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Some applications of inductive transducers with magnetic liquids

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Abstract

The paper presents the main constructive and functional characteristics of a leakage flow detector for degree of porosity control of aluminum cylinder heads and of transducers for two-axes inclination angle and air velocity, designed for wind turbine applications. © 1997 Elsevier Science S.A.

Keywords: Inductive transducers; Magnetic liquids; Pressure difference; Inclination measurement; Gas flow

1. Introduction

Fluid and magnetic properties brought together by magnetic liquids confer to these synthetic materials valuable new features, which are at the origin of various engineering and biomedical applications [1]. A particularly interesting domain is that of the inductive sensors with magnetic liquid as basic component [2–6]. The principle of functioning of an inductive magnetic liquid sensor (MLS) is illustrated in Fig. 1. A differential pressure sensor (L_1, L_2) and an inclination angle sensor (L'_1, L'_2) are rigidly coupled and electrically connected to an ac bridge, as it is shown schematically in Fig. 2. The electric signal measured between P'_1 and P'_2 depends only on the pressure difference $P_1 - P_2 = \Delta P$; small magnetic liquid level differences produced by unwanted inclinations or accelerations of the system are compensated due to the inclination angle sensor (L'_1, L'_2). In the particular case presented in Fig. 1 the sensor is used to measure the volumic flow rate $Q \sim \Delta P$ of a gas in laminar flow through a measuring tube [7], one of the promising applications of these sensors. Using various laminar measuring elements such as simple cylindrical tubes and laminarization structures or complex flow transducers with the sensitive magnetic liquid sensor in by-pass, the measuring domains easily cover a wide range from ~1 cm^3 min^{-1} to ~10 m^3 min^{-1} [8]. Various basic aspects of the calculus and design of the inductive sensors with magnetic liquids are thoroughly discussed in [4,9,10]. In what follows some special applications of these devices will be presented.

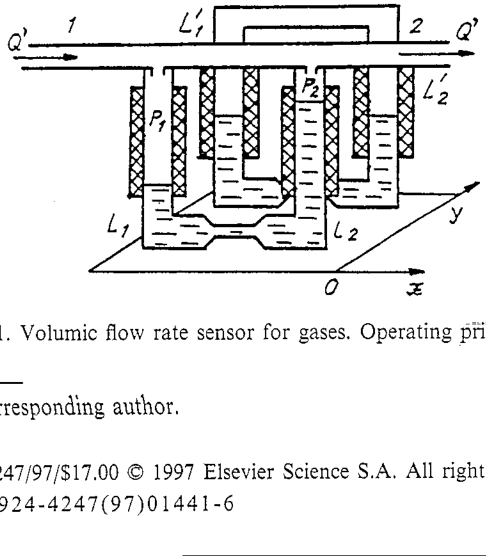

Fig. 1. Volumic flow rate sensor for gases. Operating principle.

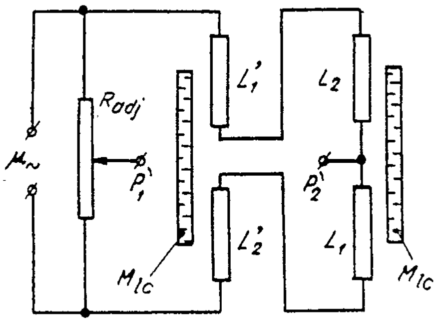

Fig. 2. Electric connection scheme of flow rate sensor. M_{lc}, magnetic liquid column; R_{adj}, variable resistor for null point adjustment.

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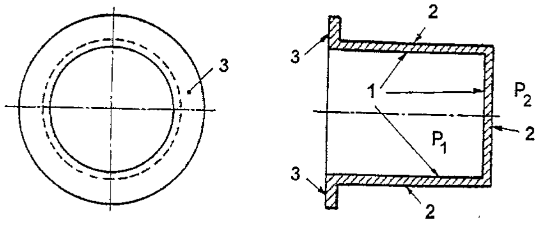

Fig. 3. Approximate shape of casting to be controlled: 1, surface at air pressure P_1; 2, surface at air pressure P_2; 3, uncontrolled surface; $(P_1 - P_2 = 1\ \text{bar})$.

