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Static Characteristics of a Fluid “Flapper-and-Nozzle” Sensor

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Abstract: *The paper investigates the static characteristics of a "flapper-and-nozzle" sensor. The relations proposed contribute to greater validity in the determination of the output informational signal within the range of sensor bedding.*

Keywords: *fluid sensor of "flapper-and-nozzle" type, static informational characteristics.*

1. Introduction

The principal diagram of a fluid “flapper-and-nozzle” sensor is shown in Fig. 1. Its main elements are the constant and inconstant choke and the circuit chamber (4).

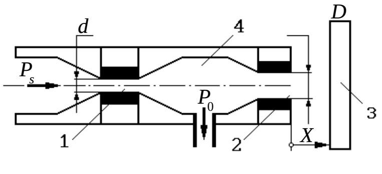

Fig. 1

The constant choke is with unchanging section (*F*), determined by the diameter *d,* and the inconstant choke – with a section (*f*), representing a cylindrical surface defined by the diameter (*D*) of the emitting flapper (2) and by the distance *X* up to nozzle (3). The obtaining of an informational signal about the alteration of a definite physical parameter of the object perceived by the sensor is a result of the alteration of the distance *X*, respectively of the section *f* of the inconstant choke, as a result of which the static pressure P_0 in the circuit chamber is changed. The alteration of this pressure with respect to the distance *X* determines the operating static characteristics of the sensor and the sensor type is defined by the characteristic form, specified by the conditions:

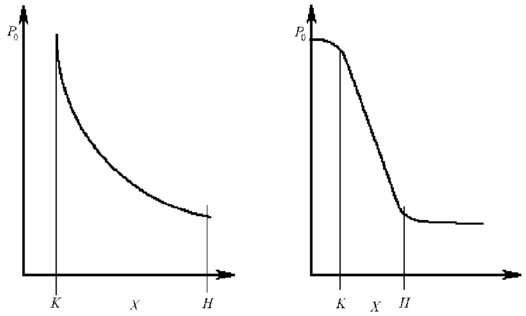

Fig. 2

$$(1)\qquad S = \frac{\Delta P_0}{\Delta X} \quad \begin{cases} S_{\Delta X \to 0} \to \infty - \text{proportional sensor,} \\ S_{\Delta X \to 0} \to \text{constant} - \text{discrete sensor,} \end{cases}$$

where: S is the slope of the characteristic in its operating range; X – the flapper shift; P_0 – the output informational signal.

In conformance with these conditions, the static informational characteristics of the "flapper-and-nozzle" pneumatic sensors may be as the one shown in Fig. 2, where H and K denote the beginning and the end of the sensor operating range.

2. Empiric determination of the static characteristics of a "flapper-and-nozzle" type sensors

The methods determining the static characteristics of the sensors of the type discussed, are described in [3, 4]. Some algorithms defining the static characteristics at different modes of flowing through the sensor constant and inconstant choke are described. The sensor static features are derived on the basis of the equality of the flow rates through the two chokes, assuming that the flow through the chokes is turbulent, isothermal and steady. At undercritical airflow for the two chokes ($P_0 > P_s/2$ and $P_a > P_0/2$), the static informational characteristic is of the form:

$$(2)\qquad P_0 = 16 \frac{\alpha_2^2 D^2 \Delta P_2^2}{\alpha_1^2 d^4 \Delta P_1^2} P_a X^2,$$

where α_1 and α_2 are discharge coefficients through the first (the constant) and the second (the inconstant) choke respectively; ΔP_1 and ΔP_2 – the pressure difference after the first and the second choke, respectively.

