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Fluid Flow Sensors with a Ring Nozzle

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1. Introduction

The fluid flow sensors with a ring supplying nozzle are used for non-contact perception of the position reached by a moving object or for the detection of its presence or absence. Discrete information signal is formed at the output of these devices, which is usually amplified by a pneumatic discrete amplifier and entered to a pneumatic positioning system or transformed by a pneumo-electrical transducer and supplied to a digital-electronic positioning system.

A sample series of fluid flow sensors with a ring nozzle has been developed for the purposes of robotics and automation, which is described in a number of publications [1, 2, 3, 6]. Two typical representatives are discussed in this paper in short and their static and dynamic characteristics are analyzed.

2. Static characteristics of the sensors

Fig. 1 shows a principal constructive scheme and Fig. 2 – the outer appearance of a "miniature" fluid flow sensor with a ring supplying nozzle and a coaxial receiving channel.

In a given operating mode the output pressure p_a is a function of the feeding pressure p_s, the distance from the sensor front up to the object l and of the output sensor pressure Q_a [6]:

(1) $$p_a = f(p_s,\ l, Q_a).$$

The distance range, in which the object D_i can be traced, is:

(2) $$D_i = l_{\max} - l_{\min},$$

where $l_{\min}$ is the minimal distance, which causes considerable alteration of the output pressure p_a. The requirement is $l_{\min} \le 1$ mm, [4].

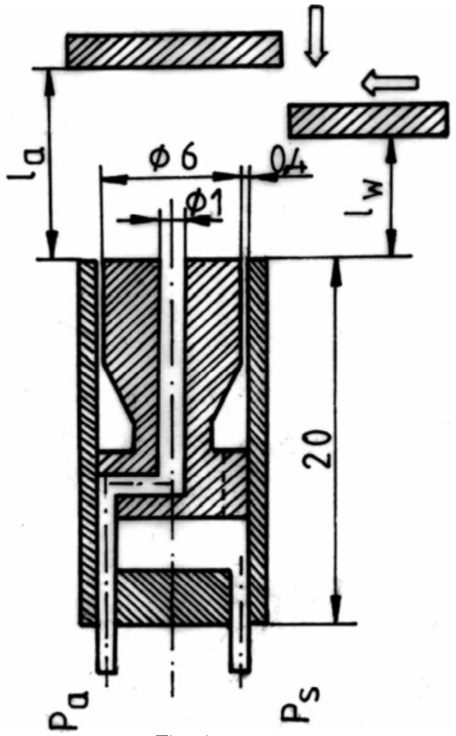

Fig. 1

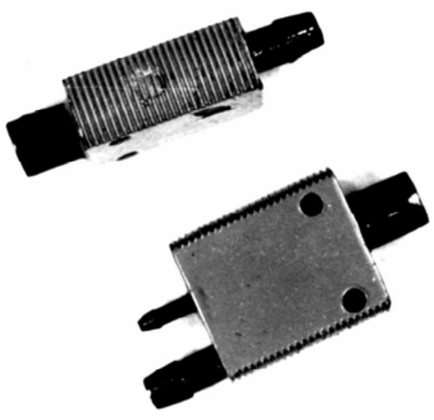

Fig. 2

l_{max} – the maximal elongation between the sensor and the object reflecting wall, which causes analogous change. It is defined as the maximal elongation of perception. The condition $l_{max} \geq 3$mm is required and it depends mainly on the sensor geometric parameters. From equation (1) it is obtained accurately enough:

(3) $$l_{max} = 1.65[(D/2) - \delta + \pi\delta],$$

where δ is the ring gap of the nozzle, D – the diameter of the ring nozzle.

The coefficient of reconstruction of the working fluid pressure K_p is determined by the relation:

(4) $$K_p = \Delta p_a / p_s\ ,$$

where Δp_a is the increase of the output pressure, p_s – the increase of the feeding pressure.

The value of K_p depends on the parameter l. The value K_p defined for the operating distance l_w, is determining when evaluating a given sensor. Expressed in percents, K_p must not be less than 1%.

