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THEORETICAL RESEARCH OF THE INFLUENCING OF THE BASIC PARAMETERS OF TUBULAR BELT CONVEYORS ON THE MAGNITUDE OF RISK OF TUBULAR BELT TORSION

Zhyhula T.I., Mishchenko T.F.

M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine

Abstract. A tubular belt conveyor (TBC) as a completely sealed transport installation is a promising solution for creating environmentally friendly transportation systems. TBC causes the least environmental damage compared to other types of conveyor transport. However, due to the more complex processes that take place during the operation of the TBC, namely the movement of a tubular belt with a load on roller supports, TBC failures and their consequences differ significantly from those of other conveyors. TBC failures can occur as a result of the tubular belt torsion, which leads to dusting and spillage. The risk of TBC belt torsion depends on its parameters: radius of the tubular belt, distance between roller supports, torsion stiffness of the belt cross-section, bulk density of the load, uneven loading of the belt, and coefficient of friction of the belt on the rollers. The torsion of the TBC belt section from the drive drum to the first roller support is considered. The cross-section of the belt on the roller support can rotate 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 rollers. The condition for belt turning is obtained. It is shown that torsion is possible if the torque from uneven loading is greater than the torque from friction forces, or the coefficient of displacement of the centre of gravity of the load is greater than the coefficient of friction of the belt on the rollers. The risk of a tubular conveyor belt torsion in a roller support due to uneven loading is determined. The coefficient of displacement of the centre of gravity of the load and the coefficient of friction of the belt on the rollers are considered as random variables with normal probability distribution functions. The cases of loading the belt at 25 % and 75 % of its volume are considered. At a minimum belt load (25 %), the risk of scrolling is 0.01, and if the load increases by 3 times, the risk of belt torsion in the roller support is $2 \cdot 10^{-5}$. The article considers the influence of the coefficient of friction of the belt on the rollers on the risk of its slippage. In cases of watering or icing of the TBC belt, the value of the coefficient of friction of the belt on the rollers can significantly decrease, and the risk of slippage can increase tenfold. The greatest risk of TBC belt torsion in the roller support occurs when the belt is minimally loaded and the coefficient of friction of the belt on the rollers decreases, which can occur due to watering or icing of the belt. To ensure the minimum risk of TBC belt scrolling on a roller support, it is necessary to ensure its maximum load and the maximum possible value of the coefficient of friction of the belt on the rollers.

Keywords: tubular belt conveyor, belt torsion, spillage.

1. Introduction

Tubular belt conveyors (TBC) are a relatively new type of machine for transporting bulk materials, especially environmentally harmful ones. Tubular belt conveyors are compact and airtight, allowing for optimal solutions to transport large flows of materials, operating on complex curved tracks, without reloading stations, and with low production costs. As a fully sealed transport unit, the TBC is a promising solution for creating environmentally friendly transport systems. The use of TBCs is constantly growing due to the growth of load flows and transport distances. Rather high capital costs are offset by low operating costs.

The operation of a tubular belt conveyor can be accompanied by the phenomenon of torsion of the tubular belt of the load-carrying branch, which leads to conveyor failures and a decrease in its reliability. The phenomenon of torsion of the tubular belt of the TBC was studied by M.S. Efimov [1], V.G. Dmitriev [2], R.V. Kiriya and G.I. Larionov [3, 4], etc. These papers consider the influence of various factors on the value of the belt twist angle, including the unevenness of the belt cross-section loading. M.S. Efimov notes that if a belt twist angle is greater than 20°, then the contact of the belt edge with the adjacent roller of a six-roller support can lead to the belt failures [1]. When the belt cross-section is significantly rotated, the bulk load acts on the joint of the belt sides, causing their separation, loss of sealing and load spillage. The probability of a significant of the twist angle of the TBC belt has not been previously determined.

The aim of this paper is to determine the probability of TBC failures due to belt torsion and theoretical research of the influence of its parameters on the risk of tubular belt torsion.

2. Methods

To determine the risk of tubular belt torsion and load spilling in the event of its uneven loading, it is necessary to have data on its main parameters - tubular belt radius, distance between roller supports, torsional stiffness of the belt cross-section, bulk density of the load, as well as data determined by experimental means – permissible twist angle of the cross-section, coefficient of friction of the belt on the rollers, or in the course of operation - the coefficient of filling the cross-section of the tubular belt and the coefficient of displacement of the centre of gravity of the load.

