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Investigations on the Design of Discrete Pneumatic-to-Electrical Transducers of Low Pressure[*]

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Abstract: *A survey is done on the main physical principles in transforming low pressure into an electrical signal, presenting the equations and the sensitivity coefficients of the transform. Some models of pneumatic-to-electrical contact and inductive transducers are designed and on their basis the possibilities for the development of discrete pneumatic-to-electrical transducers of low pressure have been investigated.*

Keywords: *Discrete pneumatic-to-electrical transducers, low pressure.*

1. Introduction

When some miniature elements and devices of fluidics are used in hybrid systems for control and automation, it is appropriate to directly transform low pressures into discrete standard electrical signals. Different principles for pressure transforming into an electrical signal are known [1-3], but not all of them could be efficiently applied for this purpose.

The authors have accomplished a thorough survey of the basic physical principles in creating pneumatic-to-electrical transducers of low pressure. Table 1 presents the results of this survey, presenting for each physical principle the transfer function, the sensitivity coefficient in signal transforming, the type of the transformed output signal and the necessity for additional processing of this output

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signal. The analysis of the research results indicates [4-7] that the resistance, the electromagnetic and the optical physical principles could be used in the design of discrete pneumatic-to-electrical transducers.

The recent references do not contain any investigations on the efficiency of the application of these principles in transforming low pneumatic signals into discrete standard electrical signals. The purpose of the present study is to estimate the efficiency in the usage of the resistance and electromagnetic principles in transforming low pressure into a discrete electrical signal.

Table 1

Physical principle	Transfer Function	Sensitivity	Type of the output signal	Additional processing of the output signal
1. RESISTANCE 1.1. Contact	$x \le x_0$, $y=0$ $x \ge x_0$, $y= y_0$	∞	Discrete	–
1.2. Micro-switch		∞	Discrete	–
1.3. Hermetic contact		∞	Discrete	Relay amplifier
1.4. Semiconductor tensoresistor DMS	$\frac{\Delta R}{R} = (1+2\mu)\frac{\Delta l}{l} = K\frac{\Delta l}{l}$	$K \approx 2$	Analog	Bridge with high sensitivity
1.5. Semiconductor Tensoresistor HLDMS		$K \approx 200$	Discrete	Bridge with low sensitivity
2. ELECTRO-MAGNETIC 2.1. Inductive	$Z = \varpi L = \frac{\varpi_{\mu} W^2 S}{\delta}$	$S_\delta = \frac{-Z_0}{\delta_0\left(1+\frac{\Delta\delta}{\delta_0}\right)^2}$	Analog	Bridge with alternating current
2.2. Inductive threshold (initiator)	$x \le x_0, y = 0$ $x \ge x_0, y = y_0$	$S = \frac{\Delta y}{\Delta x}$	Discrete	Relay amplifier
2.3. Inductive	$E = B\pi d w \frac{\partial x}{\partial t}$	$S = B\ \pi\ d\ w$	Analog	Amplifier
2.4. Mutually inductive (transformer)	$E_2 = \frac{\mu_0 W_1 W_2 S \varpi I_1}{\delta}$	$S_\delta = \frac{-E_0}{\delta_0\left(1+\frac{\Delta\delta}{\delta_0}\right)^2}$	Analog	Amplifier

Table 1 continued

2.5. Magnetoelastic	$Z \approx \varpi L = \frac{\varpi\mu W^2 S}{l}$	$S_2 = S_\mu \approx 200$	Analog	Bridge with alternating current
3. ELECTROSTATIC 3.1. Capacitive	$C = \frac{\varepsilon_S}{\delta}$; $x_C = \frac{\delta}{\varpi\varepsilon S}$	$S_\delta = \frac{-C_0}{\delta_0\left(1+\frac{\Delta\delta}{\delta_0}\right)^2}$	Analog	Bridge with alternating current
3.2. Piezoelectrical	$\frac{\partial Q}{\partial t} = \frac{U}{R} + C\frac{\partial U}{\partial t} = d_{11}\frac{\partial F}{\partial t}$	$S_{(p)} = \frac{d_{11}}{C}\frac{p\tau}{1+p\tau}$	Analog	Amplifier of charge
4. OPTICAL	$x \le x_0$, $y = 0$, $x \ge x_0$, $y = y_0$	∞	Discrete	Relay amplifier

2. A contact pneumatic-to-electrical transducer

The contact pneumatic-to-electrical transducer is a discrete transducer of the analog shift X of a closing contact as a result of the action of given pneumatic pressure, into an alteration of the electrical resistance of a circuit. In the simplest case (Fig. 1), the contact transducer consists of two conductors 1, at the ends of which two contact juts are connected, that are a part of an electrical circuit. They are either connected or disconnected with the help of a third electrical wire 3. When the conductors contact, the resistance between them practically does not exist, while when they are detached, the resistance is equal to that of insulation and converges to infinity.