The expenses of the feeding fluid Q_{ff} have to be minimal. At constant feeding pressure p_s, it is defined by the distance from the sensor front up to the reflecting surface of the object l_w:

(5) $$Q_{ff} f(p_s,\ l_w).$$

The sensitivity of the sensor towards the loading T_Q has also to be minimal. It is determined as a relation of the change of the output pressure Δp_a with respect to the alteration of the output flow (load) ΔQ_a :

(6) $$T_Q = \Delta p_a\ /\Delta Q_a\ .$$

The analytical determination of these four parameters is practically impossible due to the complexity of the gas-dynamic processes, which can be changed altering the elongation of the sensor from the object. They can be defined experimentally only, taking down the operating, input and output characteristics of the sensor.

The sensor static working characteristic is a function of the output pressure p_a on the elongation l at absence of load Q_a, determined for different values of the feeding pressure p_s:

(7) $$p_a = f(p_s,\ l).$$

The static working characteristic of the sensor must have a clearly expressed discrete form. The value of the output pressure must exceed the value necessary for the switching of the fluid discrete amplifier or fluid-electrical transducer.

The input characteristic is a function of the flow of the feeding fluid Q_s on the alteration of the feeding pressure p_s of the sensor for different elongations l of the sensor from the object:

(8) $$Q_s = f(p_s,\ l).$$

The output characteristic is a function of the output pressure p_a on the alteration of the load Q_a for different elongations l of the sensor from the object at constant feeding pressure p_s:

(9) $$p_a = f\ (Q_a,\ l).$$

Fig. 3 shows different static operating characteristics of the "miniature" sensor for different feeding pressures of the operating fluid. The "flexing" of the curves in their middle region is explained by the fact that at a small distance of the sensor from the object the throttle effect of the stream flow appears. When the distance is increased, the effect of the reflected flow is present, and at a distance greater than the perception la, the ejection effect of freely flowing stream appears.

Fig. 4 shows the principal constructive scheme of a fluid flow sensor with a ring feeding nozzle, in which an amplifier of "nozzle-barrier " type is built in. The barrier

