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QUALITATIVE EVALUATION OF THE COEFFICIENT OF HYDRAULIC RESISTANCE IN THE AREA OF THE DIVIDER OF THE FLUID FLOW OF THE AXIAL VALVE

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ABSTRACT

An expression is obtained for estimating the coefficient of hydraulic resistance using the principle of super positions of pressure losses in elementary local resistances in an separator of the axial valve. The simulation results can be used in calculating the coefficient of throughput of the valve and constructing a stochastic model for the formation of cavitation bubbles in its flowing part.

Keywords: control valve, coefficient of hydraulic resistance, constructive and mode parameters, throughput.

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1. INTRODUCTION

The problem of resource and energy saving in the transportation of liquid media in various pipeline systems is successfully solve with the help of regulating devices, including valves with an axisymmetric type. The successful designing of the latter is associated with the development of an appropriate theoretical framework related to the description of fluid flow in the flowing part of the valve [1], in order to reduce the undesirable effects of cavitation effects. At the same time, stochastic modeling of the process of regulation by liquid flows in the working volume of the valve [2-5] assumes consideration of its design and regime parameters and physico-mechanical characteristics of the transported medium, in particular, when calculating local hydraulic resistances.

The issues of managing the technological process of regulating fluid flow in pipelines with the help of regulatory bodies are related to the solution of a number of tasks to control the degree of opening of these devices and pressure drops, to predict the evolution of cavitation effects, etc. Active use of throttling elements of various types in the working volumes of control valves allows reducing undesirable manifestations of the cavitation effect. For example, in the design of new direct flow control valves [6, 7], the flow divider is a perforated hollow cylinder whose closing ratio is controlled by the position of the outer cylindrical continuous shell connected to the drive of the translational motion.

2. ON THE FEATURES OF THE SEPARATOR DESIGN

Let the divider of the liquid flow (separator) of the axial valve with the external arrangement of the locking body [6] have radial throttles of a circular shape with a diameter d_0 (m^2) with a total number of rows m_2 along m_1 the apertures in each. In this case, the value of the area of the conditional section ω_y (m^2), depending on the degree of opening x of the valve (the ratio of the current value of the position of the shell of the moving part of the shutter to its conditional position) is calculated by the formula

$$\omega_y = \pi d_0^2 m_1 m_2 x / 4 \quad (1)$$

Let the distance between the rows be equal L_0, and the length of the perforated part of the cylindrical separator $l = l_{s0} + l_{s1} + l_{h2} + l_{h3}$ is determined by the thickness H of the straight l_{s0}, l_{s1} and conical l_{h2}, l_{h3} sections of the outer body of the device. In addition, we introduce the following diameters: D_{id}, D_{ed} - respectively internal and external for the separator (fluid flow divider); D_{is1}, D_{is2} and D_{es1}, D_{es2} - internal and external to the cylindrical parts of the outer shell. The bevel angle for the cylindrical part of the shell of the moving part of the shutter is γ.

We choose the direction of the coordinate axis Ox', coinciding with the horizontal axis of the cylindrical separator, in the direction of movement of the shell of the movable part of the shutter. Note that the direction of motion for the total fluid flow is the opposite.

We assign the value of the degree of valve $x(j_2)$ opening to distances x'_{j_2} along the axis Ox' by means of the recurrence formula

$$x(j_2) \equiv x'_{j_2} / l = \left[j_2 (L_0 + d_0) + L_0 \right] / l, \quad j_2 = \overline{1, m_2}, \quad (2)$$

where l is the length of the perforated part of the cylindrical separator; m_2 - number of rows of throttles; d_0 - their diameter; L_0 - distance between rows.

3. APPLICATION OF THE PRINCIPLE OF SUPERPOSITIONS LOSS OF PRESSURE

To calculate the pressure loss Δp during the operation of valves, the superposition principle [8-10] is traditionally applied according to the Weisbach formula [8-10]

$$\Delta p = \sum_{k=1}^{n} \Delta p_k = \frac{\rho_L}{2} \sum_{k=1}^{n} w_k^2 \zeta_k, \quad (3)$$

where Δp_k is the pressure loss in elementary local resistances; ρ_L is the density of the liquid; ζ_k - coefficient of local resistance in the area $k = \overline{1, n}$; - average fluid velocity in front of the local resistance at the k-site.

For example, [11] shows the application of the super-conception principle (3) for four consecutive sections of the outer shell of the axial valve (two rectilinear l_{s0}, l_{s1} with internal diameters D_{is1}, D_{is2} and two conical l_{h2}, l_{h3} parts in the approximation $l_{s0} \approx l_{s1}$) and in the throttling passages with laminar flow of fluid, as well as for three sections of the variable section with lengths l_{s1}, l_{h2}, l_{h3} with its turbulent motion.

