Methods Of Strength Calculation Of Multi-Layer Conveyor Belts

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ABSTRACT

The article examines the essence of several works on the study of the strength and durability of conveyor belts and the methods of calculating the service life of the belts. By studying and analyzing the previous works, the ways of developing the optimal method of calculating the strength of multi-layer conveyor belts are shown.

Keywords: belt, conveyor, layer, tension, rubber, diameter, drum, force, fatigue, tension, load, strength, multilayer, bending, deformation, fabric, stretch, roller, shear.

Introduction

Today, the increase in the world's demand for natural resources, the expansion and development of open-pit mines and the launch of new mines, the wide use of conveyor transport in them and the requirements for further improvement of conveyor constructions, have determined the urgency of solving a number of problems to increase the durability of conveyor belts. One of the most important of them is to study the fatigue properties of rubber-fabric conveyor belts, to develop practical recommendations for increasing their service life.

There are a number of works devoted to the study of strength and durability of conveyor belts [1-4]. At the same time, the methods of calculating the service life of tapes are mainly based on statistical data, which do not always allow to determine the real reasons and physical characteristics of the tapes' wear due to fatigue.

In order to calculate the strength and durability of conveyor belts, it is necessary to know the magnitude and properties of the stresses generated under the influence of external forces. Investigations show that stresses in a multi-layer tensile frame can be divided into the following groups:

a) along the longitudinal axis of the tape, the stresses in the fibers based on the layers;

b) stresses transverse to the longitudinal axis of the tape;

c) tensile stresses causing separation of layers;

g) depending on the construction of the belt frame, contact stresses in the fibers of the layer, as well as local stresses in the places where the transported material and conveyor rollers come into contact. The voltages at the point where the ends of the tape are connected have special properties.

Currently, when calculating multi-layer rubber-fabric tapes, the following equation is used to determine the maximum tensile stresses:

$$S_P = S_{\max}\eta_n \qquad (1.1)$$

At the same time

$$S_P = iBS_n^1 \quad (1.2)$$

in which Sp–breaking stress, kgf; Max - maximum permissible tension, kgf;spirit–the coefficient of the reserve of static strength of the tape; S_n^1 - strength limit, kgf for 1 cm width of the layer; i is the number of tape layers. It is determined by the following equations:

$$iBS_n^1 \rangle \eta_n S_{\max} \quad (1.3)$$

and

$$i \geq \frac{\eta_n S_{\max}}{BS_n^1}, \quad (1.4)$$

In other works [5,6] spirit the following equation for determining the coefficient is recommended

$$\eta_n = \eta_H K_g P_o \quad (1.5)$$

in thisspirit- transport reserve coefficient of the tape under static tension; Kg is the coefficient of voltage increase in non-stationary processes; P_o is the coefficient of influence of operational factors.

In turn, it is proposed to determine the Ro coefficient as a product of the coefficients, i.e.:

$$P_o = P_H P_u P_k P_n \quad (1.6)$$

where P_n is the relative strength coefficient of the new tape;

P_u is the coefficient of reduction of the width of the tape as a result of the erosion of the edges of the tape;

P_k is the coefficient of reduction of the strength of the tape frame during operation;

P_n is the damage coefficient of the frame.

These coefficients are found by the following equation:

$$P_H = \frac{I}{I - 0,03i};$$

$$P_u = \frac{B}{B - \Delta B}, \quad (1.7)$$

where ΔB is tape narrowing due to edge wear

$$\Delta B = 2(\iota_o - \iota_H);$$

$$P_K = \frac{\sigma}{\sigma - f(T)}, \quad (1.8)$$

T is the duration of the tape.

$$P_n = \frac{1}{e^{-b_1 \Delta \iota lay}} \quad (1.9)$$

The value of b-coefficient is in the range of 0.12-0.15.

