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MODELING OF DISPERSE MIXTURE FLOW WITH THE FORMATION OF A BUBBLE ZONE BRINGING HYDROSYSTEM TO VIBRATION

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"Modeling of a disperse mixture flow with the formation of a bubble zone bringing hydraulic systems to vibration"

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Abstract: Dynamics of vibration, described by the equation of motion for amultiphase fluid in the form of the Kh.A. Rakhmatulin model,is considered in the paper. Analytical formulas for the steady-state flow of an incompressible fluid and the pressure distribution in the flow of dispersed mixtures are given.

Keywords: cavitation, vibration, end valves of the pipeline, cavitationformation, methods of multiphase fluid, dispersed mixtures, volume concentrations of the corresponding mixture phases, suction pumps.

In the study of the dynamics of vibration initiation in the water-supplysystems of reservoirs, the main reasonof vibrations is the violation of flow continuity and the formation of a zone filled with bubbles.

The process of vibration formation is described by an equation of motion for amultiphase fluid in the form of the Kh.A. Rakhmatulin model. It follows that at steady flow of gas or incompressible fluid, the pressure distribution in the flow substantially depends on the velocity distribution of the participating phases of dispersed mixtures. [4]

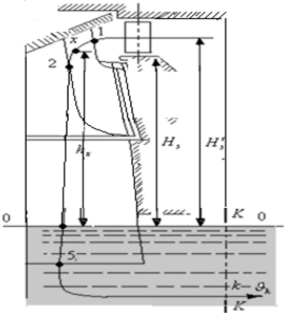

Figure 1. Disperse mixture flow with formation of bubble zone bringing the hydrosystem to vibrations

When solving practical problems of the flow of incompressible fluid of dispersed mixtures, in some points of dispersed flow, especially in the turbine blades of suction pumps, the pressure can be negative or equal to minus infinity if there are points in the flow at which the velocity value goes to infinity. Fluids found in nature and used in engineering contain suspended solids and dissolved gases. In most cases, such mixtures of fluids are unable to absorb tensile forces (negative pressures). In some cases, a flow in which tensile

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stresses arise in a moving fluidcan be observed; but usually the pressure p in the mixture flow cannot be lower than a certain positive value p_d close at temperature (-20°C).

In the flow of dispersed mixtures, when the pressure drops to values, a discontinuity of flow occurs and the zones filled with bubblesare formed, inside of which there are fluid or gas vapors released from the solution; this leads to cavitation. Such phenomena occur, for example, when the tortuous flow of the Tupalang reservoir turns. In the initial project of the Tupalang hydropower plant, the height of the dam of 185 m wasplanned, however, during operation at a head of 105 m, serious problems arose at the operation of water outlet structure; when the flow rate reached 25 m/s, due to unstable flow of water the seismograph at the end of the water outlet structure recorded seismic oscillations of 5.5 points.

Therefore, due to cavitation and vibration, the destruction of the elements of cone gate of water outlet structure - the main regulator of the structure - began. In this regard, it was decided to reduce the height of the dam of the Tupalang reservoir to 165 m. This became an obstacle for obtaining additional 350 MW of power and a reason for 1.5-2 billion m3water loss from the Tupalang river, required for the Surkhandarya region. The initial stage of cavitation, which caused great damage to water lines of the Tupalang reservoir, can be interpreted as the phenomenon of fluid mixture boiling at pressure decrease. Later, as the pressure decreases, small bubbles merge and large cavities- caverns -appear in mixture flow, filled with gases and vapors released from fluid [1].

