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Identifying factors affecting rope durability

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Abstract. Problem*. When a rope is in use, tensile stresses arise in its cross-sections due to the end load, bending stresses as it passes through pulleys and drums, torsional stresses, and contact stresses. The loads applied to the rope can be either static or dynamic. When calculating crane ropes, static tensile loads are determined without taking into account bending and torsion stresses. This approach underestimates the stress state of the rope and can lead to reduced rope durability.* ***Goal.*** *The purpose of the study was to determine the factors that actually affect the durability of crane ropes. When winding a rope onto a drum or when bending a rope on pulley blocks, a deviation of the ropes from the plane of rotation of the blocks occurs. As deflection angles increase, very negative aspects can arise due to the fact that the deflected rope slides along the side of the block groove, which itself wears out and leads to wear on the block groove.* ***Methodology****. The actual operating conditions for ropes differ significantly from those on a test machine. However, experimental studies conducted by scientists have made it possible to determine the impact of various factors on rope durability. To determine the effect of the rope deflection angle, a machine with a rocker mechanism was manufactured to study the rope's durability. At the same time, the work of the rope was studied at different angles of deflection from 3 to 7.* ***Results****. The research carried out enabled the identification of new dependencies that account for the distance between blocks, thereby refining the calculation. Experimental studies fully confirmed the obtained refined calculation.* ***Originality****. The resulting formulas allow taking into account the distance between the blocks and therefore are more accurate.* ***Practical value****. The results presented in the article allow us to obtain a more accurate calculation of the durability of the rope, taking into account the influence of the angle of deflection of the rope on the block.*

Keywords: *rope, deflection angle, rope block, rope durability, strength, experimental stand.*

Introduction

The current level of technology development requires ever new requirements for the reliability and durability of lifting ropes. The operating conditions of the rope determine the reliability of the entire lifting machine.

Many famous scientists, such as B.S. Kovalsky, D.G. Zhitkov, K.M. Maslenikov, A.I. Kolchin, I.F. Nikitin, V.I.Dvornicov [1], V.A.Malinovskiy [2] and others, conducted experimental studies to determine the durability of the rope. As a result of these studies, it was concluded that the durability of the rope is influenced by many factors and it cannot be determined only by static strength.

The work of the rope on the drum and on the blocks leads to its deflection. This is a very negative factor, which can even lead to the possibility of the rope jumping into another groove and the rope breaking at the crest of the groove. Unold, Matthias and B.S. Kovalsky indicate this in their works. It is impossible to completely avoid the angle of deviation, but we must try not to exceed the limiting permissible value of this angle.

Analysis of publications

In work [3,4], modeling of metal ropes that experience tensile and bending forces was carried out. The authors made the assumption

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that there are no friction forces between the wires, which are taken in the form of a curved beam. Research has shown that rope torsion leads to an increase in stress in the cross sections of the wire. In addition, securing the ends of the rope leads to an increase in contact stresses, especially with point contact. As a result of the research, it was concluded that determining contact stresses in multi-strand ropes is a rather complex task that must be solved in the future.

In work [5], the stress state of elements of multi-strand steel ropes is considered. The authors investigated the influence of effective initial stresses on the stress-strain state of the rope. In addition, it was concluded that the contact stresses are significantly affected by the pitch size of the rope lay.

The paper [6] discusses issues of theoretical studies of steel ropes under the influence of tensile forces. The authors showed that in a spiral rope the central wire is loaded with 15.58% of the total load, in other sections of the rope the wires have 84.4% of the load. The total torque causes It was determined that the total torque causes a stress on the external wires of 5400.4 Nmm. This allows us to conclude that the tensile stresses in the central wire are much lower than in the outer wires.

The works [7], [8] consider the modeling of steel ropes that experience tensile, torsional and bending stresses. Research has determined that stresses from contact forces increase with decreasing axial forces in the wires. The authors proposed [7] a formula for determining the stress state of the rope cross-section. For this purpose, a three-dimensional end element in the form of an end beam was considered. In [8], static and dynamic analysis of a three-dimensional end element under the influence of shear and rotation forces was performed.