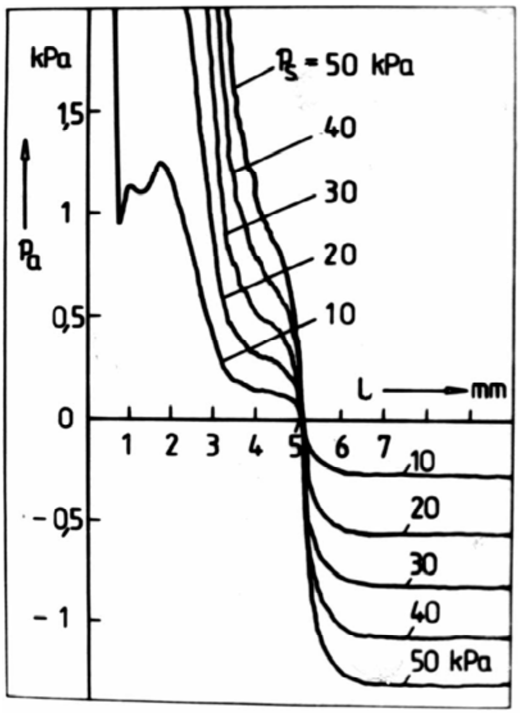

Fig. 3

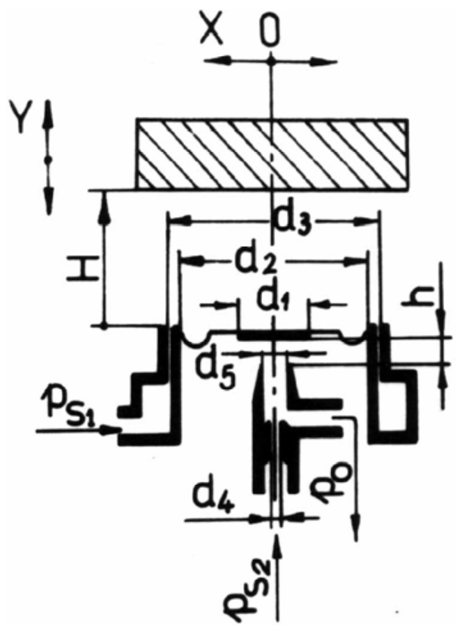

Fig. 4

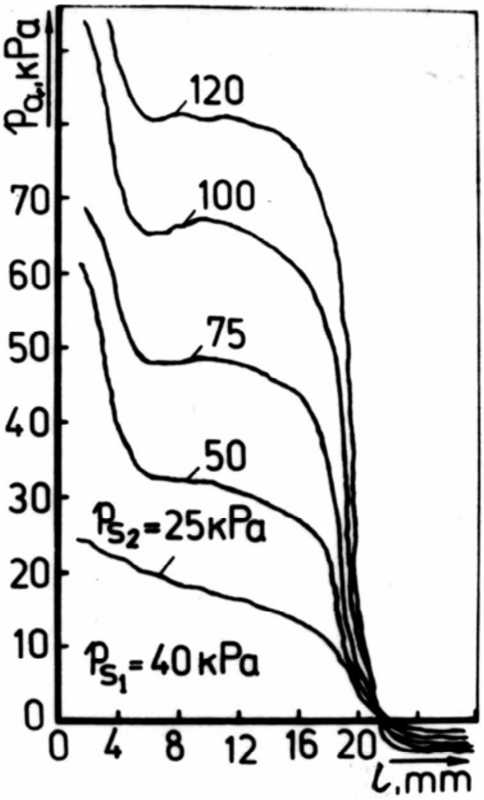

Fig. 5

is an elastic membrane [1]. The working static characteristics (Fig. 5) relate to the system sensor-amplifier. They are with high transfer coefficient of pressure and great distances of object tracing. The presence of a membrane decreases considerably the speed of the sensor, its reliability and exploitation duration.

The values of the basic functional parameters at one and the same feeding pressure p_s and working distance up to the object l_w are determined on the basis of the results obtained from the investigations of the two sensors. Table 1 represents the more important of them, denoting by H the hysteresis of the static characteristic and by Γ – the sensor dimensions.

Table 1

Sensor	D_l, mm	K_p,	Q_{ff}, 1/h	T_Q,	H, mm	Γ, mm
1. "Miniature"	0 - 5	0.22	650	0.05	0.15	24×10
2. With a membrane ampl.	0 - 20	1	2550	0.07	1.25	50×40

3. Dynamic errors of the fluid flow sensors with a ring nozzle

The evaluation of the qualities and the application of the sensors is possible only after determination and analysis of the dynamic errors obtained when establishing the object position reached under conditions of dynamic operating mode. The investigations are accomplished with the experimental sample of the "miniature" sensor given in Fig. 2. In order to realize the experiments, the equipment schematically shown in Fig. 6 is used. The object is the rotating sheave (1) with a reflecting plate (2), driven by the electrical motor (3) with regulated revolutions.

The position reached by the plate (3) is obtained by the sensor (4), as well as by an optic-electronic sensor (5) with an adaptor (9), of FESO/SOE-RT-M12-PS-K-LED type. The two sensors are mounted on one and the same axis, perpendicular to the plain of plate movement. The output signal from the sensor (4) is fed towards the pneumatic amplifier (6), FESO/VE-5 type. The signals from the optical-electronic sensor (5) and from the pnemo-electrical transducers (7) and (8), FESTO/PEV-1/4-B type, are input to the oscillograph (10).

The dynamic errors are obtained due to alteration of the parameters: v – speed of shifting of the reflecting plate; p_s – feeding pressure of the fluid sensor; l_w – working distance between the sensor and the plate; L – length of the impulse line between the sensor and the fluid amplifier.

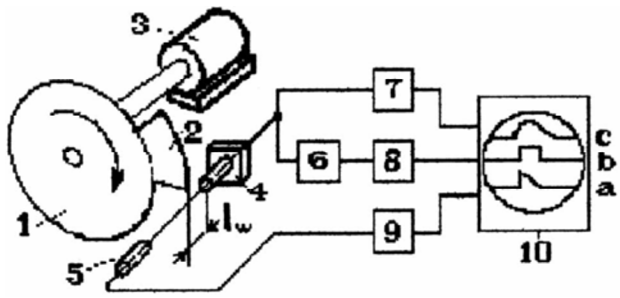

Fig. 6

The relative dynamic error of sensor (4) position perception is defined as the distance passed by the plate (3) for the time from the moment of signal receiving by the optical-electronic sensor (5) up to the moment of signal reception by the fluid sensor.