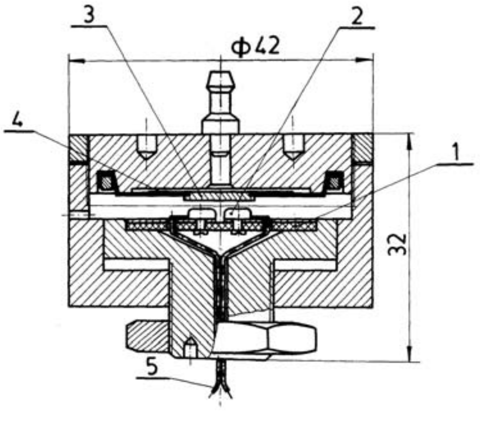

Fig. 1

An important parameter of the contact transducer is its transition resistance, which is also its output impedance. It must be as little as possible, because it is included in the external current circuit. It is determined by the material, the shape, the size and the status of the contact surfaces and by the contact effort as well [5]. The value of the transition resistance of the contact transducer is inversely proportional to the contact effort, or to the value of the pneumatic pressure applied on membrane 4, respectively (Fig. 1). The resistance depends on the dust that has fallen between the contact surfaces, the oxide particles on them and also on any absorption layers of organic nature. In all the cases the specific resistance of the contact surface layers is much larger than this of the main material. In order to completely destroy the thin oxide and organic covers, and to ensure reliable contact, contact efforts, not smaller than 0.01 N for golden contacts; 0.05-0.15 N – for silver contacts and 0.7 N – for tungsten contacts are necessary. In more powerful electrical circuits the lower limits of the necessary contact pressure increase up to 3 N.

A significant shortcoming of the contact transducers is that due to the ionization of the gas molecules between the contacts, caused by the electrostatic electron emission, there appears an electric arc, leading to contact surfaces erosion. When the pressure is slowly changed, i.e., slow movement of the closing contact plate, attached to the membrane, there appear conditions for a continuous electric arc. When the contact plate approaches the contact juts 2, their contact is accompanied by auto-electronic emission from the cathode as a result of the strong tension of the field, which causes the appearance of a spark. In the friction of the contact plate, obtained under insufficiently high pressure on the membrane, there is continuous sparkling between the contacts, causing rapid demolition of the contact surfaces and deterioration of the switching on reliability.

The results from the investigations of the designed model of a contact pneumatic-to-electrical transducer are given below. Fig. 2 shows its static characteristics – the shift of the membrane with the contact plate and the switching of the electrical circuit depending on the pneumatic pressure on the effective area of the membrane, $X = f\ (p_e)$ and $J = f\ (p_e)$ respectively. Fig. 3 presents its transfer function at pneumatic pressure $p_e = 1$ kPa.

