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Magnetic liquid sensor in orthogonal magnetic fields

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Abstract

In this paper we present a sensor set-up based on magnetic liquids and provided for devices designed to measurement and control of physical parameters as: slope, displacement, acceleration, vibration parameters, value and direction of a magnetic field, etc. The sensor is under the influence of two crossed magnetic fields; one is a continuous field and the other is an alternative field. The electromotive force induced in the pickup coils depends of the position of the magnetic liquid into the sensor. © 1997 Elsevier Science S.A.

Keywords: Magnetic liquid sensor; Orthogonal magnetic fields; Continuous magnetic field; Alternative magnetic field; Electromotive force

1. Introduction

One of the most important applications of magnetic liquids is in the construction of different sensor set-ups designed to detect a large variety of both electrical and non-electrical parameters [1–5]. A special case is that of the cylindrical shaped or 'U shaped' sensors [6] and the most recent variant of the magnetic liquid cylindrical sensors placed under the simultaneous action of two crossed magnetic fields: one having the same direction as the sensor and the other being orthogonal to the first one.

The present paper intends to perform an investigation of the sensor set-up theoretical modeling and we have focused especially on the nonlinear variation of the magnetic liquids magnetization as well as on the electromotive force (e.m.f.) induced into a sensor coil when the sensor is under the influence of two crossed magnetic fields, one of them being a continuous field while the other is an alternative field.

2. Theoretical background

The shape of the magnetization curve for a magnetic liquid placed under the influence of two orthogonal magnetic fields depends on the direction on which it is orientated, the coil representing the probe detector of the magnetic field [7,8].

In Fig. 1 it is given the vector representation for the magnetization into a mono-domain particle from a magnetic liquid situated under the action of an external magnetic field, H, resulted from the superposition of a continuous magnetic field, h, parallel to the sensor axis and an alternative circular magnetic field $H_a \sin \omega t$. The notations $M_0 \sin \omega t$ and m_h represent the two corresponding magnetization values while M is the total magnetization corresponding to H and considered to be parallel to H for low frequencies. The notation m_r represents the projection of M on the axis of the probe coils (disposed at the sensor edges) and when both h and H_a are different of zero it is given by the relation [9,10]:

$$m_r = M \sin \alpha = Mh/H \tag{1}$$

The magnetic field in the sensor magnetic liquid is not different from the exterior magnetic field since in the case of our sensor geometry no de-magnetization cause appears.

Due to

$$H \gg kT/\mu_0 V M_s \tag{2}$$

the magnetization value is:

$$M = \varepsilon M_s(1 - kT/\mu_0 V M) \tag{3}$$

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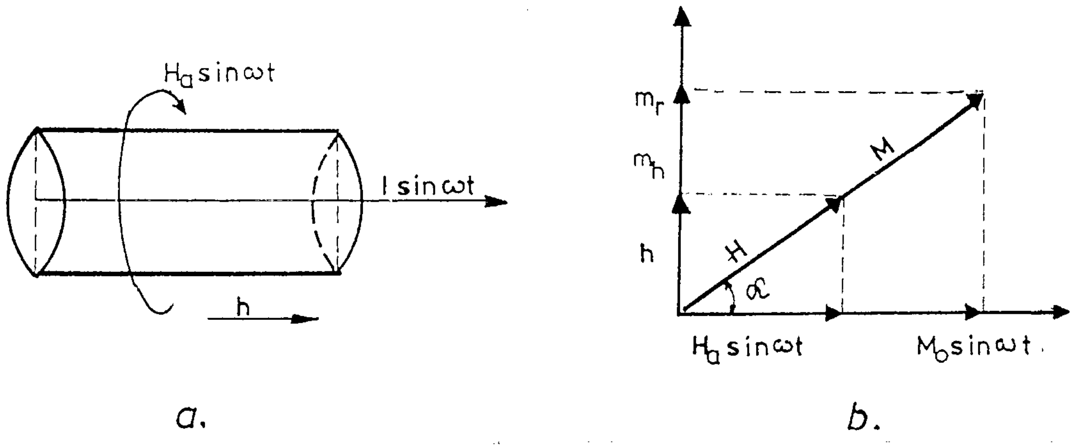


Fig. 1. The vector reprezentation for the magnetization into a monodomain particle from a magnetic liquid under the action of a continuous magnetic field, h, and an alternative circular magnetic field $H_a \sin \omega t$.

The magnetization is given under the form:

$$\Delta m = m_h - m_r \qquad (4)$$

and then the magnetic flow variation into a probe coil is:

$$\Delta\phi = \mu_0 NS(H \sin \alpha + \Delta m) \qquad (5)$$

where N is the number of the probe coil wire turns and S is the cross section of the corresponding magnetic liquid. The electromotive force, notated with E, induced in the probe coil is [11]:

$$E = (1/2)\mu_0 M_s N \varepsilon \omega h H_0^2 (1/H^3 - 2kT/\mu_0 V M_s H_n) S \sin 2\omega t \qquad (6a)$$

or:

$$E = KS \sin \omega t \qquad (6b)$$

where:

$$K = (1/2)\mu_0 M_s N \varepsilon \omega h H_0^2 (1/H^3 - 2kT/\mu_0 V M_s H_n) \qquad (6c)$$

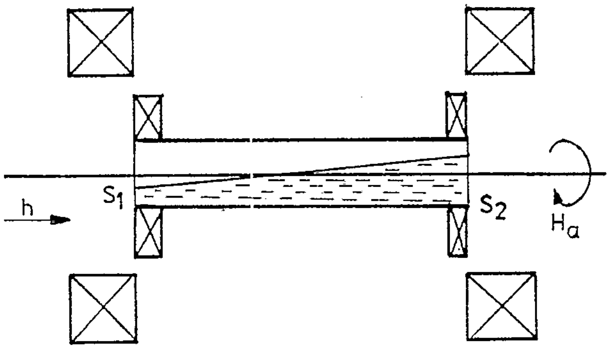


Fig. 2. Model of the sensor.

