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Magnetofluidic sensor for volume measurement

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Abstract

The magnetofluidic sensor for the volume measurement of a nonmagnetic heavy body characterized by a random surface shape is based on changes of the inductance of a coil and the capacity of an electric condenser, which are elements of an oscillating circuit. Constructive details, characteristics of the magnetic fluid used, theoretical and experimental data are presented in this paper.

Keywords: Magnetic fluid; Sensor; Volume measurement

1. Introduction

Magnetic fluids combine their fluid properties with those of strongly magnetizable materials and therefore they allow various technical applications [1–4]. A very large field of applications is represented by magnetofluidic sensors, especially for measuring devices [5–11].

The method for volume measurement of a heavy body, characterized by a random shape based on liquid dislocated when the body is immersed in it, is well known. In order to improve this method, we have chosen as liquid a magnetic fluid based on kerosene and magnetite particles coated with oleic acid, and density higher than that of water. We have realized, in this way, a magnetofluidic sensor for volume measurement of a nonmagnetic heavy body, which allows the conversion of the volume directly in an electric signal.

The sensor presented in this paper is based on magnetic fluid dislocated in a vessel positioned inside a coil, which is a component of an electric oscillating circuit. This allows obtaining the volume of the body as a function of the resonance frequency.

The constructive data, the experimental procedure and the comparison between theoretical and experimental data are analyzed in this paper.

2. Constructive data and experimental procedure

The sensor for volume measurement, schematically shown in Fig. 1, consist of a prismatic vertical nonmagnetic vessel (1), surrounded by a coil (2), filled in the bottom part with the magnetic fluid (3), characterized by magnetic permeability μ_{MF} and density ρ_{MF}. In the middle part of the vessel, over the magnetic fluid and between two plates of an electric condenser (4), is placed water (5) characterized by electric permitivity ε_w and density $\rho_w < \rho_{MF}$. The coil and the electric condenser are elements of an electric oscillating circuit that has the resonance frequency $\nu = \nu_0$ for $\mu = \mu_{MF}$ inside the coil and $\varepsilon = \varepsilon_w$ between the plates of the condenser.

If a nonmagnetic heavy body (6), which has a random shape and density $\rho_B > \rho_{MF}$ is immersed in the vessel, inside the coil, a fraction $f = V_B/V_0$ from the volume V_0 of the magnetic fluid will be dislocated by the volume V_B of the body. As a result, the level of the magnetic fluid, which initially was between the top part of the coil and the bottom part of the condenser plates, rise and the same fraction of water will be dislocated between the plates of the electric condenser. Finally, the volume of the body is equal to the volume of the water that is over its initial level.

A decrease in the coil inductance and an increase in the electric condenser capacity are simultaneously obtained after body immersion. A simple capacitive or inductive detection can be related to the body volume. However,

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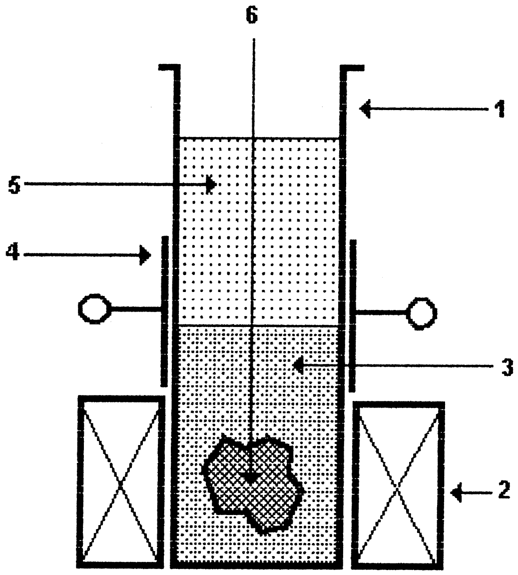

Fig. 1. Schematical diagram of the magnetofluidic sensor for volume measurement.

electric resonance measurements allow a higher accuracy than simple capacitive or inductive measurements, because, in that case, the capacitive and inductive effects are accumulated, and the increase of impedance is higher than that of capacitive or inductive reactance separately.

