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Tilt sensor with magnetic liquid

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Abstract

This paper analyses a new type of tilt sensor with pendulum and magnetic liquid which operates in conformity with the principle balancing of the forces. The sensor can be used in measuring the low tilts from ten up to several hundreds of arc seconds. It is simple to construct, has small dimensions and is robust. © 1997 Elsevier Science S.A.

Keywords: Tilt sensor; Pendulum; Magnetic liquid; Balancing of the forces

1. Introduction

Vertical gravitational pendulum sensors are usually used in order to detect the tilt of a body against horizontal and vertical plan. The slight displacements of the pendulum mass are transformed, by inductive or capacitive methods, into an electric signal dependent on the tilt. Other sensors in use would be the resistive ones, the photoelectric ones or those with electrolytes, especially for their reduced bulk, however, all these are less performant than the pendulum sensors.

Magnetic liquids (ML) may be used in devices to measure the inclination [1]. Inclinometers operation is based on the inductive detection of the ML or on a balancing method.

In what follows, a sensor with horizontal pendulum and ML operating with balancing of the forces will be presented. The inclinometer which includes this sensor represents a feedback system.

2. Suggestions for a technical solution

Two pendulums of mass m, density ρ_m and length r, one vertical and the other horizontal, introduced in a ML of density ρ_L, which undergo an inclination α from the horizontal direction, induce the inclinations θ_v and θ_h respectively, having the sensitivities $S_v = \theta_v/\alpha$ and $S_h = \theta_h/\alpha$ given by the relations:

$$S_v = \frac{1}{1 + \dfrac{C_v}{mgr(1-\rho_L/\rho_m)}}, \qquad S_h = \frac{mgr}{C_h}(1-\rho_L/\rho_m) \tag{1}$$

where C_v, C_h represent the specific resistant couple of forces.

We obtain, by direct comparison, for $C_v = C_h$, $S_h/S_v = 1 + S_h > 1$, hence it results that horizontal pendulum is more sensitive than the vertical one.

The mathematic model of the horizontal pendulum in the presence of the couple of specific resisting forces C_h, of a specific damping couple C_a, as well as of a feedback couple C_f (of magnetofluidic source) is:

$$mr^2\frac{d^2\theta}{dt^2} + C_a\frac{d\theta}{dt} + C_h\theta = mgr(1-\rho_L/\rho_m)\alpha - C_f \tag{2}$$

The coupling of the magnetic field $\boldsymbol{H}$ with the magnetization $\boldsymbol{M}$ of the ML is given by the force per unit volume, f, as

$$f = \mu_0(\boldsymbol{M}\cdot\nabla)\boldsymbol{H} \tag{3}$$

where μ_0 is the permeability of vacuum. The feedback couple C_f is the effect of this force. The magnetization $\boldsymbol{M}$ is approximately a linear function of the field $\boldsymbol{H}$, at small $\boldsymbol{H}$ values, approaching a saturation value M_s at sufficiently high field strength. Therefore, with a dc field of moderate amplitude, the force, according to Eq. (3), will be quadratic in terms of the dc current, producing the magnetic field [2].

It is possible that the magnetodielectric effect manifests itself in ML situated between the displacement capacitive sensors at large variations of the magnetic

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field created by the coils. The influences produced in practical conditions are relatively small but increase at large tilting and in the presence of the coils with magnetic core. The variation of the resulting electric permittivity $\Delta\varepsilon/\varepsilon$ may range between 1 and 3%, depending on the nature of the carrier liquid of the ML.

The operation of the horizontal pendulum, under stationary regime, is given by the relation:

$$\theta = S_h \alpha - \frac{C_f}{C_h} \tag{4}$$

The sensor with horizontal pendulum (which can also function as vertical pendulum when rotated at 90°) detects the tilt angle α produced by its rotation around the axis xx' (Fig. 1). The displacement of the blade (non-magnetic material) is detected by the capacitive sensor which is made up of a blade and two armatures. The recovery of its initial position is obtained due to the magnetofluid forces developed in ML by the magnetic field coils. The voltage, or the supply current of the coil (at a certain moment only one coil is fed, e.g. that to which the blade gets close, because of the tilt) represents the magnitude of the α angle [3].