In most of the reference sources the equation of the informational characteristics (2) is proposed in a simplified form, assuming that the discharge coefficients for the two chokes are equal and the pressure difference created by them is small:

$$(3)\qquad \frac{P_0}{P_s} = \frac{d^4}{d^4 + 16D^2X^2}\,.$$

It should be noted that the values of the output informational signal defined by equation (3) are not exact enough, since this formula does not reflect precisely the physical process of flowing out and the real discharge coefficients. The last are regarded as constant values, depending on chokes geometry only. In fact they depend on the air parameters also and hence they are with variable values. An attempt has been made by the authors [5] for more exact determination of the discharge coefficients during air flow through turbulent chokes. Here the flow characteristic of the pneumatic choke is defined as a relation of the flow rate of the passing air Q and the common pressure difference ΔP:

$$Q = C\,f\sqrt{\frac{2}{\rho_0}}\,\sqrt{\Delta P}\;, \tag{4}$$

where f is the choke cross surface; C – the corrected discharge coefficient:

$$C = \alpha\,\varepsilon, \tag{5}$$

where α is a discharge coefficient reflecting the losses from the flow shrinkage at the input and its expansion at the choke output; ε – a modifying coefficient, reflecting the alteration of the airfight during its flow through the choke, determined by the relation:

$$\varepsilon = \sqrt{\frac{\rho_0}{\rho}}\,, \tag{6}$$

where ρ_0 is the airfight under normal conditions (T_0=288 K and P_0 = 101 325 P_0 N/m^2); ρ_0 – the airfight in front of the choke.

Empiric relations for the corrected discharge coefficient with regard to the pressure difference ΔP caused by the choke and with regard to the relative geometric parameters of the choke L ($L=l\,/\,d$) and F ($F=d^2/D^2$) are derived:

$$\mathrm{C} = 0.7442 + 0.000\,\Delta P\;; \tag{7}$$

$$\mathrm{C} = 0.73 + 0.125\,L + 0.0019L^2\;; \tag{8}$$

$$\mathrm{C} = 0.8329 - 0.4334\,F + 0.4519\,F^2\;. \tag{9}$$

The equation of the static informational characteristic of the pneumatic sensor discussed, at undercritical airflow through its two chokes, can be derived using the equation for the air flow rate (4):

$$\frac{P_0}{P_s} = \frac{C_1^2\,f^2}{C_1^2\,f^2 + C_2^2\,\pi^2 D^2 X^2}\;. \tag{10}$$

where C_1 and C_2 are the corrected coefficients of air discharge through the constant and the inconstant choke respectively, determined with the help of equation (9) as follows:

$$C_1 = 0.8329 - 0.4334\,f + 0.4519\,f^2\;, \tag{11}$$

$$C_2 = 0.8329 - 0.4334\,F + 0.4519\,F^2\;. \tag{12}$$

Fig. 3 and Fig. 4 show the graphic type of the characteristics of a sensor with the most frequent diameters of the constant (d=1 mm) and of the inconstant (D=3 mm) choke, obtained at supply pressures P_s within the range 60-140 kPa, determined by the theoretic relation (3) ($P_{0t} = f\,(X)$) and by the empiric equation (10) ($P_{0e} = f\,(X)$). Fig. 4 represents also the characteristics of the same sensor experimentally obtained, confirming the considerably higher accuracy of characteristics determination with the help of the approach proposed.

