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DENSITY STANDARD LIQUIDS OF NEW CONCEPT BY THE MAGNETIC LEVITATION TECHNIQUE

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Abstract: The major uncertainty factor of the magnetic levitation densimeter, which is one of the most accurate densimeter, is the force transmission error caused by the magnetism of the fluid. We have examined this effect by FEM, and proposed a new method for the magnetic levitation densimeter.

Keyowords: densimeter, density standard liquid, magnetic levitation

1 INTRODUCTION

PVT property standard technology including a density standard of fluid is becoming more important as basic information of thermophysical properties of fluid. Currently most precise densimeter with magnetic levitation[1] has limit of accuracy due to a magnetic force-transmission loss[2], by about 100 ppm of density. In this paper, the authors analyzed this effect by FEM, and proposed a new technique for precise density measurement with magnetic levitation.

2 CONVENTIONAL TECHNIQUE

2.1 Principle

Fig. 1 shows the principle of the conventional magnetic levitation densimeter (MLD) developed by Wagner *et al.* [1]. By changing the vertical levitation position from the TARE position, TP (A) to the MEASUREMENT position, MP (B), the apparent mass of the titanium sinker can be measured by the electric balance. The fluid density is obtained by

$$\rho_{\text{fluid}} = \rho_{\text{sinker}} - (M - M^0)/V_{\text{sinker}} \quad (1)$$

where M^0 and M are the apparent mass at TP and MP.

It should be noted that the permanent magnet levitate at *Zero power position* where the magnetic attraction force between the electromagnet (ferromagnetic core) and permanent magnet balance the gravitational and buoyancy force working on the permanent magnet (and the sinker), so as to eliminate the coil current which induces the convection around the magnet and disturb the mass measurement.

The experimental uncertainty of this method is about 1×10^{-4}, mainly due to the volume calibration by measuring pure water.

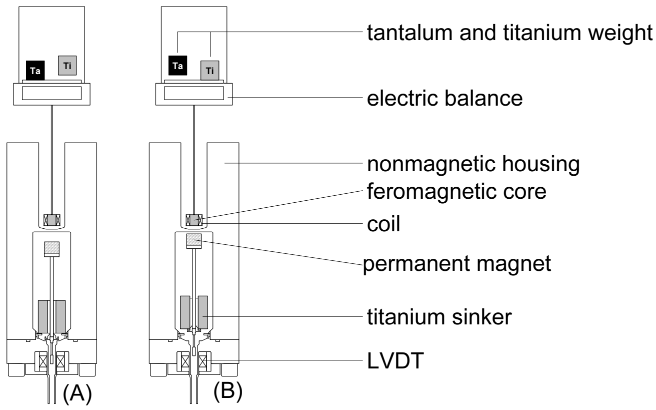

Fig. 1 . Single sinker magnetic suspension densimeter[1]、A：tare position、B：measuring position

2.2 Error in measurement

Kuramoto *et al.* [2] from our group, developed the system for calibrating density standard liquids by using MLD. They employed silicon single-crystal as sinker material since its density can be precisely compared with silicon single-crystal sphere of 1 kg[3], used as the solid density-standard in Japan, with relative uncertainty about 1.4×10^{-6}. It is expected to decrease the density measurement uncertainty, however, there was certain density discrepancy of about 1×10^{-4} between their data and those by other experimental method. Kuramoto *et al.* pointed out this error is caused by weak magnetism of the fluid. They corrected this effect by using the literature values of the magnetic susceptibility to decrease the density measurement uncertainty to 6.7×10^{-6} in minimum.

3 DISCUSSION

3.1 FEM analysis

In order to study the error mechanism of the magnetic force working on the fluid, F_{fluid}, present authors conducted a FEM analysis of magnetic forces working on the fluid, as shown in Fig. 2. As a result (see Fig. 3), it is found that the F_{fluid} primary depends on the vertical position of the permanent magnet. Then F_{fluid} change before and after exchanging the sinker will decrease to 1/10 by keeping the permanent magnet position constant. The attraction force between the permanent maget and the electromanget, F_{magnet}, can be regulated by adjusting the vertical position of the electromagnet.

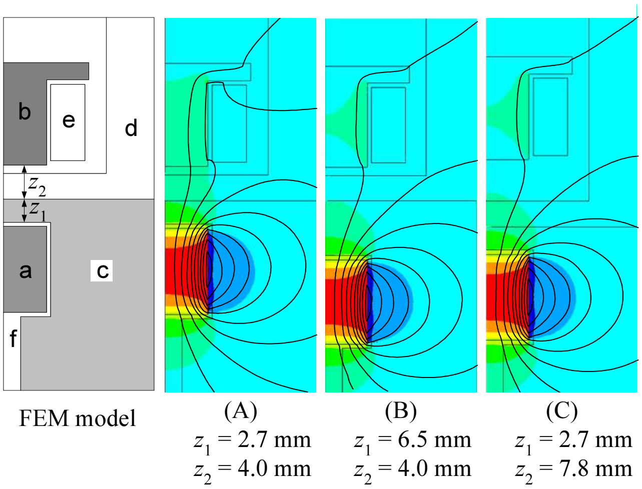

Fig. 2 . FEM model and results—magnetic flux lines and a contour of magnetic flux density, B_y: a, permanent magnet; b, ferromagnetic core; c, paramagnetic fluid; d, cell material; e, coil; f, magnet cover/suspension rod.

