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Magnetic fluid actuator

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Abstract

The paper presents a non-conventional actuator with magnetic fluid, generating low forces and very small displacements, controlled by an electric current. A comparative study of the two versions is performed by means of the transfer characteristics. The device might be used in the fine control of some small mechanisms (e.g., the blades of the pneumatic and hydraulic pressure amplifiers of a flapper-nozzle type). © 2000 Elsevier Science S.A. All rights reserved.

Keywords: Magnetic fluid actuator; Magnetic force; Current to force conversion

1. Introduction

Magnetic fluids can be utilized to generate some low forces for the sensitive elements of transducers that work in accordance with the principle of the compensation of the forces in a loop feedback system, as it is shown in our researches [1–3]. Many other applications of the magnetic fluids are based on the magnetic force acting upon the magnetic fluid (e.g., magnetic fluid seal) [4–6].

In a magnetic fluid with the magnetization M placed in a magnetic field H, a magnetic force having the volume density f appears as:

$$f = \mu_0 (M \cdot \nabla) H \quad (1)$$

where μ_0 is the permeability of the vacuum. The magnetization M is approximately a linear function of the field H, but it approaches a saturation value, M_s at sufficiently high field strength. Therefore, with a dc field of moderate amplitude, the force will be quadratic in terms of the dc current producing the magnetic field [7].

In the paper, a new type of a device with magnetic fluid action is described. It produces the driving force for a vertical rod, through which is transmitted to the outside, the force necessary for the fine control of the position of a mobile mechanical part, for instance, the plate fin of a pneumatic amplifier or a hydraulic one of a nozzle-flap valve type. Two main versions of the actuator are presented: with suspension axle and with elastic support.

2. Actuator operation principle

If the field H is produced by an inductor with a ferromagnetic core having the cross-section S and a magnetic circular layer is placed in the nearby position x_0 on the core axis, then the magnetic force acting upon the magnetic fluid layer having the thickness d is given by the relation (2), demonstrated in [8]:

$$F = S\int_{x_0}^{x_0+d} \mu_0 M |\nabla H| \mathrm{d}x = \mu_0 S \int_{H_0(x)}^{H_1(x_0+d)} M(H)\,\mathrm{d}H \quad (2)$$

where $|\nabla H|\mathrm{d}x \cong \mathrm{d}H$ (the axial gradient of a magnetic field is much less than a radial one).

The magnetic fluid layer is in equilibrium with the surrounding layers and consequently it does not change in position. If a non-magnetic plate replaces this layer, having the same size as the layer, a repellent force acts upon this plate. The repellent force may be calculated approximately with Eq. (2). The plate is fixed to the down edge of a vertical rod, suspended by a horizontal axle or an elastic support. At the upper edge of the rod we obtain a force and a displacement corresponding to the control current in the coil that produces the field H.

3. Suspension axle actuator

The schematic diagram of the actuator with suspension axle is presented in Fig. 1a. Due to the control current that

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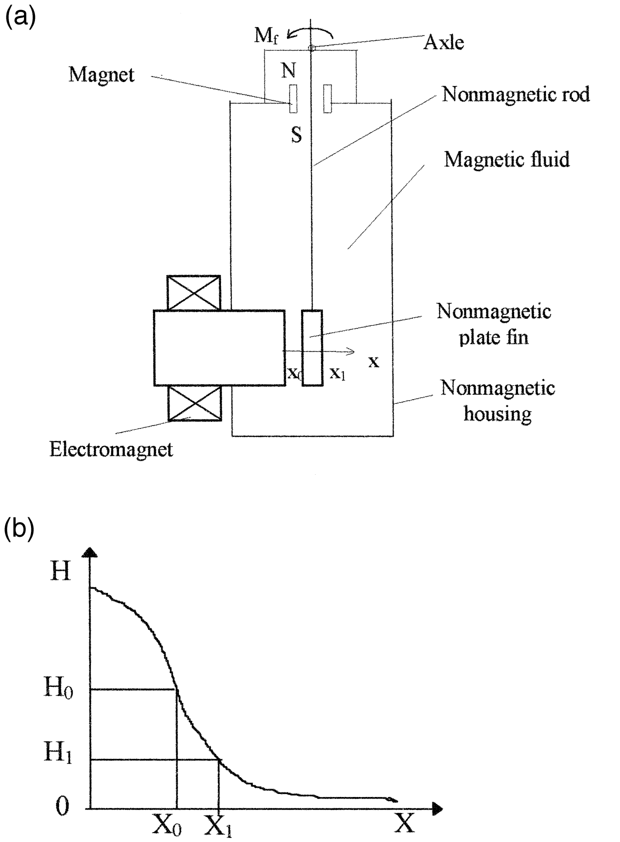

Fig. 1. (a) Actuator with suspension axle. (b) Rate of the magnetic field curve.

