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PARAMETRIC OSCILLATIONS OF A LATERALLY STRENGTHENED, ORTHOTROPIC, DAMAGED, VISCOUS FLUID-FILLED SHELL

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Abstract- Reliable analysis of a medium-contacting cylindrical shell for a durable strength assumes account of the formed and accumulated defects and damages and influence of external media and forces. The destruction of contact ructions happens when damages achieve dangerous level. Namely in this connection the study of interaction of these processes, i.e. study of influence of fluid on stability parameter and oscillations of thin shelled laterally strengthened structural elements, especially on the frequency of parametric oscillations.

Keywords: Parametric Oscillations, Orthotropic Property, Healing Function, Damageability, Viscosity.

I. INTRODUCTION

It is known that external medium may have a great effect on the strength of materials present in it. So, for example, strength test of metallic viscous-fluid contacting structural elements, testifies that fluid has a significant influence on dynamical strength characteristics of metals. The said one relates especially to thin shelled structural elements that are disposed in the greatest degree to such form of the loss of load carrying capacity as loss of stability. Namely in this connection the study of interaction of these processes, i.e. study of influence of fluid on stability parameter and oscillations of thin shelled laterally strengthened structural elements, especially on the frequency of parametric oscillations.

The papers [1-3] were devoted to detection of some aspects of interaction of damageability of a medium on the process of oscillations of smooth thin shelled constructions. Stability and oscillations of thin shelled strengthened structural elements taking into account the phenomenon of damageability of the material of the construction were studied in the papers [4-7]. The papers [8-11] devoted to definition of stress-strain state of ribbed shells contacting with solid and fluid media should be also noted. In the papers [8, 9], by means of the asymptotic method, frequency equations of ribbed fluid-filled cylindrical shells were constructed; approximate frequencies of the equation and prime calculation formulas allowing to find the values of minimal eigen values of oscillations of the system under consideration were obtained; forced oscillations of a strengthened, fluid-filled shell were studied and amplitude-frequency characteristics of the considered oscillatory processes were determined.

II. PROBLEM STATEMENT

In the present paper, by means of the variation principle, we solve a problem of parametric oscillation of a laterally strengthened, damaged, viscous fluid-filled cylindrical shell under action of the external pressure $q = q_0 + q_1 \sin \omega t$ (where q_0 is the mean or basic load, q_1 is the amplitude of change of the load, ω_* is the frequency of its change). Based on the Ostrogradsky-Hamilton variation principle, we construct systems of differential equations with respect to the amplitude of displacements of a laterally strengthened, damaged viscous fluid-filled orthotropic cylindrical shell and realize them numerically. The surface loads acting on a laterally strengthened shell as viewed from fluid, are determined from the solutions of Navier-Stock's linearized equation.

One of the experimentally confirmed theories of damageability is the hereditary theory of damageability developed for compound stress state in [12]. According to this theory the determining equations for a homogeneous body ($\bar{x}$ is the vector-coordinate of the body's point) are written in the form:

$$\bar{\varepsilon}_{ij} = \varepsilon_{ij} + M^* \cdot \sigma_{ij}$$

where, E is the Young modulus, M^* are hereditary type integral operators describing damageability processes and for which it hold the representation:

$$M^* \cdot \sigma_{ij} = \sum_{k=0}^{n} f(t_k^+) \int_{t_k^-}^{t_k^+} M\left(\bar{x}, t_k^+ - \tau\right) \sigma_{ij}(\tau)\, d\tau + \int_{t_{n+t}^-}^{t} M\left(\bar{x}, t - \tau\right) \sigma_{ij}(\tau) d\tau \tag{1}$$

where, $M(\bar{x}, t-\tau)$ is a damageability kernel; $\left(t_k^-; t_k^+\right)$ are the intervals of active stress periods contributing to rate of damageability; $f(t_k^+)$ is a defects healing function dependent on damageability volume accumulated for the given cycle. For example, the value $f(t_k^+)=0$ corresponds to total healing of defects accumulated for the given cycle, the values $f(t_k^+)=1$ to the absence of the defects healing effect. All intermediate values from zero to unit correspond to the effect of partial healing of defects. For determining the intervals $\left(t_k^-;t_k^+\right)$ it is necessary to give special conditions. It is convenient to formulate them for a concrete problem taking into account specifics of a construction, its operation conditions and the kinds of loadings. In this paper we behave in this way and the similar conditions will be formulated below.