The sensor allows a higher accuracy of the measurements and an easy connection with a computer because V_B is a function of the changes of μ, ε, L and C.

3. Theory of the sensor

As a result of the magnetic fluid dislocated by the nonmagnetic body, the magnetic permeability inside the coil will be:

$$\mu = f\mu_B + (1-f)\mu_{MF} \tag{1}$$

and the electric permitivity between the condenser plates becomes:

$$\varepsilon = f\varepsilon_{MF} + (1-f)\varepsilon_w \tag{2}$$

If, in the absence of the nonmagnetic heavy body inside of coil, the inductance is L_0 and the condenser capacity is C_0, these become:

$$L = \left[1 - \left(1 - \frac{\mu_B}{\mu_{MF}}\right) f\right] L_0 \tag{3}$$

$$C = \left[1 - \left(1 - \frac{\varepsilon_{MF}}{\varepsilon_w}\right) f\right] C_0 \tag{4}$$

as a result of the changes of μ and ε caused by the magnetic fluid dislocated inside the coil and the water dislocated between the condenser plates.

In these new conditions, the resonance frequency will be given by the relation:

$$\nu = \left\{\left[1 - \left(1 - \frac{\mu_B}{\mu_{MF}}\right) f\right]\left[1 - \left(1 - \frac{\varepsilon_{MF}}{\varepsilon_w}\right) f\right]\right\}^{1/2} \nu_0 \tag{5}$$

If we choose the notations for constant values

$$1 - \frac{\mu_B}{\mu_{MF}} = k_1 \text{ and } 1 - \frac{\varepsilon_{MF}}{\varepsilon_w} = k_2 \tag{6}$$

relation (5) becomes

$$(1 - k_1 f)(1 - k_2 f) = \frac{\nu_0^2}{\nu^2} \tag{7}$$

which allows us to write V_B as a function of resonance frequency as follows:

$$V_B = \left\{\frac{k_1 + k_2}{2k_1k_2} - \left[\frac{(k_2 - k_1)^2}{4k_1^2k_2^2} + \frac{\nu_0^2}{k_1k_2\nu^2}\right]^{1/2}\right\} V_0 \tag{8}$$

Fig. 2 shows theoretical curves $f = f(\nu)$ using formula (8) for five values of χ_{MF} taking into account that $\chi_B < \chi_{MF}$ and that the values of relative electric permittivity of water and magnetic fluid are $\varepsilon_w = 81$ and $\varepsilon_{MF} = 2$, respectively.

For these five curves, representing the function $f = V_B/V_0 = f(\nu)$, we have taken $\mu_B = \mu_0(1 + \chi_B)$ approximately equal with vacuum permeability μ_0 because the magnetic susceptibility χ_B of the body is very small in comparison with unity, $\chi_B < 1$, and $\mu_{MF} = \mu_0(1 + \chi_{MF})$.

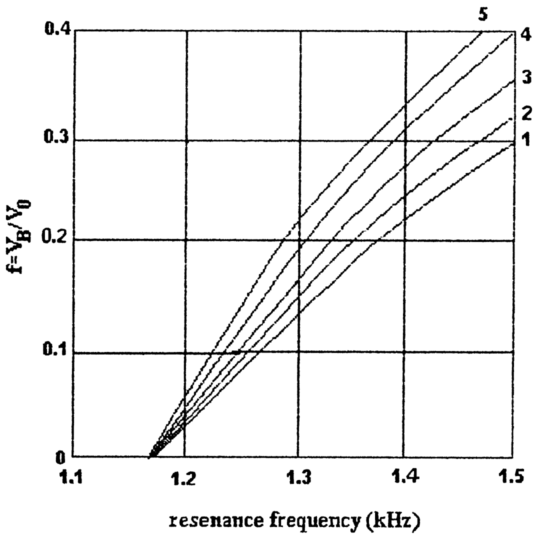

Fig. 2. Theoretical curves for the ratio $f = V_B / V_0$ as a function on the resonance frequency of the oscillating circuit. Curves 1 to 5 correspond to the magnetic susceptibility of the magnetic fluid χ_{MF} with the values: 1, 0.5, 0.25, 0.1 and 0.05 respectively.

