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DAMPING OF LIQUID OSCILLATIONS IN A RIGHT CIRCULAR CYLINDER WITH RADIAL RIBS

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Abstrakt. *The problem of damping of liquid oscillations in a right circular cylinder with radial ribs is considered. Software that allows obtaining characteristics of processes in a circular tank was developed. Reducing load on the tanks with extinguisher liquid by introducing the dampers ensures the dynamic stability of firefighting aircraft.*

Keywords: damping, tank, ribs, fluid oscillations.

Introduction. Study of damping of liquid oscillations in tanks of firefighting aircrafts is one of the most important problems of the dynamics of elastic structures with tank partially filled with water. Along with determining of frequencies spectrum of natural oscillations of structure and liquid in tanks, the study of damping and, in particular, oscillation decrements, is quite necessary for a proper choice of the parameters of control systems, because in the case of convergence of natural frequencies of the structure or fluid with a frequency bandwidth of control system, violation of the normal operation of the latter and the loss of stability and controllability of the aircraft is possible.

However, if the frequency response of an elastic structure with tanks do not meet the requirements, then it is common to try by artificial means to change them in the desired direction by using damping baffles of different shapes and sizes into the tank. Effective means of limiting the mobility of the fluid are dampers in the form of ring and radial walls. With a specific choice of parameters of elastic baffles, there can be a significant gain in the magnitude of damping developed by them, as well as in the weight ratio.

Two simplest laws of dissipative forces are of the greatest interest:

– dissipative forces proportional to the velocity – viscous damping;

– dissipative forces that bear the harmonic character – hysteretic damping – proportional to displacement.

In the practice, along with the viscous (linear) damping of fluid, the non-linear damping is often encountered, due to the presence in the cavity of various structural elements – stringers, frames, partitions, screens, etc. These items have a strong resistance to the movement of fluid, which leads to intense dissipation of energy of oscillations. Nonlinear damping is usually much greater than the linear one and, therefore, is of particular interest.

Let us consider the main features of the nonlinear damping on the example of the damping fluid in a right circular cylinder with radial ribs arranged on the walls.

Formulation of the problem. In engineering practice, special devices are used to restrict the mobility of liquid in the cavities: vibration dampers. They are especially widespread in rocketry, where they are used as one of the effective means to address the dynamic instability of missiles in the active part of the trajectory.

The principle of operation of most liquid vibration dampers is based on the ability of different elements, such as ribs, perforated diaphragm, grids, etc., to have a significant resistance to the movement of fluid, which leads to a strong damping of the oscillations. This damping, as shown in the previous section on the example of the radial and annular ribs, greatly exceeds the viscous damping in magnitude and essentially depends on the amplitude of the oscillations.

Let us consider the nonlinear fluid vibration damping with radial ribs, located on the cylinder walls at the same distance from each other, for the fundamental tone of oscillations and the case of deep fluid (h>1,5r_0) fig. 1. Sought-for logarithmic decrement depends on three dimensionless parameters of the system [1]

$$\delta_1 = f_1\left(k, \frac{b}{r_0}, \frac{s_{01}}{r_0}\right),$$

where k – the number of edges; b – width of the rib.

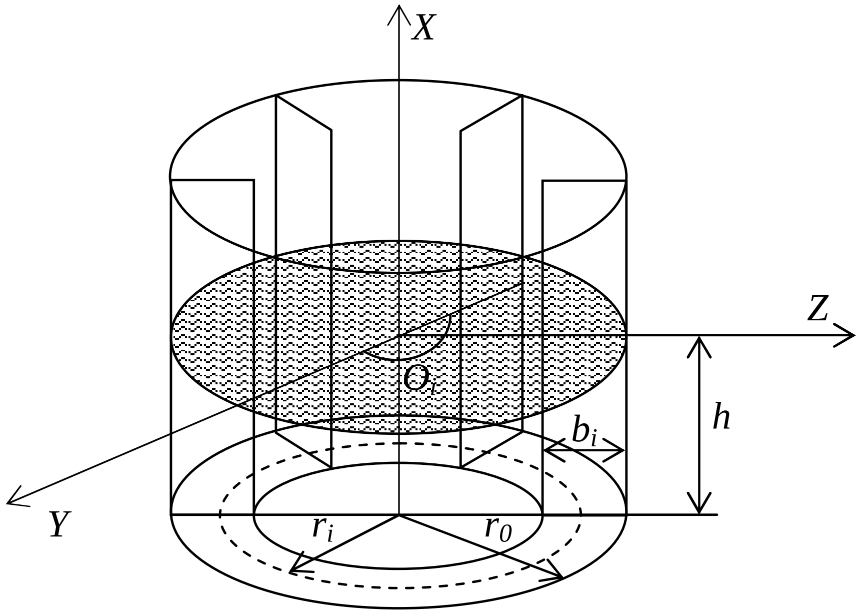

Fig. 1. General view of a cylindrical tank with radial ribs

Following [1] we can write a formula which relates the logarithmic decrement of dissipation energy for the period ΔE and the maximum potential energy of the system E. First, we establish approximate view of analytical dependence for one rib. Assuming that the width of a rib is small compared with the radius of the cylinder, and the natural frequency and the shape of oscillations of free fluid surface differ little from the natural frequency and the shape of the oscillations of the ideal fluid in the cylinder without ribs, we determine ΔE and E by solving the problem of the vibrations of a perfect fluid in the cylinder without rubs.

