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Vertical Vibration Analysis of Conveyor With Compound Screw and Belt Bearing Support

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Annotation. The article presents the construction scheme and the principle of operation of the conveyor for transporting and cleaning cotton with two screw, strap element supports. Calculation scheme and mathematical model of two-screw and belt-supported shaft vibrations were obtained, and the expression for calculating the vibration amplitude was obtained. Connection graphs are presented for different modes of operation, taking into account the number of strap support singularities and dissipative coefficients. Based on the analysis, the recommended values of the parameters were determined.

Keywords: conveyor, screw, shaft, belt support, bearing, vibration, step, amplitude, singularity, dissipation, technological resistance, frequency, displacement, speed, coverage, oscillation, efficiency.

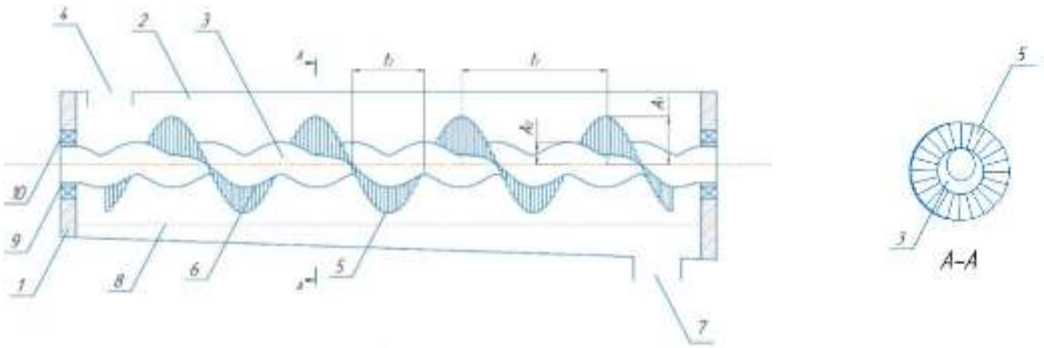


Figure 1. Complex screw conveyor scheme.

A screw conveyor is known that contains a fixed trough, the lower part of which has the form of a semi-cylinder, closed on top with a lid, and a drive screw installed inside the trough along its axis in bearings fixed to the trough. The lower working part of the trough is made in the form of a mesh surface. The movement of the load along the trough is carried out by the turns of the rotating screw [1].

The disadvantage of this analogue is the high energy consumption and the possibility of the load slaughtering in the trough with an increased feed of material.

Another known conveyor, which contains a trough, the lower part of which has the shape of a semi-cylinder, closed on top with a lid. Ring bandages are attached to the trough in the lower cylindrical part, by means of which the trough is mounted on rollers with the possibility of oscillating the trough around its axis. The rollers rest against the end planes of the ring bandage on the trough. The trough is suspended on bearings on the screw shaft to enable oscillation. The lid has an inlet on the left side, and the trough has an outlet on the right side [2].

The disadvantage of this design is the impossibility of removing foreign impurities from the total mass of transported cotton seeds, released as a result of the screw movement. As a result, the released foreign impurities get into the technological machine-linter and heavily contaminate the resulting product-lint. The following well-known design of a screw conveyor contains a trough with a lower semi-cylindrical part, installed with the possibility of oscillation around its axis, a screw installed inside the trough along its axis, holes are made in bearings fixed in the lower semi-cylindrical part of the trough [3].

The disadvantage of this design is insufficient transportation of bulk material (cotton, fibrous waste) due to significant braking of the material due to their interaction with the edges of the holes and insufficient friction between the surface of the screw turns and the transported cotton.

