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Sensors and Actuators A 91 (2001) 150–152

SENSORS AND ACTUATORS A PHYSICAL

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Current to pressure transducer with magnetic fluid

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Abstract

The paper presents a new type of current-to-pressure transducer that consists of a ferromagnetic nozzle and an electromagnetic actuator with two diaphragms and a magnetic fluid, which ensures a correspondence between the air line pressure and the control current in the coil. The experimental results obtained in stationary steady-state show that by a suitable choice of the technical parameters, transfer characteristics with low hysteresis effect may be obtained, the dependence pressure versus current being practically linear.

Keywords: Current to pressure transducer; Magnetic fluid; Electromagnetic actuator; Hysteresis effect

1. Introduction

Compressed air is used in many systems for controlling machinery because compressed air is immune to electrical interference and is safe in explosive environments. Compressed air is generally used, for example, to control valves and other mechanical devices in industrial systems. In automation, the sensors and regulators are generally provided to generate small electrical currents, in the range of 4–20 mA, for example. The conversion from electrical current to a corresponding pressure is accomplished by using a current-to-pressure transducer that is capable of regulating the pressure of a small volume of air, wherein the volume of air is amplified by using standard pneumatic amplifiers. In the conventional current-to-pressure transducer, a nozzle directs compressed air to the atmosphere at a rate determined by the proximity of a flapper valve to the nozzle orifice. The flapper valve is generally mounted on a rotating suspension and is rotated by magnetic forces that are generated by an electromagnet. Such prior art devices are formed as delicate mechanical assemblies that require several adjustments during fabrication and are relatively expensive to produce [1,2].

Magnetic force in a ferrofluid (magnetic fluid), proportional to the field gradient and to the liquid magnetization, makes possible the control and position of a mechanical small piece [3–5]. If a dc field of moderate amplitude is applied, the magnetic force will be quadratic in terms of the dc current producing the magnetic field.

A magnetic fluid incorporated in a current-to-pressure transducer may eliminate the above mentioned disadvantages produced by the mechanical assembly, ensuring the system insensibility to shocks. In the case of such a current-to-pressure transducer [1,2] a magnetic fluid deforms a flexible diaphragm in response to an electrical input current that is applied to a coil and magnetic circuit. The deformed diaphragm varies the air space between the diaphragm and a nozzle connected to the air line so that the pressure within the air is effectively controlled.

This paper presents a new type of current-to-pressure transducer that consists of a ferromagnetic nozzle and an electromagnetic actuator with two diaphragms and a magnetic fluid, which ensures a correspondence between the air line pressure and the control current in the coil.

2. Experimental model

As shown in Fig. 1, due to the current in the coil, the magnetic field in the neighbourhood of the magnetic core extremities produces a magnetic force that distorts upwards the diaphragm system. The components of this force are the resultant differential force in the two ferrofluid regions bounded by the diaphragms and the core extremities, oriented upwards, the attraction force core — ferromagnetic disc and the attraction force magnetic fluid — magnetic nozzle, also oriented upwards. The displacement of the non-magnetic disc, *d*, and its vicinity to the nozzle reduces the flow rate of the air evacuated in the atmosphere and

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0924-4247/01/$ – see front matter
PII: S0924-4247(01)00467-8

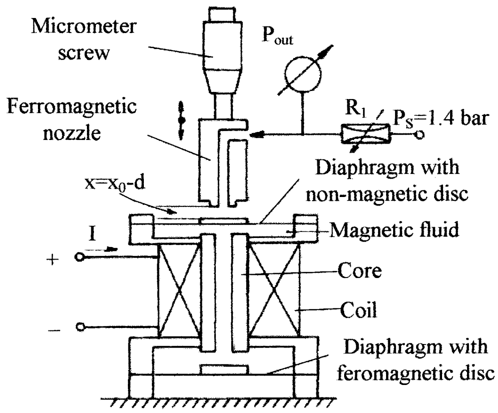

Fig. 1. Experimental set-up.

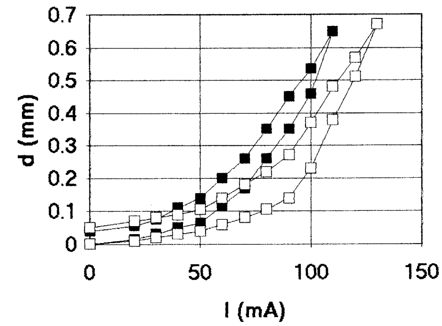

Fig. 3. Non-magnetic disc displacement vs. current — (■): $p_{out} = 0.3$ bar; (□): $p_{out} = 0.6$ bar.

increases the pressure in the compressed air supply-line delivered by the pressure source p_s. The resistive divisor formed of the pneumatic adjustable resistance R_1, the fix resistance of the nozzle capillar R_2, and the varying resistance of the space between the nozzle and the disc, R_x, ensures the control of the pressure p_{out} in the air line only by modifying the distance x.

3. Results and discussion

Two types of magnetic fluids were used: MF1 (based on transformer oil, saturation magnetization $M_s = 45$ kA/m, susceptibility $\chi = 1.9$, viscosity $\eta = 0.13$ Pa s) and MF2 (based on kerosene, $M_s = 20$ kA/m, $\chi = 0.52$, $\eta = 7 \times 10^{-3}$ Pa s). The experimental results illustrated in Figs. 2–4 correspond to MF1 and those in Figs. 5 and 6 to MF2. The electromechanical device was filled with the magnetic fluid MF1 ensuring the membranes to remain flexionless.

Fig. 2 presents the dependence pressure versus the distance x between the nozzle and the diaphragm, for two values of the pneumatic resistance R_1.