In general, after setting the values of all the coefficients, the formula for determining the coefficient of static strength reserve of the tape is as follows:

$$\eta_n = 3,05 \frac{I}{I - 0,03i} \frac{B}{B - 2\iota_o + 2\iota_H} \frac{\sigma}{\sigma - f(T)} \frac{I}{e^{-b_1 \Delta \iota lay}} \quad (1.10)$$

Calculations according to the above formula (1.10) give the value of the coefficient of static stability in the range from 11 to 12 [5]. However, when determining the coefficient of static strength according to this method, only the tensile stresses of the tape are taken into account.

The above-mentioned method of determining the number of layers based on operational data is simple and easy to use. This method is reliable for simple design calculation of conveyors. However, due to the increase in load flow and the need to design long, heavy-duty conveyors using expensive belts, it is necessary to have a more accurate method that can account for all the phenomena that occur during the operation of the belt. is appropriate.

Resilience reserve factor in recent timesspiriton the basis of various components of a number of works on identification have appeared.

[5-11] To account for the uneven distribution of stresses between layers, a roughness factor is introduced, which indicates how much of the tape's ultimate strength can be realized by i layers.

$$K_H = \frac{S_{\max \cdot p}^1}{S_n^1 i} \quad (1.11)$$

Here $S_{\max \cdot p}^1$ – true tape break voltage.

The following formula is used to determine the strength of the tape:

$$S_{\max \cdot p}^1 = S_n^1 i \left[1 - (i-1)0,05\right] \quad (1.12)$$

Thus, using the formula (1.11), the unevenness coefficient is found:

$$K_H = \frac{(I - 0,05 + 0,05)S_n^1 i}{S_n^1 i} = I,05 - 0,05 \quad (1.13)$$

Basically, a complex tension state occurs in the bends in the leading and leading (tensioning) drums, in the frame of the tape.

There are several considerations for determining bending stresses in drums. A number of researchers [12-19] recommend calculating the bending stress of the tape on the drum by the following formula:

$$\sigma_u = \frac{E\delta i}{D}, \text{kgf/cm layer} \qquad (1.14)$$

Here E is the tension modulus of layers, kgf/cm;

d - layer thickness, cm;

i- the number of layers;

D - drum diameter, cm.

At the same time, it was hypothesized that the multi-layered tape is not of the same thickness, but there is a big difference between the fabric and rubber layers in terms of tension and strength properties [20-27]. On the basis of the following formula, it was proposed to assume that each layer bends separately during bending of the tape around the drum, without taking into account the connection between the layers:

$$\sigma_{u.max} = E\frac{\delta}{D+\delta_1+(i-1)\delta}, \text{kgf/cm layer} \; (1.15)$$

Here d is the thickness of one layer together with the rubber layer, cm;

d1 is the thickness of the lower rubber coating, cm.

Since the value d1+(i-1)d in the denominator is much smaller than the diameter of the drum, it can be ignored.

Properties of stress distribution along the bending arc of the tape were first found experimentally in the researches of A.V. Andreev using strain gauge [28-31]. An increase in voltage was found in layers located above the neutral axis, and a decrease in those located below. Thus, stress is added in the outer layers of the tape during bending. The tensile stresses are found by the following formula:

$$\sigma_p = \frac{S_{run}}{Bi}, \text{kgf/cm layer} \qquad (1.16)$$

Here, Sug is the tension of the running part of the tape;

V - the width of the tape, cm;

i- the number of layers.

Through experiments, a bond was established to determine the maximum stress in the upper layer of the tape as a result of stretching during bending:

$$\sigma_u = \frac{E\delta^2 i}{D}, \text{kgf/cm layer} \qquad (1.17)$$

E is the tensile modulus of the tape

d - thickness of one layer, cm;

i- the number of layers;

D - drum diameter, cm.

Total tension in the upper layers:

$$\sigma_{sum} = \sigma_p + \sigma_u, \qquad (1.18)$$

Conveyor belt strength margin:

$$\eta_n = \frac{\sigma_{break}}{\sigma_p + \sigma_u}, \qquad (1.19)$$

where is the breaking strength of the tape, kgf/cm layer.