feeds the coil of the electromagnet, the magnetic field H appears (Fig. 1b), close to the core of the electromagnet. On the plate fin, placed at the distance x_0 from the core,

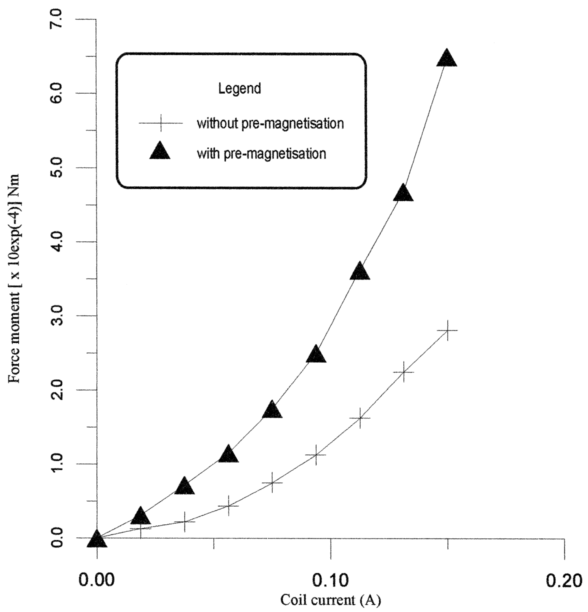

Fig. 2. Force moment vs. current characteristics without and with pre-magnetisation, for $x_0 = 2$ mm.

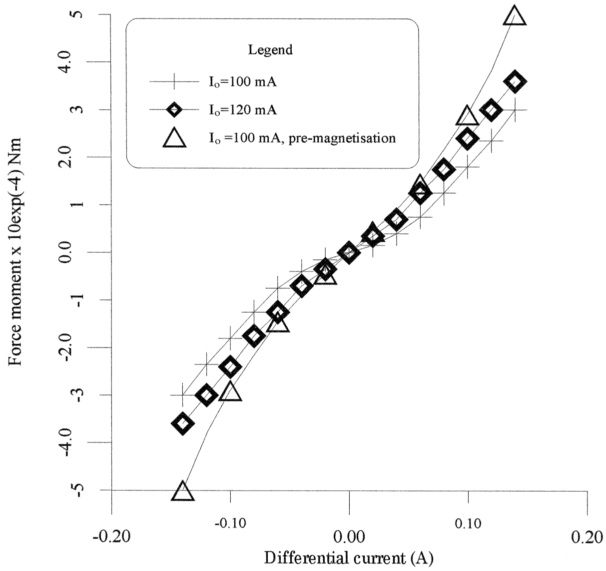

Fig. 3. Force moment vs. differential current characteristics.

operates a force, according to Eq. (2), with a maximum value estimated by the relationship:

$$F_{max} = \mu_0 M_s (H_0 - H_1) S \tag{3}$$

where M_s is the saturation value of the magnetic fluid and S is the area of the two surfaces of the plate, perpendicular on the axis of the electromagnet and equal with the area of the cross-section of the ferromagnetic core.

The rod passes through the canal of a small magnet that prevents the leakage of the magnetic fluid from the housing. Outside of the device it is conveyed the moment of the force M_f relative to the axle around which it can make small angular shifting.

Fig. 2 shows the moment of the force vs. current characteristic, with or without pre-magnetising of the core with a permanent magnet placed on the external edge of it. A transformer oil based magnetic fluid with $M_s = 50$ kA/m produced by R.C.H.C.M.F. Timisoara, Romania,

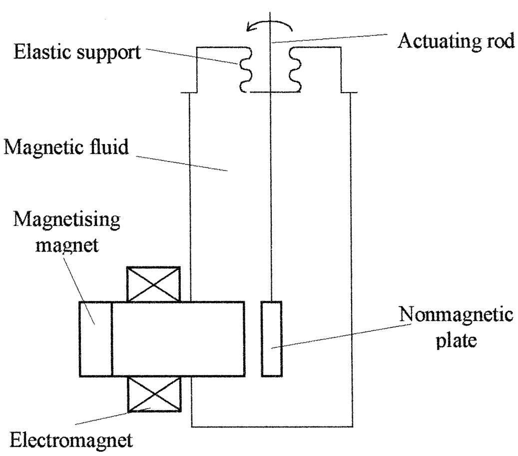

Fig. 4. Actuator with elastic support.

