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Ring Jet Reflection Fluid Sensors Designed for Severe Operating Conditions

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Abstract: *The paper presents results of investigation of laboratory samples of ring jet reflection fluid sensors designed to indicate the positions of moving objects in severe operating conditions.The static characteristics and information signal errors are determined during sensor operation in dynamic mode. 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.*

Keywords: *Fluid flow sensor, ring jet, reflected jet, pneumatic discrete amplifier, information signal.*

1. Introduction

The fluid flow sensors with ring jet reflection are used for non-contact perception of the position reached by a moving object. 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. For the purposes of robotics and automation the authors have developed a series of samples of ring jet reflection fluid sensors described in a number of publications [1, 2, 3, 6].

Further on the characteristics of two typical representatives of the developed ring jet reflection fluid sensors for operation in extreme operation conditions are discussed in brief: a fluid flow sensor with coaxial receiving channel (Fig. 1); a fluid flow sensor with a membrane air detector (Fig. 2).

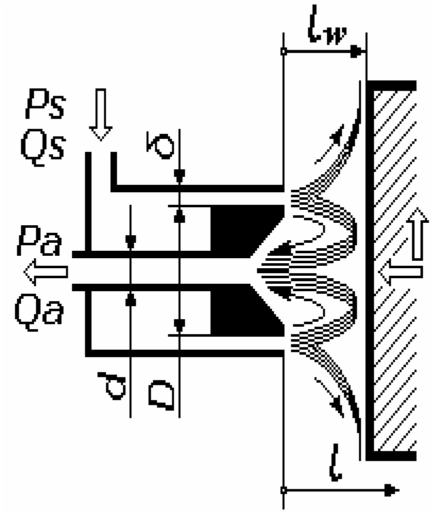

Fig. 1. Functional diagram of ring jet reflection fluid sensor and coaxial receiving channel

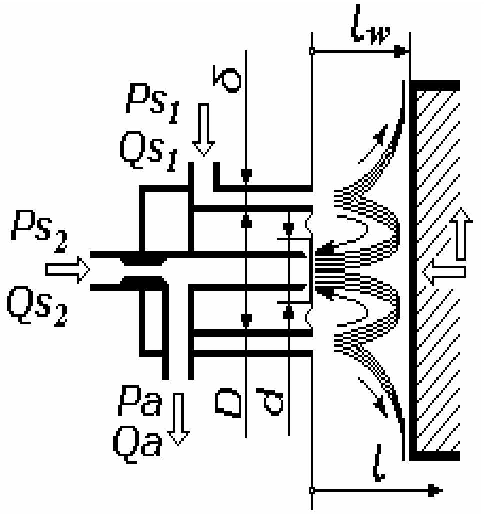

Fig. 2. Functional diagram of ring jet reflection fluid sensor and membrane air detector

2. Functional characteristics of the ring jet reflection fluid flow sensors

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

(1) $$D_l = l_{\max} - l_{\min},$$

where $l_{\max}$ and $l_{\min}$ are the minimal and the maximal distance, which cause considerable alteration of the output pressure p_a. The requirement is $l_{\max} \geq 3$ mm and $l_{\min} \leq 1$ mm [4].

$l_{\max}$ is defined as the maximal distance of perception and it depends mainly on the sensor geometric parameters. It is defined with sufficient for the practice accuracy by equation (2)

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

where D and δ are the diameter of the ring nozzle and the ring gap of the nozzle.

The output pressure p_o for the sensor with receiving channel in a given operating mode is a function of the supply pressure p_s, the distance from the sensor to the object l and of the output sensor loading Q_o [6]:

(3) $$p_o = f\left(p_s, l, Q_o\right).$$

For the sensor with membrane air detector and pneumatic amplifier "flapper-and-nozzle" the output pressure p_o is a function of the pressure supply p_{s_2} and of the constant and variable throttle valve parameters. Assuming that the flow rate coefficients for both throttle valves are approximately the same and that the created by them pressure difference is comparatively small the simplified dependence [7] can be used

(4) $$p_o = \frac{p_{s2} d^4}{d^4 + 16D^2 l_{\max}}.$$

The output characteristic of the sensor is a function of the output pressure p_o on the alteration of the load Q_o for different distances l of the sensor from the object at constant pressure supply p_s

(5) $$p_o = f\left(Q_o, l\right).$$

The sensor static operation characteristic is a function of the output pressure p_o on the distance l at absence of load Q_o, determined for different values of the supply pressure p_s

(6) $$p_o = f\left(p_s, l\right).$$

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

The coefficient of the pressure supply restoration K_p is determined by the relation

(7) $$K_p = \Delta p_o / \Delta p_s,$$

where Δp_o end Δp_s are the elementary increases of the output pressure and of the supply 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%.