In all of these studies, the tape is treated as a homogeneous beam acting in tension and bending. The focus is mainly on the study of bending of the tape in the drums, because the bending of the tape causes additional tensile stresses in the layers. Based on the research, the strength reserve values of the tape were recommended [28-33].

V.S. Bondarev, based on the study of the dynamic loads resulting from the load on the belt at the loading points of the conveyor, to determine the permissible stresses:

$$\sigma_{P_o} = \frac{S_{max}}{Bi} + \frac{0{,}86P\sqrt{E_o}}{B_K\sqrt{\sigma_P}} \qquad (1.20)$$

suggested the formula.

Here, E_o is the dynamic modulus of tension;

P is the base reaction of the roller;

B_k is the length of the contact part of the tape with the roller;

I- the number of tape layers.

Analysis of the research results shows that the uneven distribution of stresses between the layers leads to a decrease in the actual strength limits and an increase in the elongation of the tapes.

D.SH.Monastirskiy obtained the following theoretical relationship from the coefficient of use of layers [34-41]:

$$K_u = \frac{K\sum_{i-1}^{x}\left[a_{0i} + a_{1i}\left|\varepsilon_e - (\varepsilon_y - \varepsilon_i)\right|(\varepsilon_e - \varepsilon_y - \varepsilon_i))\right]}{\sum_{i=1}^{n}(a_{0i} + a_{1i}\left|\varepsilon_e\right|)\varepsilon_e} + \frac{\sum_{i=x+1}^{n}\left[a_{0i} + a_{1i}\left|\varepsilon_e - (\varepsilon_y - \varepsilon_i)\right|(\varepsilon_e - \varepsilon_y - \varepsilon_i))\right]}{\sum_{i=1}^{n}(a_{0i} + a_{1i}\left|\varepsilon_e\right|)\varepsilon_e}$$

Here K is the proportionality coefficient (K=0.25);
X is the number of compressed layers of the tape;
η is the total number of tape layers;
a_{0i} – initial modulus of tension;
a_{1i} is the coefficient describing the growth of the elastic modulus with the increase of the relative elongation ei;
$\mathcal{E}_i$ - relative elongation of individual layers during tape assembly;
$\mathcal{E}_y$ - the shrinkage of the tape after it is finished and removed from the assembly machine.
It was also suggested that tape breakage has a fatigue character, which should be taken into account when calculating its strength parameters. During the operation of belt conveyors, it is seen that the separation of rubber coverings from the traction frame and the fabric layers is the main indicator of the wear and tear of rubber-fabric conveyor belts. This condition occurs as a result of long-term alternating stresses in the backing rollers and drums of the tape. It has been confirmed in several studies that the maximum bending stresses occur in the top coating of the tape, and this gradually leads to the failure of the bond between the top coating and the working layers. In such cases [42-47], the value of the stresses in the upper most loaded part of the tape:

$$\sigma = \sigma_p + \sigma_u, \qquad (1.21)$$

will be
Here, s is the total tensile and bending stress in the upper fabric layer;
σ_r – tensile stress;
σ_u – the bending stress.
In practical calculations, you should not set operating modes where the voltage on the tape is minimal. From the economic point of view, it was suggested to make the number of layers slightly higher than the minimum value of stresses. Calculations in this case