Let us consider a laterally strengthened, annular cross section, viscous fluid-filled cylindrical shell of radius R, of thickness $2h$, of length ℓ. It is assumed that the ends of the shell are hingely supported, i.e. for $x=0;\ell$ it holds:

$$N_{xx}=0;\ M_{xx}=0$$
$$w=0;\ \vartheta=0$$

where, N_{xx} is axial force, M_{xx} is a bending moment, w,ϑ are the of the displacement vector components of the point of shell-flexure and radial displacement, respectively.

Strain state of the shell may be determined by three components of displacements of its median surface u,ϑ and w. Therewith, the turning angles of the normal elements φ_1,φ_2 with respect to coordinate lines y and x are expressed by w and ϑ by means of the dependences $\varphi_1=-\frac{\partial w}{\partial x}$, $\varphi_2=-\left(\frac{\partial w}{\partial x}+\frac{\vartheta}{R}\right)$.

For describing the strain state of ribs, in addition to three components of displacements of gravity centers of their cross sections (u_j, ϑ_j, w_j of the *j*th lateral bar) it is necessary to define the twisting angles φ_{kpj} as well.

Taking into account that according to the accepted hypothesis it holds constancy of radial flexures along the height of cross sections, and also equality of appropriate twisting angles following from the conditions of rigid connection of ribs and shell, we write the following relations:

$$\begin{aligned}
&u_j\left(y\right)=u\left(x_j,y\right)+h_j\phi_1\left(x_j,y\right)\\
&\vartheta_j\left(x\right)=\vartheta\left(x_j,y\right)+h_j\phi_2\left(x_j,y\right)\\
&w_j\left(x\right)=w\left(x_j,y\right) \qquad (2)\\
&\varphi_j=\varphi_2\left(x_j,y\right)\\
&\varphi_{kpj}\left(x\right)=\varphi_1\left(x_j,y\right)
\end{aligned}$$

where, $h_j=0.5h+H_j^1$, h is the shell's thickness, H_j^1 is the distance from the axes of the *j*th lateral bar to the shell surface, φ_j, φ_{kpj} are the turning and twisting angles of cross sections of annular ribs.

III. METHOD OF SOLUTION

For solving the stated problem, Ostrogratsky-Hamilton's variation principle is used. According to this principle, true trajectories differ from other possible trajectories by the fact that for first ones the following condition should be fulfilled:

$$\delta\int_{t_0}^{t_1}\left(K-\Pi\right)dt=0 \qquad (3)$$

where, under K we understand kinetic energy of the system, under Π the potential energy and $\delta'W$ the sum of elementary works of external forces, $\left[t_0,t_1\right]$ is the time interval at which the motion process occurs.

It is accepted that the stress strain state of the cylindrical shell may be completely determined within linear theory of thin shells based on Kirchhoff-Lia hypotheses, and for calculating the ribs, theory of Kirchhoff-Klebsch curvilinear bars is applicable. The system of coordinates is chosen so that the coordinate lines coincide with principal lines of curvature of the shell median surface. The total energy of elastic deformation of an orthotropic, laterally strengthened, damaged cylindrical shell is in the form:

$$\begin{aligned}
J=\frac{1}{2}R^2\int_{x_1}^{x_2}\int_{y_1}^{y_2}\{&N_{11}\varepsilon_{11}+N_{22}\varepsilon_{22}+N_{12}\varepsilon_{12}-\\
&-M_{11}\chi_{11}-M_{22}\chi_{22}-M_{12}\chi_{12}+\\
&+N_{11}\left(\sum_{k=0}^{n}f(t_k^+)\int_{t_k^-}^{t_k^+}M\left(\bar{x},t_k^+-\tau\right)\cdot N_{11}d\tau+\right.\\
&\left.+f\int_{t_{n+1}^-}^{t}M\left(\bar{x},t-\tau\right)\cdot N_{11}d\tau\right)+\\
&+N_{22}\left(\sum_{k=0}^{n}f(t_k^+)\int_{t_k^-}^{t_k^+}M\left(\bar{x},t_k^+-\tau\right)\cdot N_{22}d\tau+\right.\\
&\left.+\int_{t_{n+1}^-}^{t}M\left(\bar{x},t-\tau\right)\cdot N_{22}d\tau\right)+\\
&+N_{12}\left(\sum_{k=0}^{n}f(t_k^+)\int_{t_k^-}^{t_k^+}M\left(\bar{x},t_k^+-\tau\right)\cdot N_{12}d\tau+\right.\\
&\left.+\int_{t_{n+1}^-}^{t}M\left(\bar{x},t-\tau\right)\cdot N_{12}d\tau\right)-\\
&-M_{11}\left(\sum_{k=0}^{n}f(t_k^+)\int_{t_k^-}^{t_k^+}M\left(\bar{x},t_k^+-\tau\right)\cdot M_{11}d\tau+\right.\\
&\left.+\int_{t_{n+1}^-}^{t}M\left(\bar{x},t-\tau\right)\cdot M_{11}d\tau\right)-\\
&-M_{22}\left(\sum_{k=0}^{n}f(t_k^+)\int_{t_k^-}^{t_k^+}M\left(\bar{x},t_k^+-\tau\right)\cdot M_{22}d\tau+\right.\\
&\left.+\int_{t_{n+1}^-}^{t}M\left(\bar{x},t-\tau\right)\cdot M_{22}d\tau\right)-
\end{aligned}$$

