Dynamics And Stability Of A Composite Feed Cylinder In The Feeding Area Of Rotor Spinning Machines

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Abstract

The quality of yarn is largely determined by the properties of the fibers from which it is produced. There is a certain correlation between the properties of the fibers and the yarn. Toothed feeding cylinders with elastic casings act on the fiber tape according to the laws of mechanics. Thin shells are widely used in the design of elements in many branches of modern technology, particularly in mechanical engineering. In this feeding cylinder thin shells are installed, which helps to obtain high-quality yarn on rotor spinning machines. The calculated results of the feed cylinder with elastic casings in the feed area of rotor spinning machines are given. Each parameter is conditionally discussed according to the laws of dynamics and resistance of materials.

Keywords: feeding cylinder, shell, Poisson's ratio, bending moment, thickness,normal stress, elasticity, layer, frequency, vibrations.

Introduction. The determination of the stress-strain state of the shell and its associated filler is reduced to the joint integration of the equations of shell theory and three-dimensional elasticity theory under certain conditions at the surface of their contact. A typical example of such structures is the cylindrical shell-viscous elastic cylinder system with a centrally located channel.

Main part. We consider only a cut metal plate of thickness h_0 lying on an elastic rubber layer of thickness h and length 2R (Fig. 1). Especially we should say that in this picture the second part of the cylinder is not shown. After the shaft there is nothing notionally depicted.

A dynamic load of the form $\sigma_{\text{пит.ст}} = q(t) = A\sin\rho t$ at $z = h + h_0$, where p −frequency of forced vibrations acts on the teeth of the feeding cylinder distributed over the entire area. The base of the rubber elastic layer of the feed cylinder is stationary. Conditionally, we believe so. Because the force acting on the feeding cylinder from the springs of feeding stage $q(t) = 25 \div 30$ H.

$\varpi_{\text{ос.п.ц.}} = 0, z = 0.$

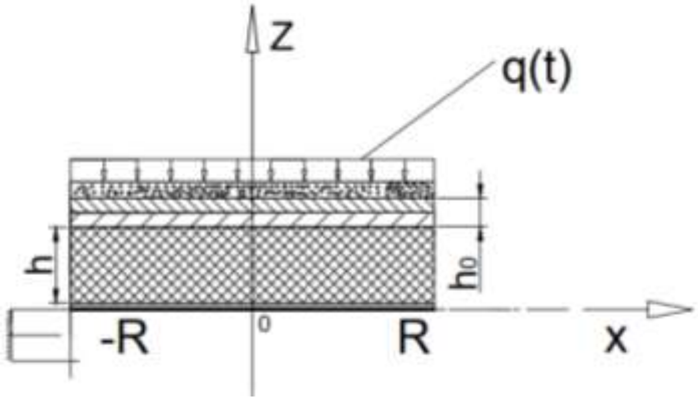

Fig. 1 A sectional view of a feeding cylinder with elastic casings

$\sigma_{\text{пит.ст}} =$ at $= \mathrm{h}$, $\varpi_{\text{ос.п.ц.}} = 0, \mathrm{z} = 0$ at discontinuity of tension and displacement. The metal tooth part of the feeding cylinder is articulated along the contour $\mathrm{x} = \pm\mathrm{R}$, the deflection of the metal tooth part of the feeding cylinder and the bending moment along the edge are zero.

$$\varpi = 0, \frac{d^2\varpi}{dx^2} = 0, x = \pm R.$$

The edges of the rubber layer of the feeding cylinder are free of stresses. The normal stresses of the layer are defined by the formula $\sigma_{\text{нор.напр.}} = \mathrm{Ke}$, where $\mathrm{K} = \frac{\mathrm{E}}{3(1-2\upsilon)}$ −volumetric compression modulus , E and υ - Young's modulus and Poisson's ratio of rubber shells of the feeding cylinder. e −relative volume increment [1]. Then at the edges of the feeding cylinder $\mathrm{x} = \pm\mathrm{R}$ is $\mathrm{e} = 0$. We consider a planar deformation, so the functions depend on two predominant

$\mathrm{x}, \mathrm{t}: \varpi = \varpi(\mathrm{x}, \mathrm{t}), \mathrm{e} = \mathrm{e}(\mathrm{x}, \mathrm{t})$.