It should be noted that in existing screw conveyors, when transporting fibrous materials, especially cotton, due to insufficient loosening of the material, there is insufficient separation of debris. In addition, due to insufficient friction between the screw surface and the fibrous material, they lag behind during transportation, which leads to additional mechanical damage to the fibrous material (cotton and their waste). The interaction of the screw surface on the fibrous material occurs monotonously in one direction, with a constant moving force, which does not ensure the effectiveness of their cleaning. The essence of the design is that the screw conveyor contains a fixed trough, the lower part of which has the shape of a semi-cylinder, closed on top with a lid, and a composite drive screw installed inside it, including an axle-screw, mounted on bearings by means of elastic bushings on the surface of the axle-screw, the turns of the outer screw are rigidly installed on the surface of the axle-screw, while the pitch of the axle-screw is two times less than the pitch of the outer screw. In this case, the axle-screw allows for additional loosening and effective transportation of the material. Elastic bushings provide absorption of complex vibrations of the composite screw and protect it with a bearing. The lower working part of the body is made in the form of a mesh surface. The movement of the load along the axis is carried out by the turns of the rotating screw, the working surface of the screw turns is made in the form of a sinusoid. This shape of the working surface of the screw allows for an increase in the contact area with the transported cotton (fibrous waste), the degree of loosening and the cleaning effect increase [4]. The screw conveyor comprises a housing 1, the lower part of which has the shape of a semi-cylinder, closed at the top by a cover 2. Inside the housing 1, along its axis, there is a composite screw 6 transporting the material. At the top of the housing 1 there is an inlet opening 4, and at the end, at the bottom, there is an outlet opening 7. The lower working part of the housing 1 is made in the form of a mesh surface 8. The working surfaces of the outer screw (coil) 5 are made in a sinusoidal shape 6 (Fig. 1).

In this case, the pitch t2 of the axle-screw 3 is chosen to be two times smaller than the pitch t1 of the outer screw 5. The amplitude of the axle-screw 3 A2 is 2,5 times smaller than the amplitude A1 of the outer screw 5. The axle-screw 3 is installed in the housing 1 by means of elastic bushings 9 and bearings 10.

In this case, it has the ratio: t1=2t2; A1=2,5A2.

Where, t1, t2 are the pitch of the axle-screw and the pitch of the outer screw; A1, A2 are the amplitude of the axle-screw and the amplitude of the outer screw.

The screw conveyor operates as follows. Fibrous material (raw cotton, fibrous waste) is fed into the body 1 through the inlet 4 in the cover 2 and, when the composite screw 6 rotates, it moves by sliding along the axis, dragged by the sinusoidal working surface of the rotating outer screw 5 to the outlet 7. The sinusoidal shape of the working surfaces of the outer screw 5 acts on the seeds and cotton voles with a force of varying magnitude and direction, which leads to additional loosening of the cotton, which allows for the effective separation of debris from the fibrous material (cotton). The axis-screw 3 with a pitch of $2t_2=t_1$ allows for additional loosening of the transported material, which leads to the effective separation of foreign impurities from it. The waste impurities separated from the fibrous material fall out through the opening of the mesh surface 8 and are discharged into the waste discharge through the opening 7. The recommended design of the screw conveyor allows for the efficient transportation of fibrous materials, increased productivity, and provides the necessary cleaning effect.

Oscillating screw calculation scheme and mathematical model. In the proposed screw design, the bearing supports are mounted on the housing through rubber bushings. In this case, during the execution of the technological process, that is, during the transportation and cleaning of the material, the screw moves both vertically and horizontally. Also, in the rotational movement, there will be rotational-oscillating movements. Figure 2 presents a diagram of this situation, where the presence of vertical and transverse vibrations mainly depends on the singularity-dissipative properties of rubber bushings on bearing supports.

Figure 2. The scheme of the support of the propeller shaft with a belt bearing.

It should be noted that if C_1=C_2 va b_1=b_2 (1)

and the external loading Ft is centered on the center of gravity, the composite screw moves mainly vertically. In other cases, its oscillations also occur. We define the mathematical model of vertical vibrations of the screw for the given option using Lagrange's second-order equation [5,6].

$$\frac{d}{dt}\left(\frac{\delta T}{\delta q}\right) - \frac{\delta T}{\delta q} + \frac{\delta \Pi}{\delta q} + \frac{\delta \Phi}{\delta q} = Q(q) \qquad (2)$$

Here T, Π, Φ – kinetic and potential energies of the oscillating screw, and Rayleigh's dissipative function q, Q(q) – generalized coordinates and forces, t – time.