For the present discussion, a simplified version of the calculation is also proposed, with the division of the coefficient of hydraulic resistance ζ_{12} in the transition region of the fluid flow according to expression

$$\zeta_{12} = \sum_{j=1}^{2} \zeta_j \qquad 4$$

on the linear ζ_1 and quadratic ζ_2 parts, depending on the zones of movement of the working medium.

Here ζ_1 and ζ_2 are the values of the hydraulic resistance coefficients for the regions: laminar (linear at $\mathrm{Re} \le 10$ [8-10]) and turbulent (quadratic at $\mathrm{Re} \ge 10^4$ [8-10]), when the Reynolds number for the conditional passage diameter D_{1y} (cm) with allowance for (1)

$$D_{1y} = \left(4\omega_{1y} / \pi\right)^{1/2}, \qquad 5$$

is proposed to be estimated using the reference formula [9]

$$\mathrm{Re}_y = 353 Q_{1\max} / (\nu_1 D_{1y}), \qquad 6$$

where $Q_{1\max}$ (m^3 / h) is the maximum achievable liquid flow through the regulating device; ν_1 - kinematic viscosity (cm^2 / s) for a given temperature of the medium t_1 (^{0}C).

In this case, the value ζ_1 is set by the laminar flow in the throttling cylindrical channels of a length $H = D_{es} - D_{is}$ equal to the thickness of the separator, with a diameter d_0 made by radial rows m_2 with a total number m_1 of holes in each.

Then, taking into account the recurrence formula (2) to correspond to the value of the valve opening degree $x(j_2)$ to the distances x'_{j_2} along the axis Ox', the dependence of the linear coefficient of hydraulic resistance $\zeta_1(x)$ on the parameter x takes the form [12]

$$\zeta_1(x) = 64 m_1 H D_y^{\,2} \left(\mathrm{Re}_y\, d_0^{\,3}\right)^{-1} \left[\left(lx - L_0\right) / \left(L_0 + d_0\right) - 1/2\right], \qquad 7$$

where D_y (m) is the diameter of the conditional pass similarly to (5); Re_y - the Reynolds number for a conditional passage with a diameter from (6); l - length of the perforated part of the cylindrical separator; d_0 - diameter of throttle channels; L_0 - the distance between rows of holes.

The value ζ_2 is determined by the turbulent motion when the liquid flow turns through an angle γ; when it flows in channels of variable cross-section, using the Borde formula [9, 12], wherein the area of the narrowed section ω_3 is equal to the area of the section of the throttle channel ω_{d_0}, and the cross-sectional area of the wide conditional channel ω_2 is calculated through the internal and external diameters D_{id}, D_{ed} of the outlet section of the separator, taking into account the annular and slit fluid flows.

The dependence of the quadratic coefficient of hydraulic resistance $\zeta_2(x)$ on the degree of valve opening according to the recurrence formula (2) has the form

$$\zeta_2(x)=\gamma m_1 D_y^4 / \left\{90^0[(D_{ies}-2\Delta)^2-D_{eis}{}^2]^2\right\}^{-1}+2D_y^{-4}[(D_{ies}-2\Delta)^2-$$

$$-D_{id}{}^2]^2\left\{2D_{ed}(L_0+d_0)\times\left[\pi m_1 d_0{}^2(lx-L_0)\varepsilon(x)\right]^{-1}\left(L_0+d_0+7lx/2\right)-1\right\}^2 . \quad 8$$

In the expression (8): m_1 is the number of throttles in one row; D_y - diameter of the conditional pass from (5); γ (grad) - the bevel angle for the cylindrical part of the shell; D_{ies} - the inner diameter of the cylindrical part of the outer shell of a thickness Δ. In addition, it is indicated: D_{id}, D_{ed} - respectively internal and external for the separator; D_{eis} - outer diameter of the inner valve body; l - the length of the perforated part of the cylindrical separator; d_0 - the diameter of throttle channels; L_0 - the distance between rows of holes.

Expression (8) contains the dependence $\varepsilon(x)$ for the compression coefficient of the jet, modeled by the Alshtul formula from [8-10],

$$\varepsilon(x)=0,57+0,043\left\{1,1-[n_{31}+n_{32}(x)]/2\right\}^{-1} \quad 9$$

when the compression ratio of the jet n is proposed to be calculated using the following expression, taking into account the ring and slit fluid flows, depending on the degree of valve opening x

$$n(x)\equiv[n_{31}+n_{32}(x)]/2 \quad 10$$

where

$$n_{31}\equiv m_1 S_{\varphi 1} H(1+D_{id}/D_{ed})\left\{90^0[(D_{ies}-2\Delta)^2-D_{id}{}^2]\right\}^{-1}, \quad 11$$

$$n_{32}(x)\equiv 2m_2(S_{\varphi 1}+d_0)\left(L_0+d_0+7Lx/2\right)/(\pi d_0{}^2), \quad 12$$

$S_{\varphi 1}$ – the arc distance between throttles in one row.

