Torsion of an unevenly loaded tubular belt on a straight route of a belt tubular conveyor

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Abstract. The problem of torsion of a tubular belt on a straight route of a belt tubular conveyor (BTC) under the influence of stationary de-centering factors is considered. The effect of torques from uneven loading of the belt on the possibility of its torsion is investigated. It is shown, that the angle of rotation of the tape depends not only on the magnitude of the applied torque, but also on the design of the BTC, the geometric characteristics of the section of the tubular belt, the physical properties of its material. The effect of the coefficient of friction of the belt on the rollers on the possibility of its rotation has been investigated for various belt loading options with maximum irregularity. It is shown, that with a decrease in the load of the belt, the danger of its torsion increases. The boundaries, in which the coefficient of friction of the belt on the rollers must be found, are determined, so that the torsion of the belt does not occur.

Introduction

The belt of the tubular conveyor is rolled up into a pipe and moves inside the roller supports, each of the representing a regular polygon (most often a hexagon) formed by supporting rollers. When moving along the roller supports, the belt of the tubular conveyor is subjected to the action of torsional moments resulting from the coagulation of the belt into the pipe, the bending of the conveyor belt, the skewing of the supporting rollers, the uneven loading of the belt. These moments can lead to a significant angular rotation of the belt, which, in turn, will cause instability, spillage of the load, dusting.

On the straight rout of the belt tubular conveyor (BTC), the greatest danger in terms of the occurrence of torques is represented by stationary de-centering factors – skews of the roller supports in the horizontal plane and deviations of the sections of the base from the axis of the conveyor. Off-center belt loading can also be considered a static factor if the steady-state load flow is shifted by a constant value relative to the central axis of the tubular belt.

The studies of the torsion of the tubular belt on the straight part of the conveyor route are devoted to the work of R.V. Kiriya, G.I. Larionov and N.G. Larionov [1, 2]. The authors, considering the tubular belt as a cylindrical shell, obtained mathematical models of the stress-strain state of the belt, considered issues of torsion and loss of stability of the section of the tubular belt, taking into account its uneven loading. Since the unevenness of

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the cargo traffic is not possible to establish exactly, the torsion estimates are qualitative, there are no specific recommendations for eliminating torsion.

To set the limits of the possible angular movement of the tubular belt on the straight section of the conveyor and to give specific recommendations on the choice of parameters of the belt and roller supports, it is necessary to consider the torsion of the belt under the action of an uneven load in extreme cases: maximum and minimum loads, considering the center of gravity displacement, in both cases, is maximum.

Methods

In the study of the torsion of a tubular conveyor belt on a straight route, we represent it in the form of a tubular rod with one rigidly fixed ($x = 0$) and another free end ($x = l$), to which torque M (N·m) is applied [3].

The total twist angle θ along x, measured from the terminated end, is determined by the integral

$$\theta = \int_0^x \frac{Mdx}{GI_p}, \quad (1)$$

where GI_p is the stiffness of the section during torsion, N·m^2.

If the section stiffness GI_p is constant throughout the integration area, then

$$\theta = \frac{Mx}{GI_p}. \quad (2)$$

The tubular belt on the straight part of the track is supported by n roller supports mounted at a distance l_s from each other. There is a moment M_i attached to the belt on each roller support. Consider the torsion of the section of the belt BTC from the drive drum to the first roller support. We believe that the left end of the belt is fixed relative to the corner turns, and the right end, located on the roller, can be rotated under the action of the torques applied to it, due to the uneven loading of the conveyor and the friction forces of the belt on the roller:

$$M_1 = M_l - M_f, \quad (3)$$

where M_1 is the torque applied to the belt on the first roller support, N·m; M_l is torque due to uneven loading of the tape, N·m; M_f is torque from the friction forces of the tape on the roller, N·m.

Thus, to determine the angle of twist θ_1 of the cross section of the belt, located on the first roller support , you can use the formula (2), substituting in it the value of M_1, defined by the formula (3), and taking as x the distance between the roller supports, that is $x = l_s$:

$$\theta_1 = \frac{M_1 l_s}{GI_p}. \quad (4)$$

In order to determine θ_n – the twist angle of the belt on the n-th roller supports, it is necessary to sum the values of the torques acting on all the roller supports, counting from the fixed end of the belt to the n-th roller supports, and as the length of the rod take the distance from the fixed end to the n-th roller supports, then

$$\theta_n = \frac{nl_s}{GI_p}\sum_{i=1}^{n} M_i \,.$$

Since it is impossible to accurately determine the value and direction of torques on each roller supports, for approximate calculations we can assume that moments equal in magnitude and acting in one direction are attached to each roller supports, then

$$\theta_n = \frac{M_1 n^2 l_s}{GI_p} \,. \tag{5}$$

To ensure stable operation of the tubular conveyor, the following condition must be met

$$\theta_n \leq [\theta] \,, \tag{6}$$

where [θ] is the permissible twist angle of the tubular belt, i.e. such an angle at which the divergence of the sides of the belt and the spilling of the load will not occur.

