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Measurement of a Liquid-Sodium Flow with a Local Velocity Probe

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1. Introduction

Local velocity measurements are still challenging in a liquid metal flow since the widely used methods such as LDV or PIV or Hot-wire are not applicable owing to an opaqueness and an endurance of high temperature. The local velocity probe (LVP) has been continuously developed to apply it to the measurement of a liquid sodium flow for the study of the reactor thermal phenomena [1][2][3].

A LVP was newly designed and fabricated to investigate several problems for a local flow measurement. The preliminary performance test of the probe was conducted in a sodium circulation loop under a temperature around 160^{o}C. The signal output was successfully obtained in the range of the mean velocity from 0 to 1.7m/s, despite the very weak electromotive force.

2. Fabrication of a LVP and Experimental Results

2.1 Fabrication of a Local Velocity Probe

The measuring principle of the LVP is based on Faraday's induction law. If a liquid metal flows in a magnetic field, an electromotive force is generated perpendicular to both the liquid metal flow and the magnetic field. The induced potential difference $\Delta\phi$ between the two electrode wires of a local probe is governed by Ohm's law for moving media

$$\vec{j} = \sigma(\vec{E} + \vec{u}\times\vec{B}_m) \approx \sigma\left(\frac{\Delta\phi}{\Delta l}\vec{e}_p + \vec{u}\times\vec{B}_m\right) \qquad (1)$$

where $\boldsymbol{j}$ is the electric current density, $\boldsymbol{u}$ is the fluid velocity, $\boldsymbol{e_p}$ the unit vector between the tips of the wires spaced by Δl, and $\boldsymbol{B_m}$ the applied magnetic field density. Provided an orthogonal configuration, and under the assumption of vanishing electric currents, equation (1) reduces to a simple linear relation (2)

$$u = \frac{\Delta\phi}{B_m \Delta l} \qquad (2)$$

which directly estimates one velocity component. The magnetic field $\boldsymbol{B_m}$ can either be applied globally over the entire volume or be locally confined to the wire tips [4].

Figure 1 shows the demagnetizing characteristics of the permanent magnets. An AlNiCo magnet is more proper for a high temperature application due to a lower temperature coefficient as well as a maximum operating temperature.

Figure 2 shows the local velocity probe which has a length of 150mm and an outer diameter of 9.53mm made by using stainless steel SUS316 tube. A total of four electrodes were flush-mounted on the probe surface, which were made by a 0.5mm diameter stainless steel wire and electrically separated with ceramic insulation. An upper-down electrode-pair was displaced along the magnetic field direction(FD) and another pair along the vertical direction to the magnet field(VD). A cubic AlNiCo-8 magnet of a length of 4mm was mounted in the center of the electrode pair. A ceramic paste was used to insulate each component and the fabricated probe was cured in a vacuum electric furnace below the Currie temperature.

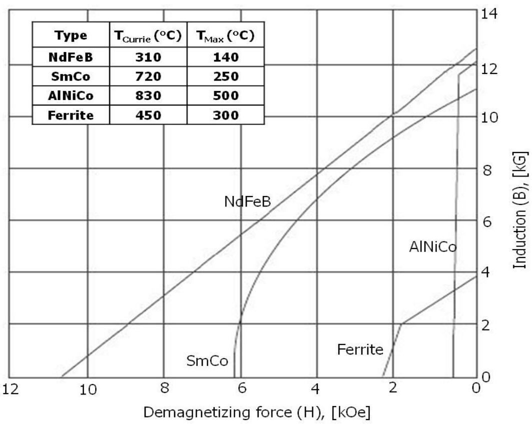

Figure 1. Demagnetizing curve of the permanent magnets

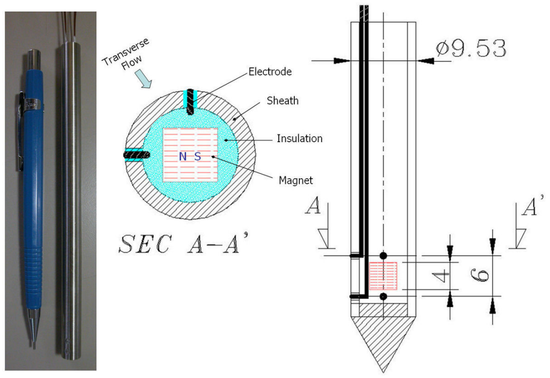

Figure 2. Local velocity probe with permanent magnet

Figure 3 and Figure 4 show the distributions of the magnetic field density $\boldsymbol{B}$ around the tip of the LVP, which were measured with the transverse hall-type sensor together with the gaussmeter(F.W. Bell 6010). The magnetic field density of the tip surface was around 56mT for the field direction and around 12mT for the vertical direction.

Assuming a field density of 50mT and an electrode wire-spacing of 6mm on the LVP tip-surface, the sensitivity of the LVP was estimated at around 3μV/cm/s.

