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VIBRATIONS OF A CURVED VISCOELASTIC PIPE WITH INTERNAL PRESSURE

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Abstract: The article presents a resolving system of equations of free oscillations of thin-walled multilayer curved composite viscoelastic pipes with internal pressure. For two types of boundary conditions, depending on internal pressure, geometric and structural factors, their proper oscillation is investigated. Taking into account the initial irregularities of the cross section and the rheological properties of the material, the dynamic state of a composite viscoelastic pipe under pressure is considered. The results of numerical analysis of the spectra of lower complex natural frequencies depending on internal pressure, geometric, structural factors, rheological properties and boundary conditions are presented.
Keywords: fluctuations, initial irregularities of the section, boundary conditions, flexibility, viscoelastic pipe, internal pressure.

Аннотация: В статье представлена разрешающая система уравнений свободных колебаний тонкостенных многослойных изогнутых композитных вязкоупругих труб с внутренним давлением. Для двух типов граничных условий, зависящих от внутреннего давления, геометрических и структурных факторов, исследуется их собственное колебание. С учетом начальных неровностей поперечного сечения и реологических свойств материала рассмотрено динамическое состояние композитной вязкоупругой трубы под давлением. Представлены результаты численного анализа спектров нижних комплексных собственных частот в зависимости от внутреннего давления, геометрических, структурных факторов, реологических свойств и граничных условий.
Ключевые слова: колебания, начальные неровности сечения, граничные условия, гибкость, вязкоупругая труба, внутреннее давление.

Introduction

The problem of vibrations is relevant not only for oil and gas pipelines, but also for aircraft. Pulsating flows and intense vibrations associated with them also occur in power plants [1]. Analysis of the behavior of pipelines in nuclear power plants showed [2,3] that vibrations are observed at frequencies from 0.5 to 1000 Hz, vibration amplitudes - 3-5 mm. The phenomena of pulsations in the coolant circulation circuit [4] and vibration of equipment acquire the greatest acuteness. There are cases of violation of the integrity of pipes. The nature of the fractures indicates the fatigue nature of the destruction. The origin and development of cracks is associated with elastic vibrations and hydraulic shocks. Thus, the problem of pipeline vibrations acquires an important national economic significance. When the frequencies of the excitation spectrum coincide with the natural frequencies of the pipeline, resonance develops in the system. Obviously, this approach is justified only for thick-walled structures. The development and creation of composite structures is a more complex problem, which is effectively solved only in an inseparable unity: material -construction - technology. The subject of design becomes the material itself, or rather its structure. The new material is designed taking into account technological capabilities for a given design and a given load. Only in such unity is it possible to realize the potential inherent in the composite. However, the method of calculating the dynamic parameters of multilayer pipes, taking into account the layered-fibrous structure and anisotropy of the material, is practically absent to date. The influence of inhomogeneity's in the structure of the material, as well as initial ovalities and different thicknesses of the cross-section on the stress state and dynamic properties of composite pipes has not been sufficiently studied.

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Problem statement and solution methods

Consider a composite viscoelastic tube whose centerline represents an arc of a circle of radius R with length L. The pipe has a cross-section with a nominal average radius r and a wall thickness h. Let us confine ourselves to thin-walled sufficiently long pipes of small curvature: The pipe is considered as an element of a pipeline conducting a liquid. The internal flow is considered homogeneous, the liquid is single–phase, ideal and incompressible. The end sections of the pipe are closed with absolutely rigid weightless flanges, which are supported by fixed hinge supports. The boundary conditions have the form: when and *s=0* and *s=L* *(0≤s≤L*) at points with coordinates and displacements, to describe the viscoelastic properties of the body material, we adopt the linear hereditary Boltzmann-Voltaire theory, while we define the physical relations for the m-th viscoelastic element of the system in the form [5]

$$\sigma_{mk}^{n}(t)=\tilde{\lambda}_n\Theta^n(t)\delta_{mk}+2\tilde{\mu}_n\varepsilon_{mk}^{n}(t) \qquad (1)$$

Here is Voltaire integral operators, which are replaced by one operator below. The Poisson's ratio in the proposed formulation of the problem is assumed to be constant. This means that for a structurally inhomogeneous viscoelastic system, the forms of natural oscillations will be equal to the eigenvectors of the corresponding elastic problem [6,7].