Fig. 7 shows the generalized final results for any errors in perception of the position for different speeds of plate movement within the range from 0.1 up to 1.2 m/s, at pressures of the air supplied to the sensor – 20 kPa. The errors in the perception are determined by the face (Δs_{V_1}) and back (Δs_{V_2}) front of the output signal of the system sensor-amplifier, its equations being represented as linear relations respectively:

(10) $$\Delta s_{V_1} = 10\ V,$$

(11) $$\Delta s_{V_2} = 35\ V.$$

The analysis of the results obtained shows that the dynamic error is significantly greater when the back front of the discrete output signal of the sensor-amplifier system is used as an information signal and also that in order to achieve sufficiently high accuracy the object must not be shifted at a speed exceeding 1 mm/s.

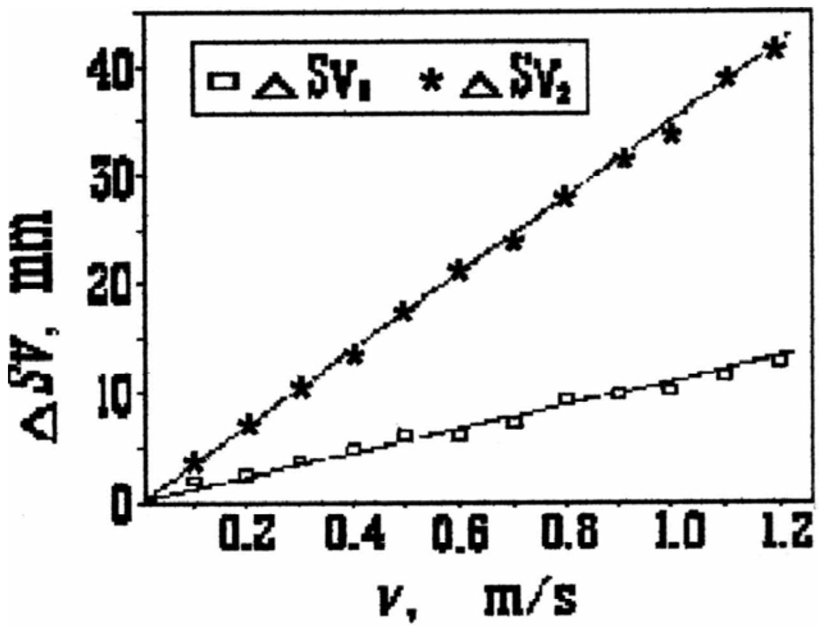

Fig. 7

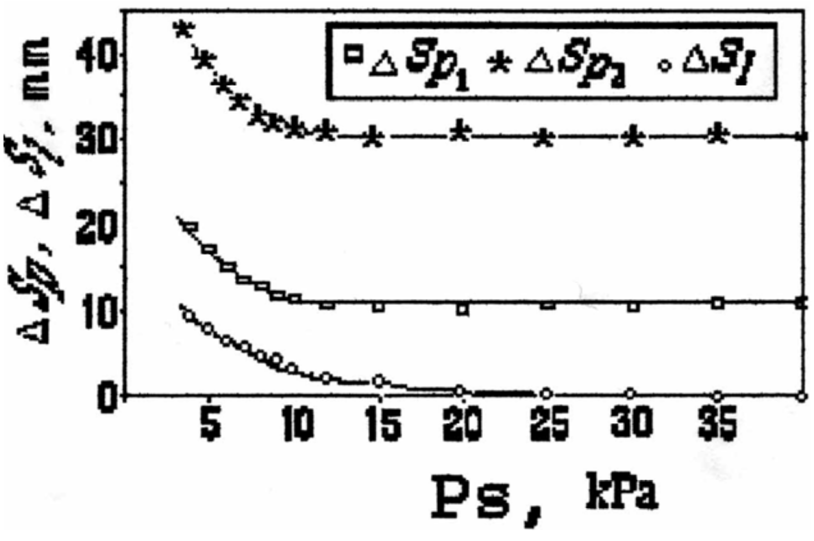

Fig. 8

Fig. 8 shows the results from the study of the errors Δs_{p_1} – when using the face front of the information signal and Δs_{p_2} – when using the back front. The feeding pressure p_s of the sensor is changed within the range 4-40 kPa. The shifting speed of the plate is preserved constant – 1 m/s, and the working distance l_w – 3 mm. It is obvious that in this case the errors in the application of the back front of the output signal Δs_{p_2} are quite larger than those of the face front. It should be noted here that the dynamic error preserves its absolute value constant for values of the feeding pressure not larger than 10 kPa, hence it can be neglected in practice.

