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INVESTIGATION OF ACOUSTIC FIELDS OF HYDRODYNAMIC RADIATORS WITH ACCOUNTING ATTENUATION OF SOUNDS WAVES

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The ultrasonic technics is widely applied to clearing of details and fluids. However, specific conditions of technological process of clearing of wool limit ultrasound application. Complexity of removal of pollution and high requirements to quality of wool fibers after technological operations leads to that washing is one most labor-consuming operation [1].

The present work deals with the process of vibrations of hydrodynamic radiators taking into account attenuation of sound waves. Sound attenuation is decrease of amplitude and sound-wave intensity in process of its extending. An attenuation principal cause is decrease of wave amplitude depending on distance from a source, caused by the shape and the wave sizes of a source that is a wave divergence.

The radiator consists of a conic-cylindrical nozzle, a reflector and resonant oscillatory system in the form of the rods located along the forming cylinder. The converter cylinder has 16 rods in width of 6 mm through 22.5 degrees. The ends of rods are rigidly fixed. The length of the cylinder is equal 126 mm, and its diameter of 37 mm. The stream from a nozzle energizes a bending vibration in the rod. The outflow speed of fluid is $v = 30$ km/s, the pressure is 0.61 MPa. Radiators are established in the cylindrical tank filled with a liquid with surface-active substances. Its density is equal 1010 kg/m^3, sound speed is $a = 1500$ km/s, kinematical viscosity $\mu = 2 \cdot 10^{-6}$ m^2/s. Intensity of one radiator is $J = 2$ W/sm^2. For effective operation of a radiator it is necessary to select such geometrical and mechanical parameters that its frequency was close to frequency of the first tone of the radiator rod.

Let's construct mathematical model of studied process. The equation of transverse vibrations of the rod under the impulse force P_0 suddenly affixed in point z_0 is of the form

$$\frac{\partial^4 w}{\partial z^4} + \frac{1}{a^2}\frac{\partial^2 w}{\partial t^2} = P_0 \delta(z - z_0), \qquad (1)$$

where $\delta(z - z_0)$ is Dirac delta-function in the point z_0;

$$a=\sqrt{EI/\rho F}, \quad I=bh^3/12, \quad F=bh,$$

E is Young's modulus for the material of the rod, ρ is density for the material of the rod, b and h is width and height of cross-section of the rod.

The solution of the equation (1) has the form

$$w=\frac{P_0 l^3}{EI}\sum_{i=1}^{\infty}\frac{X_i X_{i0}}{(k_i l)^4}\cos p_i t,$$

where l is length of the radiator rod; $p_i=k_i^2 a$ are fundamental circular frequencies of vibrations; X_i are normal functions of the problem,

$$X_i=\operatorname{ch}k_i z-\cos k_i z-\frac{\operatorname{ch}k_i l-\cos k_i l}{\operatorname{sh}k_i l-\sin k_i l}(\operatorname{sh}k_i z-\sin k_i z);$$

X_{i0} is value of normal function in the point $z=z_0$. We accept that $z_0=l/2$.

Fundamental frequencies of radiator vibrations f_i are defined as

$$f_i=(0{,}5+i)^2\pi^2 a/(2\pi l^2).$$

The frequency of the first tone calculated under this formula is equal 1750 Hz. In technical calculations fundamental frequency of radiator rods is defined by the formula

$$f=(\alpha t/l^2)\sqrt{E/\rho},$$

where $\alpha=1.03$. It is 1767 Hz. Thus, for effective operation of radiators it is necessary to select such parameters that radiator frequency was close to frequency of the first tone.

The general equations of dynamics of a fluid and gas turn out from three main principles: conservation relations of masses; the law on equality between an impulse of forces and a corresponding increment of quantity of movement; the law of conservation of energy.

Theoretical and experimental researches show [2] that radiators at their immersing in a fluid on depth from 0.2 to 0.3 m can be observed as spherical sources of the zero order, and the estimation of efficiency of their operation in the closed areas can be made on magnitude of a sound pressure. In this case expressions for sound pressure p and speeds of movement of environment v

$$p=\frac{Q_0}{4\pi}\frac{\omega^2\rho}{a}\frac{e^{ikr}}{ikr}, \quad v=v_r=\frac{Q_0}{4\pi}\frac{\omega^2\rho}{a^2}\frac{e^{ikr}}{ikr}, \tag{2}$$

where Q_0 is productivity of a sound source, a is a sound speed; $k=\omega/a$, ω is circular frequency of vibrations; $r=\sqrt{\rho^2-2\rho\rho_0\cos(\varphi-\varphi_0)+\rho_0^2+(z-z_0)^2}$, ρ, φ, z are cylindrical coordinates.

Intensity of a sound field of a dot source is calculated by the formula

$$I=\frac{\omega^2\rho}{32\pi^2 a}\frac{Q_0^2}{r^2}.$$

Characteristics of a sound field were defined from Euler's nonlinear equations in the form of Navier-Stokes jointly with the equation of a condition

$$\mu\nabla^2\mathbf{V} + \frac{\mu}{3}\text{graddiv }\mathbf{V} = \bar{\rho}\frac{d\mathbf{V}}{dt} + \text{grad } p, \quad (3)$$

$$\frac{\partial\bar{\rho}}{\partial t} + (\mathbf{V}, \text{grad }\bar{\rho}) + \bar{\rho}\,\text{div }\mathbf{V} = 0, \quad (4)$$

$$f(\bar{\rho}, p, \mathbf{V}) = 0, \quad (5)$$

where $\bar{\rho}$ is density of the liquid environment.

The solution of system of the nonlinear differential equations was carried out by an iteration method.

As the first iteration it was supposed, that the radiator is replaced with equivalent system of the dot sources (2). The solution of the homogeneous equations (3), (4) is the generalized potential of a simple layer. On the found values of speeds from the equations (4) the density and pressure of a fluid is defined. The following stage consists in calculation of the right part of the equations (3), construction of the common solution of system (3)–(5) and refinement of values of density and pressure of a fluid. Process is completed at reaching of demanded exactitude of the solution. The system (3)–(5) also considers attenuation of vibrations of the sound field connected with viscosity of environment.

The account of a sound attenuation with absorption factor is computed by the formula

$$\alpha = \frac{\omega^2}{2\rho a^3}\left(\frac{4}{3}\eta + \varsigma\right),$$

where η and ς are factors of shift and volume viscosity, accordingly.

Analysis of numerical solution of ultrasonic field parameters at $\varsigma/\eta = 2.81$ shows that results changes insignificantly.

Thus, the technique of theoretical research of hydrodynamic radiating system operation is offered. It is established that for the given structural system parameters the consideration of attenuation of acoustic waves does not lead to appreciable change of results. In the future, a problem can have solved in optimal arrangement of hydrodynamic radiators [3, 4] with specified parameters.

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