2. Automatic control of degree of porosity of casting

The concrete problem solved was related to aluminum cylinder heads of cars, manufactured by casting under pressure and worked out by mechanical cutting. An automatic manufacturing line was provided by a pneumatic quality control system of cylinder's degree of porosity. Each cylinder, whose approximate shape is given in Fig. 3, was supposed to a pressure difference of 1 atm. To ensure the required quality, the leakage flow through the walls of the cylinder had to be below 50 cm^3 min^{-1}. The pneumatic control system is sketched in Fig. 4, while the time sequence of electric valves and the variation of pressure and temperature in the controlled cylinder and the porosity free cylinder of equivalent volume are presented in Fig. 5.

At the moment t_0, when all the valves are closed, a cylinder C to be controlled is automatically inserted in the pneumatic system. At t_1 the electric valves V_1, V_2 and V'_2 are opened and the pressurized air from the source PS fills up the cylinder C and the equivalent volume leakage free cylinder, EV. After the time interval τ_1 the system pressure is stabilized at P_1, valve V_1 is closed and during time interval τ_2 thermal stabilization is also fulfilled. In this period, valve V_3 is opened in order to introduce the magnetic liquid transducer in the pneumatic system. At the moment t_4 the valves V_2 and V'_2 are closed and during time interval τ_3, a certain quantity of air from C is lost through its porous walls. To equalize the pressures from C and EV, one half part of the air lost is completed from EV through the MLS. The volume of C, EV and pneumatic circuit is much larger than the lost air volume, therefore practically P_1 is constant in the whole period $\tau_2 + \tau_3$. The MLS may be for differential pressure or for volumic flow rate.

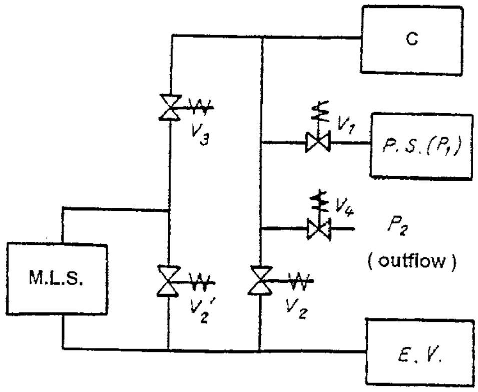

Fig. 4. Scheme of the pneumatic system for controlling leakage flow through porosities: C, cylinder head to be controlled; EV, equivalent volume cylinder; MLS, magnetic liquid sensor; V_n, electric valves; PS (P_1), pressurized air source.

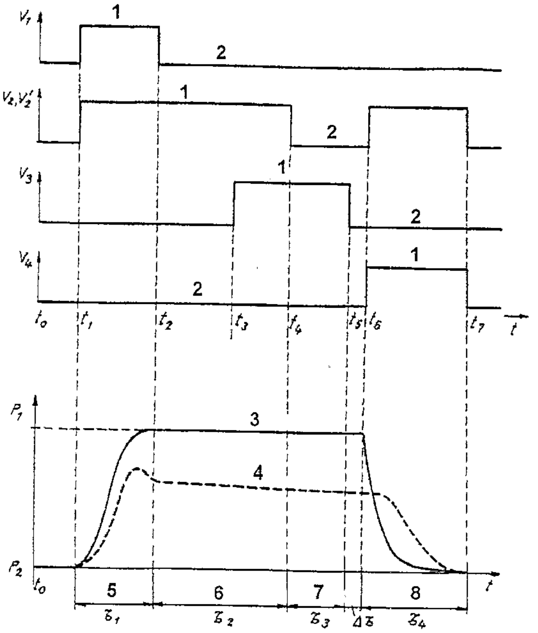

Fig. 5. Time sequence of electric valves and variation of pressure and temperature of air in cylinder head to be controlled and in equivalent volume cylinder. 1, opened; 2, closed; 3, pressure variation; 4, temperature variation; 5, filling up; 6, stabilizing; 7, measuring; 8, emptying.