$$-M_{12}\left(\sum_{k=0}^{n} f(t_k^+)\int_{t_k^-}^{t_k^+} M\left(\bar{x},t_k^+-\tau\right)\cdot M_{12}d\tau + \right. \quad (4)$$

$$\left.\left. + \int_{t_{n+1}^-}^{t} M\left(\bar{x},t-\tau\right)\cdot M_{12}d\tau\right)\right\}dxdy +$$

$$+\frac{1}{2}\sum_{j=1}^{k_2}\int_{y_1}^{y_2}\left[\tilde{E}_j F_j\left(\frac{\partial \vartheta_j}{\partial y}-\frac{w_j}{R}\right)^2+\tilde{E}_j J_{xj}\left(\frac{\partial^2 w_j}{\partial x^2}+\frac{w_j}{R^2}\right)^2+\right.$$

$$\left.+\tilde{E}_j J_{zj}\left(\frac{\partial^2 u_i}{\partial y^2}-\frac{\varphi_{kpj}}{R}\right)^2+\tilde{G}_j J_{kpj}\left(\frac{\partial \varphi_{kpi}}{\partial y}+\frac{1}{R}\frac{\partial u_j}{\partial y}\right)^2\right]dy+$$

$$+\rho h\int_{x_1}^{x_2}\int_{y_1}^{y_2}\left[\left(\frac{\partial u}{\partial t}\right)^2+\left(\frac{\partial v}{\partial t}\right)^2+\left(\frac{\partial w}{\partial t}\right)^2\right]dxdy+\rho_j F_j\sum_{j=1}^{k_2}\int_{y_1}^{y_2}\times$$

$$\times\left[\left(\frac{\partial u_j}{\partial t}\right)^2+\left(\frac{\partial \vartheta_j}{\partial t}\right)^2+\left(\frac{\partial w_j}{\partial t}\right)^2+\frac{J_{kpj}}{F_j}\left(\frac{\partial \varphi_{kpj}}{\partial t}\right)\right]dy-$$

$$-\int_{x_1}^{x_2}\int_{y_1}^{y_2}\left(q_x u+q_y\vartheta+\left(q_z+q\right)w\right)dxdy$$

where, F_j, J_{zj}, J_{yj}, J_{kpj} are the area and inertia moments of the cross section of the *j*th lateral bar, respectively with respect to the axis Oz and the axis parallel to the axis Oy and passing through the gravity center of the cross section, and also it inertia moment at torsion; $\tilde{E}_j, \tilde{G}_j$ are elasticity and shear module of the material of the *j*th bar; t is a time coordinate, ρ, ρ_j is the density of materials from which a shell is made, j is the lateral bar, q_x, q_y, q_z are presser vector components acting as viewed from viscous fluid.

We represent the expressions for internal forces and moments as follows:

$$N_{ij}=\int_{-h/2}^{h/2}\left(\sigma_{ij}+zw_{ij}\right)dz;\; M_{ij}=-\int_{-h/2}^{h/2}\left(\sigma_{ij}+zw_{ij}\right)zdz$$

$$w_{11}=b_{11}\chi_{11}+b_{12}\chi_{22};\; w_{22}=b_{12}\chi_{11}+b_{22}\chi_{22} \quad (5)$$

$$w_{21}=w_{12}=b_{66}\chi_{12}$$

The stresses σ_{ij} and strains ε_{ij} in the median surface in Equations (5) are determined as follows:

$$\sigma_{11}=b_{11}\varepsilon_{11}+b_{12}\varepsilon_{22};\; \sigma_{22}=b_{12}\varepsilon_{11}+b_{22}\varepsilon_{22}$$

$$\sigma_{12}=b_{66}\varepsilon_{12};\varepsilon_{11}=\frac{\partial u}{\partial x};\; \varepsilon_{22}=\frac{\partial v}{\partial y}+w;\; \varepsilon_{12}=\frac{\partial u}{\partial y}+\frac{\partial \vartheta}{\partial x} \quad (6)$$

$$\chi_{11}=\frac{\partial^2 w}{\partial x^2};\; \chi_{22}=\frac{\partial^2 w}{\partial y^2};\; \chi_{12}=-2\frac{\partial^2 w}{\partial x\partial y}$$