According to [7,8] respectively:

$$T = \frac{1}{2}\left(2m_n + m_b + m_{b_1} + m_{b_2}\right) \cdot z^2 ;$$

$$\Pi = \frac{1}{2} C_k z^2; \quad C_k = C_1 + C_2 ; \qquad (3)$$

$$\varphi \frac{1}{2}\, b_k z^2 \;\; ; \;\; b_k + b_1 + b_2 \;\; ;$$

Here, m_n, m_b, m_{b_1}, m_{b_2} – bearings on shaft supports, internal and external screws and shaft masses; C_1, C_2, b_1, b_2 – uniformity and dissipative coefficients of rubber bushings, z – vertical displacement.

Technological resistance, that is, external generalized force [9, 10].

$$F_{TQ} = \left[F_1 + \left(F_{b_1} + F_{b_2} cos\omega t\right) sin\omega t\right] \pm \delta F_b \qquad (4)$$

Here, F_1 – average constant value of resistance;

F_{b_1}, F_{b_2} – technological resistance values corresponding to internal and external screws;

δF_b – is a random component of resistance;

ωt – change point.

Given (2), we mainly determine its components and replace them, forming a differential equation representing the vibrations of a complex screw with the following content:

$$\left(2m_2 + m_2 + m_{b_1} + m_{b_2}\right)\frac{d^2z}{dt^2} + \ (C_1 + C_2)x + (b_1 + b_2)\frac{dz}{dt} = \left[F_1 + \left(F_{b_1}F_{b_2}\cos\omega t\right)\sin\omega t\right]\delta F_b$$
(5)

Accordingly, based on the solution given in [11, 12], the vibration amplitude of the shaft of the screw shaft with a belt bearing is:

$$A_z = \frac{\omega_1 P_0^2\left[\left(P_1 + P_{b_1} + P_{b_2}\right) \pm \delta F_b\right]}{(C_1 + C_2)\sqrt{\left(P_0^2 - \omega_1^2\right)^2 + 4\omega_1^2 n^2}}\ ; \qquad (6)$$

$$\text{Here, } P_0^2 = \frac{C_1 + C_2}{2m_2 + m_2 + m_{b_1} + m_{b_2}}\ ; \qquad 2n = \frac{b_1 + b_2}{2m_2 + m_2 + m_{b_1} + m_{b_2}}$$

Analysis of the results of the numerical solution of the problem. The following initial values of the parameters were taken into account when obtaining the vibration values of the two-screw shaft with a complex structure, for which the numerical solutions of the obtained expressions (5) and (6) are recommended.

F_{TQ} = (15÷35) N; $b_1 + b_2$ = (2,5÷3,5) N/m; $C_1 = C_2$ = (0,75÷1,0)·104 N/m,

The ratio of external amplitudes of screws A2/A1=(0,2÷0,7)

The pitch ratio of the screws T1=(1,5÷4,5)T

Organizers of technological resistance: F1=(12÷32) N; F_{b_1}=(2,5÷4,0) N;

F_{b_2}=(1,5÷2,0) N; δF_b = (0,05÷0,1)F1

The laws obtained as a numerical solution of the problem were obtained in the form of changes in the displacement z values. is presented in Figure 3.

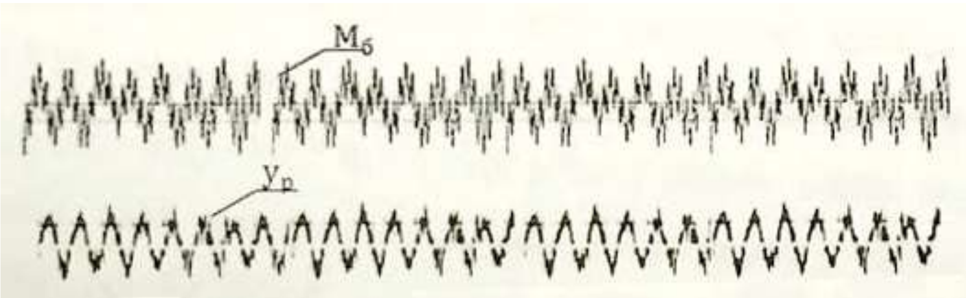
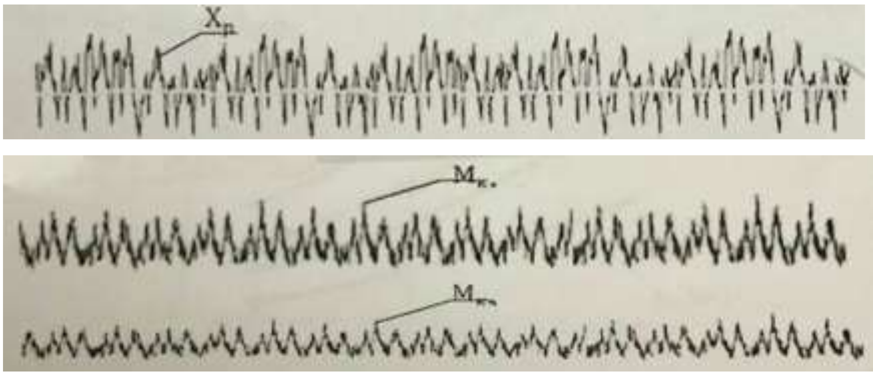