Thus, the dependence of the coefficient of hydraulic resistance in the transition region of the fluid flow from (4) on the parameter with allowance for (7), (8) has the representation

$$\zeta_{12}(x)=C_2+C_1\left[\left(lz-L_0\right)C_0^{-1}-1/2\right]+ +C_4\left\{C_0C_3(C_0+C_6x)/\left[2(Lx-l_0)\varepsilon(x)\right]-1\right\}^2, \quad 13$$

where the compression ratio of the jet at $U_0=0,57$; $U_1=0,043$; $U_2=1,1$ from (9) is equal to

$$\varepsilon(x)=U_0+U_1\left\{U_2-[C_7-C_5(C_0+C_6x)/2]/2\right\}^{-1}, \quad 14$$

and the following notation is used according to (7) - (12)

$$C_0\equiv L_0+d_0, \quad 15$$

$$C_1\equiv 64m_1HD_y{}^2/\left(\mathrm{Re}_y d_0{}^3\right), \quad 16$$

$$C_2\equiv m_1\gamma D_y^4/\left\{90^0[(D_{ies}-2\Delta)^2-D_{eis}{}^2]^2\right\}, \quad 17$$

$$C_3\equiv 4D_{id}/\left(\pi m_1 d_0{}^2\right), \quad 18$$

$$C_4 \equiv 2[(D_{ies} - 2\Delta)^2 - D_{ed}{}^2]^2 / D_y^4 , \quad (19)$$

$$C_5 \equiv 4m_2(S_{\varphi 1} + d_0) / \left(\pi d_0{}^2\right) , \quad (20)$$

$$C_6 \equiv 7l/2 , \quad (21)$$

$$C_7 \equiv n_{31} . \quad (22)$$

In addition, when the expression (13) is substituted into the following known formula [8, 9]

$$K_{vy} = \pi U_3 D_{1y}{}^2 [\zeta_{12}(x)]^{-1/2} . \quad (23)$$

It is possible to estimate the conditional throughput of the valve, depending on the degree of its opening. In the formula (23) is denoted: $U_3 = 5{,}04$; D_{1y} - the conditional passage diameter D_{1y} (cm) which is defined similarly to (5).

4. RESULTS AND DISCUSSIONS

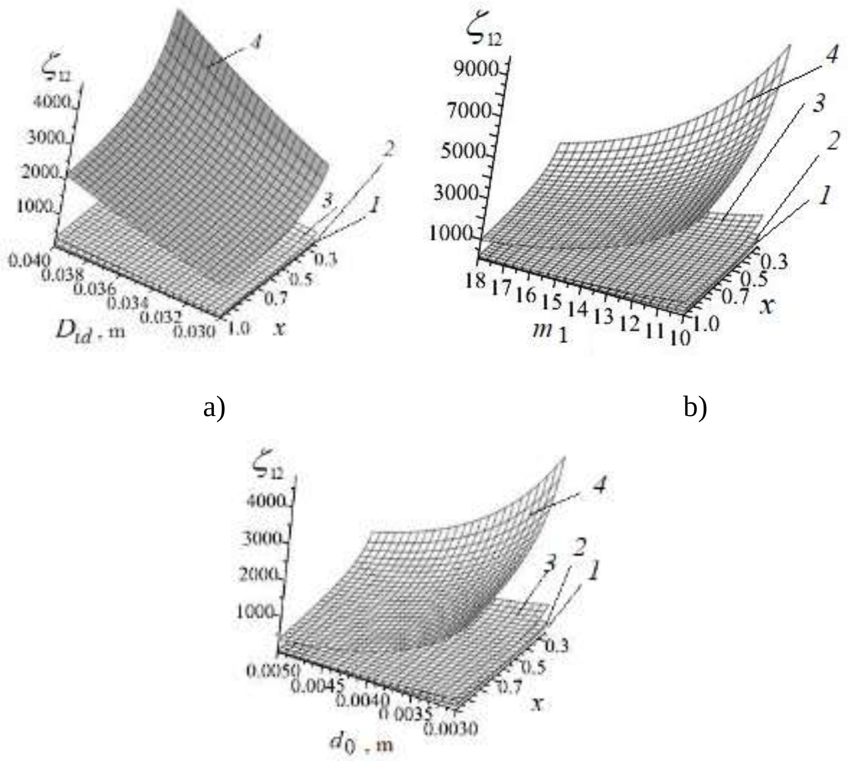
Let us consider an example of calculating the required dependence $\zeta_{12}(x)$ for an axial valve separator with an external locking body.