The surface loads q_x, q_y and q_z acting as viewed from viscous fluid on a laterally strengthened shell are determined from the solutions of Navier-Stock's linearized equations:

$$\rho_0\frac{\partial \vec{\vartheta}}{\partial t}=-grad\,p-\frac{\bar{\mu}}{3\rho_0 a_*^2}qrad\left(\frac{\partial p}{\partial t}\right)+\bar{\mu}\nabla^2\vec{\vartheta} \quad (7)$$

where, $\bar{\mu}$ is a dynamic viscosity coefficient, p is pressure at some point of fluid, ρ_0 is density fluid, a_* is sound velocity in fluid, ∇^2 is Laplace's operator, $\vec{\vartheta}\left(\vartheta_x,\vartheta_y,\vartheta_z\right)$ is velocity vector of an arbitrary point of fluid.

On the contact surface a shell-viscous fluid $(r=R)$ it is fulfilled:

$$\vartheta_x=\frac{\partial u}{\partial t},\; \vartheta_y=\frac{\partial \vartheta}{\partial t},\; \vartheta_r=\frac{\partial w}{\partial t} \quad (8)$$

$$q_x=-\sigma_{rx},\; q_\theta=-\sigma_{r\theta},\; q_z=-p \quad (9)$$

where the viscosity forces are determined by the qualities

$$\sigma_{rx}=\bar{\mu}\left(\frac{\partial \vartheta_z}{\partial x}+\frac{\partial \vartheta_x}{\partial z}\right),\; \sigma_{r\theta}=\bar{\mu}\left(\frac{\partial \vartheta_z}{\partial y}+\frac{\partial \vartheta_y}{\partial z}\right) \quad (10)$$

Equation (6) by means of the continuity equation and equation of state arrives at the equation with respect to p:

$$\frac{1}{a_*^2}\frac{\partial^2 p}{\partial t^2}=\nabla^2 p+\frac{4}{3}\frac{\bar{\mu}}{\rho_0 a_*^2}\frac{\partial p}{\partial t} \quad (11)$$

We look for displacements vector components of the shell median surface in the form

$$u=A(t)\cos n\theta\cos\frac{m\pi}{\xi_1}\xi;\; \vartheta=B(t)\sin n\theta\sin\frac{m\pi}{\xi_1}\xi$$

$$w=C(t)\cos n\theta\sin\frac{m\pi}{\xi_1}\xi \quad (12)$$

where, A, B, C are unknown functions. We accept these functions for the frequencies lying near $\omega/\omega_*=1/2$ in the form

$$A(t)=A_1\cos\omega_1 t_1+A_2\sin\omega_1 t_1$$

$$B(t)=B_1\cos\omega_1 t_1+B_2\sin\omega_1 t_1 \quad (13)$$

$$C(t)=C_1\cos\omega_1 t_1+C_2\sin\omega_1 t_1$$

where

$$t_1=\omega_0 t, \omega_0=\sqrt{\frac{E}{\left(1-\nu^2\right)\rho R^2}}, \omega_1=\omega/\omega_0\,.$$

After separation of variables, equation (12), has the form:

$$p=p_0 J_n(\lambda r)\cos n\theta\frac{m\pi}{\xi_1}\xi\sin\omega_1 t_1 \quad (14)$$

where, J_n is the first kind Bessel function of $n$order, p_0 is a pressure amplitude.

Using (14) and (7), we can determine the velocity components in fluid and by formula (10) the viscosity forces. Complementing by contact conditions (8), (9) the total energy of system (4) of fluid motion Equations (7), (1) and (2), we arrive at a contact problem on parametric oscillations of viscous fluid-filled orthotropic shell strengthened with lateral ribs. In other words, a problem on parametric oscillations of a viscous-fluid-filled, orthotropic cylindrical shell strengthened with lateral ribs is reduced to joint integration of total energy of the system and fluid motion equations subject to indicated conditions on their contact surface.