While the main parameters of the belt are specified during the design of the tubular conveyor and can be considered constant, the coefficient of friction of the belt on the rollers depends on external conditions and can vary within a fairly wide range, and the fill factor and the coefficient displacement of centre of gravity the belt cross-section can only be determined from operational data.

Consider the torsion of the TBC belt section from the drive drum to the first roller support (Fig. 1).

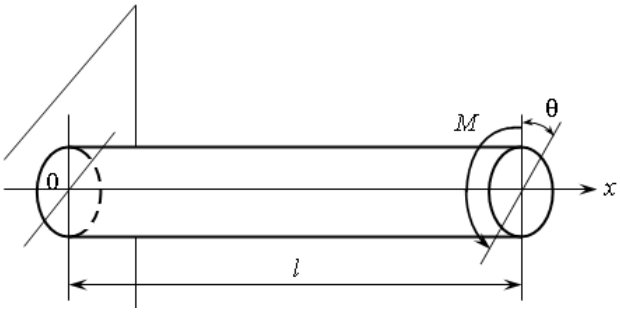

Figure 1 – Design scheme for torsion of a section of a tubular belt [5]

We assume that the left end of the belt is fixed with respect to angular turns, and the right end, which is on a roller support, can rotate under the action of torques applied to it due to the uneven loading of the conveyor and the friction forces of the belt on the rollers:

$$M_1 = M_l - M_f ,$$

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

Then, according to [6], the twist angle of the cross-section θ_1 of the belt located on the first roller support is equal to

$$\theta_1 = \frac{M_1 l_s}{GI_p}, \qquad (1)$$

where l_s is the distance between the roller bearings, m; GI_p is the torsional stiffness of the tubular belt cross-section, N·m^2.

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

$$\theta_1 \le [\theta], \qquad (2)$$

where $[\theta]$ is the permissible twist angle of the belt cross-section, rad.

According to [1], we take $[\theta] = 20°$.

Taking into account (1), we obtain

$$\frac{M_1 l_s}{GI_p} \le [\theta]. \qquad (3)$$

Then the condition for the occurrence of spilling

$$\frac{M_1 l_s}{GI_p} > [\theta]. \qquad (4)$$

3. Theoretical part

Rotation of the cross-section of a tubular belt is possible if the following condition is met

$$\frac{M_1 l_s}{GI_p} > 0, \ \frac{(M_l - M_f) l_s}{GI_p} > 0,$$

or else

$$M_l > M_f. \qquad (5)$$

In other words, the belt can turn if the torque from uneven loading is greater than the torque from friction. According to [6], the torque from uneven loading

$$M_l = k_c k_l \pi \rho g l_s R^3, \qquad (6)$$

where k_c is the coefficient of displacement of the centre of gravity of the load; k_l is the coefficient of filling the cross-section of the tubular belt; ρ is the bulk density of the load, kg/m^3; R is the radius of the tubular belt, m; g is the acceleration of gravity, m/s^2.

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

$$M_f = k_l f \pi \rho g l_s R^3, \tag{7}$$

where f is the coefficient of friction of the belt on the rollers.

Substituting (6) and (7) into inequality (5), we obtain

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

whence the condition of torsion the belt

$$k_c > f. \tag{8}$$

Let's determine the risk of a tubular conveyor belt torsion in a roller support due to uneven loading.

Consider the case of incomplete loading, when the belt is loaded to ¼ of its volume. In this case, the coefficient of displacement of the centre of gravity of the load per roller support can be within the following range [6]

$$0 \le k_c \le 0.425.$$

The value of the friction coefficient f is in the range of

$$0.3 \le f \le 0.5.$$

Both coefficients are considered as random variables with normal probability distribution functions [7]. The torsion of the belt is characterised by condition (8).

Let us denote

$$m = f - k_c,$$

if $m > 0$, no scrolling will occur.

For all variables, we use the normal distribution law, characterised by two parameters – median and variance $(\check{k}_c, \check{f}, \check{m}; \sigma_{k_c}, \sigma_f, \sigma_m)$.