3. The experimental procedure

The sensor set-up designed by us (Fig. 2) is mainly composed of a cylindrical container, having the length of 2×10^{-1} m and a cross section diameter of 10^{-2} m, which contains the magnetic liquid. Parallel to the container axis and placed in the container interior is a cooper wire (having the cross section diameter of 10^{-3} m) and at the container edges two pickup coils, each with a length of 2×10^{-3} m. An electrical current circulates in the wire generating an alternative magnetic field while the Helmholtz coils generate a continuous magnetic field. In this arrangement one may accept that the magnetic liquid has a constant cross section.

The difference voltage induced in the pickup coils connected in series-opposition [12] is:

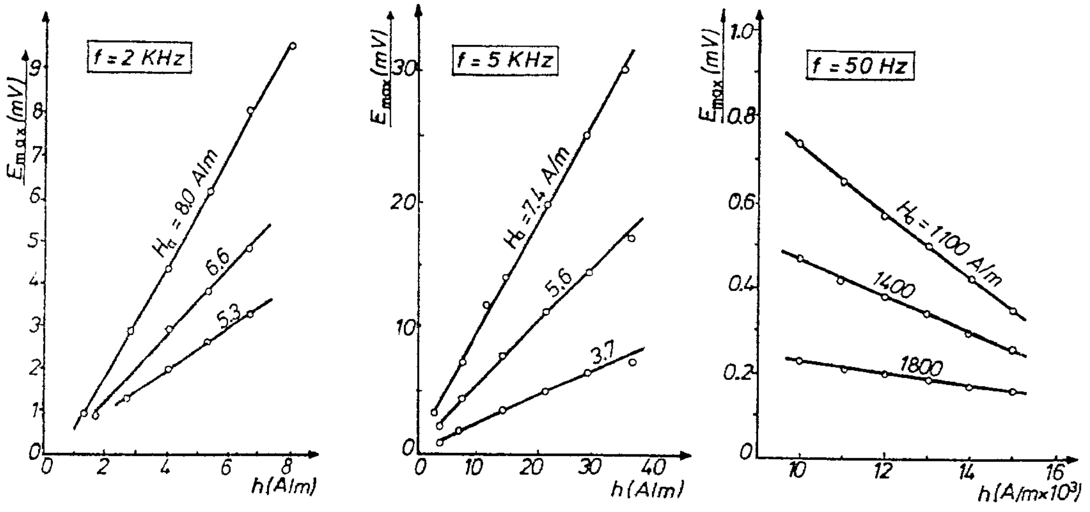
$$U_d = K(S_1 - S_2) \sin 2\omega t \qquad (7)$$

The experimental studies carried out in this work concentrated on the influence of the two magnetic field amplitudes and frequencies as well as the influence of the magnetic particles concentration on the electromotive force induced into a pikcup coil, according to the above presentation of the experimental installation [6].

The studied magnetic liquids have the volumetric concentration of the solid particles ε between 0.01 and 0.06.

4. Results and discussion

The measurements carried out by us emphasized that in the presence of only the alternative magnetic field (in the absence of the continuous field) the electromotive force induced in the probe coil is null. In the presence of a continuous magnetic field, as a consequence of the nonlinear processes, the variation of the magnetic liquid magnetization causes the appearance in the probe coil



a. b. c.

Fig. 3. Electromagnetic tension induced of second harmonic related to the both magnetic fields when the frecquency of the alternative magnetic field is 2 kHz (a), 5 kHz (b) and 50 Hz (c).

of an electromotive force characterized by a large spectrum of pare harmonics. The second harmonic has a high amplitude related to both magnetic fields intensities (Fig. 3).

In Fig. 4 we present the dependence of the electromagnetic tension induced into the pickup coil versus the continuous magnetic field intensity h, for three volume concentration ε, of the solid phase particles in the suspension.

The graphic representations suggest the existence of a linear dependence of the second harmonic amplitude on the frequency and the intensity values of the two magnetic fields as well as on the magnetic particle concentration.

The relations (6) and (7) emphasize a linear dependence of the induced electromagnetic tension on the magnetic liquid volume (or cross section).

The experimental results indicate that the second harmonic amplitude is increasing linearly with the continuous magnetic field intensity when the frecquency is high (2.5 KHz), while for low frequency values the second harmonic amplitude decreases with the magnetic field intensity.

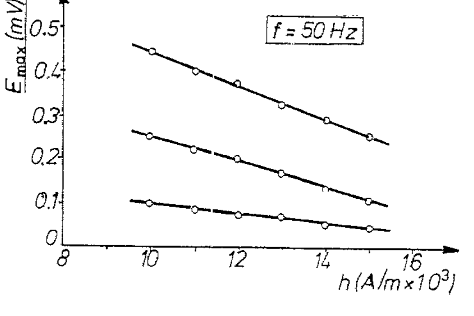


Fig. 4. Dependance of the electromagnetic tension induced versus the continuous magnetic field, for three volume particles concentrations ε.

5. Conclusions

The quasilinear dependence of the second order harmonics on the two magnetic fields amplitudes and frequencies, on the one hand, and the dependence on solid phase suspended particles concentration on the other hand, allows an optimal design for the magnetic liquids traducers of slope, displacement, etc.

The experimental devices are suitable for vector measurement of a magnetic field if the synchrony detection of the induced tension polarity is used, when the continuous magnetic field direction is changed. This way, the application sphere of the magnetic liquids traducers, functioning on the basis of two superposed magnetic fields, can be considerably extended.

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