The pressure p_d can be considered as a physical characteristic that does not affect the fluid flow at $p \succ p_d$. At $p = p_d$, a cavitation may occurin fluid, leading to vibration of the entire systemof hydrostructure; and this may exert a significant impact on the law of fluid flow. Cavitation and vibration can occur not only in the end valves of the pipeline, it can also occur, for example, near the least cross-section of the pipeline at compression, in apiston pump, when the pressure behind the rising piston tends to zero and when fluid flows past various bodies. The processes to study cavitation, leading to vibration are simulated using the multiphase fluid methods;the following parameters are introduced for the participating phases in dispersed mixture: $\vartheta_{см}$ - velocity of dispersed mixture; $\rho_{см}$- density of dispersed mixture:

$$\rho_{см} = \rho_1 + \rho_2 \ , \ \rho_1 = \rho_{1i} f_1 \ , \ \rho_2 = \rho_{21i} f_2 \ , \ \rho = \frac{\rho_{2i}}{\rho_{1i}} \quad (1)$$

Here$\rho_{ni}$is thereal density; ρ_1, ρ_2, $\rho_n$are the reduced densities; f_1, $f_2$are the volume concentrations of the corresponding phases of fluid mixture. According to the law of a multiphase dispersed mixture, a pattern can be found for the concentrations [2-4]

$$\sum_{i=1}^{n} f_i = 1 \qquad (2)$$

In particular cases, when studying the laws of a two-phase flow, we can write.

$$f_1+f_2=1 \qquad (3)$$

This flow corresponds to the flow of dispersed mixture in the suction pumps to raise the water to a specific height (Fig. 1) of the Tupalang reservoir. Investigatingtheaboveconditions,theequationoffluidmixture flowhasthefollowingform: [3]

$$\frac{\vartheta_{\text{см}x}^{\;2}}{2g}+\frac{p_x}{\gamma}+U+\frac{1}{2g}\sum_{S,n=1}^{m}\frac{\overset{\circ}{\rho}_{Si}\overset{\circ}{\rho}_{ni}f_S f_n}{\sum\limits_{n=1}^{m}(\overset{\circ}{\rho}_{ni}f_n)^2}(\vartheta_S-\vartheta_n)^2+h_x=$$

$$=\frac{\vartheta_2^{\;2}}{2g}+\frac{p_2}{\gamma}+U+\frac{1}{2g}\sum_{S,n=1}^{m}\frac{\overset{\circ}{\rho}_{S-2i}\overset{\circ}{\rho}_{n-2i}f_{S-2}f_{n-2}}{\sum\limits_{n=1}^{m}(\overset{\circ}{\rho}_{n-2i}f_{n-2})^2}(\vartheta_{S-2}-\vartheta_{n-2})^2+h_{wx-2} \quad (4)$$

where$h_{w,x-2}$isthe energy loss of the mixture between the points $x$and 2. Solving equation (1) under certain conditions, velocity of dispersed mixture has the following form:

$$\vartheta=\vartheta_{\text{см}}=\frac{\vartheta_1+\dfrac{f_2}{f_1}\rho\,\vartheta_2}{1+\rho\,\dfrac{f_2}{f_1}}. \quad (5)$$

From the equation of motion of a multiphase fluid(4), the interaction coefficient is:

$$k=\frac{1}{2g}\sum_{S,n=1}^{m}\frac{\overset{\circ}{\rho}_{S-2i}\overset{\circ}{\rho}_{n-2i}f_{S-2}f_{n-2}}{\sum\limits_{n=1}^{m}(\overset{\circ}{\rho}_{n-2i}f_{n-2})^2}(\vartheta_{S-2}-\vartheta_{n-2})^2 \quad (6)$$

where k is the interaction coefficient. According to studies in [1], the potential of the velocity for a dispersed mixture of fluids is:

$$\varphi_{\text{см}}=\varphi_1 f_1^*+\varphi_2 f_2^*,$$

where

$$f_1^*=\frac{f_1}{f_2+\rho f_1},\; f_2^*=\frac{f_2}{f_2+\rho f_1},\; \rho=\frac{\rho_{1i}}{\rho_{2i}}.$$