Expressing by known formulas through, and considering that, instead of (1) we get

$$\sigma_{mk}^{n}(t)=\frac{\tilde{E}_n}{1+\nu_n}\left[\frac{\nu_n}{1-2\nu_n}\Theta^n(t)\delta_{mk}+\varepsilon_{mk}^{n}(t)\right], \qquad (2)$$

where $\widetilde{E}_n$ is the Volterra operator having the following form:

$$\widetilde{E}_n\varphi(t)=E_{0n}\left[\varphi(t)-\int_0^t R_{En}(t-\tau)\varphi(\tau)d\tau\right] \qquad (3)$$

here E_{0n} is the instantaneous modulus of elasticity, and here R_{En} -is the relaxation core.

Given (1), the function of time in equality (3) will be with $\varphi(t)=\exp(-i\omega t)$ a slowly varying amplitude. Assuming the smallness of $\int_0^\infty R(\tau)d\tau$ the integral term, using the freezing method [8] we replace the relation (3) with an approximate one:

$$\widetilde{E}_n\varphi(t)\cong E_{0j}\left[1-\Gamma_n^c(\omega_R)-i\Gamma_n^s(\omega_R)\right]\varphi(t)\equiv\overline{E}_n\varphi(t)\,, \qquad (4)$$

where, $\Gamma_E{}^C(\omega_R)=\int_0^\infty R_E(\tau)\cos\omega_R\tau\,d\tau,$

$\Gamma_E{}^S(\omega_R)=\int_0^\infty R_E(\tau)\sin\omega_R\tau\,d\tau$ - respectively, the cosine and sine of the Fourier images of the relaxation kernel of the material, ω_R- is the real value. As an example of a viscoelastic material, we take a three $R_E(t)=Ae^{-\beta_1 t}/t^{1-\alpha_1}$ - parameter relaxation core.

For the given boundary conditions, we present the following forms of motion [9]:

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$$w(s,\varphi,t)=\sum_{m=1}^{\infty}\sum_{n=1}^{\infty} w_{mn}\cos n\varphi\sin\frac{m\pi s}{L},$$
$$\vartheta(s,\varphi,t)=-\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\frac{1}{n}w_{mn}\sin n\varphi\sin\frac{m\pi s}{L}, \tag{5}$$
$$u(s,\varphi,t)=\frac{\pi r}{L}\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\frac{m}{n^2}w_{mn}\cos n\varphi\cos\frac{m\pi s}{L}.$$

Here and u,ϑ and w are the displacements of the points of the median surface of the shell in the axial, circumferential and radial directions. The wave numbers m and n characterize the shape of the oscillations: m is the number of half-waves in the axial direction, n - is the number of waves in the circumferential direction.

The kinetic energy of the pipe motion is determined by the following equation:

$$K=\frac{1}{2}\rho_T rh_m\int_0^L\int_0^{2\pi}\left(\dot u^2+\dot\vartheta^2+\dot w^2\right)h(\varphi)dsd\varphi=\frac{1}{8}(m_T)\sum_{m-1}^{\infty}\sum_{n=1}^{\infty}\left(\frac{n^2+1}{n^2}+\frac{m^2\pi^2r^2}{n^4L^2}\right)\dot w_{mn}^2 \tag{6}$$

The viscoelastic potential constructed on the basis of the semi-instant theory of multilayer thin shells and approximations (5) has the form:

$$\Pi=\frac{1}{2}r\int_0^L\int_0^{2\pi}\left(B_{1m}\varepsilon_1^2+D_{2m}k_2^2\right)dsd\varphi=$$
$$=\frac{\pi B_{1m}}{4}rL\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\left[-\left(\frac{m\pi}{L}\right)^2\frac{r}{n^2}w_{mn}+\frac{n-2}{n-1}\frac{w_{m\,n-1}}{D}+\frac{n+2}{n+1}\frac{w_{m\,n+1}}{D}\right]^2+ \tag{7}$$
$$+\frac{\pi D_{2m}L}{4r^3}\sum_{m=1}^{\infty}\sum_{n=1}^{\infty}(n^2-1)^2w_{mn}^2\quad .$$