The load on the metal part (together with the teeth) consists of a given function $\mathrm{q} = \mathrm{A}\sin(\mathrm{pt})$ and the reaction of the rubber layer equal to Ke. The dynamic equation for the deflection of the metal part (together with the teeth) has the form [2,3].

$$D\frac{\partial^4\varpi}{\partial x^4} + \rho h_0 \frac{\partial^2\varpi}{\partial t^2} = q(t) - Ke(x,t) (1)$$

where $\mathrm{D} = \frac{\mathrm{E_0 h_0^2}}{12(1-\mathrm{v_0^2})}$ −cylindrical stiffness , $\mathrm{E_0}$ and $\mathrm{v_0}$- Young's modulus and Poisson's ratio of toothed metal part of the feeding cylinder, ρ −material density of toothed metal part of the feeding cylinder. The problem of dynamic compression of the rubber (elastic) layer is reduced to the solution of the Helholtz equation for the function of the relative increment of the volume [4].

$$R^2\frac{d^2e^0}{dx^2} - 12\overline{c}e^0 = -\frac{12\overline{c}}{h}\varpi^0 \quad (2)$$

where $\overline{\mathrm{c}} = \frac{\mathrm{ck^2}}{12(\frac{2}{\mathrm{k}}\mathrm{tg}\frac{\mathrm{k}}{2-1})}, \mathrm{c} = \frac{\mathrm{GR^2}}{\mathrm{Kh^2}}, \mathrm{k} = \frac{\mathrm{ph}}{\mathrm{b}}$, b −shear wave velocity,(transverse wave velocity). In equation (2), amplitude values of functions are written out, multiplier sinpt is omitted. We begin by solving the problem.

Let us solve the system of equations (1) and (2) with the given conditions by methods of separation of variables. Let

$$e(x,t) = e^0(x)\sin pt, \quad (3)$$

$$\varpi(x,t) = \varpi^0(x)\sin pt \quad (4)$$

Let us substitute relations (3) into equation (1). As a result, we obtain two ordinary differential equations of one variable x:

$$D\frac{d^4\varpi^0}{dx^4} - p^2\rho h_0\varpi^0(x) = A - Ke^0(x) \quad (5)$$

$$R^2\frac{d^2e^0}{dx^2} - 12\overline{c}e^0(x) + 12\overline{c}\frac{1}{h}\varpi^0(x) = 0 \quad (6)$$

Express the function $\varpi^0(x)$ from equation (6) and substitute it in (5). We obtain the following differential equation

$$\frac{d^6e^0}{d\xi^6} - 12\overline{c}\frac{d^4e^0}{d\xi^4} - \frac{\rho h_0 p^2}{D}R^4\frac{d^2e^0}{d\xi^2} + \frac{12\overline{c}}{D}R^4\left(\rho h_0 p^2 - \frac{K}{h}\right)e^0 + \frac{12\overline{c}}{Dh}R^4 A = 0 \quad (7)$$

Here we introduce a dimensionless variable $\xi = \frac{x}{R}$. The solution will be sought as the sum of the general solution of one equation and the partial solution $e^0(x) = e_0^0(x) + e_1^0(x)$. The partial solution of equation (7) is $e_1^0(x) = \frac{A}{K-\rho h h_0 p^2}$.

Let's find a general solution of the homogeneous equation

$$\frac{d^6e_0^0}{d\xi^6} - 12\overline{c}\frac{d^4e_0^0}{d\xi^4} - \frac{\rho h_0p^2}{D}R^4\frac{d^2e_0^0}{d\xi^2} + \frac{12\overline{c}}{D}R^4\left(\rho h_0p^2 - \frac{K}{h}\right)e^0 = 0 \quad (8)$$

We look for this solution in the form $e_0^0 = e^{\lambda\xi}$,where λ −root of the characteristic equation

$$\lambda^6 - 12\overline{c}\lambda^4 - \frac{\rho h_0p^2}{D}R^4\lambda^2 + \frac{12\overline{c}}{D}R^4\left(\rho h_0p^2 - \frac{K}{h}\right) = 0 \qquad (9)$$

Solving equation (9) yields two different substantial roots and four complex conjugates.