We accept

$$\check{k}_c = 0.2;\ \check{f} = 0.4;\ \sigma_{k_c} = 0.1\check{k}_c;\ \sigma_f = 0.2\check{f},$$

then

$$\check{m} = \check{f} - \check{k}_c = 0.2\,;\ \sigma_m = \sqrt{\sigma_f^2 + \sigma_{k_c}^2} = 0.0825\,.$$

Let's introduce the variable u by the formula

$$u = (0 - m)/\sigma_m = -\frac{0.2}{0.0825} = -2.42\,.$$

The possibility of torsion the belt due to uneven loading

$$P(m < 0) = \Phi(u)\,,$$

where $\Phi(u)$ is the normalised function for the normal distribution.

According to Table 1 of the values of the normalised function for the normal distribution given in [7], we determine Φ(-2.42) = 0.01.

The risk of torsion of a tubular conveyor belt loaded to ¼ of its volume with a shift of the centre of gravity is

$$\text{risk} = \Phi(-2.42) = 0.01\,.$$

Table 1 – Values of the normalised function for the normal distribution

u	$\Phi(u)$	u	$\Phi(u)$
–3.29	0.0005	0.00	0.50
–3.09	0.0010	0.25	0.60
–2.58	0.0050	0.52	0.70
–2.33	0.0100	0.84	0.80
–1.96	0.0250	1.28	0.90
–1.64	0.0500	1.64	0.95
–1.28	0.1000	1.96	0.975
–0.84	0.2000	2.33	0.990
–0.52	0.3000	2.58	0.995
–0.25	0.4000	3.09	0.999
0.00	0.5000	3.29	0.9995

Consider also the case of loading the tubular belt by ¾ of the volume, then according to [6], the coefficient of displacement of the centre of gravity of the load per roller support can vary within

$$0 \le k_c \le 0.14\,.$$

We accept

$$\check{k}_c = 0.07\,;\ \check{f} = 0.4\,;\ \sigma_{k_c} = 0.1\check{k}_c\,;\ \sigma_f = 0.2\check{f}\,,$$

then

$$\check{m} = \check{f} - \check{k}_c = 0.33\,;\ \sigma_m = \sqrt{\sigma_f^2 + \sigma_{k_c}^2} = 0.0803\,;$$

$$u = (0 - m)/\sigma_m = -\frac{0.33}{0.0803} = -4.101\,.$$

Table 1 shows that $\Phi(-4.101) = 2 \cdot 10^{-5}$,

$$\text{risk} = \Phi(-4.101) \approx 2 \cdot 10^{-5}.$$

4. Results and discussion

The greatest risk of spinning occurs when the belt load is minimal. When the tubular belt is loaded to ¼ of its volume, the risk of its torsion in the roller support is 0.01, i.e. torsion can occur on one roller support in a hundred. If the belt load is ¾ of its volume, then the risk of torsion in this case is equal to $2 \cdot 10^{-5}$. Thus, a 3-fold increase in the load of a tubular belt reduces the risk of torsion by 500 times.

Consider the effect of the belt's friction coefficient on the rollers on the risk of belt torsion when the belt is unevenly loaded. In the most unfavourable case, the belt is loaded by ¼ of its volume, and the load centre of gravity displacement is $0 \le k_c \le 0.425$. The coefficient of friction of the belt on the rollers in case of watering or icing of the belt may be less than 0.3.

Accept

$$\check{k}_c = 0.2\,;\ \check{f} = 0.25\,;\ \sigma_{k_c} = 0.1\check{k}_c\,;\ \sigma_f = 0.2\check{f}\,,$$

then

$$\check{m} = \check{f} - \check{k}_c = 0.05\,;\ \sigma_m = \sqrt{\sigma_f^2 + \sigma_{k_c}^2} = 0.0539\,;$$

$$u = (0 - m)/\sigma_m = -\frac{0.05}{0.0539} = -0.926\,.$$

According to Table 1, we determine

$$\text{risk} = \Phi(-0.926) \approx 0.23.$$

Thus, the risk of torsion of a partially loaded tubular belt scrolling when it is watered increases by 23 times.

5. Conclusions

1. The condition for the torsion of a tubular conveyor belt in the case of uneven loading was obtained, depending on its parameters: belt radius, distance between roller supports, torsional stiffness of the belt cross-section, bulk density of the load, coefficient of friction of the belt on the rollers, and cross-sectional filling factor.