Using Lagrange equations:

$$\frac{d}{dt}\left(\frac{\partial K}{\partial \dot w_{mn}}\right)+\frac{\partial\Delta}{\partial\dot w_{mn}}-\frac{\partial(K-\Pi-W)}{\partial w_{mn}}=Q_{mn}$$

and dependences (2) - (10), we obtain a connected system of homogeneous differential equations with complex coefficients of the form

$$[A]\{\ddot w\}+D_{1m}(1-\Gamma_n^{\circ}(\omega_R))[C]\{w\}=0\ , \tag{8}$$

where $\Gamma_n^{\circ}(\omega_R)=\Gamma_n^{C}(\omega_R)+i\Gamma_n^{S}(\omega_R)$, $D_{1m}=\frac{h_m}{1-\nu_{12}\nu_{21}}E_{02}$, E_{02} is the instantaneous modulus of elasticity, $[A]$ is a square diagonal matrix whose elements are determined by recurrent formulas: $a_{nn} = \frac{n^2+1}{n^2} + \frac{m^2\pi^2 r^2}{n^4 L^2}$, $[C]$-is a square matrix whose elements are determined by the following recurrent formulas :

$$c_{nn} = \frac{n^2+1}{n^2} + \frac{2\beta_m{}^2}{n^4} + \frac{1}{6}\varsigma\lambda^2(n^2-1)(n^2-1+3p'_m),$$
$$c_{n\,n+1} = -2\beta_m \frac{n^2+n+1}{n^2(n+1)^2}, \tag{9}$$
$$c_{11} = 2\beta_m^2 \,, c_{n\,n+2} = -2\beta_m \frac{n^2+2n-3}{2n(n+2)}.$$

Here $\beta_m = (\frac{m\pi}{L})^2 rR$ and $p'_m = \frac{p_m r^3}{3D_{2m}}$ are dimensionless parameters, $D_{2m} = \frac{h_m^3}{1-\nu_{12}\nu_{21}}E_{02}$.
Analysis of the structure of the matrix [C] shows that the generalized coordinates are related to each other. The interaction of generalized coordinates is caused by elastic bonds, the intensity of which is characterized by non-diagonal elements of the matrix [C] and depends on the length of the pipe, where $L=\theta_0 R$ is the θ_0 central angle. The shorter the pipe, the greater the number of half-waves *m* on the segment *L* and the greater the curvature parameter *r/R*, the stronger their interaction. With an increase in the radius of curvature *R*, the interaction of generalized w_{mn} coordinates weakens

Evaluation of the flexibility of curved viscoelastic composite pipes

Depending on the boundary conditions and geometric factors, we investigate he flexibility of samples of viscoelastic composite pipes. The geometric characteristics of the samples are given in Table 1.

Table 1. Geometric characteristics of samples

Sample Number	*R*, mm	r, mm	*h*, mm	φ_0	*r/R*	*h/r*	λ
1	835	80	4,2	180°	1/10	1/20	0,50
2	1250	80	4,2	180°	1/15	1/20	0,70

The samples are made of Kevlar 49/PR-286 organoplasty with physical characteristics $E_\alpha = 64{,}10\,GPa$, $E_\beta = 5{,}38\,GPa$, $G_{\alpha\beta} = 2{,}07\,GPa$, $\nu_{\alpha\beta} = 0{,}35$ and relaxation core parameters $A = 0{,}048;\ \beta_1 = 0{,}05;\ \alpha_1 = 0{,}10$. The number of layers is six. Effective elastic constants with a wall, as a multilayer orthotropic body, depending on the reinforcement, are given in [10].

Conclusion

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1. Based on the approximate energy method, a resolving system of equations of free oscillations of thin-walled curved composite viscoelastic pipes with hinged supports is constructed.

2. The layered-fibrous STRUCTURE and anisotropy of the material are taken into account. In a particular case, the resolving equations describe the free oscillations of a cylindrical shell and a hinged straight-rod. The resulting equations correspond to well-known classical solutions.

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