Taking into account parity of the function $e_0^0(\xi)$ the solution of equation (8) will look like [5,7]

$$e_0^0(\xi) = c_1ch\lambda\xi + c_2ch\alpha\xi cos\beta\xi + c_3sh\alpha\xi sin\beta\xi.$$

c_i −unknown constants to be determined, α, β −value and imaginary parts of the complex root, λ −value root of the characteristic equation (9).

To determine the unknown constants we use the boundary conditions

$$e^0 = 0, \frac{d^2e^0}{d\xi^2} = 0, \frac{d^4e^0}{d\xi^4} = 0, \xi = 1.$$

Thus, the solution of the differential equation (7) will be

$$e^0(\xi) = c_1ch\lambda\xi + c_2ch\alpha\xi cos\beta\xi + c_3sh\alpha\xi sin\beta\xi + \frac{A}{K - \rho hh_0p^2}.$$

$$c_1 = -\frac{2Ae^{\lambda}(\alpha^4 + 2\alpha^2\beta^2 + \beta^4)}{(K - \rho hh_0p^2)(1 + e^{2\lambda})B};$$

$$c_2 = -\frac{A\lambda^2e^{\alpha}}{(K-\rho hh_0p^2)\alpha\beta BC}(2\alpha\beta cos\beta(1 + e^{2\alpha})(2\alpha^2 - \lambda^2 - 2\beta^2) + sin\beta(1 - e^{2\alpha})(6\alpha^2\beta^2 + \alpha^2\lambda^2 - \beta^2\lambda^2 - \alpha^4 - \beta^4);$$

$$c_3 = -\frac{A\lambda^2e^{\alpha}}{(K - \rho hh_0p^2)\alpha\beta BC}(cos\beta(1 + e^{2\alpha})(\alpha^4 + \beta^4 + \beta^2\lambda^2 - 6\alpha^2\beta^2 - \alpha^2\lambda^2) + 2\alpha\beta sin\beta(e^{2\alpha} - 1)(\lambda^2 - 2\alpha^2 + 2\beta^2));$$

Where $B = \alpha^4 + \beta^4 + \lambda^4 + 2\beta^2\lambda^2 + 2\beta^2\alpha^2 - 2\alpha^2\lambda^2, \quad C = 1 + e^{4\alpha} + 2e^{2\alpha}cos2\beta$

Deflection function of the metal part of the feeding cylinder (4)

$$\varpi(\xi,t) = \left(c_1hch\lambda\xi\left(1 - \frac{\lambda^2}{12\overline{c}}\right) + hcos\beta\xi ch\alpha\xi\left[c_2 - \frac{1}{12\overline{c}}\left(2\alpha\beta c_3 + c_2(\alpha^2 - \beta^2)\right)\right] + hsin\beta\xi sh\alpha\xi\left[c_3 - \frac{1}{12\overline{c}}\left(c_3(\alpha^2 - \beta^2) - 2\alpha\beta c_2\right)\right]\right)sinpt + \frac{A}{K-\rho hh_0p^2}sinpt \qquad (10)$$

The calculation of the deflection of the metal part $\varpi(\xi)$ for the parameters $R = 12\ mm$ was performed, the results of the theoretical examination are shown in Table 1.