There were experimented both type of transducers with good results, taking into account their high resolution, ~ 1 µm H_2O and ~ 10 cm^3 h^{-1} respectively. Due to some unavoidable pressure variations associated with the operation of valves V_2, V'_2 and because of the relatively long measuring time (τ_3) needed by the differential pressure sensor, the final equipment used a magnetofluidic leakage flow detector manufactured in cooperation with AEM S.A. Timişoara (Magnetic fluid transducers, Products catalogue, 1991), which well satisfied all the sensitivity and measuring time requirements (~ 1 s). Other type of high sensitivity sensors, e.g. thermoresistive micro flow sensors, have relatively long measuring time (~ 10 s).

3. Two-axes inclination and velocity measurements in wind energetic

A two-axes inductive inclination sensor with magnetic liquid consists, in essence, of two U-shaped sensors as in Fig. 1, however both should be closed and mounted along two orthogonal axes: $N-S$ and $E-V$. The electronic system has two independent ways to treat the signals provided by the two orthogonal sensors. The sensor, its electronic unit and power supply, were constructed in cooperation with AEM S.A. Timişoara (Magnetic fluid transducers, Products catalogue, 1991) for a measuring domain of -3° to $+3^\circ$ and a precision of $\pm 2\%$. The characteristic curves for the axes $N-S$ and $E-V$ are practically superposed and show good linearity (Fig. 6). A robust and portable device of this type was used to control the correct position of supports for wind generators assembled in Semenic mountains.

An other application in this field of the magnetic liquid differential pressure sensors is a wind velocity sensor presented schematically in Fig. 7 experimented in laboratory conditions. The laminarization structure ensures good linearity of the air velocity–voltage difference curve. Various differential pressure sensors with magnetic liquid are currently used in laboratory aerodynamic measurements [1].

4. Conclusions

Magnetic fluids proved to be a very efficient component for design and construction of a wide variety of sensors, illustrated by some special applications presented in this paper. The leakage flow detector, two-axes inclination angle transducer and the air velocymeter are constructively simple and their functional characteristics were easily tailored to the requirements of an automatic porosity control system and of a wind energy station respectively.

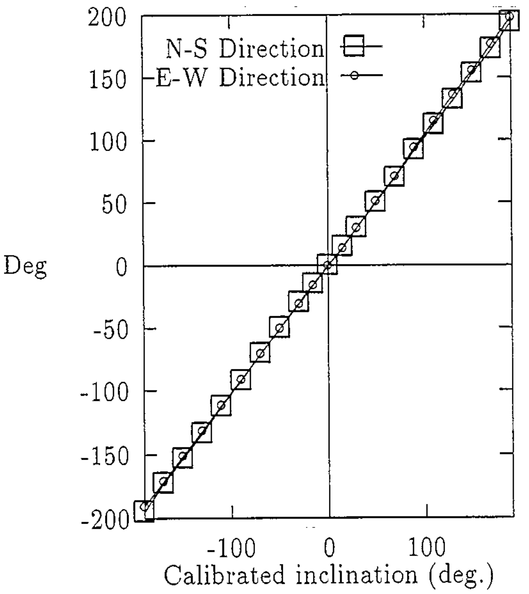

Fig. 6. Calibration curve of two-axes inclination sensor.

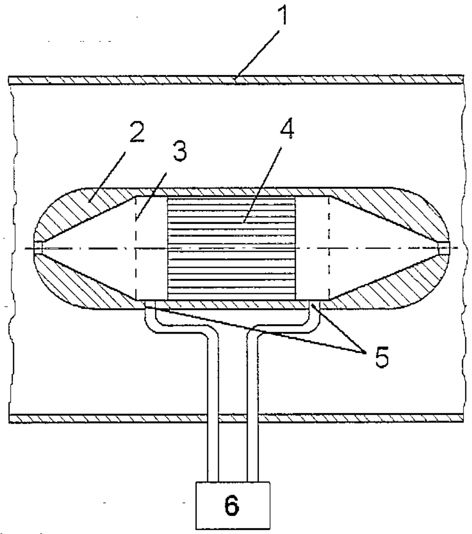

Fig. 7. Air velocity sensor: 1, external cylinder; 2, sensor body; 3, metallic sieve; 4, laminarization structure; 5, pressure tapes 6, differential pressure sensor with magnetic liquid.