Figure 3. Vibration patterns of internal and external twin screw shafts with different steps.

When the vertical vibrations of two screw shafts are considered to be equal, when the center of gravity z shift values are analyzed, the pitch of the inner screw is T_2, and the pitch of the outer screw is $T_2=T_1$ (4,0÷4,5). In this case, the internal screw amplitude is 3,5 times smaller than the external one. Therefore, the law of change "z" is mainly influenced by the outer screw, and the effect of the inner screw has created high-frequency oscillations added to it. In this case, the piece of cotton is not enough, the volume of transportation is high. Under the influence of the internal screw, the separation of small waste is high. Also shown in Figure 4.



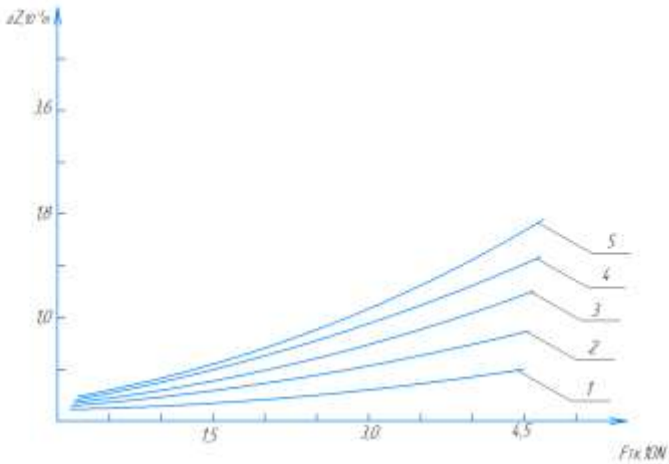
$T_1=2{,}5T_2$, $C_1=C_2$; $A_1=1{,}25A_2$, phase change bπ/2.

Figure 4. Variation of vertical vibration patterns depending on the performance of a two-screw shaft with belt supports.

In this option, A1=1.25A2 and the pitch of the internal screw is reduced by 2.5 times, so the pattern of vibration of the center of shaft theft is almost uniform, and both the amplitude and frequency are large. In this case, cotton picking intensifies, waste is quickly separated. With an increase in work output, that is, FTQ, the shape of the screw shaft vibration law is maintained, the frequency remains almost unchanged, and the amplitude increases. (Fig. 4, rules a, b, c)

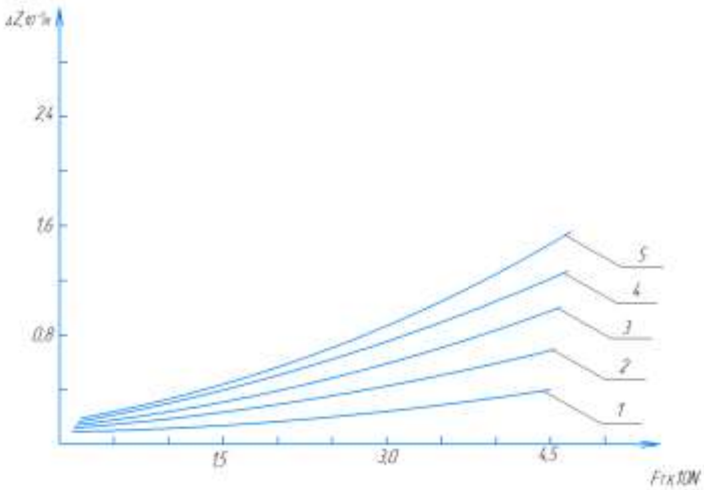
Connection graphs were constructed based on the above rules. It is presented in Figure 5. In this case, T1=4,5T2, and the amplitude ratio increases, Dz values increase from 0,2·10-3 m to 0.58·10-3 m. But when A2/A1=0.2, the swing range of the center of gravity of the two-screw shaft increases from 0,3·10-3 m to 1,85·10-3 m in the nonlinear connection.