Maximum potential energy for the fundamental tone of oscillations can be calculated by the formula [1]:

$$E = \frac{1}{2}\rho j s_{0n}^2 \int_\Sigma \psi_n^2 dS \qquad (1)$$

The shape of the free surface for the fundamental tone of fluid oscillations is given by [2]:

$$\psi_1 = \frac{J_1\left(\xi_1 \dfrac{r}{R}\right)}{J_1(\xi_1)} \sin\theta. \qquad (2)$$

We calculate dissipation energy ΔE as the work of resistance forces, which are caused to the movement of the liquid in the tangential direction by the rib:

$$\Delta E = \int_0^{\frac{2\pi}{\omega_n}} \int_S \frac{1}{2} c_b \rho \upsilon_n^2 |\upsilon_n| dS dt,$$

where c_b – the coefficient of resistance of a rib.

Speed ϑ_n can be approximated by the tangential component of the velocity for ideal fluid on the cylinder side in the location of the rib, and a drag coefficient c_x – by experimental dependence

$$c_b = 19{,}1\left(\frac{2\pi\vartheta_{01}}{b\omega_1}\right)^{-\frac{1}{2}}\left(1+0{,}4e^{\frac{0{,}238(x-h)}{b}}\right),$$

obtained for the plate in the range of values of the radicand $2 \le \frac{2\pi\vartheta_{01}}{b\omega_1} \le 20$. Here ϑ_{01} – the amplitude of the vibration velocity. It is significant that the resistance coefficient is a function of a dimensionless parameter, which is equivalent to Strouhal number, and is not independent of the Reynolds number. For moderate vibration amplitudes $s_{01} < 0{,}1r_0$ and ribs with width $b > 0{,}015r_0$, the values of the dimensionless parameter do not exceed the upper limit of the given range. This range is applied to all practically relevant cases.

For values $\frac{2\pi\vartheta_{01}}{b\omega_1} \ge 100$, the other relationship is recommended: $c_x = 2$, that is, a constant coefficient of resistance. Assuming coefficient of resistance to be constant for our range of interest, as shown by comparison with experiment, gives much worse results.

Calculating dissipation energy for a period and using the expression (1), we find the desired logarithmic decrement for one rib:

$$\delta = \Delta\left|\sin\theta_i\right|^{\frac{5}{2}}\left(\frac{b}{r}\right)^{\frac{3}{2}}\left(\frac{s_{01}}{r}\right)^{\frac{1}{2}},$$

where Δ – constant factor; θ_i – angle between the surface of oscillations and the rib. Thus, the decrement depends considerably on the geometry parameters and, what is the very important, on the amplitude of the fluctuations in the power 1/2.

In the case of k edges, located not very often, the required dependence of the logarithmic decrement can be written as follows:

$$\delta = \Delta\sum_{i=1}^{k}\left|\sin\theta_i\right|^{\frac{5}{2}}\left(\frac{b}{r_0}\right)^{\frac{3}{2}}\left(\frac{s_{01}}{r_0}\right)^{\frac{1}{2}}.$$

Based on the obtained dependence, a computer program was developed in VC ++ [3], which interface is shown in fig. 2.

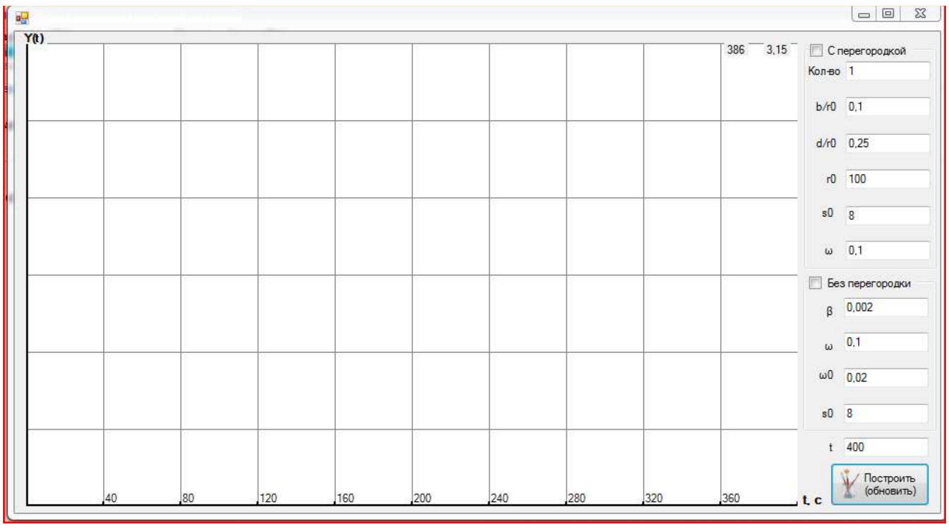

Fig. 2. Software interface

Conclusions. The results fit well with results obtained in [1]. The software can be used for the design of tanks of firefighting aircrafts, and by pilots when transporting liquids.

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Загасання коливань у рідині прямого кругового циліндра з радіальними ребрами

Розглянуто проблему загасання коливань в рідині прямого кругового циліндра з радіальними ребрами. Розроблено програмне забезпечення, яке дозволяє отримати характеристики процесів у круговому баці. Зниження навантаження на баки з вогнегасною рідиною шляхом введення демпфіруючих перегородок забезпечує динамічну стійкість протипожежних літаків.

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Затухание колебаний в жидкости прямого кругового цилиндра с радиальными ребрами

Рассмотрена проблема затухания колебаний в жидкости прямого кругового цилиндра с радиальными ребрами. Разработано программное обеспечение, которое позволяет получить характеристики процессов в круговом баке. Снижение нагрузки на баки с огнетушительной жидкостью путем введения демпфирующих перегородок обеспечивает динамическую устойчивость противопожарных самолетов.