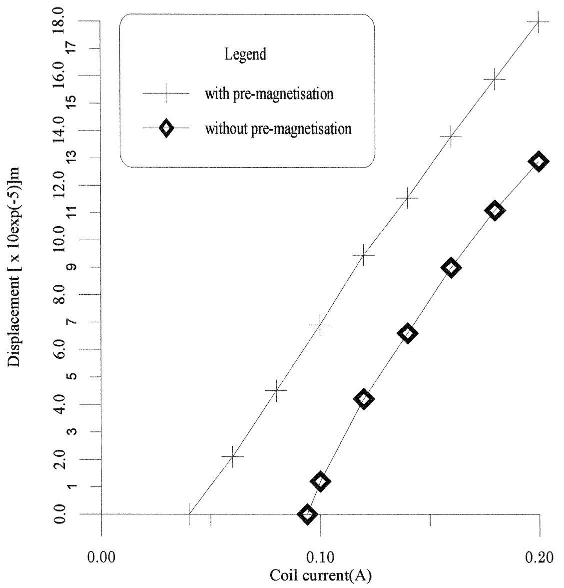

Fig. 5. Displacement vs. current characteristics for the actuator with elastic support ($x_0 = 2$ mm; the ratio of the displacement transfer, $r = r_2 / r_1 = 0.5$).

was used. The force was measured at the upper edge of the rod with tensiometer marks fixed with glue. They are coupled on an electronic tensiometer bridge. For example, the force measured at 170 mA, the magnetic core pre-magnetised, was 1.32×10^{-2} N, with $x_0 = 2$ mm.

Using another electromagnet, similar with the previous and symmetrically placed to the plate, it is possible to obtain a differential actuator, with bi-directional action, being able to control small displacements of a mechanical part, in both directions. In this case, the force vs. current and the force moment vs. current curves become much more linear comparing to the simple, unidirectional option, Fig. 3. The control current represents the difference $\Delta I = I_1 - I_2$ between the currents running through the two coils of the electromagnets. The initial running current $I_1 = I_2 = I_0$ may be chosen from the second part of the curve, where the non-linearity is less evident. So, for $I_0 = 120$ mA, the dependence force–current becomes proportional in a large range. Applying magnets to the outside edges of the electromagnetic cores, a greater action force is obtainable.

4. Elastic support actuator

Using an elastic support is possible to obtain a stronger and safer actuator (Fig. 4). Its elastic force determines the angular displacement value of the rod. If the elasticity constant is great enough, a current to force conversion device may be obtained, generating very small displacements. The linear displacement of the upper edge of the rod depends proportionally on the control current in both situations of the core's pre-magnetisation, with or without magnet, the two lines being practically parallel (Fig. 5). The slope of the lines is about 11×10^{-3} m/A.

5. Conclusions

The actuator proposed in the paper generates low forces and very small displacements controlled rigorously by a dc current. In the version with a support axle (utilising a mechanic ensemble of a pendulum type), the actuator can develop displacements (several millimetres) larger compared with the situation of an elastic support utilisation. The actuator with elastic support is sturdier and easier in manipulation than the type with support axle. Depending on the elastic constant, the generated displacements may be of 0.1–0.4 mm. The study of this device by means of some static behaviour characteristics suggests the possibilities of design, construction and optimisation of the performances according to the application.

The load behaviour is influenced by the value of the resistant force, produced by the actuated piece. We believe that a possible application of this actuator can be the fine drive of the blades of the pneumatic and hydraulic pressure amplifiers of a flapper-nozzle type.

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Biographies

Radu Olaru was born in 1949 and is an Associate Professor at the Faculty of Electrical Engineering, Technical University of Iaşi, Romania. He graduated at this University in 1972 and in 1994 received his PhD on Magnetic Fluid Transducers. His main scientific interests are connected with magnetic sensors and devices for measuring and control.

Alexandru Salceanu was born in Iaşi, in 1955. He received his degree in Electronic Engineering in 1980, from the Technical University of Iaşi. Before he joined the Faculty of Electrical Engineering, he had worked as a research engineer at The Institute of Technical Physics, Department of Magnetic Devices and Materials. He earned his doctoral degree in Electrical Measurements at Technical University of Iaşi, in 1997 with a thesis on Preisach-type hysteresis modelling. He is senior lecturer, delivering courses on Electrical Measurements and EMC. Current fields of interest include magnetic behaviour modelling and virtual instrumentation.

Doru Calarasu was born in Suceava in 1949. He received his Electrical Engineering degree in 1972. He earned his doctoral degree in Electrical Technologies at Technical University of Iaşi, in 1997. He is senior lecturer at this University, having researches concerning automatic hydraulic systems and hydraulic devices.

Constantin Cotae was born in Vaslui, Romania in 1949. He received his Diploma in 1972 and PhD degree in 1982, both in Physics from the University ‘Al.I.Cuza’, Iaşi, Romania. From 1972 till 1978, he was with The Technical Physics Institute of Iaşi, dealing with magnetic measurements and magnetic fluids. Since 1978, he has been with the Physics Department, Technical University of Iaşi, where he develops theoretical and experimental research concerning magnetic fluids.