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The study of a magnetic fluid-based sensor

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Abstract

In this paper, the magneto-electric physical properties of the magnetic liquids and the possibilities to realize some sensors and capacitive transducers with magnetic fluid as dielectric material are studied. The characteristic functional parameters, with a linear variation, and the possibility to use the magnetic liquids for the quantitative and qualitative evaluation of some electric and non-electric parameters, are analyzed. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Magnetic liquids; Sensors; Dielectric constant

1. Introduction

The use of the magnetic liquids as a working element in sensors and transducers, aims to turn into account both physical properties characteristic to the liquids, and the magnetic and magnetofluidic behavior of these materials, under the action of various field configurations.

In general, the magnetic liquid sensors and transducers can work on the principle of the inductive, capacitive or inductive–capacitive detecting, exploiting the magnetic levitation, optical, thermal, acoustic, viscous and physical magneto-electric properties.

The capacitive sensors that work with magnetic liquids, as a dielectric, have plane, cylindrical or spherical geometry. They are meant to measure either some non-electric parameters (like displacements, angles, forces, pressure, acceleration, temperature, etc.) or some electric parameters (like the current strength, magnetic strength field, frequency, etc.).

The running of the capacitive magnetic fluid sensors depends on the following three parameters: the distance between the armatures, the surface common to the armature and the dielectric; the permitivity of the dielectric (the dielectric constant). These parameters can take various values according to the intensity and the orientation of the magnetic field.

In this paper, the physical magneto-electric behavior of the magnetic liquids and the possibilities

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to realize some sensors for electric or non-electric quantities have been investigated.

2. Theoretical aspects

In the presence of both the magnetic and electric uniform fields, the magnetic liquids point out (as in the case of the liquid crystals) magneto-dielectric effects that can be measured. The effective dielectric parameters of the magnetic liquids depend on the orientation of the magnetic field with respect to the electric field.

The dielectric constant of the magnetic liquids in the direction parallel to the magnetic field ($\varepsilon_{\|}$), as well as in the perpendicular one ($\varepsilon_{\perp}$), are given by the expressions

$$\varepsilon_{\|} = (1 - \varphi) + \varepsilon_2 \varphi [\varepsilon_1 + N(\varepsilon_2 - \varepsilon_1)]^{-1} \quad (1)$$

and

$$\varepsilon_{\perp} = (1 - \varphi) + 2\varepsilon_2 \varphi [\varepsilon_1 (1 + N) + \varepsilon_2 (1 - N)]^{-1} \quad (2)$$

in which ε_1 and ε_2 represent the dielectric constants of the carrier medium, respectively, of the particles in suspension and N is the average depolarization factor in the direction of the applied magnetic field. Because of the formation of chains of solid particles (aggregates) in the inner structure of the magnetic fluids, the value of the average depolarization factor is given as

$$N = \frac{1}{\varphi} \sum_{k=1}^{n} K V_0 V_k N_k \quad (3)$$

in which φ represents the volumic ferromagnetic fraction, V_0 the volume of a colloidal particle in suspension (considered to be spherical and all identical), N_k the depolarization factor along a chain (aggregate) consisting of k particles in the magnetic field, and V_k the number of the chains.

3. Experimental procedure

The experimental set-up used and the measuring method are presented in Fig. 1. The magnetic liquid is introduced in a cylindrical thermostatic recipient, placed in a system with Helmholtz coils that can create a continuous magnetic field parallel or perpendicular to a multilamellar plane condenser. The capacity in air of the condenser is measured under the influence of a 10 kV/m electric field.

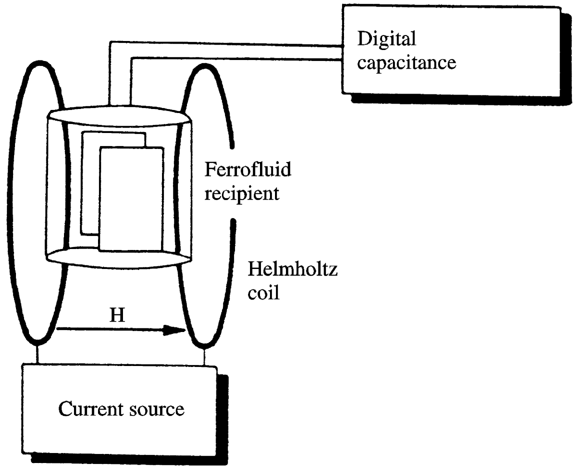

Fig. 1. Experimental set-up.

The experimental studies established the dependence of the dielectric constant (the real component) on the volumic fraction φ of the ferromagnetic particles, the temperature of the liquids and the frequency of the electric field. The magneto-dielectric constant was determined in a magnetic field with an orientation parallel or perpendicular to the electric field.