When C1=C2 is taken into account and T1=2T2, the value of Δz increases significantly when the load value reaches 45 N (Fig. 6).



1–A_2/A_1=0,2; 2–A_2/A_1=0,3; 3–A_2/A_1=0,4; 4–A_2/A_1=0,6; 5–A_2/A_1=0,7; T_1=4,5T_2, C_1=C_2.

Figure 5. Graphs of dependence on technological resistance of a shaft with a bearing support with two screw belt elements with the recommended conveyor composition.



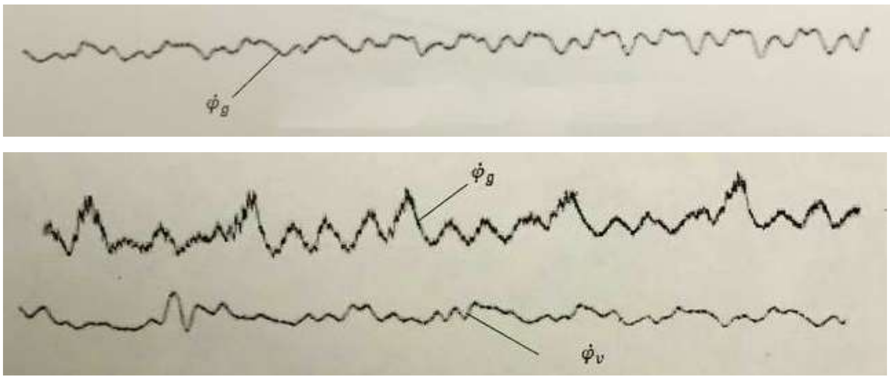
1–A2/A1=0,2; 2–A2/A1=0,3; 3–A2/A1=0,4; 4–A2/A1=0,6; 5–A2/A1=0,7; T1=4,5T2, C1=C2.

Figure 6. Dependence graphs of the vibration range of the two-screw belt support shaft of the conveyor structure with the technological resistance.

Analysis shows that if the difference between the amplitudes (outer radii) of internal and external screws decreases, the values of Δz increase sharply. In particular, when A2/A1=0,12, the values of Δz increased from 0.21·10-3 m to 0,78·10-3, when A2/A1=0,7, the vertical vibration range of the shaft increased by nonlinearly from 0,34·10-7 m to 2,33·10-3 m. (Fig. 6, graphs 1, 5). Therefore, to ensure that the two-screw shaft does not exceed the vertical vibration range, $F_{TQ} \leq (40 \div 42)$ N; It is recommended that $T1=(3,5 \div 4,0)$ and $A2/A1=(0,45 \div 0,55)$.

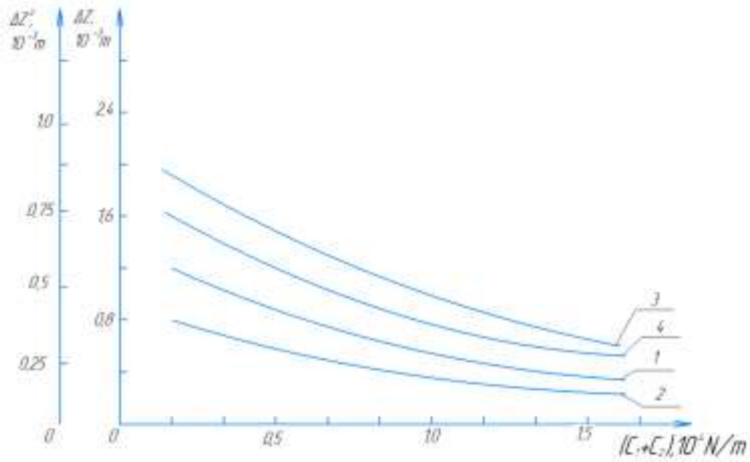
It should be noted that if C2=C1, the screw shaft produces both vertical and horizontal vibrations. In this case, cotton transportation will increase significantly.