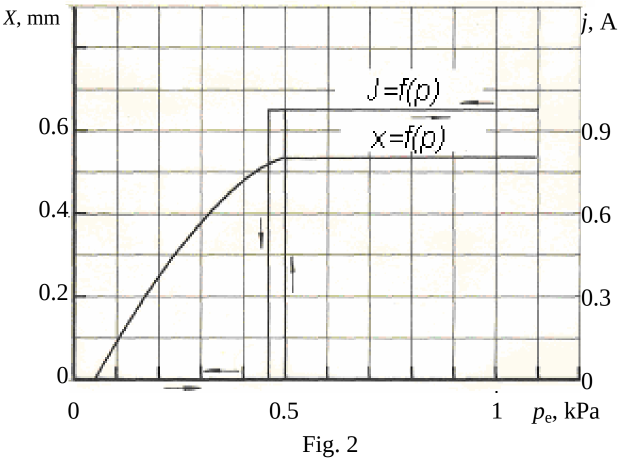

Fig. 2

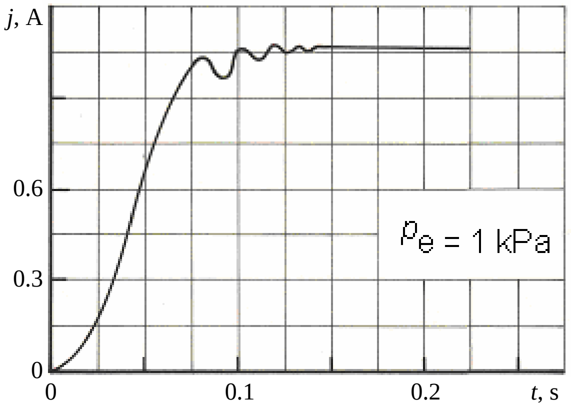

Fig. 3

The disadvantages above mentioned make the contact transducers inappropriate for use in fluidic logical schemes with low pressure. Considerable improvement of the technical operation features of the contact transducers is achieved with the help of micro-switches with a “jump” spring [2]. Here the displacements, necessary to move the switch from one position into another, i.e. for circuit switching on or off, are within the range of 0.02 up to 0.01 mm, but the actuation effort is quite large – from 0.05 up to 7 N. Their application in devices with low pressure would require multiple increase of the membrane diameter, if no intermediate membrane is used. This increases the transducer size and decreases its speed, which makes it inadequate for use in fluidic logical schemes in the general case.

3. Pneumatic-to-electrical transducer with a hermetic contact

The hermetic contacts are a modification of the directly controlled contacts. The oxidation, the sulphonation and the dust found on the contact surfaces is completely avoided in them. Their output resistance is almost zero in a switched on status and very big in a switched off status. They have longer life-time – from 10^6 up to 10^9 cycles, small mass and acceptable high speed of 0.5-2 μs. The basic shortcomings of the hermetic contacts are [2]: the low power, which they commutate – from 10 up to 15 W, the presence of considerable hysteresis, defined as the difference between the necessary magnetizing force for switching on and off. Besides this, they have low actuation accuracy, being $\pm(0.5\div1)$ mm at usual operation.

Fig. 4 shows the experimental model designed for the purpose of discovering the possibilities for application of the hermetic contacts in pneumatic-to-electrical transducers in fluidic systems of low pressure. The constant magnet 1 controls the size of the magnetic current, switching on or off the contacts. The use of two magnets, as shown in Fig. 4, considerably improves the device functioning.

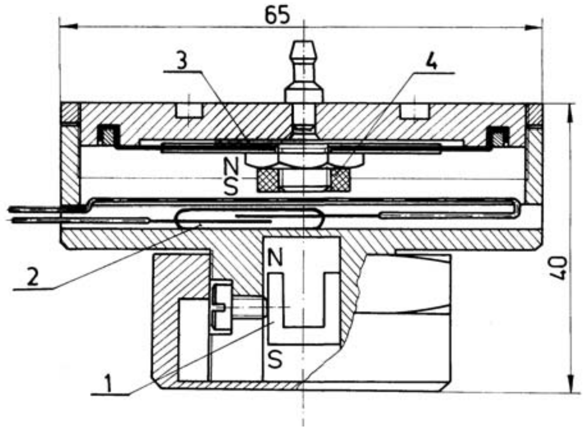

Fig. 4

Fig. 5 presents the static characteristics of the movement of membrane 3 with a constant magnet 4, $x = f(p_e)$ and the switching on and off $J = f(p_e)$ of the hermetic contact 2 in the experimental sample of the pneumatic-to-electrical transducer.

Due to the necessity for a considerable displacement of the membrane, the large hysteresis, the low actuation accuracy, etc., the use of the hermetic contacts is not recommended in the design of pneumatic-to-electrical transducers for fluidic schemes of low pressure.