The stress state in the wires of the rope, which is wound around the drum and block, is considered in [9]. To determine additional loads in the rope, a formula was obtained that took into account the geometric parameters of the rope, as well as the bending radius of the rope. The calculations obtained using this formula were compared with experimental data obtained by I.F. Nikitin. The difference was approximately 5%.

In [10], a study was carried out of various factors on the durability of the rope and blocks, in particular the angle of deflection of the rope. Based on the conducted research, it was concluded that with an increase in the angle of the rope, the wear of the rope block increases and the durability of the rope decreases.

Presentation of the main material

When the rope hits the pulley, the elongation of the wire on the convex side of the rope, depending on the frictional forces, will be distributed in the direction of compression on the concave side of the rope. This elongation changes the axial force in the wire.

The area of force change can be divided into two parts: the area of the transition section to the point of contact of the rope with the pulley and the area of the rope that is bent on the pulley.

The forces acting on the wire element ds during its movement on the transitional section consist of the tension force T, the pressure per unit wire P and the friction force F.

We project all forces onto the horizontal axis and get

$$dT = Fds \tag{1}$$

The force of friction can be written in the form

$$F = \mu P \tag{2}$$

The pressure per unit of wire is expressed by the formula

$$P = \frac{T}{\rho} \tag{3}$$

where $\frac{1}{\rho}$ – the curvature of the wire of the curved rope.

The curvature of the wire in the curved edging

$$\frac{1}{\rho} = \frac{\sin^2\alpha}{r} + \frac{\cos^2\alpha}{R_1 + r\sin\varphi}\sin\varphi \tag{4}$$

where r – wire strand radius; R_1 – the radius of the pulley, which is wrapped by the rope; α – angle of twist of the wires in the rope; φ – is the polar angle relative to the rope axis.

We accept the force of tension of the wire in the form

$$T = T_1 \exp(-k\mu\varphi) \tag{5}$$

where T_1 – tensioning of the wire at the point of the beginning of the bend; k is a coefficient that takes into account the geometric and elastic parameters of the rope and the block [11].

Then we will get

$$dT = \mu T_1 \exp(\text{-}k\mu\varphi)\times$$
$$\times\left(\frac{\sin^2\alpha}{r}+\frac{\cos^2\alpha\sin\varphi}{R+r\sin\varphi}\right)r\cdot d\varphi \qquad (6)$$

After integrating (6), we get

$$T = \mu T_1 \exp(\text{-}k\mu\varphi)\times$$
$$\times\left[\frac{\sin^2\alpha}{k\mu}+\frac{r\cos^2\alpha\left(\cos\varphi+k\mu\sin\varphi\right)}{R\left(1+k^2\mu^2\right)}\right] \qquad (7)$$

Expression (7) describes the law of changes in the axial force in the wire of the straight section when distributing the elongation that will be received by the wire on the side of the convex rope.

In Fig. 1 presents the function $T(\varphi)$ for the following parameters: $T_1 = 30\,\text{H}$, $\alpha = 12^\circ$, r =5мм, R = 100 мм, k = 0,0738, $\mu = 0{,}14$.

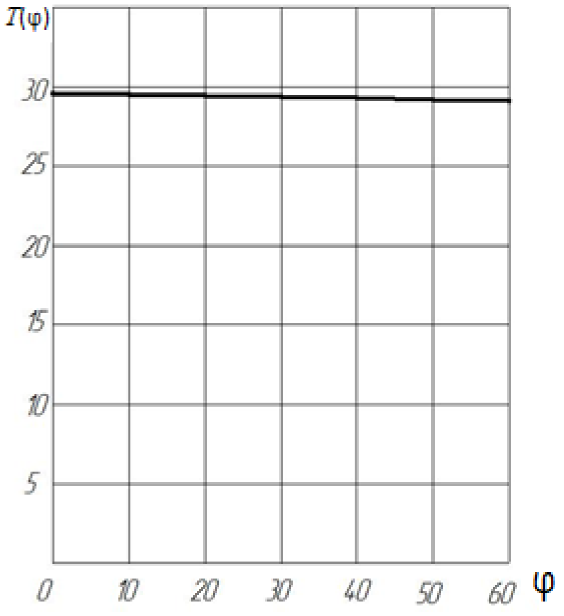

Fig. 1. Function $T(\varphi)$

The service life of the rope depends on its design, properties of the wire, operating conditions, and on the suitability of the properties of the rope for its work on a specific machine. Depending on the operating conditions, the service life of the rope ranges from several weeks to several years. As the practice and experiments of many authors show, the destruction of wires occurs in the places of contact between the wires, as well as the contact of the rope and the surface of the block or drum, where contact stresses are added to tensile, bending and torsional stresses.