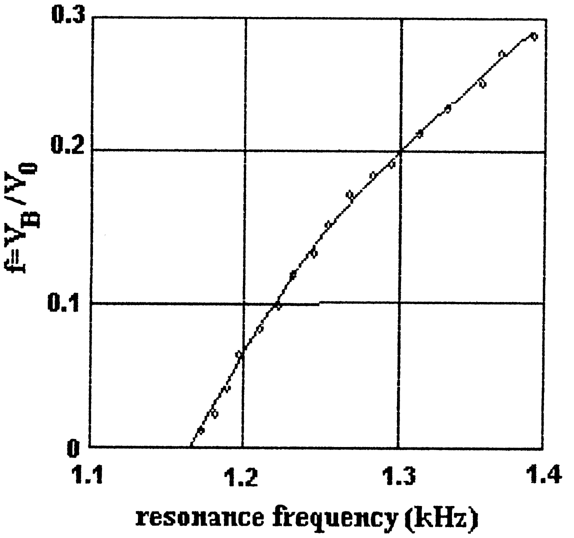

Fig. 3. Experimental dependence for the ratio $f = V_B / V_0$ as a function on the resonance frequency of the oscillating circuit: circles — experimental results, line — theoretical results.

The values of the magnetic susceptibility of the magnetic fluid taken into account were: $\chi_{MF} = 1$, 0.5, 0.25, 0.1 and 0.05. By using these data, five values for k_1, given by formula (6), were obtained. The value for k_2 vas the same for all curves, $k_2 = 0.975$.

A brief analysis of the curves shown in Fig. 2 reveals that the sensibility of the sensor increases if the magnetic susceptibility of the magnetic fluid is higher. On the other hand, we can remark that for a narrow range of the ratio values of $f = V_B/V_0$, all curves may be approximate as a straight lines.

4. Experimental data and comparison with theory

Experimental data have been obtained using the device shown in Fig. 1, having the characteristics: volume inside the coil $V_0 = 48 \times 10^{-4}$ m^3, diameter of copper wire used for a number of turns $N = 48{,}000$ was $d = 5 \times 10^{-4}$ m, and the magnetic fluid used was based on magnetite particles dispersed in kerosene and coated with oleic acid. The best results were obtained for a magnetic fluid with the characteristics: $\rho_{MF} = 1080$ kg/m^3, $\chi_{MF} = 0.1$ and $\varepsilon_{MF} = 2$. Using this magnetic fluid inside the coil and pure water between the condenser plates, the volume of a lot of heavy bodies as a function of resonance frequency was obtained.

The experimental measurements have been obtained for a lot of nonmagnetic heavy bodies characterized by volumes corresponding to ratios $f = V_B/V_0$ with values between 0.05 and 0.31.

The obtained experimental results are presented in Fig. 3, where the theoretical curve is represented by the continuos line. A good agreement between theoretical and experimental results was obtained. All nonmagnetic heavy bodies, of different shapes, used in these experimental measurements, were surrounded by the magnetic fluid after immersion, and no dependence of the resonance frequency on bodies shapes were observed. Over $f = 0.3$, the shape of the body can perturb the sensor response if a part of the body is out of the interior volume of the coil.

5. Conclusions

Theoretical and experimental data obtained with the magnetofluidic sensor for volume measurement allow us to conclude that the method of liquid dislocation by a nonmagnetic heavy body characterized by a randomize shape may be improved so that the volume of the body is obtained as an electric signal. The sensor allows a higher accuracy than simple capacitive or inductive ones, because the increase of the LC circuit impedance is higher than the increase if the capacitive or inductive reactance are separate.

The sensor can be used also for ratio f higher than 0.3 if the shape of the body allows it to be entirely contained in the interior volume of the coil.

In this way, the information given by the magnetofluidic sensor may be directly connected to a computer.

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