After replacing the variables, according to the Bernoulli equation, for the mixture flow between the points 2 and 5, we get the expression:

$$\frac{p_2}{\gamma}+\frac{\vartheta_{\text{см}2}^{\;2}}{2g}+z_2+\frac{1}{2g}\sum_{S,n=1}^{m}\frac{\overset{\circ}{\rho}_{S-2i}\overset{\circ}{\rho}_{n-2i}f_{S-2}f_{n-2}}{\sum\limits_{n=1}^{m}(\overset{\circ}{\rho}_{n-2i}f_{n-2})^2}(\vartheta_{S-2}-\vartheta_{n-2})^2=$$

$$=\frac{p_5}{\gamma}+\frac{\vartheta_{\text{см}5}^{\;2}}{2g}-z_5+\frac{1}{2g}\sum_{S,n=1}^{m}\frac{\overset{\circ}{\rho}_{2-5i}\overset{\circ}{\rho}_{n-2i}f_{2-5}f_{n-5}}{\sum\limits_{n=1}^{m}(\overset{\circ}{\rho}_{n-5i}f_{n-5})^2}(\vartheta_{2-5}-\vartheta_{5-2})^2+h_{w2-5} \quad (7)$$

Solving equations (3) and (4) and taking into account $\frac{p_5}{\gamma} - z_5 = \frac{p_{am}}{\gamma} = B$ - barometric pressure in the form of insignificance of the values of the phase interaction coefficients at the points 2 and 5 at the turbine level, we get

$$\frac{1}{2g}\sum_{S,n=1}^{m}\frac{\overset{\circ}{\rho}_{S-2i}\overset{\circ}{\rho}_{n-2i}f_{S-2}f_{n-2}}{\sum\limits_{n=1}^{m}(\overset{\circ}{\rho}_{n-2i}f_{n-2})^2}(\vartheta_{S-2}-\vartheta_{n-2})^2-\frac{1}{2g}\sum_{S,n=1}^{m}\frac{\rho_{(2-5)i}\rho_{n-5i}f_{s-5}f_{n-5}}{\sum\limits_{n=1}^{m}(\rho_{n-5i}f_{n-5})^2}(\vartheta_{2-5}-\vartheta_{5-2})^2 \rightarrow 0, \quad (8)$$

that is, the calculation formula to determine the interaction coefficient in the Poiseuille flow of dispersed mixture is determined by formula (3):

The violation of continuity in dispersed flows and the formation of a zone filled with bubbles, is written in the form:

$$\frac{1}{2g}\sum_{S,n=1}^{m}\frac{\overset{\circ}{\rho}_{S-2i}\overset{\circ}{\rho}_{n-2i}f_{S-2}f_{n-2}}{\sum\limits_{n=1}^{m}(\overset{\circ}{\rho}_{n-2i}f_{n-2})^2} \quad (9)$$

The formation of cavitation in dispersed mixtures occurs at pressure drop to a value below the vapor pressure andat flow discontinuity: hereappears a zone filled with bubbles. Inside the bubbles there is a vapor of fluid or gas released from the solution. The initial stage of cavitation can be described as the phenomenon of fluid boiling at decreasing pressure. With further decrease in pressure, small bubbles merge, this can be written in the form of formula (9) and large cavities-caverns- appear in the flow, which cause the entire hydrosystem to vibrate.

Usually, the areas of cavitation and vibration appear on the back of the exit edges of the impeller blades on the back side, and on the rim of the axial-radial wheels and the impeller chamber of axial turbines in the area close to the exit edges. At intensive formation, the cavitation covers the entire area of the impeller and in a very short time destroys it and theparts surrounding it.

Besides the destruction of parts in the cavitation zone, it decreases the performance index, efficiency, wheel capacity and turbine power. The phenomenon of cavitation is accompanied by a characteristic crash, noise and sharp impacts. In large turbines, cavitation impacts sometimes cause shaking of the basement and the building of the plant.

Conclusions:

1. The equation is given for the steady flow of an incompressible fluid and the pressure distribution in the flow, which substantially depends on the velocity distribution of the participating phases of dispersed mixtures.
2. An analytical expression is given that defines the initial stage of cavitation, as the phenomenon of fluid boiling at pressure decrease in pipelines filled with dispersed mixture depending on the initial stage of suction.

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