The magnetic liquids used during these experiments were based on kerosene (K) and transformer oil (UT) carrier liquids, having the volumic concentrations φ of the solid ferro or ferrimagnetic particles between 0 and 0.16. These magnetic liquids have the following characteristics: kerosene-based liquid (K: density $\rho = 1168\ \mathrm{kg/m^3}$, viscosity $\eta = 3.5 \times 10^{-3}\ \mathrm{Ns/m^2}$, volumic concentration $\varphi = 0.085$, saturation magnetization $M_s = 18.3 \times 10^3$ A/m); transformer oil-based liquid (UT: $\rho = 1220\ \mathrm{kg/m^3}$, $\eta = 23.8 \times 10^{-3}\ \mathrm{Ns/m^2}$, $\varphi = 0.077$, $M_s = 1.4 \times 10^3$ A/m).

4. Experimental results and discussions

The realized measurements pointed out a linear concentration dependence of the dielectric constant

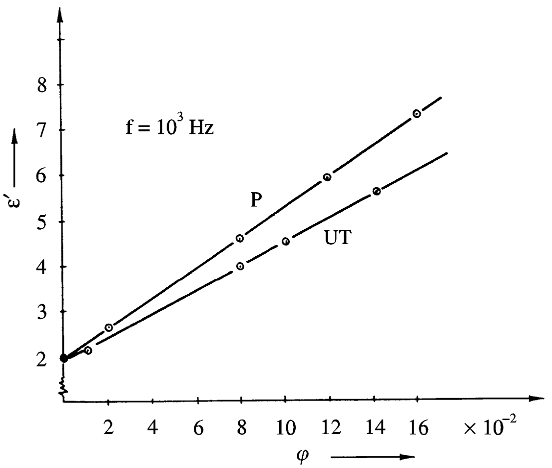

Fig. 2. Dependence of the dielectric constant versus concentration of the solid particles in suspension.

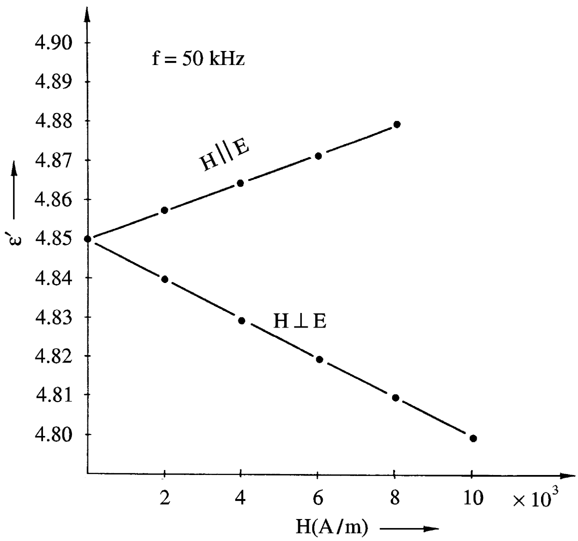

Fig. 3. Dependence of the magnetodielectric constant versus orientation and intensity of the magnetic field.

on the concentration of solid particles in suspension (Fig. 2), within the range $\varphi = 0$–0.16, for all experimentally investigated kerosene and transformer oil samples. The domain of linear variation of the dielectric constant with respect to the volumic concentration φ of the magnetic liquids was experimentally observed in the frequency range 1–100 kHz and the temperature range 10–40°C.

In the frequency domain 0.3–300 kHz, the dielectric constant of the carrier liquids always has a constant value. This behavior is analogous to non-polar liquids, while the behavior of the magnetic liquids is characteristic to the dielectrics with a small polarity.

The dependence of the magnetodielectric constant on the orientation and the intensity of the magnetic field, for a frequency of 50 kHz of the electric field, is presented in Fig. 3.

Analyzing the obtained curves, a linear dependence of the value of the dielectric constant on the volumic fraction may be noticed, for both orientations of the electric field (parallel or perpendicular). The experimental curves point out an increase of the magnetodielectric constant of the magnetic fluids when the orientation of the magnetic field is parallel to the direction of the electric field, and a linear decrease when the direction of the magnetic field is normal to that of the electric field in accordance with the theoretical relations (1)–(3).

It has been found that the variation of the dielectric constant with respect to the volume concentration of the solid particles in the magnetic fluids, their temperature, as well as the frequency of the electric field, are dependent on the mode used to obtain the magnetic fluids [1–4] and the thermal treatment [5] to which all these are subjected to.

5. Conclusions

The linear dependence of the dielectric and magnetodielectric constant in accordance with the concentration of the magnetic particles in suspension, upon the frequency, the temperature, the intensity and the orientation of the magnetic field lead to the possibility of designing and evaluating the electric and non-electric parameters of some sensors and transducers with magnetic liquids.

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