3.2 Levitation position

From the present FEM analysis result shown in Fig. 3, it is also found that F_{fluid} linearly changes with F_{magnet}. It is written as

$$\Delta F_{\mathrm{fluid}} = a \Delta F_{\mathrm{magnet}}. \tag{2}$$

If there is two different density sinkers 1 and 2, apparent mass difference is expressed as Eqs. (3) and (4), so that the fluid density is obtained as given in Eq. (5) by eliminating the linearity parameter, a.

$$\Delta M_1 = (a+1)(\rho_{\mathrm{sinker1}} - \rho_{\mathrm{fluid}})V_{\mathrm{sinker1}} \tag{3}$$

$$\Delta M_2 = (a+1)(\rho_{\mathrm{sinker2}} - \rho_{\mathrm{fluid}})V_{\mathrm{sinker2}} \tag{4}$$

$$\rho_{\mathrm{fluid}} = \frac{M_2 V_{\mathrm{sinker1}} \rho_{\mathrm{sinker1}} - M_1 V_{\mathrm{sinker2}} \rho_{\mathrm{sinker2}}}{M_2 V_{\mathrm{sinker1}} - M_1 V_{\mathrm{sinker2}}} \tag{5}$$

The imparfectness of the assumption in Eq. (2) is about 5 μgf, correspoinding to density relative uncertainty of 0.2×10^{-6}. Hence it is concluded that by using dual sinkers, the magnetic force transmission error can be decreased and corrected to be negligible.

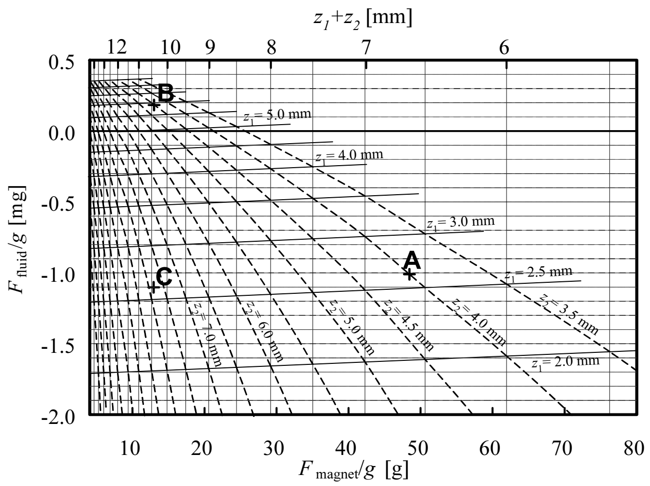

Fig. 3 . Magnetic force working on water calculated with FEM.

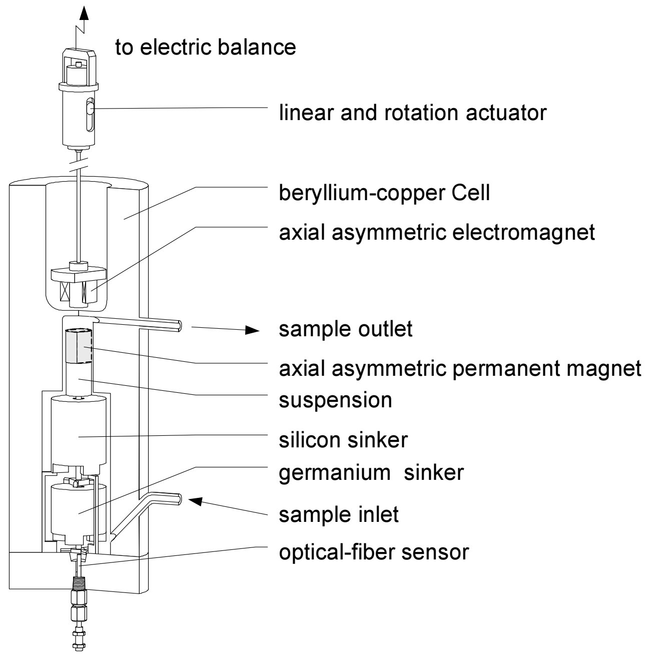

Fig. 4 . New Magnetic Levitation Densimeter with Dual Sinker

3.3 New magnetic levitation densimeter

Based on the present analytical results, the present authors have designed a new dual-sinker MLD shown in Fig. 4. To control the permanent magnet position constant, a tiny linear actuator is installed. Germanium single-crystal were decided to be used as the second sinker material, since it is excellent in isotropy, stability and universality of thermophysical properties as silicon single-crystal. By adjusting the surface area of both sinkers same, an adsorption effect of gas can be also canceled.

4 CONCLUSION

In order to improve the density measurement performance of the magnetic levitation densimeter, the present authors have proposed a couple of techniques to eliminate the uncertainty caused by magnetic force working on diamagnetic fluid, F_{fluid}, by using (I) dual sinkers and (II) controlling the levitation height of the magnetic coupling. Careful FEM analysis was made to examine an effectiveness of the present techniques. A magnetic levitation densimeter with dual sinker is now under development.

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