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Mathematical Modelling of Oscillation Process of the Belt With Starting Tension Under Influence of Roller Carriages

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ABSTRACT

Background: A physical model of a conveyer belt represents a continuous strip passing on two blocks between two roller carriages significantly influencing firm properties of the junctions directing the belt without friction with a constant axial speed of belt transfer.Purpose: Creation of mathematical model, oscillating motion of artificial starting tension in conveyer belts, for the purpose of ensuring their working capacity, possessing the properties of the environment with starting tension. Results: Initial stress caused by constructive need of machines, influencing significantly firm properties of their junctions is determined. Artificial initial stress, being in the static loaded condition in process of machine operation, pass into dynamic condition that furthers emergence of difficult wave phenomena in the belt.The results of the research were received; nature of interference of static fields of initial stress and disturbed state of the conveyer belt during its operation is of great practical interest. The solution of this problem demands attraction of the theory of environments with initial stress. Conclusions: Pretension is necessary for transfer of friction by drive pulley of pulling power, and also for limiting sagging of the belt between the roller carriages. It is characterized by tighting force and the motion of the movable pulley.

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INTRODUCTION

Initial stress which is found in solid bodies are of great importance at construction strength calculation.

As initial stress can be residual stress existing in details at absence of external actions on them. As a rule, this stress remains in details after their production. We will notice that formation of residual stress at different technological processes occurs in different ways. The base of their appearance is usually irreversible volumetric change in their material. One of the most typical processes is occurrence of residual stress as the result of preliminary plastic deformation. For example, natural state of Earth surface can be considered as the environment with initial stress. It is known that stress state of the continuous medium has impact on its mechanical properties. In particular, stressed state influences the value of speed of elastic wave transmission. This phenomenon is called elasto-acoustical effect and can be used for determination of stress state of rocks that is of great interest in connection with the problem of earthquakes forecast. Elasto-acoustical effect has also some other applications in geophysics and technology.

Besides, there are some machines which have artificially entered initial stress to improve the work of some junctions.

Methodology and theoretical part:

Conveyer belts with a preliminary tension are a striking example of machines containing junctions with initial stress. Preliminary tension is necessary for transfer of friction by drive pulley of pulling power, and also for limiting sagging of the belt between the roller carriages. It is characterized by tighting force and the motion of the movable pulley.

Let stress state of a conveyer belt in a static state be determined by initial stress tensor σ^0_{ij} in disturbed state (oscillation wave processes), in this connection an additional stress tensor S_{ij} occurs.

In this connection we assume correctness of principle of superimposed stresses. Then action of external forces will be determined by stress tensor which components have the following view:

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$\sigma_{ij} = \sigma^0_{ij} + S_{ij}$ (1.1)

Then, respectively, the values σ_{xx} , σ_{xy} ,σ_{yy} will be determined by the following dependencies:

$$\sigma_{xx} = \sigma_{xx} + S_{\bullet\bullet}$$
$$\sigma_{xy} = \sigma_{xy} + S_{yy} \quad (1.2)$$
$$\sigma_{yy} = \sigma_{yy} + S_{\bullet y}$$

by analogy

$$\sigma_{11} = \sigma^0_{xx} + S_{11}$$
$$\sigma_{22} = \sigma^0_{yy} + S_{22} \quad (1.3)$$
$$\sigma_{12} = \sigma^0_{xy} + S_{12}$$

Between (1.2) and (3\1.3) there is an ordinary connection in the following view:

$$\sigma_{11} = \sigma^0_{xx}\cos^2\alpha + \sigma^0_{yy}\sin^2\alpha + \sigma^0_{xy}\sin 2\alpha$$
$$\sigma_{22} = \sigma^0_{xx}\sin^2\alpha + \sigma^0_{yy}\cos^2\alpha + \sigma^0_{xy}\sin 2\alpha \quad (1.4)$$
$$\sigma_{12} = ½(\sigma^0_{yy} + \sigma^0_{xx})\sin 2\alpha + \sigma^0_{xy}\sin 2\alpha$$

Substituting in (1.4) ratios (1.2) and (1.3) and supposing that

$$\mathrm{Cos}\alpha \approx \cos 2\alpha \approx 1$$
$$\sin 2\alpha \approx \frac{1}{2}\sin 2\alpha \approx \alpha \quad (1.5)$$

i.e. correct at small $\alpha(\alpha \approx w)$, we will get the following Biot's formulas:

$$S_{\bullet\bullet} = S_{11} - 2\sigma^0_{yy}w,$$
$$S_{yy} = S_{22} + 2\sigma^0_{xy}w, \quad (1.6)$$
$$S_{\bullet y} = S_{12} + (\sigma^0_{xx} + \sigma^0_{yy})\ w.$$