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References

[1] I. Anton, I. De Sabata and L. Vékás, Application orientated researches on magnetic fluids, *J. Magn. Magn. Mater.*, *85* (1990) 219–226.

[2] R. Olaru, C. Cotae, I. Grosu and Gh. Călugăru, Investigation of an inclination transducer, *J. Magn. Magn. Mater.*, *39* (1983) 162–164.

[3] J.-C. Bacri, R. Perzynski, D. Salin and J. Servais, Magnetic fluid sensors: inclinometer and accelerometer, *Int. J. Appl. Electromagn. Mater.*, *2* (1991) 197–206.

[4] I. De Sabata, N.C. Popa, I. Potencz and L.Vékás, Inductive transducers with magnetic fluids, *Sensors and Actuators A*, *32* (1992) 678–681.

[5] N.C. Popa, I. Potencz, L. Vékás and G. Giula, Transducer for the measurement of inclinations relative to the horizontal, *Romanian Patent No. 98430/1989.*

[6] I. Potencz, N.C. Popa, L. Vékás, E. Suciu and A. Melinte, Transducer for the measurement of small pressure differences, *Romanian Patent No. 98431/1989.*

[7] N.C. Popa, I. Potencz and L. Vékás, Magnetic fluid flow meter for gases, *IEEE Trans. Magn.*, *30* (1994) 936–938.

[8] I. Potencz and L. Broştean, Experimental investigations on volumic flow transducers, *Romanian Rep. Phys.*, *47* (1996) 493–502.

[9] N.C. Popa, I. De Sabata and R. Potencz, The calculus of the inductance for a coil of real current loops, vertically and partially immersed in magnetic liquid, *Romanian Rep. Phys.*, *47* (1995) 455–472.

[10] N.C. Popa, I. De Sabata and R. Potencz, The calculus of the inductance for a coil of filiform current loops, vertically and partially immersed in magnetic liquid, *Romanian Rep. Phys.*, *47* (1995) 473–492.

Biographies

Iosif Potencz was born in 1935. He received his degree in electromechanical engineer in 1958 from the University 'Politehnica' Timişoara. From 1967 to 1990 he was a senior researcher at the Laboratory of Hydraulic Machines and since 1991 at the Research Center for Hydrodynamics, Cavitation and Magnetic Fluids of the University 'Politehnica' Timişoara. His current fields of interest include engineering applications of magnetic fluids (sensors, rotating seals, magnetogravimetric separators, bearings, dampers) and cavitational phenomena.

Lazăr Broştean was born in 1940. He received his mechanical engineering degree in 1966 from the University 'Politehnica' Timişoara. From 1966 to 1980, he worked as a design engineer and from 1980 to 1990 he was a senior researcher at the Laboratory of Hydraulic Machines and at the Research Center for Hydrodynamics, Cavitation and Magnetic Fluids (1991–1996) of the University 'Politehnica' Timişoara. He died on 9 October, 1996. His research fields include hydraulic engineering and applications of magnetic fluids.

Ladislau Vékás was born in 1945. He received his physics degree in 1968 from the West University Timişoara and his Doctorat in physics in 1983 from the University 'A.I. Cuza' Iaşi). From 1977 to 1990 he was a senior researcher at the Laboratory of Hydraulic Machines and since 1991 at the Research Center for Hydrodynamics, Cavitation and Magnetic Fluids in the University 'Politehnica' Timişoara. Since 1996, he has been Director of the Condensed Matter Research Institute Timişoara and also has been a member of the International Steering Commitee of Magnetic Fluids since 1993. His current fields of interest include physicochemistry of magnetic fluids, magnetohydrodynamics, phase transitions, nanoscale physics.

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