In view of (5), we write condition (6) for the n-th roller supports in the form:

$$\frac{M_1 n^2 l_s}{GI_p} \leq [\theta] \,,$$

or else

$$\frac{n^2 l_s}{GI_p} \leq \frac{[\theta]}{M_1} \,. \tag{7}$$

Given the value [θ] and estimating the moment M_1 applied to the first roller supports, you can choose the parameters of the conveyor (the number of roller supports and the distance between them) and the torsional rigidity of the belt, satisfying inequality (7). The numerator of the left side of this inequality linearly depends on the length of the conveyor and the number of roller supports, i.e. the twisting angle of the conveyor belt is the greater, the greater its length. Increasing the number of roller supports also plays the role of a destabilizing factor.

We give an estimate of the moments of M_l and M_f acting on the roller supports. Let the fill factor of the tubular belt k_l be 0.75, i.e. filled 3/4 section. Consider the worst variant of uneven loading, when the right half of the cross section is completely filled, and the left by half only. Determine the coordinates of the point C – the center of gravity of the section (Fig. 1).

The center of gravity of the circular sector with the central angle α lies on the bisector of the angle AOB at a distance $OC = 4R\cdot\sin(\alpha/2)/(3\alpha)$ from the center of the circle.

In our case $\alpha = \frac{3}{2}\pi$; $\sin\frac{\alpha}{2} = \frac{\sqrt{2}}{2}$; $OC = \frac{4\sqrt{2}}{9\pi}R$.

Then the coordinates of the point C:

$$x_c = OC\cos\left(\frac{\alpha}{2} - \frac{\pi}{2}\right) = \frac{4R}{9\pi}; \quad y_c = OC\sin\left(\frac{\alpha}{2} - \frac{\pi}{2}\right) = -\frac{4R}{9\pi} \,. \tag{8}$$

Denote $k_c = x_c/R$ – the coefficient of displacement of the center of gravity of the load. According to (8), when filling the cross section of the belt by 3/4 ($k_l = 0.75$), $k_c = 4/9\pi = 0.14$.

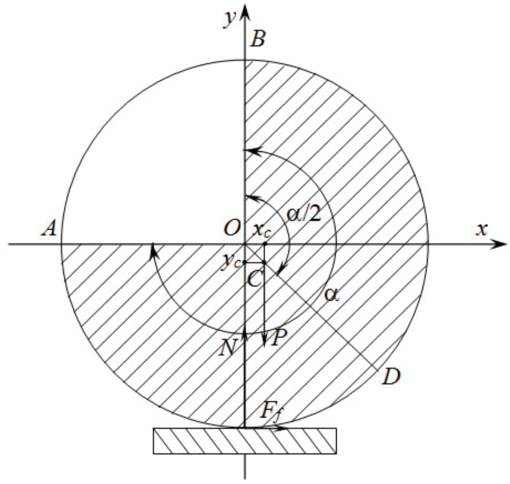

Fig. 1. Section of a tubular belt, unevenly loaded by 3/4 volume.

Torque from uneven loading of the belt, acting on the first roller supports, we calculate by the formula

$$M_l = Pk_cR ,$$

where $P = \rho gSl_s$ is the weight of the load per one roller support, N; ρ – density of load, kg/m^3; $S = k_l\pi R^2$ – loading area, m^2; g – acceleration of gravity, m/s^2.

Because $P = \rho g k_l \pi R^2 l_s$, that

$$M_l = k_c k_l \pi \rho g l_s R^3 . \quad (9)$$

This moment is counteracted by the torque M_f, caused by the friction F_f of the belt on the rollers:

$$F_f = fN ,$$

where N is the resultant of normal reactions of the rollers, N; f is coefficient of friction of the belt on the rollers.

Because N=P, the torque of the friction force is

$$M_f = PfR = k_l f \pi \rho l_s g R^3 . \quad (10)$$

The tubular belt can turn in the roller support, if the torque from uneven loading is greater, than the moment created by the friction force of the belt on the rollers, that is, when

$$M_l > M_f . \quad (11)$$

Substituting (9) and (10) into inequality (11), we get

$$k_c k_l \pi \rho g l_s R^3 > k_l f \pi \rho l_s g R^3 ,$$

from where the belt scrolling condition

$$k_c > f . \quad (12)$$

When the fill factor is $k_l = 0.75$, the coefficient of displacement of the center of gravity of the load is $k_c \le 0.14$. The coefficient of friction of the belt on the rollers (rubber for steel) is in the range of $0.3 \le f \le 0.5$ (0.5 for dry surfaces; 0.3 for flooded). In the worst case, uneven loading ($k_c = 0.14$) and flooded surfaces ($f_c = 0.3$) $k_c < f$, i.e. scrolling of the belt will not happen.

We considered the option of maximum load belt BTC. From the practice of operating BTC it is known that the scrolling of the belt can occur when it is not fully loaded. Consider the case when the belt is loaded by 1/4 of the volume, while loading is performed with a shift of the center of gravity of the load. In Figure 2 shows the most unfavorable option of such a load.