In a three-dimensional case $\sigma^*_{ij} = \sigma^0_{ij} + S_{ij} + \sigma^0_{\mu j}\ w_{i\mu}$ (1.7)

As before:

$$\vartheta_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \quad (1.8)$$

$$w_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \quad (1.9)$$

Substituting values (1.7) in the classic equation of elasticity theory in deformed state and considering lengthening and displacement to be small in comparison with unity, we have the following equation set of motion for media with initial stress:

$$\frac{\partial s_{ij}}{\partial x_j} + \sigma^0_{jk}\left(\frac{\partial w_{ir}}{\partial x_j}\right) + \sigma^0_{ik}\left(\frac{\partial w_{ik}}{\partial x_i}\right) - e_{jk}\left(\frac{\partial \sigma^0_{jk}}{\partial xj}\right) = \rho\frac{\partial^2 u}{\partial t^2} \quad (1.10)$$

$$\Delta f_i = (S_{ij} + \sigma^0_{jk}w_{ik} + e_{kk}\sigma^0_{ij} - \sigma^0_{ik}e_{jk})n_j \quad (1.11)$$

The received equation sets (1.10) and (1.11) are the main equations of motion and boundary conditions of media with initial stress [Guz,1986]. An advantage of the systems (1.10) and (1.11) is that in them initial stress make a differential form, and boundary conditions correspond to Euler coordinates. Thus, the system (1.10) with boundary conditions (1.11) can be successfully used for analysis of nonlinear oscillatory processes, in belts with initial stress.

Conveyer belts with a preliminary tension are a striking example of machines containing junctions with initial stress. Preliminary tension is necessary for transfer of friction by drive pulley of pulling power, and also for limiting sagging of the belt between the roller carriages. [Poincare,1947, Andronov and others,1979]. It is characterized by tighting force and the motion of the movable pulley. Oscillation of flexible belt with initial stress in a one-dimensional case are described by nonlinear equation. We will note that in a one-dimensional case only the longitudinal wave is considered which speed is determined.

For disturbed state of a conveyer belt connection between tension and deformation is set as follows:

$$S_{\xi\xi} = B_{11}e_{xx} + B_{12}e_{yy} + B_{13}e_{zz},$$
$$S_{\eta\eta} = B_{21}e_{xx} + B_{22}e_{yy} + B_{23}e_{zz,}, \quad (1.12)$$
$$S_{\zeta\zeta} = B_{31}e_{xx} + B_{32}e_{yy} + B_{33}e_{zz.}$$

$$S_{\eta\xi} = 2\Theta_2 e_{yz},$$
$$S_{\xi\zeta} = 2\Theta_2 e_{zx}, \quad (1.13)$$
$$S_{\zeta\eta} = 2\Theta_3 e_{xy.}$$

Thus shift coefficients θ_i are determined by the following ratios:

$$\theta_1 = \tfrac{1}{2}\left(\sigma_{22}^0 - \sigma_{33}^0\right)\tfrac{\lambda_2^2+\lambda_1^2}{\lambda_3^2-\lambda_1^2},$$
$$\theta_2 = \tfrac{1}{2}\left(\sigma_{33}^0 - \sigma_{11}^0\right)\tfrac{\lambda_3^2+\lambda_1^2}{\lambda_3^2-\lambda_1^2}, \qquad (1.14)$$
$$\theta_3 = \tfrac{1}{2}\left(\sigma_{11}^0 - \sigma_{22}^0\right)\tfrac{\lambda_1^2+\lambda_2^2}{\lambda_1^2-\lambda_2^2}$$

Oscillations of flexible belt with initial stress in a one-dimensional case can be described with nonlinear equation of the following view:

$$\frac{\partial^2 u}{\partial t^2} + \frac{1}{\alpha}\frac{\partial \sigma_{xx}^0}{\partial_{xx}}\frac{\partial u}{\partial x} = \frac{1}{a_1^2}\frac{\partial^2 u}{\partial t^2} \qquad (1.15)$$

Where

$$a_1 = \sqrt{\tfrac{1}{\rho}E\left(1+e_{xx}\right) \pm \tfrac{\sigma_{xx}^0}{\rho}}, \qquad (1.16)$$

a_1 - speed of propagation of elastic wave. We will note that in a one-dimensional case only the longitudinal wave is considered which speed is determined by the following dependence. Depending on simplification systems different formulas are used for determining the speeds of longitudinal wave, for example, (1.17)

$$a_2 = \sqrt{\tfrac{1}{\rho}E\left(1+e_{xx}\right) \pm \tfrac{\sigma_{xx}^0}{\rho}}, \qquad (1.17)$$

It was ascertained that in belts with initial stress longitudinal waves occur before emergence of transverse vibration in them. The velocities of propagation of these waves depend on the initial stress σ^0_{ij}. At determination of durability of belts it is necessary to use dynamic coefficient of Young modulus [Butenin and others 1986]. In case when lengthening and displacement are small in comparison with unity it is possible to linearize the main nonlinear equation (1.15) that considerably simplifies its research and obtaining the analytical decision [Feygin,1994, Bogolyubov, Mitropolsky,1994].