In general, increasing the values of C1 and C2 will decrease the values of Δz and $\Delta z0$.



T1=1,5T2 , C1>C2 , A1=2A2 .

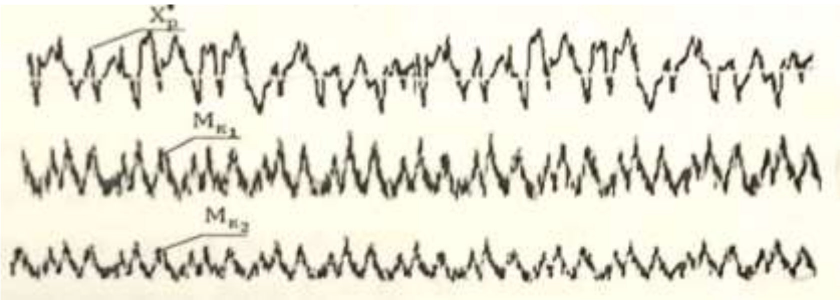
Figure 7. The recommended screw conveyor is the laws of vibration of the shaft with belt element supports with a coefficient of uniformity of two.



1,4–F_{TQ} =10 N; 1,3–F_{TQ}=3,5 N; 1,2–Δz =f(c); 3,4–Δz=f(c).

Figure 8. Conveyor two-screw shaft vertical vibration displacement and speed ranges of belt supports are presented graphs of dependence.

The values of Δz range from $0,81 \cdot 10^{-3}$ m to $0,23 \cdot 10^{-3}$ m when the singleness coefficients of two-screw belt supports are from $0,27 \cdot 10^{4}$ N/m to $1.45 \cdot 10^{4}$ N/m and F_{TQ}=20 N decreases in non-linear connection up to, when the resistance increases up to 35 kg, the range of shaft vibration is from $1,2 \cdot 10^{-3}$ m to $0.33 \cdot 10^{-3}$ m. Accordingly, the twin-screw shaft vibration decreases nonlinearly from 7,35 m/s to 0,28 m/s when Δz values are $F_{TQ} \leq 20$ N, and Δz values from 9,3 m/s to 4 when the resistance is 35 N. It decreases to 2 m/s. Therefore, to ensure that the center of gravity of the two-screw shaft does not exceed the values of the vertical vibration range $(1,0 \div 1,5) \cdot 10^{-3}$ m, the values of the unity coefficients of the strapping elements on the supports are $(0,7 \div 0,95) \cdot 10^{4}$ N/m It is desirable to get between.



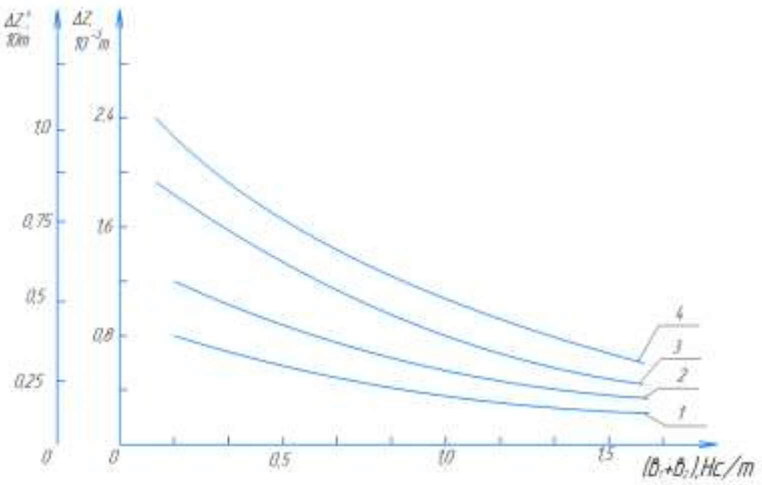
T1=T2, Phase shift, $\pi/2$

C1=C2, A1=1,5A2

Figure 9. The pitch of the screws on the shaft is equal to each other and the difference in amplitude is 1.5, and the laws of vibration of the shaft.

The resulting laws of change of Δz show that the vibration amplitude stabilizes, although the frequency of the shaft vibration does not change with the increase in resistance. It also improves the cleaning effect.