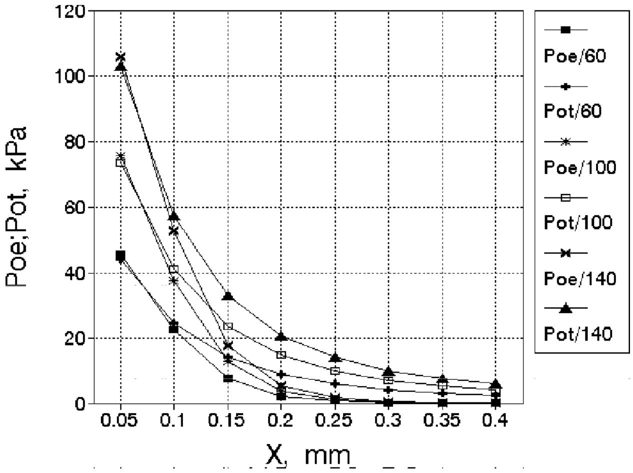

Fig. 3

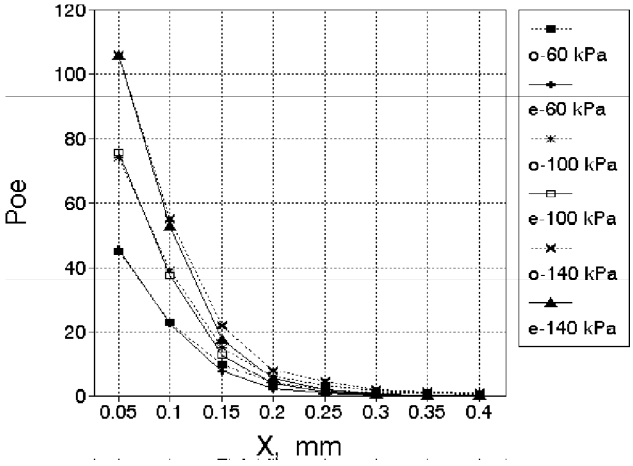

Fig. 4

3. Sensitivity of "flapper-and-nozzle" sensors towards the input signal

The sensitivity of "flapper-and-nozzle" sensors towards the input signal is defined by the steepness S ($S=\Delta P_0/\Delta X$) of the informational feature in its operating range. In many references [1, 3, 4] some algorithms and approaches are proposed which increase the sensitivity (the transfer coefficient) of the sensors of the type discussed altering the size and the form of the chokes and of the circuit camera. In cases of an already built pneumatic sensor, its sensitivity can be increased rising the supply pressure PS. Fig. 5 shows the graphic relations of the steepness on the feeding pressure for the two cases of their determination – theoretic and empiric. Similar relations can be analytically represented with the help of the equalities:

(13) $$S_t = 4.99\,P_s,$$

(14) $$S_e = 6.29\,P_s.$$

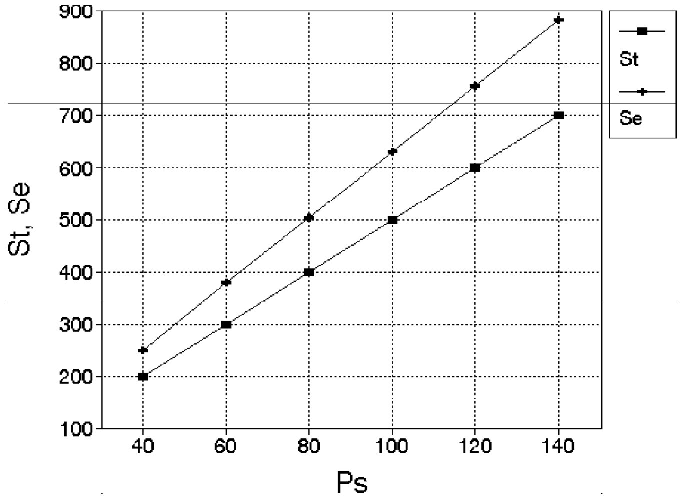

Fig. 5

As evident from the graphics and equations (13) and (14), the sensitivity towards any alteration of the output informational signal with respect to the input is changed proportionally to the value of the supply pressure, being with a greater coefficient in (14). This fact must be taken in mind when selecting the sensor operating pressure supply.

4. Sensitivity of the “flapper-and-nozzle” sensors towards supply pressure

The sensitivity of the “flapper-and-nozzle” sensors towards the supply pressure, expressed in the change of the output informational signal with respect to the pressure supply, can be defined for each value of X with the help of the proportionality coefficient in the equalities, obtained from equations (3) and (10) respectively,

(15) $$P_{0t} = K_t P_s,$$

(16) $$P_{0e} = K_t P_s,$$

in which K_t and K_e are coefficients determined by the expressions:

(17) $$K_t = \frac{d^4}{1 + 16D^2X^2},$$

(18) $$K_e = \frac{C_1^2 f^2}{C_1^2 f^2 + C_2^2 \pi^2 D^2 X^2},$$

where C_1 and C_2 are defined by equalities (11) and (12).

Fig. 6 shows as a comparison the values of the two coefficients in three typical cases. It is obvious that the proportionality coefficients Ke are with greater values than the coefficients K_t in the bedding region of the sensors (X=0÷0.2 mm) and they are smaller outside it. On the other hand the two coefficients enlarge with the decrease of distance X and vice versa – they diminish with its increase. Hence, the sensitivity of the output informational signal with respect to the supply pressure depends to a great extent (in inverse quadratic relation) on the distance X between the sensor and the object of perception.