$K = \frac{E}{3(1-2\upsilon)} = \frac{40}{0{,}18} = 225\frac{Н}{мм^2}$ −volume compression modulus, $E = 40\frac{Н}{мм^2}$, $\upsilon = 0.47$, h=6 mm, $h_0 = 3$ mm.

where $D = \frac{E_0h_0^2}{12(1-v_0^2)}$ −cylinder stiffness ,

$E_0 = 2 \times \frac{10^5Н}{мм^2}, v_0 = 0.3, G = \frac{E}{2(1+\upsilon)} = \frac{40}{2.9} \approx 14\frac{Н}{мм^2},$

$\rho = 0.0000078;$ −density of steel metal part of the feeding cylinder.

The free shear rate is determined from the formulas

$b = \sqrt{\frac{G}{\rho}} = \sqrt{\frac{14}{0.0000078}} = 479000,$

$\overline{c} = \frac{ck^2}{12(\frac{2}{k}tg\frac{k}{2-1})}, c = \frac{GR^2}{Kh^2}, k = \frac{ph}{b}, b -$ shear wave velocity,(shear wave velocity). $k = \frac{1180\times6}{479000} = 0{,}015$

Таблица 1.

№	Designations	Name	Numerical values
1	K	Volumetric compression modulus	$225\frac{N}{mm^2}$
2	E	Modulus of elasticity of the cylindrical rubber casing of the feeding cylinder.	$40\frac{N}{mm^2}$
3	h	Thickness of the elastic shell of the feeding cylinder	$6\ mm$
4	h_0	Thickness of the metal part of the feeding cylinder	$3\ mm$

5	b	Shear wave velocity,(shear wave velocity).	$479000\ mm/s$
6	υ	Poisson's ratio for rubber	0.47
7	G	Shear modulus	$14\frac{N}{mm^2}$
8	ρ	Steel density	0.0000078
9	E_0	The modulus of elasticity of the toothed metal part of the feeding cylinder,	$2\frac{10^5 N}{mm^2},$
10	υ_0	Poisson's ratio of the toothed metal part of the feeding cylinder,	0.3
11	D	Cylindrical stiff metal part of the feeding cylinder	$1{,}6 \times 10^5$
12	p	Frequency of forced oscillations of the feeding cylinder.	$1180\frac{1}{sek}$
13	k	Conditional parameter	0,015

To analyze the stability of the elastic shell of the composite feeding cylinder, we first of all make equations of equilibrium taking into account the change in shape of the shell. First, we denote by $N_1, N_2 -$ Normal force (tensile),S- displacement force, u- linear displacement of the cylindrical shell of the feeding cylinder along the x-axis, v- linear displacement of the cylindrical shell of the feeding cylinder along the y-axis. $\varpi -$linear displacements of the cylindrical shell of the feeding cylinder along the z-axis. The geometric and force designations are shown in Fig. 2. To clarify the calculation, the toothed part of the feeding cylinder is not shown in Figure 2.

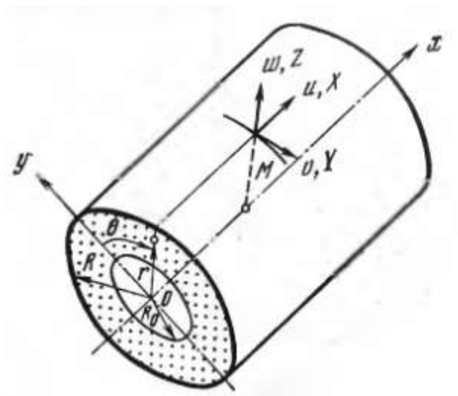

Fig. 2 . Geometric and force designation of the composite feed cylinder of rotor spinning machines.

Most often, the shell is given a constant load q, which does not change along the length of the supply cylinder with a cylindrical rubber shell. (see Fig. 1 above)

The decomposition of the constant q in trigonometric series in the interval $-l/2 \leq x \leq l/2$ is

$q = \frac{4}{\pi} q \sum_{n=1}^{\infty} \frac{1}{n} cos\lambda x (11)$

here the summation is performed for odd n (n=1,3,5,...). For each term of the series n the system should be solved as given in the literature [6].