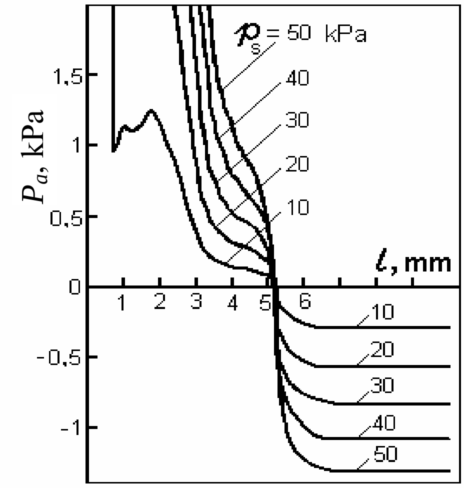

Fig. 3. Static operation characteristics of the ring jet reflection fluid sensor and coaxial receiving channel

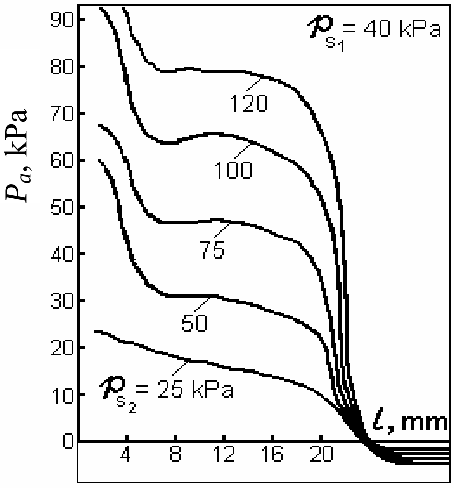

Fig. 4. Static operation characteristics of the ring jet reflection fluid sensor and membrane air detector

Figs. 3 and 4 show static operating characteristics of the considered sensors for different pressures supply. 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 $l_{\max}$, the ejection effect of freely flowing stream appears.

The presented in Fig. 4 static operation charcteristics refer to the sensor-amplifier system. They are with high transfer coefficient of pressure and great distances of object tracing. The presence of a membrane decreases considerably the operation speed of the sensor, its reliability and exploitation life.

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_o with respect to the alteration of the output flow (load) ΔQ_o

$$T_Q = \Delta p_o / \Delta Q_o . \tag{8}$$

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

$$Q_s = f(p_s, l) . \tag{9}$$

The consumption of the supply fluid $Q_{s\max}$ should be minimal. At constant pressure supply p_s, it depends on the distance from the sensor front up to the reflecting surface of the object l_w

$$Q_{s\max} = f(p_s, l_w) . \tag{10}$$

The precise analytical determination of the characteristics of the considered sensors is practically impossible due to the complexity of the gas-dynamic processes, which change with altering the distance of the sensor from the object. They can be defined experimentally only, taking down the operating, input and output characteristics of the sensor.

Comparison of the results of the experimental investigations. 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 G – the sensor dimensions.

Table 1. Comparison of the parameters of the studied ring jet reflection fluid sensors

Sensor	D_1, mm	K_p	$Q_{s\,max}$, l/h	T_Q	H, mm	G, mm
With receiving channel	0-5	0.22	650	0.05	0.15	24×10
With membrane air detector	0-20	1	2550	0.07	1.25	50×40

3. Dynamic errors of the ring jet reflection fluid flow sensors

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 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.

The relative dynamic error of sensor position perception is defined as the distance passed by a moving object for the time from the moment of signal receiving by optical-electronic sensor up to the moment of signal reception by the studied fluid sensor.

Fig. 5 shows the generalized final results for any errors ΔS_v in perception of the position for different speeds of object 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 by formulas (11) and (12).