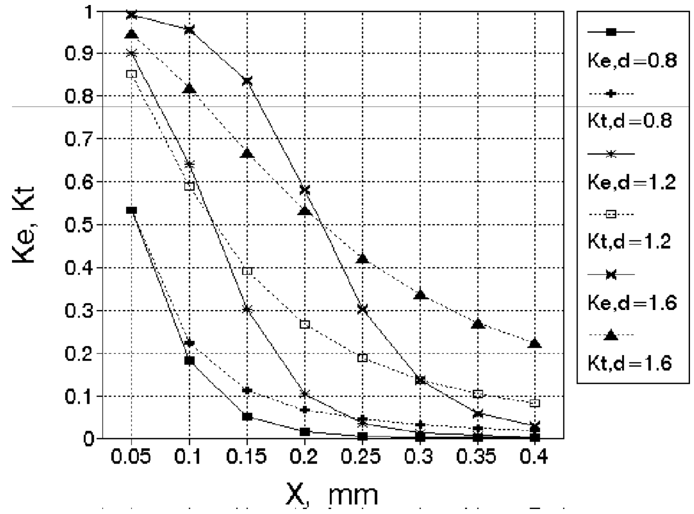

Fig. 6

Fig. 7 is an illustration of the degree of influence of the geometric parameter *d* on the alteration of the sensitivity of the output informational signal considering the pressure supply. The results are obtained for typical distances *X* between the sensor and the object percieved. It is clearly observed that for values of *d* up to 1 mm the sensitivity increases slowly and very quickly – after this value. This fact should be accounted in the selection of the cross section of the sensor constant choke.

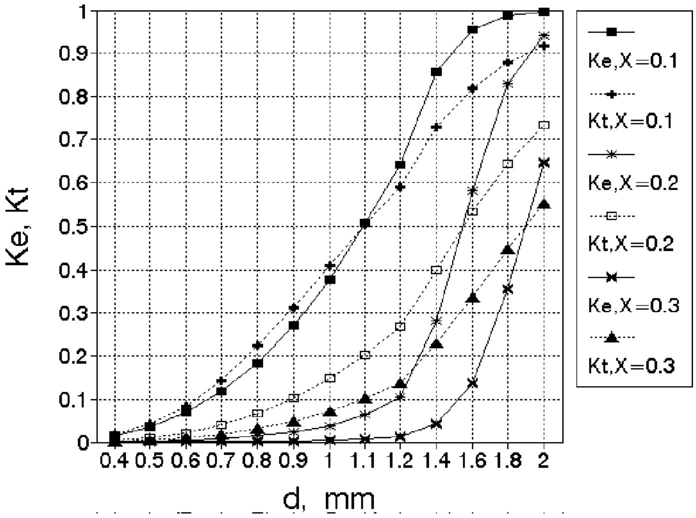

Fig. 7

Fig. 7

5. Conclusion

On the basis of the theoretic-experimental results obtained after investigations connected with the static informational characteristics of some fluid sensors of "flapper-and-nozzle" type, the following main inferences can be done:

– a semi-empiric relation (10) is derived for the informational static characteristics of the pneumatic sensor of a "flapper-and-nozzle" type, in which corrected coefficients are introduced for the undercritical air flow through its two chokes. The relation proposed contributes to greater validity in the determination of the output informational signal within the range of sensor bedding.

– a semi-empiric relation is defined from the study and the analysis of the sensitivity of the output informational signal with respect to the input, in the sensor bedding region. This relation makes quantitative estimation of the alteration of the informational signal sensitivity with respect to the input in the range of sensor bedding, depending on the supply pressure value.

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Статични характеристики на флуидни сензори "дюза-преграда"

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(Резюме)

Статията изследва статичните характеристики на сензор "дюза - преграда". Предложените зависимости допринасят за по-голяма достоверност при определяне на изходния информационен сигнал в участъка на сработване на сензора.