$$-u_n\left(\lambda^2 + \frac{1}{2}\right) - \nu_n \frac{\lambda}{2} = 0,$$

$-u_n \frac{\lambda}{2} - \nu_n \left(1 + \frac{\lambda^2}{2}\right) - \varpi_n = -q_n \frac{R^2}{Eh}$ (12)

$$\nu_n + \varpi_n[1 + \Phi(\lambda^2 + 1)^2] = q_n \frac{R^2}{Eh}$$

and determine the partial solution. The series (11) is not among the fast converging ones. However, in practice they often limit themselves to its first term by taking

$$q = \frac{4}{\pi} q cos \frac{\pi x}{l},$$

$$p_2 = \frac{4}{\pi} q sin\theta cos \frac{\pi x}{l},$$

$p_3 = -\frac{4}{\pi} q cos\theta cos \frac{\pi x}{l}.$ (13)

The partial solution in this case is:

$$u = u_1 cos\theta sin\frac{\pi x}{l},$$

$$v = v_1 sin\theta cos\frac{\pi x}{l} \qquad (14)$$

$$\varpi = \varpi_1 cos\theta cos\frac{\pi x}{l}.$$

Let's substitute (14) into equations (14-A)

$$\frac{\partial^2 u}{\partial x^2} + \frac{1}{2R^2}\frac{\partial^2 u}{\partial \theta^2} + \frac{1}{R}\frac{\partial^2 v}{\partial x \partial y} = 0,$$

$$\frac{1}{2R}\frac{\partial^2 u}{\partial x \partial \theta} + \frac{1}{R^2}\frac{\partial^2 v}{\partial \theta^2} + \frac{1}{2}\frac{\partial^2 v}{\partial x^2} + \frac{1}{R^2}\frac{\partial \varpi}{\partial \theta} = -\frac{p_2}{Eh}, \quad (14\text{-A})$$

$$\frac{1}{R^2}\frac{\partial v}{\partial \theta} + \frac{\varpi}{R^2} = \frac{p_3}{Eh},$$

We obtain an algebraic system of equations to determine the constants u_1,v_1 and ϖ_1

$$-u_1\left(\frac{\pi^2}{l^2} + \frac{1}{2\pi R^2}\right) - \mathrm{v}_1\frac{\pi}{2\mathrm{Rl}} = 0,$$

$$-\mathrm{u}_1\frac{\pi}{2\mathrm{Rl}} - \mathrm{v}_1\left(\frac{1}{\mathrm{R}^2} + \frac{\pi^2}{2\mathrm{l}^2}\right) - \frac{\varpi_1}{\mathrm{R}^2} = -\frac{4}{\pi}\frac{\mathrm{q}}{\mathrm{Eh}}, \qquad (15)$$

$$\frac{\mathrm{v}_1}{\mathrm{R}^2} + \frac{\varpi_1}{\mathrm{R}^2} = -\frac{4}{\pi}\frac{\mathrm{q}}{\mathrm{Eh}}$$

Solving the system , we write

$$\mathrm{u} = -\frac{4}{\pi}\mathrm{q}\frac{1}{\mathrm{Eh}}\frac{2\mathrm{l}^3}{\pi^3\mathrm{R}}\cos\theta\sin\frac{\pi\mathrm{x}}{\mathrm{l}},$$

$$\mathrm{v} = \frac{4}{\pi}\mathrm{q}\frac{1}{\mathrm{Eh}}\frac{4\mathrm{l}^2}{\pi^2}\left(1 + \frac{\mathrm{l}^2}{2\pi^2\mathrm{R}^2}\right)\sin\theta\cos\frac{\pi\mathrm{x}}{\mathrm{l}}. \qquad (16)$$

$$\varpi = -\frac{4}{\pi}\mathrm{q}\frac{1}{\mathrm{Eh}}\mathrm{R}^2\left(1 + \frac{4\mathrm{l}^2}{\pi^2\mathrm{R}^2} + \frac{2\mathrm{l}^4}{\pi^4\mathrm{R}^4}\right)\cos\theta\cos\frac{\pi\mathrm{x}}{\mathrm{l}}.$$

