The definition of the integral characteristics of the process of formation of cavitation bubbles when operating the control valve

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Statement of problem: the efficiency of the control equipment for the transportation of fluid flows depends on the degree of protection of the valve from the undesirable effects of cavitation phenomenon. The study of the formation of cavitation bubbles at the initial stage of hydrodynamic cavitation in a flowing part of the control valve allows identify from a set of its constructive-regime parameters to identify the main factors influencing the evolution of bubbles.

Introduction: The formation of bubbles is proposed to be described by a random process Markov A. A., when the transition to the subsequent state of the macrosystem of the bubbles is determined by its instantaneous state. It is assumed that there is the energy isolation of macro bubbles of spherical shape according to the Gibbs ensemble.

The study. The use of the equation of Fokker-Planck with diffusion and drift terms relative allows to determine the number of bubbles

$$dN = A\exp[-E(u,q)/E_0]d\Omega \qquad (1)$$

in the element of phase volume $d\Omega = r_c v_L du dq$, $u = r/r_c$, $q = v/v_L$ and build a differential distribution function of bubbles in the specific radius of the element of phase volume $F(u) \equiv N^{-1}(dN/du)$ where are r_c и v_L - typical values for the radius of the bubble.

The purpose of this study is to determine the integral characteristics of the process of formation of cavitation bubbles when operating the control valve. . The modeling of the stochastic energy of a single bubble is based on the stages of its formation during the liquid flow in the flow path of control valve

$$E(u,q) = v_L^2 q^2 f_1(u) + f_2(u)\,. \qquad (2)$$

The expressions (2) contain: functions $f_1(u) \equiv (b_1 r_c^4 u^4 + b_2)/(r_c u)$ and $f_2(u) \equiv b_3 M^2/(r_c u)^5 + (b_4 + b_5 r_c u) r_c^2 u^2$; constants $b_0 = \alpha_g \rho_g + \alpha_s \rho_s$, $b_1 \equiv 2\pi b_0/3$, $b_2 \equiv \rho_L k_\zeta \zeta_{12}/4$, $b_3 \equiv 5\pi b_1/12$, $b_4 \equiv 4\pi\sigma$, $b_5 \equiv 8\pi P_s/3$; α_g, α_s - the volume fractions of gas and vapor in the cavity of the bubble; ρ_g, ρ_s, ρ_L - the densities of gas, vapor and liquid; M - the random component of the angular momentum for a single bubble; k_ζ - the coefficient of proportionality; $\zeta_{12} = \zeta_1 + \zeta_2$ -the coefficient of resistance of liquid for its transition region movement (the range of variation of the Reynolds criterion $10 < \mathrm{Re} < 10^4$), which by the principle of superposition of local losses is defined by two components ζ_1, ζ_2 for laminar ($\mathrm{Re} \le 10$) и and turbulent ($\mathrm{Re} \ge 10^4$) plots of the current; σ - the surface tension coefficient; P_s - the saturated steam pressure. Applying expression $F(u)$ the integral characteristics of the process of formation of cavitation bubbles (its average for the ensemble characteristics of the radius, volume and surface) in the flow path of the valve can calculate

$$\langle r\rangle = r_c\int_\Omega u dN,\ \langle V\rangle = (4r_c^3/3)\int_\Omega u^3 dN,\ \langle S\rangle = 4r_c^2\int_\Omega u^2 dN. \qquad (3)$$

Methods: On the basis of the stochastic approach the model of formation of cavitation bubbles proposed by the authors is used. The application of the formalism of process Ornstein-Ulenbek [Klimontovich Y.L.] with the description of stochastic energy of a spherical bubble depending on its radius and the velocity of the center of mass allows to use the differential distribution function of the cavitation bubbles according to their sizes for the estimation of the integral characteristics of the process.

