration factor estimated is 0.614 mV/lps.

4. Conclusions

It is expected that the PMPF voltage signals are linearly proportional to flow rates range of 0.0059 to 1.96 lps. This suggests that simple calibration technique using the linearity between flow rate and the voltage signal can be adopted in calibration of the PMPF.

Acknowledgement

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REFERENCES

[1] Von Weissenfluh, T., and Sigg, B., Experience with Permanent Magnet Probes for the Measurement of Local Velocity in Liquid Metals, Fifth Beer-Sheva Int. Seminar on MHD Flows and Turbulence, Israel, March 1987
[2] Rollin J. Parker, Advances in permanent magnetism, John Wiley & Sons, New York, 1990.