Substituting (16) in

$$\mathrm{N}_1 = \mathrm{Eh}\frac{\partial \mathrm{u}}{\partial \mathrm{x}}$$

$$\mathrm{N}_2 = \mathrm{E}\frac{\mathrm{h}}{\mathrm{R}}\left(\frac{\partial \mathrm{v}}{\partial \theta} + \varpi\right), \qquad (16\mathrm{A})$$

$$\mathrm{S} = \frac{\mathrm{Eh}}{2}\left(\frac{1}{\mathrm{R}}\frac{\partial \mathrm{u}}{\partial \theta} + \frac{\partial \mathrm{u}}{\partial \mathrm{x}}\right),$$

get it

$$\mathrm{N}_1 = \mathrm{Eh}\frac{\partial \mathrm{u}}{\partial \mathrm{x}} = -\frac{4}{\pi}\mathrm{q}\frac{2\mathrm{l}^2}{\pi^2\mathrm{R}}\cos\theta\cos\frac{\pi\mathrm{x}}{\mathrm{l}},$$

$$\mathrm{N}_2 = \mathrm{E}\frac{\mathrm{h}}{\mathrm{R}}\left(\frac{\partial \mathrm{v}}{\partial \theta} + \varpi\right) = -\frac{4}{\pi}\mathrm{qR}\cos\theta\cos\frac{\pi\mathrm{x}}{\mathrm{l}},$$

$$\mathrm{S} = \frac{\mathrm{Eh}}{2}\left(\frac{1}{\mathrm{R}}\frac{\partial \mathrm{u}}{\partial \theta} + \frac{\partial \mathrm{u}}{\partial \mathrm{x}}\right) = -\frac{8}{\pi}\mathrm{q}\frac{\mathrm{R}}{\pi}\sin\theta\sin\frac{\pi\mathrm{x}}{\mathrm{l}}, \qquad (17)$$

The angle of rotation of the tangent tangent to the cross section of the shell at deformation . According to (3,2) [6], we have

$$\psi = \frac{1}{\mathrm{R}}\left(\mathrm{v} - \frac{\partial \varpi}{\partial \theta}\right) = -\frac{\mathrm{R}}{\mathrm{Eh}}\frac{4}{\pi}\mathrm{q}\sin\theta\cos\frac{\pi\mathrm{x}}{\mathrm{l}}. \qquad (18)$$

The results and some data in the process of deformation of the feeder cylinder shell of rotor spinning machines are shown in Table 2.

Table 2.

№	Designations	Title	Numerical values
1	u	Linear displacements of the cylindrical shell of the feeding cylinder along the x-axis.	−1,1 mm
2	v	Linear displacements of the cylindrical shell of the feeding cylinder along the y-axis	0,64 mm
3	ϖ	Linear displacements of the cylindrical shell of the feeding cylinder along the z-axis.	−2,29 mm
4	N_1	The normal force is applied longitudinally to the x-axis.	−12N/mm
5	N_2	The normal force is directed toward the y-axis	−17.8N/mm

6	S	Shifting forces	−226 N
7	R	Radius of the shell of the compound feeding cylinder.	12 mm
9	h	Thickness of the elastic shell of the feeding cylinder	6 mm
10	q	Constant load	30 N
11	θ	Relative angle	1 rad
12	x	Geometric boundary of the composite supply cylinder	11 mm
13	l	Length of the composite feeding cylinder with elastic casings	22 mm
14	ψ	Angle of rotation of the tangent tangent to the cross-section of the shell during deformation	0,05
15	p_2	Approximated load in the feeding process	2,24 N
16	p_3	Approximated load in the feeding process	−1,5 N

Conclusion: In order to obtain a quality yarn in rotor spinning machines it is necessary to install in the feeding area the feeding cylinders with elastic casings. Two tables show the results of the theoretical experiment of the feeding cylinder receiving a constant load along its length. Theoretical and technology of textile materials is a body of knowledge about processes and equipment providing production of yarns, twisted threads, fabrics, knitwear, nonwoven materials and other textile products from fibers and threads.

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