The obtained Δz change patterns were constructed. In particular, twin-screw shaft bearing supports depend on the proper selection of the dissipation characteristic in order to reduce vibration to the desired level.



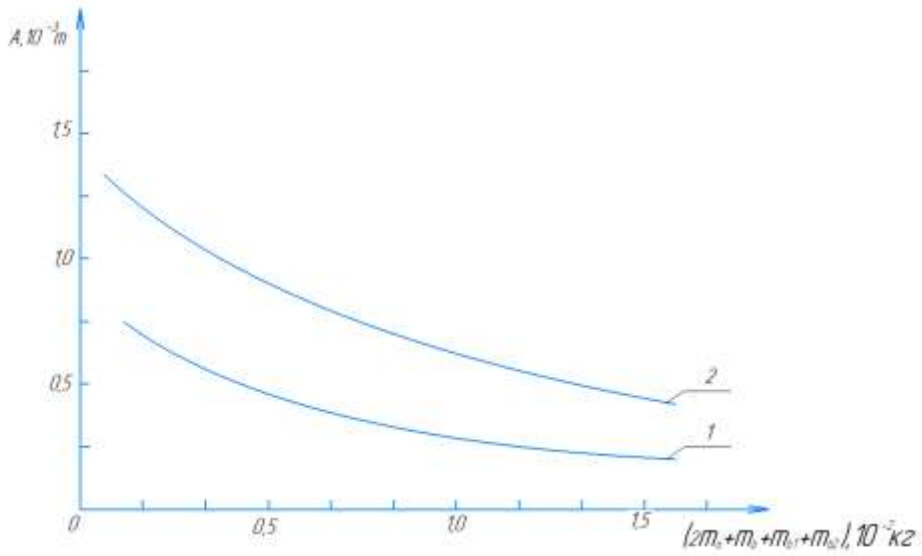
1,2 – Δz=f(b); 3,4 – Δz=f(b); 2,4 – F_{TQ} =36 N; 1,3 – F_{TQ} =20 N

Figure 10. Graphs of dependence of displacement and velocity ranges in vertical vibration of a conveyor twin-screw shaft on the dissipation coordinates given by belt supports.

According to the analysis, when the values of the dissipation coefficients of the supports are increased from 0,6 N s/m to 2,8 N s/m and the technological resistance is set to 20 N, the values of Δz are decreases from 0,71·10-3 m to 0,2·10-3 m. And $\Delta z0$ values decrease from 8,6 m/s to 2,3 m/s in nonlinear coupling. Correspondingly, if the resistance increases, the values of Δz and $\Delta z0$ will be higher. In particular, when FTQ=36 N, Δz values decrease from 0,94·10-3 m to 0,6·10-3 m. It can be seen that Δz values decrease from 10.7 m/s to 2.9 m/s in the appropriate state (Fig. 10, graphs 2, 4).

Recommended values of dissipation coefficients in belt supports to adequately reduce screw shaft vibrations b1=b2=(1,8÷2,3) N s/m.

It is known that the greater the mass of the shaft, the smaller the amplitude of the oblique vibration. Link graphs were constructed based on (6).



1–F_{TQ} =20 N; 2–F_{TQ}=35 N;

Figure 11. The coefficient of dependence on the variation of the vibration amplitude of the double-screw conveyor shaft is presented.

Analyzing the graphs, the vibration amplitude decreases from 0,76·10-3 m to 0,29·10-3 m when the total mass of the two-screw shaft increases from 4,5 kg to 18 kg and FTQ=20 N. Also, Az values decrease from 1,28·10-3 m to 0,56·10-3 m in nonlinear coupling when the resistance increases to 35 N. (Figure 11, graph 2). In order to ensure that the vertical vibration amplitude of the two-screw shaft does not exceed 1,0·10-7 m, it is recommended that the total mass be in the range of (14÷17) kg.

Conclusion. A high-efficiency twin-screw conveyor with belt-bearing supports has been developed. A mathematical model representing the vibrations of a shaft with two screw belt element bearing supports is obtained. Based on the numerical solution of the problem, the laws of vibration of the two-screw shaft were obtained. Based on the analysis of the connection graphs, the recommended values of the parameters of the conveyor with two screw shafts are based.

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