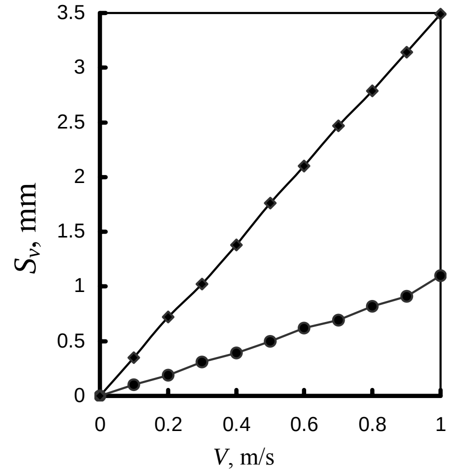

Fig. 5. Dynamic errors at alteration of the speed of object movement

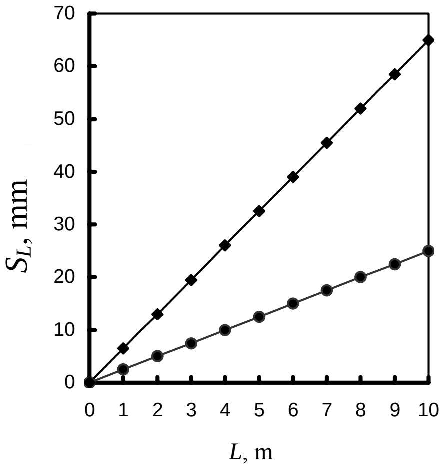

Fig. 6. Dynamic errors at alteration of the length of impulse line

$$\Delta S_{v_1} = v \times 10^{-3}, \tag{11}$$

$$\Delta S_{v_2} = 3.5 \times 10^{-3} v. \tag{12}$$

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 m/s.

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. 6), 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

$$\Delta S_{L_1} = 2.5 \times 10^{-3} L; \tag{13}$$

$$\Delta S_{L_2} = 6.5 \times 10^{-3} L. \tag{14}$$

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. 2.

Fig. 7 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 ΔS_{p_2} of the sensor is changed within the range 4-40 kPa.

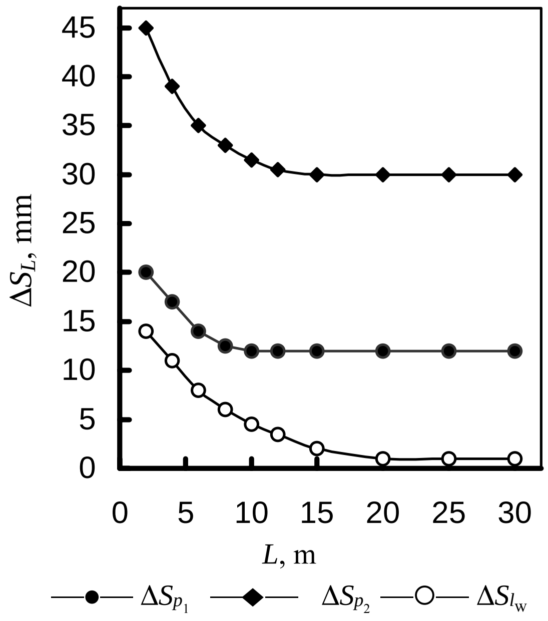

Fig. 7. Dynamic errors at alteration of the pressure supply

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.

The same figure demonstrates the results of the dynamic error ΔS_l depending on the alteration of the feeding pressure at alteration of the working distance Δl_w by ± 0.5 mm. A similar relation is analytically represented by a second order equation (15) and it can be used for numerical 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.

$$\Delta S_{\mathrm{lw}} = 12 - 0.8 p_s + 0.12 p_s^2 . \tag{15}$$

4. Conclusion

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

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

– the fluid output signal of the sensors is capable of actuating some available (offered by companies) fluid amplifiers and transducers;

– the static operation 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 taken into account when using the sensors in practice.

– the errors from the change in the sensor pressure supply, when it is within sensor nominal operation range, and from the alteration of the distance between the sensor and the radially shifting object, when the alteration is less than - 0.1 mm, are insignificant and in most of the cases in practice 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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