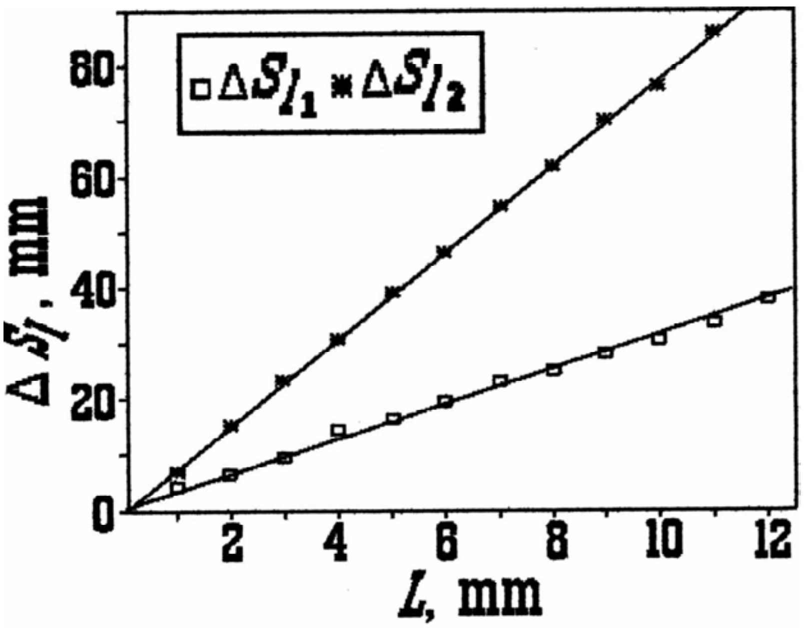

Fig. 9

The same figure demonstrates the results of the dynamic error sl depending on the alteration of the feeding pressure at alteration of the working distance l_w by ± 0.5 mm. A similar relation is analytically represented by a second order equation (12) and it can be used for digital determination of the dynamic error in the perception of the position of an object passing radially before the sensor at a distance $l = l_w \pm 0.5$ mm:

(12) $$\Delta s_{l_w} = 12 - 0.8\, p_s + 0.12\, p_s^2.$$

The length of the impulse line L is determined by the length of the tube connecting the sensor output with the amplifier input. It can be seen from the experimental results obtained, (Fig. 9), that the dynamic error increases significantly with the increase of L as been expected. The relation of the coefficients in the linear analytical expressions (13) and (14) determine the relation of the errors Δs_{L_1} and Δs_{L_2} for the two cases of position perception, with the face and back front of the amplifier discrete output signal:

(13) $$\Delta s_{L_1} = 0.25\, L;$$

(14) $$\Delta s_{L_2} = 0.65\, L.$$

The considerable influence of the of the impulse line length L on the dynamic error value in position perception presumes the creation of an integrated system sensor-amplifier, as the one in Fig. 4.

4. Conclusions

The following more important conclusions can be done on the basis of the investigations realized and the analysis of the results obtained:

– The main disadvantages of these sensors are the relatively large expense of air and the low coefficient of pressure restoration;

– The fluid output signal of the sensors is able to actuate some available (suggested by companies) fluid amplifiers and transducers;

– The static working characteristics are with hysteresis, allowing unambiguous perception of the objects;

– The information and transferring unit can be constructively integrated in a comparatively simple way, by a stream or a movable elastic element;

– The errors from the alteration of the movement speed of the object and the impulse line length are significant and they must be accounted when using the sensors in practice.

– The errors from the change in the sensor feeding pressure, when it is within sensor nominal working range, and from the alteration of the distance between the sensor and the radially shifting object, when the alteration is less than $\pm$ 0.1 mm, are insignificant and in more practical cases they can be neglected;

– Because of the fact that the receiving nozzle is protected from air entry and that the out flowing stream is turbulent, the sensors of this type can be used under conditions of dust and rubbish, presence of strokes, vibrations, high temperature, electrical and radioactive field, etc.

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Флюидные струйные сензоры с перстеновидной питающей дюзой

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(Р е з ю м е)

Исследованы образцы флюидных струйных сензоров с перстеновидной питающей дюзой. Определены их статические характеристики, а также и ошибки информационных сигналов при работе сензоров в динамическом режиме. Показано применение сензоров в практике.