$$\sigma_{add} = \frac{E\delta i}{D}K\psi + \frac{S}{iB}, \qquad (1.22)$$

depending on the dependency.
Here $\sigma_{add} = \frac{\sigma_p}{\eta_n}$, and η_n – is the true limit of stability [48-51].
Based on the above analysis, it can be concluded that calculating the strength limit of tapes only with tensile and bending stresses does not give sufficiently accurate results.
The right side of the expression is valid if $\sigma_u \geq \sigma_r$. The value of the Ψ_1 coefficient varies depending on the diameter of the drum D=10÷70 sm, Ψ_1=0.2÷0.8, Ψ_1 – is a coefficient that takes into account the ratio of the tension modules of compressed and stretched layers.
In the reviewed works on the study of the strength and performance of conveyor belts, attention was mainly paid to the study of external loads acting under operating conditions. In this direction, a number of important and useful studies were carried out, as a result of which information was obtained about the loading properties and structural features of conveyor belts for use in certain conditions.
However, in the above methods, the stress state of multilayer conveyor belts was not sufficiently studied and the fatigue of their frames due to changing loadings was not taken into account. The estimated reserve of strength of conveyor belts is not important for the service life, excessive reserve of strength does not improve the working conditions of the belts and does not help to extend their service life, although it causes an increase in the cost of conveyor transport. On the other hand, the decrease in strength reserves of tapes is limited by their fatigue strength conditions. Therefore, when calculating conveyor belts, it is necessary to take into account their dynamic strength as well as their static strength.
In addition, most of the methods developed to estimate belt life are based on performance data from relatively short conveyors installed in processing plants and transporting lumped rock and ore. These recommended calculated

dependencies do not take into account a number of factors that affect the life of tapes.

Also, it does not take into account that one of the main manifestations of tape degradation is separation of layers due to fatigue, peeling of coatings, loss of strength of tapes caused by cyclic effects of stresses during bending and rotation around drums.

The listed formulas are valid only for tapes made of tapes based on cotton fabrics. But today, conveyor belts are mostly made of synthetic materials. Therefore, these formulas require justification.

Although other fatigue degradation studies [13-26] have already been conducted, they did not consider the effect of torque (rotational stress) and temperature conditions on the life of the tape.

It can be concluded that most of the recommended calculation methods are based on determining the maximum stresses in the flat parts of the tapes and the additional stresses caused by the bending of the tapes on the drums. According to these conditions, the required number of layers in the tape and its reserve of strength are calculated. But these coefficients and its strength reserve do not fully reflect the real traction capabilities of conveyor belts.

However, it is estimated that reducing the number of layers on the belt by only 20% will reduce the cost of the conveyor by at least 10% and reduce the cost of conveyor transport by 4% [27,28]. On the other hand, the currently available experimental data and theoretical studies do not yet describe with sufficient accuracy the complex phenomena of stresses appearing in the tape. In addition, the conveyor belt experiences fluctuating stresses during operation, so it is not sufficient to calculate its static strength. Until now, there have been separate studies on the study of the phenomena of fatigue caused by cyclic stretching and bending stresses in tape materials [49-55].

In turn, when the torque is transmitted, the tension in the layers of the tape changes, and the tension in the tapes and bending in the drums also changes [51-57]. The change in tape tension occurs due to the frictional forces that occur between the tape and the drum within the angle of coverage. In addition, although it has been found that significant local shear stresses occur in the tape during the transfer of shear force by contact friction, the effect of these stresses on the tape's durability remains unclear.

The following conclusions can be drawn based on the analysis of previous studies.

Due to the various reasons for tape deterioration, the criteria for evaluating the strength reserve, the selection of the number of layers, determining the service life and other parameters of the tapes lead to significant differences.

Most of the recommended methods for the calculation of tapes are based on determining the maximum stresses in their flat parts and the additional stresses caused by bending of the tape on the drum and support rollers. According to these conditions, the number of layers and the reserve of strength of the tape are calculated. But these indicators do not fully reflect the real traction capabilities of conveyor belts.

The mechanical properties of the tapes have not yet been sufficiently studied. Therefore, using the same formulas to calculate stresses can lead to significantly different results.

Based on the consideration of the tape as a multi-layered package without integral bracing or shear bonds, methods for determining bending stresses are based on many assumptions and assumptions. They do not take into account that the force of gravity is transmitted through friction. Therefore, they do not provide sufficiently reliable results.

Load factors together with temperature conditions affect the life of the tape. Therefore, the effect of temperature cannot be neglected when studying tapes' corrosion resistance.

The fatigue resistance of conveyor belts in stretching and bending on drums without transmitting torque does not fully characterize the performance of the belt.

The purpose of the presented work, based on the analysis of previous studies, can be considered as an improvement of the methods of calculating resistance to variable stresses caused by the stretching and bending of the drums during the transmission of the traction force, taking into account the temperature conditions of the conveyor belts.

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