2. The risk of tubular belt torsion at uneven belt loading is determined. The greatest risk of belt torsion occurs when the belt is minimally loaded and the coefficient of friction between the belt and the rollers decreases, which can occur due to watering or icing of the belt.

3. To ensure the minimum risk of the tube conveyor belt torsion on the roller support, it is necessary to ensure the maximum belt load and the highest possible value of the coefficient of friction of the belt on the rollers.

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About the authors

Zhyhula Tetiana Illivna, Candidate of Technical Sciences (Ph.D.), Senior Researcher in Department of Geomechanics of Mineral Opencast Mining Technology, M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM of the NAS of Ukraine), Dnipro, Ukraine, zhigulat@gmail.com.

Mishchenko Tamara Fedorivna, Master of Science, Senior Specialist in Department of Geomechanics of Mineral Opencast Mining Technology M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM of the NAS of Ukraine), Dnipro, Ukraine, mishenkotamaraf@gmail.com.

ТЕОРЕТИЧНІ ДОСЛІДЖЕННЯ ВПЛИВУ ОСНОВНИХ ПАРАМЕТРІВ ТРУБЧАСТИХ СТРІЧКОВИХ КОНВЕЄРІВ НА ВЕЛИЧИНУ РИЗИКУ КРУЧЕННЯ ТРУБЧАСТОЇ СТРІЧКИ

Жигула Т.І., Міщенко Т.Ф.

Анотація. Трубчастий стрічковий конвеєр (ТСК) як повністю герметична транспортна установка є перспективним рішенням при створенні екологічно чистих систем транспортування. ТСК наносять найменшу шкоду навколишньому середовищу в порівнянні з іншими видами конвеєрного транспорту. Але через більш складні процеси, що відбуваються при експлуатації ТСК, а саме при русі трубчастої стрічки з вантажем по роликоопорах, відмови ТСК і їх наслідки суттєво відрізняються від тих, що характерні для інших конвеєрів. Відмови ТСК можуть статися внаслідок прокручування трубчастої стрічки, що призводить до пиління і просипу вантажу. Ризик прокручування стрічки ТСК залежить від її параметрів: радіуса трубчастої стрічки, відстані між роликоопорами, жорсткості перетину стрічки, насипної щільності вантажу, нерівномірності завантаження стрічки, коефіцієнта тертя стрічки об ролики. Розглянуто кручення ділянки стрічки ТСК від приводного барабана до першої роликоопори. Переріз стрічки, що знаходиться на роликоопорі, може повертатися під дією прикладених до нього крутильних моментів, зумовлених нерівномірністю завантаження конвеєра і силами тертя стрічки об ролики. Отримано умову повороту стрічки. Показано, що поворот можливий, якщо крутильний момент від нерівномірного завантаження більше крутильного моменту від сил тертя, або коефіцієнт зміщення центру ваги вантажу більше коефіцієнта тертя стрічки об ролики. Визначено ризик прокручування стрічки трубчастого конвеєра в роликоопорі, зумовленого нерівномірністю її завантаження. Коефіцієнт зміщення центру ваги вантажу і коефіцієнт тертя стрічки об ролики розглядаються як випадкові величини, що мають нормальні функції розподілу імовірності. Розглянуто випадки завантаження стрічки на 25% та 75% її об'єму. При мінімальному завантаженні стрічки (25%) ризик прокручування дорівнює 0,01, а якщо завантаження збільшується в 3 рази, то ризик прокручування стрічки в роликоопорі дорівнює $2 \cdot 10^{-5}$. Розглянуто вплив коефіцієнту тертя стрічки об ролики на ризик її прокручування. У випадках обводнення або заледеніння стрічки ТСК значення коефіцієнту тертя стрічки об ролики може значно знизитись, а ризик прокручування збільшитись в десятки разів. Найбільший ризик прокручування стрічки ТСК в роликоопорі виникає при мінімальному її завантаженні та зниженні значення коефіцієнта тертя стрічки об ролики, яке може статися внаслідок обводнення або заледеніння стрічки. Для забезпечення мінімального ризику прокручування стрічки ТСК на роликоопорі необхідно забезпечити максимальне її завантаження, та максимально можливе значення коефіцієнта тертя стрічки об ролики.

Ключові слова: трубчастий стрічковий конвеєр, кручення стрічки, просип вантажу.