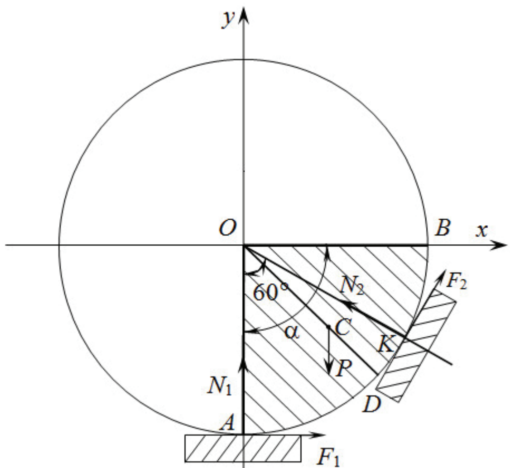

Fig. 2. Section of a tubular belt loaded by 1/4 of the volume and based on two rollers of six-rollers support.

As shown above, the center of gravity of the circular sector *AOB* lies on the bisector *OD* of the angle α, and

$$OC = \frac{4}{3\alpha} R \sin\frac{\alpha}{2} .$$

Since in our case α=π/2,

$$OC = \frac{4\sqrt{2}}{3\pi} R = 0.6R .$$

Coordinates of the center of gravity *C*

$$x_c = OC\cos\frac{\pi}{4} = 0.425R \; ; \quad y_c = -OC\sin\frac{\pi}{4} = -0.425R .$$

The coefficient of displacement of the center of gravity of the belt, in this case, is equal to:

$$k_c = \frac{x_c}{R} = 0.425 . \qquad (13)$$

We believe that the loaded section of the belt is in contact with two rollers, the normal reactions of which we denote N_1 and N_2 (Fig. 2). Through F_1 and F_2 we denote the friction forces of the belt on the rollers

$$F_1 = fN_1, \quad F_2 = fN_2.$$

Equilibrium equations of the belt section:

$$\sum X = fN_1 - \frac{1}{2}N_2 + \frac{\sqrt{3}}{2}fN_2 = 0; \tag{14}$$

$$\sum Y = N_1 - \frac{\sqrt{3}}{2}N_2 + \frac{1}{2}fN_2 = P. \tag{15}$$

Solving the system of equations (14) and (15), we define the normal reactions of the rollers

$$N_1 = P\frac{1-\sqrt{3}f}{1+f^2}; \quad N_2 = \frac{2Pf}{1+f^2}.$$

Belt unscrew condition

$$M_f > M_l$$

or

$$f(N_1 + N_2)R > Pk_cR.$$

From where

$$\frac{1+(2-\sqrt{3})f}{1+f^2}f > k_c. \tag{16}$$

In this case, the rotation of the tubular belt does not occur if the coefficient of friction of the belt on the rollers f and the coefficient of displacement of the center of gravity k_c are related by the relation (16), which, taking into account (13), is converted to

$$0.157f^2 - f + 0.425 < 0,$$

from where

$$0.4575 < f < 5.911.$$

Condition (16) is satisfied if $f > 0.4575$.

Thus, at the minimum load of the belt, the condition of its non-twisting is tightened – for the case of a flooded belt ($f = 0.3$), the belt can be rotated.

Results and discussion

Uneven loading of the belt creates the danger of belt twisting on the straight section of the conveyor route. If at the maximum load and the worst case its unevenness ($k_c = 0.14$) is the torque from the load $M_l = 0.14RP$, then at the minimum load ($k_l = 0.25$) and the maximum for this case non-uniformity ($k_c = 0.425$) the torque from the load $M_l = 0.425RP$.

Friction of the surface of the belt on the rollers acts as a stabilizing factor. It is shown that torsion does not occur if at maximum load the coefficient of friction $f > 0.14$, at minimum load the coefficient of friction $f > 0.4575$.

The coefficient of friction of rubber on steel does not exceed 0.5 for dry surfaces. If the surfaces are flooded or frozen, the friction coefficient may be halved. Such values of the friction coefficient can lead to belt torsion with minimal uneven loading.

Thus, when choosing materials for the belt and rollers (or their linings), one should choose pairs with $f > 0.5$, and when using BTC, try to avoid watering or freezing of the belt.

Conclusions

1. The factors affecting the torsion of an unevenly loaded tubular belt as it moves along the straight part of the conveyor are investigated. It is shown that the angle of rotation of the belt depends not only on the magnitude of the applied torque, but also on the design of the BTC, the geometric characteristics of the section of the tubular belt, the physical properties of its material.

2. For various options for loading the belt with maximum irregularity, the influence of the coefficient of friction of the belt on the rollers on the possibility of its rotation has been investigated. It is shown that with a decrease in the load of the belt, the danger of its torsion increases. To ensure that the tape does not turn, the coefficient of friction of the belt on the rollers must be at least 0.5.

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