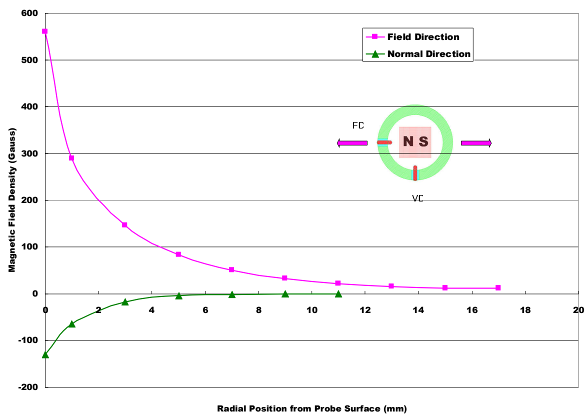

Figure 3. Magnetic field density with radial position

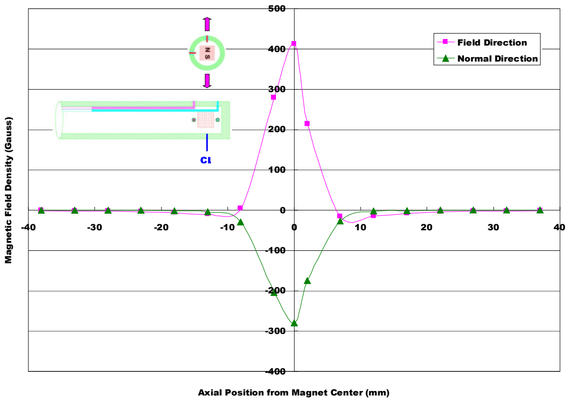

Figure 4. Magnetic field density along the axial position

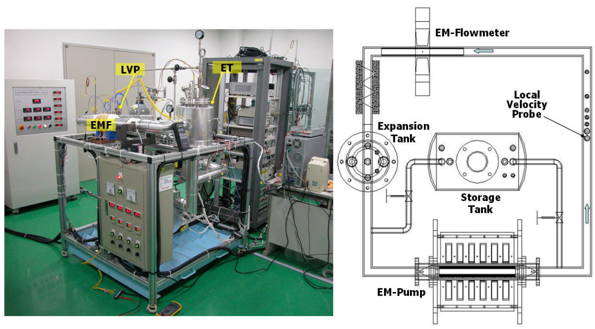

Figure 5. Sodium facility for the velocity measurement

2.2 Experimental results

The experiment was conducted by changing the EM-pump input over the range from 0 to around 5.5 Ampere with a variable voltage controller. The liquid sodium temperature was maintained at around 160°C.

Figure 5 shows the sodium facility to conduct a performance test of the LVPs, which has a circulation loop of 1 inch inner diameter. The measuring tip of the LVP was located at the center of the pipe cross-section. A permanent magnet EM-flowmeter was also installed in the circulation line to check the mean sodium velocity, as a master meter and its pre-calibrated sensitivity was 0.3175 m/sec/$A_{(EMP\text{-}Input)}$. The signal lines of the LVP electrodes were previously connected with the Keithley nanovoltmeter 2182, and then its output was sampled with a data acquisition system.

Figure 6 shows the electromotive forces of the LVP which were sampled at 1000Hz (10000 samples) with the data acquisition system of the NI-6015 board (16bit, 200kS/s). The emf of the field-direction electrode shows a good linearity compared with that of the vertical direction electrode since the induction is stronger. The measured emf shows the same order as the estimated value by using the sensitivity.

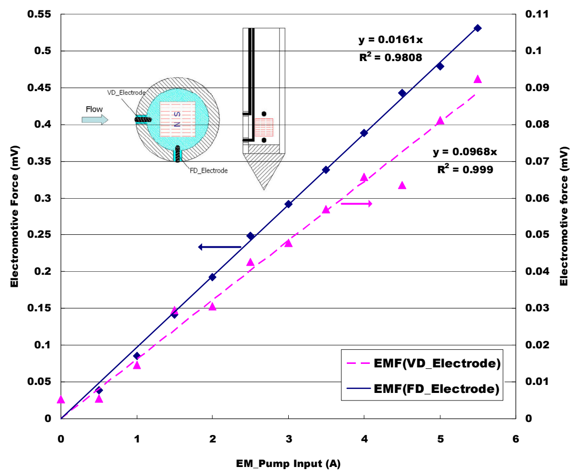

Figure 6. Electromotive forces of the LVP with EMP-input

3. Summary

A LVP was newly designed and fabricated to measure a local sodium velocity. The preliminary performance test of the probe was conducted in a sodium facility. The measured emf shows the same order as the calculated value with an estimated sensitivity in the range of a mean velocity from 0 to 1.7m/s at around 160°C.

Acknowledgement

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