To simplify the technique of further research of belt oscillations with initial stress determination of stability of their motion was introduced according to which movement of the belt will be considered dynamically steady up to the high-speed modes when transverse vibration occurs in the belt.

The results of the research:

Summing up the research results, there is a velocity value of traverse speed of belt ν with which excess nonlinear transverse vibrations occur in the belt. Then, according to the offered criterion of dynamic stability, equation of motion (1.15) can be used as the main equation before critical state of the belt. In case of loss of belt stability, transverse vibrations will be actuated, and the equation of motion of oscillation process will be difficult.

From the linear theory of oscillation it is known that bending vibrations of a moving belt is determined with the following equation of motion [Almukhambetov, 2008]:

$$EJ\frac{\partial^4 \vartheta}{\partial z^4} + P\frac{\partial^2 \vartheta}{\partial z^2} - m\vartheta = -m\frac{\partial^2 \vartheta}{\partial t^2}, \qquad (1.18)$$

Solving the equation (1.18) with the method of separation of variables, at $\vartheta = f(z)T(t)$, we will get the system with the following view:

$$f^{IV} + \alpha^2 f^{II} + \beta^3 f = \lambda f, \qquad (1.19)$$
$$-\gamma^2 T^{II} = \lambda T$$

Where

$$\alpha^2 = \tfrac{P}{EJ}, \quad \beta^2 = -\tfrac{m\vartheta}{EJ}, \quad \gamma^2 = \tfrac{m}{EJ}.$$

In this case the frequency of oscillation is determined with the following formula:

$$\Omega^2 = \frac{\lambda}{\gamma^2}, \qquad (1.20)$$

And the integral for (1.19), is dependence of the following view:

F= $AchP_1 z + BshP_1 z + CcosP_2 z + DsinP_2 z$

T= $A_n \cos C_1 z + B_n \sin C_2 t$, (1.21)

Where P1, P2 are the roots of the characteristic equation of system (1.19):

$$P_1^2 = 0.,5\left[\sqrt{\alpha^4 + 4\left(\alpha - \beta^2\right)} - \alpha^2\right], \qquad (1.22)$$
$$P_2^2 = 0.5\left[\sqrt{\alpha^4 + 4\left(\lambda - \beta^2\right)} + \alpha^2\right]$$

Considering the part of the belt between two roller carriages to be hinge supporting, we will set the following boundary conditions:

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$$\vartheta = 0\ ,\quad \frac{\partial^2 \vartheta}{\partial z^2} = 0 \text{ при z = 0,l.} \qquad (1.23)$$

Having determined P1, P2 from the ratio (1.22) λ_n, we will find the frequency of n-tone of oscillation which according to (1.20) is determined as follows:

$$\Omega_n = \frac{n^2\pi^2}{\iota^2}\sqrt{\frac{EJ}{m}\left(1 - \frac{\alpha^2\iota^2}{\pi^2 h^2} + \frac{\beta^2\iota^4}{h^4\pi^4}\right)}\ ,\ n=1,2,3,\ldots \qquad (1.24).$$

As it is known that $c = \sqrt{\frac{E}{\rho}}$ is the velocity of longitudinal wave in the belt. Using the expression for velocity of longitudinal wave in the medium with initial stress:

$$c = \sqrt{\frac{E}{\rho}\left(1 + e_{zz}\right) + \frac{\sigma_{zz}^0}{\rho}}$$

We have the frequency of transverse vibration of previously stressed tape:

$$\Omega_n = \frac{n^2\pi^2}{l^2}\sqrt{\frac{EJ}{\rho F}\left(1 + e_{zz}\right) + \frac{\sigma_{zz}^0 J}{\rho F}}\sqrt{1 - \frac{\alpha^2 l^2}{n^2\pi^2} + \frac{\beta^4 l^4}{n^4\pi^4}}\ , \qquad (1.25)$$

Dependence (1.25) enables to determine the value of critical velocity of movement of the conveyer belt with initial stress:

$$\omega_k^2 = \Omega_n^2\left[1 - \frac{1}{1 + e_{zz} + \frac{\sigma_{zz}^0}{E}} - \frac{Pl^2}{EJn^2\pi^2}\right], \qquad (1.26)$$

On the base of specific features of a conveyer belt, the criterion of dynamic stability is offered according to which the formula (1.26) determines the field of operating modes depending on geometrical and physical parameters of the latter. Changing parameters can bring to management of dynamic mode of the set systems.

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