The experimental results show that displacements $d \cong 1$ mm of the upper diaphragm may be obtained for a current of 150 mA. The aspect of the curve $d(I)$ shows an approximate quadratic dependence $d = kI^2$ (Fig. 3), similar to the characteristic magnetic force versus current.

The characteristic $d(I)$, obtained by maintaining a constant output pressure in the test points and by modifying the distance nozzle–disc, exhibits a dependence on the reaction force created on the disc surface by the air jet. A pronounced hysteresis effect created by the two plane diaphragms may be also observed. Due to this hysteresis effect, the input–output characteristic of the transducer is also hysteretic (Fig. 4).

Fig. 5 presents the dependence of the output pressure with the coil current after the magnetic fluid MF1 was replaced with MF2. The hysteresis effect was still visible in the case when the ferrofluid did not ensure the necessary tension of the plane membranes. Adding an amount of magnetic fluid and thus realizing a curvature of the diaphragms towards the exterior, the hysteresis effect was strongly diminished. This may be explained by a reciprocal compensation of the hysteresis effects produced by each of the two diaphragms, a fact that does not occur in the case of plane diaphragms.

In practice, such a transducer is usually connected to a pneumatic pressure amplifier in order to ensure the necessary volume of air. Consequently, the transducer was connected to a conventional pneumatic amplifier that gives an output pressure in the range 0.2–1 bar, for an input pressure of 0.2–0.24 bar. The plots in Fig. 6 confirm the results illustrated in Fig. 5. If the two membranes are flexioned towards the exterior, the hysteresis effect is considerably smaller. At the same time, the dependence pressure versus

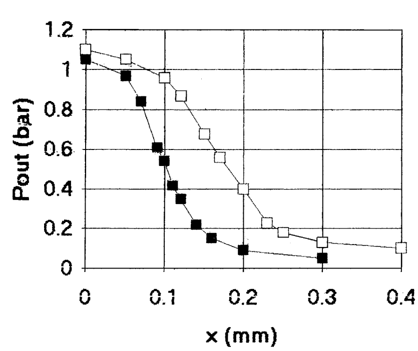

Fig. 2. Pressure vs. nozzle-diaphragm distance: R_1 (□) < R_1 (■).

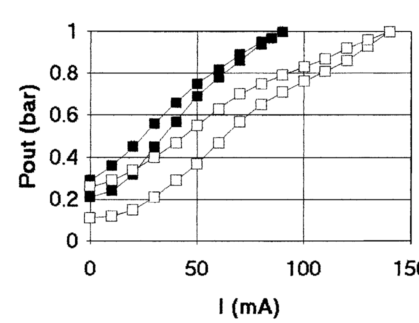

Fig. 4. Output pressure vs. current at $x_0 = 0.15$ mm for different R_1: R_1 (□) > R_1 (■).

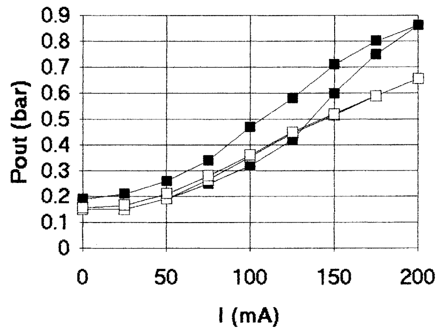

Fig. 5. Pressure vs. current for MF2 — (■): flexionless diaphragms; (□): outside flexion of diaphragms.

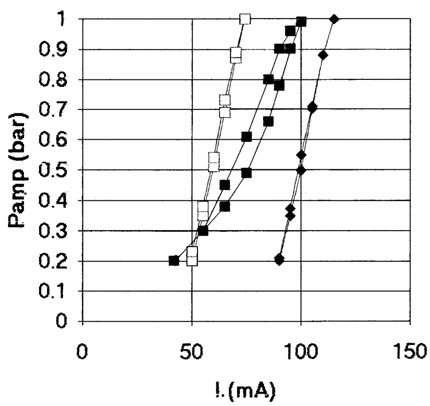

Fig. 6. Amplifier pressure vs. current — (■): Fig. 5; (□, ◆): MF2, flexed diaphragms, for $I_0 = 50$ and 90 mA, respectively.

current is practically linear if the minimum current, I_0, in the coil is greater than 50 mA.

Consequently, the following general conclusions may be formulated.

- The current-to-pressure transducer presented in this paper has a simple and solid construction, and may be easily realised, without the need for elaborate mechanical processing of its components.
- The experimental results obtained in stationary state prove that the hysteresis effect decisively depends on the stress in the two diaphragms. A higher stress, producing an outwards curvature, decreases the hysteresis effect.
- By a suitable choice of some technical parameters (such as the distance nozzle-diaphragm, x_0, the input pneumatic resistance R_1, the initial coil current I_0, the amount of magnetic fluid that defines the stress in the diaphragms) a practically linear characteristic of the transducer may be obtained.
- The transducer sensitivity, $\Delta p/\Delta I$, depends, among other things, on its geometry, on the magnetic properties of the magnetic fluid, on the elastic properties of the diaphragms and their flexion.
- In order to work properly in dynamic state, the transducer must use a low viscosity ferrofluid, so that the viscous forces would not introduce large delays of the output signal and thus produce an inertial behaviour of the transducer.
- The ferrofluid damps the vibrations produced by the interaction air jet-diaphragm.

Future studies will deal with the stationary and dynamic behaviour of the transducer–amplifier assembly, enhancing its stability and transfer characteristic by using a feed-back circuit.

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Biographies

R. Olaru was born in 1949 and is a Professor at the Faculty of Electrical Engineering, Technical University of Iasi, Romania. He graduated from this University in 1972 and in 1994 received his PhD on Magnetic Fluid Transducers. His main scientific interest is connected with electromagnetic devices and systems for measuring and control.

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