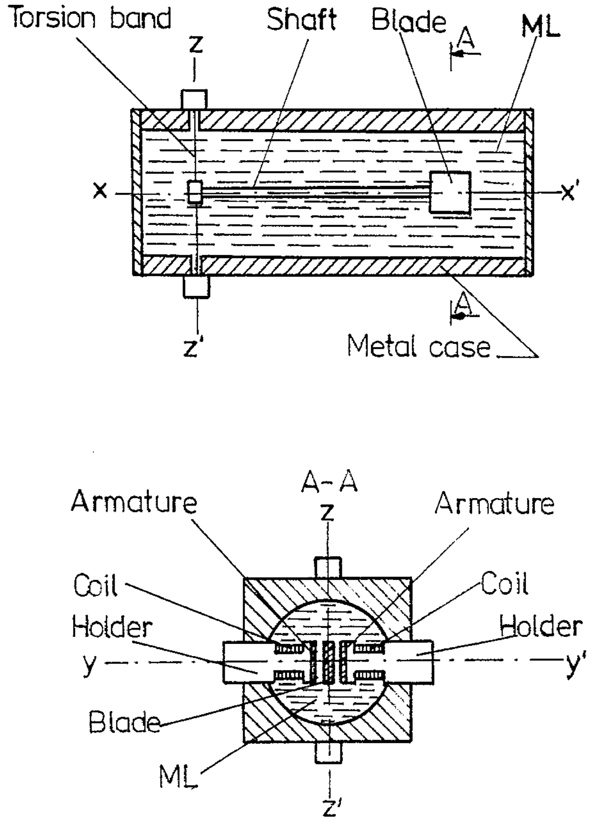

Fig. 1. Sensor with horizontal pendulum and magnetic liquid.

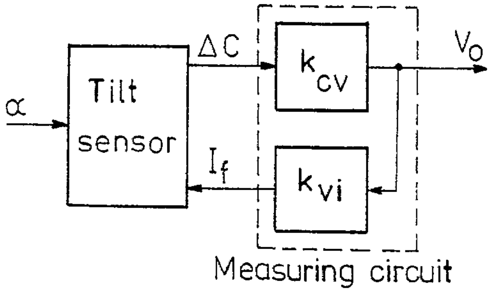

Fig. 2. Experimental inclinometer.

3. Experimental results

The sensor has a duralumin case with 80 × 32 × 32 mm dimensions. The blade dimensions are 12 × 12 × 2 mm. A petrol base ML with a saturation magnetization $M_s \cong 30$ kA m^{-1} and a kinematic viscosity $\nu = 7.5$ cSt was used.

The block diagram of the inclinometer with tilt sensor is presented in Fig. 2. The measuring circuit contains a block for the conversion of ΔC capacity to voltage and its gain, characterised by the transfer factor k_{cv} and a voltage–current convertor on the feedback circuit characterised by the factor k_{vi}. A feedback coil with ML will be characterised by factor $k_{if}(I_f) = C_f/I_f$ which is not constant, depending on the coil current I_f.

For a high amplification factor k_{cv} of the measuring circuit, the output voltage of the inclinometer is

$$V_0 = \frac{mgr(1 - \rho_L/\rho_m)}{k_{vi}k_{if}} \alpha \tag{5}$$

Non-linearity $k_{if} = f(I_f)$ has been compensated by a functions generator contained in block so that $k_{vi}k_{if} =$ constant.

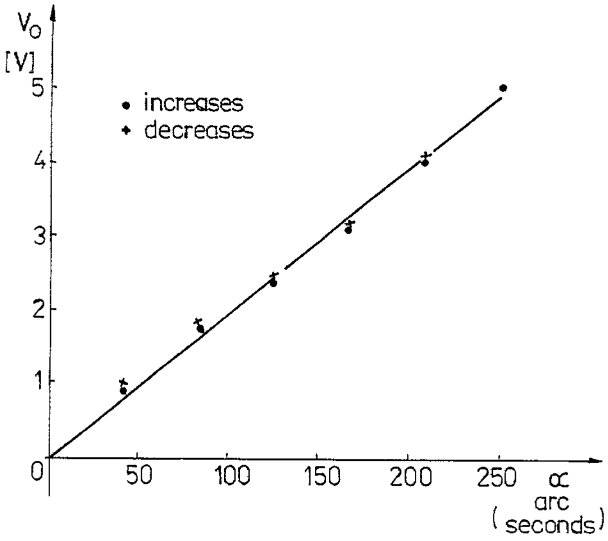

Fig. 3. Angle diagram.

A linear voltage–inclination angle dependency is obtained by linearising the feedback circuit (Fig. 3).

We have measured the tilts in the range ±250 arc seconds (approximately ± 1.25 mm m^{-1}), the minimum measured magnitude equal to that of a division of the indicating instrument, being 10 arc seconds (approximately 0.05 mm m^{-1}). The sensor's response time is $t_r = 3$ s.

4. Conclusions

The sensor with horizontal pendulum and ML presented here can be used for measuring the low tilts of some surfaces and bodys, from ten up to several hundreds of arc seconds.

Improvements in the sensor's performances may be obtained by increasing the amplification of the measuring circuit as much as possible, by increasing m and r, according to Eq. (5), and by optimizing the magnetofluid feedback arrangement (using magnetic cores, selecting a ML with a high degree of magnetization and with low viscosity in order to decrease the time response).

As compared with the conventional sensors with vertical pendulum, the sensor with horizontal pendulum and ML is simpler to construct, has smaller dimensions and is more robust.

References

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