Using (5)-(7), (12)-(14) and (3) the problem is reduced to a homogeneous system of sixth order linear algebraic equations

$$a_{i1}A_1 + a_{i2}A_2 + a_{i3}B_1 + a_{i4}B_2 + a_{i5}C_1 + \\ +a_{i6}C_2 = 0 \qquad (i = 1, 2, ..., 6) \tag{15}$$

The elements $a_{i1}, a_{i2}, a_{i3}, ..., a_{i6} (i = 1,2,3,..,6)$ are of bulky form and we don't cite them. The elements of nontrivial solution of the system of linear algebraic equations (15) of sixth order are possible only in the case when ω_1 is the root of its determinant. The definition of ω_1 is reduced to a transcendental equation, as ω_1 is contained in the arguments of the Bessel function J_n:

$$\det\|a_{ij}\| = 0 \tag{16}$$

Note that for $\bar{\mu} = 0$ Equation (16) passes to the frequency equation of parametric oscillations of an ideal fluid-filled strengthened, orthotropic cylindrical shell.

IV. RESULTS AND CONCLUSIONS

Let us consider some results of calculations conducted proceeding from above dependences by means of ECM. For geometrical physical parameters characterizing the materials of a shell, fluid and lateral bars we accepted:

$$h^* = \frac{h}{R} = 0.25\times10^{-2}; \quad \xi_1 = 1; \quad E_j = 6.67\times10^9\,\text{n/m}^2$$

$$\nu = 0.3; \quad h_j = 1.39\text{ mm}; \quad R = 160\text{ mm}$$

$$L = 800\text{ mm}; \quad F_j = 5.75\text{ mm}^2; \quad J_{xj} = 19.9\text{ mm}^4$$

$$J_{kp,j} = 0.48\text{ mm}^4; \quad \rho_0/\rho = 0.105; \quad \nu_2 = 0.19$$

$$\nu_1 = 0.11; \quad a_* = 1350\ \frac{\text{m}}{\text{sec}}; \quad \bar{\mu} = 10.02\ \frac{\text{kg}}{\text{sec.m}}$$

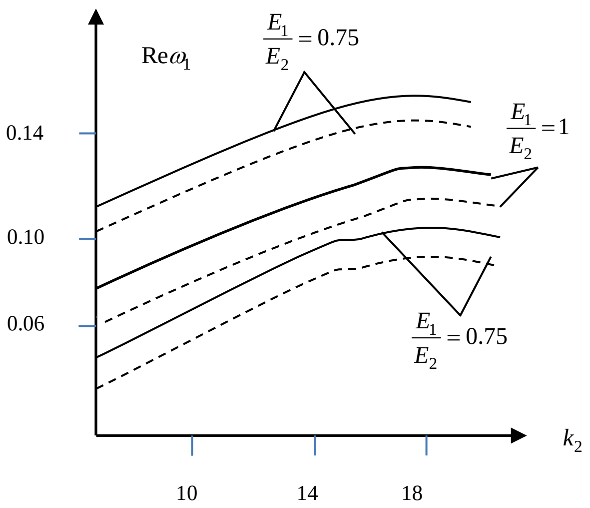

Figure 1. Dependence of oscillations frequency parameter on the number of lateral bars. The dotted line is a damaged shell; the solid line is a damageless shell

The results of calculations are represented in Figure 1. It illustrates the dependence of frequency parameter on the number of lateral bars for different ratios of elasticity module. The results of calculations show that account of damageability of the shell material reduces to decrease of frequencies of eigen oscillations of the system in comparison with the case when a shell is considered as damageless. Furthermore, with increasing the ratio $\frac{E_1}{E_2}$ the frequencies of eigen oscillations of the system increase. With increasing the number of lateral ribs, the frequencies of eigen oscillations of the system at first increase, and then at certain values of k_2 began to decrease. This is explained by the fact that by increasing k_2 the influence of inertia actions of bars on the oscillation process of the system becomes significant.

V. CONCLUSIONS

The results of calculation show that account of viscosity of fluid material and damageability of the shell material reduces to decrease of frequencies of eigen oscillations of the system in comparison when fluid is ideal, a shell is damageless. With increasing the ratio $\frac{E_1}{E_2}$ the frequencies of eigen oscillations of the system increase. With increasing the number of lateral ribs, the frequencies of eigen oscillations of the system at first increase, an then at certain values of k_2 began to decrease.

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BIOGRAPHIES

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