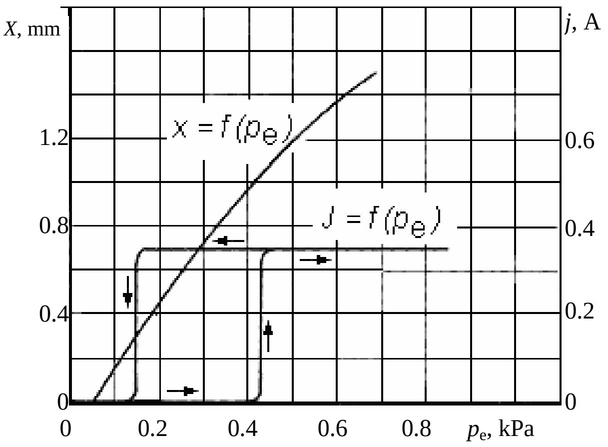

Fig. 5

4. Inductive threshold pneumatic-to-electrical transducer

The experimental model of an inductive threshold pneumatic-to-electrical transducer is shown in Fig. 6. The inductive initiator 1 reacts to the approach of the metal membrane 2, mounted at a given distance from the initiator’s front, so that the output electrical signal is zero in the absence of pneumatic pressure. The membrane displacement must be sufficient for the switching of the transducer and for the obtaining of a discrete electrical signal at its output.

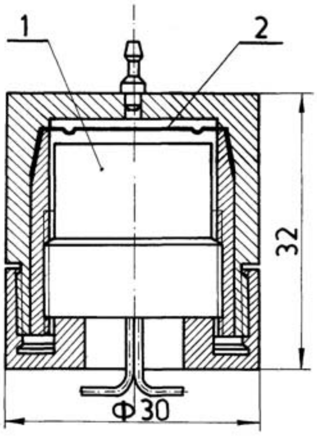

Fig. 6

The inductive threshold transducer investigated consists of a generator and a two-step transistor current amplifier. When a metal plate is placed between the coils and when it moves towards the transducer, the generations are interrupted and a signal is obtained at the output. The nominal supply voltage is 12 V. The model studied operates steadily at 5 V as well, but with lower sensitivity. The nominal resistance of the relay, connected to the transducer, must be $500\ \Omega$. The basic advantage of this transducer is that the membrane displacement is done with no inertia and it is contactless.

The static characteristics of three transducers of the type considered are shown in Fig. 7. It could be noticed, that the transducers have different points of actuation, which is due to some inaccuracy in their construction. This requires independent graduation for each transducer.

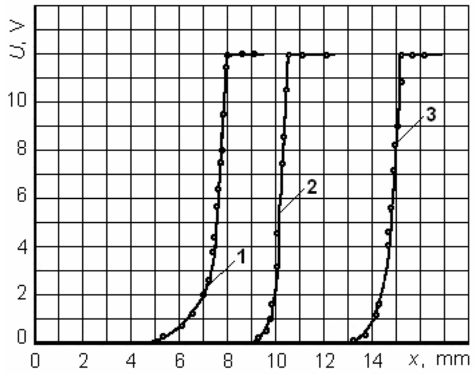

Fig. 7

The following threshold transfer functions with good sensitivity are obtained, (for supply voltage of 12 V and R_a = 500 Ω), namely:

$$S_1 = \frac{\partial y}{\partial x} = \frac{10}{0.7} = 14.3\ \text{V/mm}\,,\ S_2 = \frac{10}{0.6} = 16.7\ \text{V/mm}\,,\ S_3 = \frac{10}{0.9} = 11.1\ \text{V/mm}.$$

At sensitivity threshold of ±1 V of the relay, connected after the transducer, the threshold sensitivity of the transducer is less than 0.1 mm. This low threshold determines the necessary shift of the membrane as 0.5 mm. No hysteresis is observed after an alteration in the plate direction of movement.

The dynamic features of the transducers considered have been investigated with the help of an electric motor with two plates. Frequency of 200 Hz is obtained at 6000 rev./m. Rectangular pulses with a duration of 0.5 ms and a period of 5 ms are observed at the transducer output. The pulses fronts are not steeper than 0.1 ms. This frequency satisfies the requirements of the fluidic automation systems.

There are not any oscillations in the output signal of these transducers, which are characteristic for the contact transducers, particularly for the micro-switches. The switching in them does not require any force, due to the contactless nature of the impact.

5. Conclusion

The analysis of the experimental results of the developed models of pneumatic-to-electrical transducers has indicated that the inductive threshold transducer has proved possessing the best static and dynamic characteristics.

Its advantages are high accuracy and reliability of operation; good high speed; comparatively small dimensions; small size, weight and displacement of the membrane; relatively simple structure and long life-time.

All these advantages completely justify the comparatively high cost of the device and make it the most appropriate discrete pneumatic-to-electrical transducer, applied in fluidic systems of low pressure.

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