Results: The graphs of the dependence $F(u)$

$$F(u) = \beta\left[E_0/f_1(u)\right]^{1/2}\exp\left[-f_2(u)/E_0\right]\mathrm{erf}\left\{v_L\left[f_1(u)/E_0\right]^{1/2}\right\} \qquad (4)$$

according to Fig. 1 allow us to estimate the most likely values for the conditional radius of the cavitation bubble u_p = (2-7) or for its size r_p =(0,2-0,7)·10^{-2} m at various values of the parameters K_{vy} and D_y within the specified limits. With increasing values D_y up to the maximum specified interval and with increased of parameter K_{vy} 1.28 times the radius value $\langle r\rangle$ is reduced to 1.08% (Fig. 2, a); volume $\langle V\rangle$ - 1.04% (Fig. 2, b).

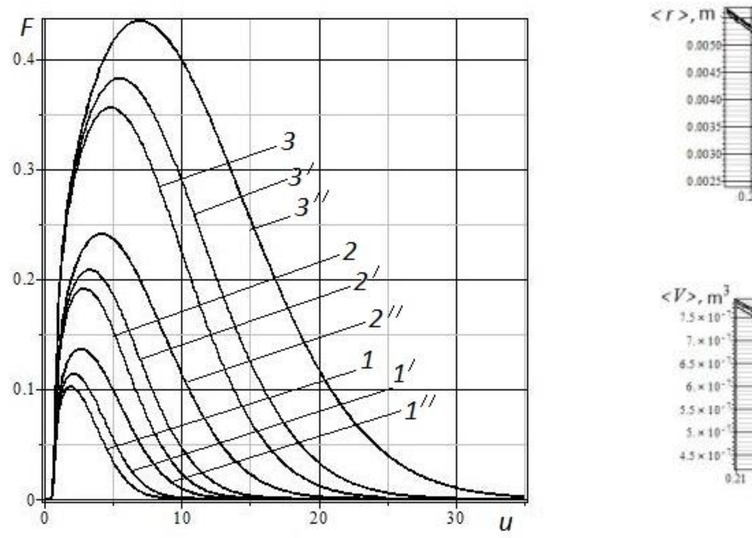
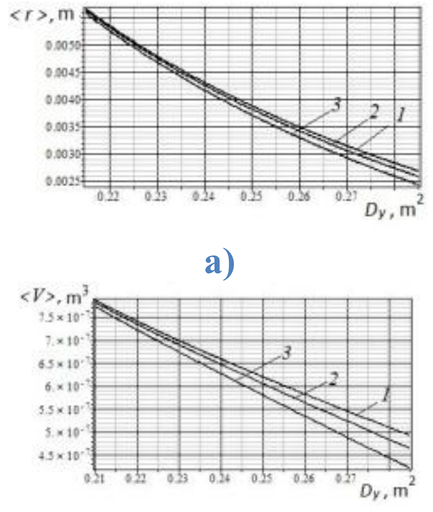


Fig. 1.



a)

b)

Fig. 2.

Fig. 1. The dependence $F(u)$ for the differential distribution function of the number of cavitation bubbles at a specific radius in the early stages of cavitation in a flowing part of the axial valve: $\alpha_g = \alpha_s = 0{,}5$; 1, 2, 3 – K_{vy} = 1,4·10^3 m^3/h; 1', 2', 3' – K_{vy} = 1,6·10^3 m^3/h; 1", 2", 3" – K_{vy} = 1,8·10^3 m^3/h; 1, 1', 1" – D_y = 0,28 m^2; 2, 2', 2" – D_y = 0,25 m^2; 3, 3', 3" – D_y = 0,22 m^2.

Fig. 2. The dependence of averages on the ensemble characteristics of the radius, volume of the bubble from the nominal diameter D_y of the axial valve: $\alpha_g = \alpha_s = 0{,}5$; a) $\langle r\rangle$; b) $\langle V\rangle$; 1 – K_{vy} = 1,4·10^3 m^3/h; 2 – K_{vy} = 1,6·10^3 m^3/h; 3 – K_{vy} = 1,8·10^3 m^3/h.

Conclusions: Modeling the initial stage hydrodynamic cavitation can be performed from the positions of the stationary and homogeneous Markov process. The results obtained here can be used in the formation of methods of engineering calculations of control valves.