We set the basic design parameters of the axial valve for the calculation of the dependence $\zeta_{12}(x)$ of (13): D_{ies} =6,5·10^{-2} m - inner diameter of the cylindrical part of the outer shell; D_{eis} =5,3·10^{-2} m - outer diameter of the internal valve body; thickness of their walls Δ =0,28·10^{-2} m; length of rectilinear (l_{s1}=1,0·10^{-2} m) and conical (l_{h2}=0,6·10^{-2} m, l_{h3}=0,75·10^{-2} m) sections of the outer shell; diameter throttle holes d_0=3,5·10^{-3} m; number of rows of holes $m_2 = 5$; number of holes in one row $m_1 = 16$; internal diameter of the separator D_{id} =3,4·10^{-2} m; tickness of separator H =0,15·10^{-2} m; angle for the cylindrical part of the shell γ =45^0.

Valve parameters include the following parameters: maximum achievable liquid flow through $Q_{1\max}$ =0.5 m^3/h; minimum differential pressure $\Delta p_{\min}$ =1.5 kPa; medium temperature t_1 = 300 ° C.

The obtained expression (13) makes it possible to calculate the value of the hydraulic resistance coefficient for the transition region of fluid motion $\zeta_{12}(x)$ from various parameters of the process of regulating its flow in the separator of the axial valve with an external arrangement of the locking body: the internal diameter of the separator D_{id} (Fig. 1, a); the number of throttling holes in one row of the separator m_1 (Fig. 1, b); diameter of these holes d_0 (Fig. 1, c). The indicated surfaces *1-4* (Fig. 1, a-c), constructed for specific values of the conditional pass diameter D_y, show a smooth increase in values ζ_{12} with decreasing D_{id} as well as an increase d_0 and m_1.

The use of expressions (13) and (23) for estimating the conditional throughput of the valve, depending on the degree of its opening, is illustrated in Fig. 2 using the function $K_{vy}(x, D_y)$. Obviously, with an increase in both the parameter x and the diameter of the conditional cross-section D_y, an increase in the throughput of the axial valve is observed (Fig. 2).



a) b)

c)

Figure 1 Dependence of the coefficient of hydraulic resistance on various parameters of the process of regulating the flow of liquid in the separator of the axial valve with an external arrangement of the locking body

a) $\zeta_{12}(x, D_{id})$; d_0 =3,5·10^{-3} m; $m_1 = 16$; b) $\zeta_{12}(x, m_1)$; D_{id} =3,4·10^{-2} m; c) $\zeta_{12}(x, d_0)$;

D_{id} =3,4·10^{-2} m; 1 – D_{y1} = 1,40·10^{-2} m; 2 – D_{y2} == 2,21·10^{-2} m;

3 – D_{y3} == 2,80·10^{-2} m; 4 – D_{y4} == 3,31·10^{-2} m

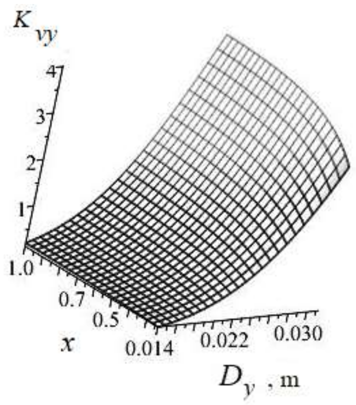


Figure 2 Dependence $K_{vy}(x, D_y)$ of the conditional throughput of the axial valve on the degree of its opening and the conditional passage diameter D_y

d_0 =3,5·10^{-3} m; $m_1 = 16$; D_{id} =3,4·10^{-2} m

5. CONCLUSION & SIGNIFICANCE

Thus, the expression (13) obtained for the coefficient of hydraulic resistance ζ_{12} in the transition region of the fluid flow makes with allowance for (14) - (22) it possible to construct a dependence for the energy of the stochastic motion of a single bubble on the selected phase variables, as well as the differential distribution function of the number of cavitation bubbles over a parameter x , using the approach [4, 5].

In addition, the proposed method of calculating the coefficient of hydraulic resistance ζ_{12} is used to evaluate one of the main characteristics of the process of regulating fluid flows in the valve - the conditional flow capacity of the valve K_{vy}, depending on the degree of its opening.

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