When the rope is wound on the drum or when the rope is bent on the hoist blocks, the ropes deviate from the plane of rotation of the blocks.

When the deviation angles are increased, very negative moments can occur, caused by the fact that the deviated rope slides along the side of the block stream, while it wears itself out and leads to wear of the block stream. As the deflection angle increases, the contact line of the rope with the side of the block stream and the relative speed of the rope displacement increases.

The deviation angles are limited taking into account the ratio D/d, where D is the diameter of the block, d is the diameter of the rope and the mode of operation of the lifting mechanism. When the rope is deflected on the drum, it is necessary to take into account the possibility of the rope jumping into another groove and the rope breaking on the rowing grooves.

The works of Unold, Matthias and B.S. Kovalskyi were devoted to these questions. The equation of the elastic line, which arises when the ropes of the blocks that are separated from each other at a distance of 2a (Fig. 2).

$$y = \frac{l\tan\alpha}{\lambda l-\tanh(\lambda l)}\times$$
$$\times\left[\tanh(\lambda l)\left(\cosh(\lambda x)-1\right)-\sinh(\lambda x)+\lambda x\right] \qquad (8)$$

where y – beam deflection (displacement) at point x; x – coordinate along the beam length; l – beam length (or span length); α – initial angle of inclination or boundary angle (in radians); λ – system parameter, typically related to stiffness

$$\lambda=\sqrt{\frac{T}{B}}=\frac{1}{kd}$$

where T – rope tension, $T = F\sigma = cd^2\sigma$, B is the stiffness of the rope when bending, $B=\varepsilon EI$, F is the plane of the rope, c is the filling factor of the rope, σ – tension in the rope, k is a constant for ropes of a certain design.

From Fig. 2 we get the equation

$$\left(0.5D+z\right)^2=\left(0.5D\right)^2+x^2 \qquad (9)$$

The solution of equation (2) will have the form

$$z_{1,2} = -\frac{D}{2} \pm \sqrt{\frac{D^2}{4} + x^2} \qquad (10)$$

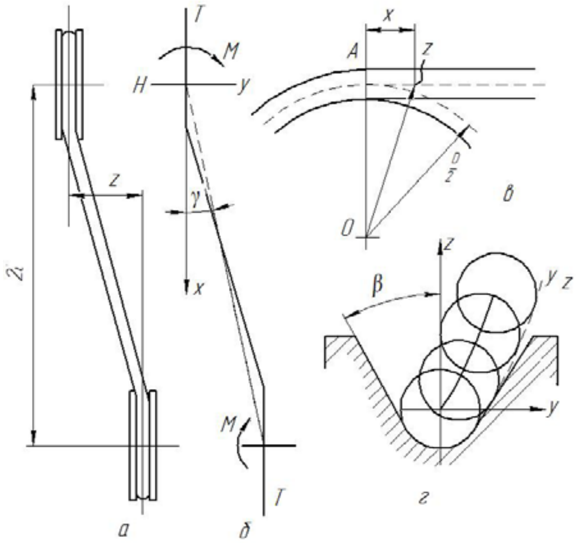

Fig. 2. Calculation scheme

Equations (9) and (10) can help determine the curve of movement of the centers of the intersection of the ropes (Fig. 2) when they are displaced in the OA plane. The curve that surrounds these points can be written by two equations

$$Y = y + \frac{d}{2}\frac{z'}{\sqrt{y'^2 + z'^2}} \qquad (11)$$

$$Z = z - \frac{d}{2}\frac{y'}{\sqrt{y'^2 + z'^2}}$$

Let's represent the hyperbolic sine and cosine in the form

$$\sinh(\omega x) = \frac{1}{2}\left(\exp(\omega x) - \exp(-\omega x)\right)$$

$$\cosh(\omega x) = \frac{1}{2}\left(\exp(\omega x) + \exp(-\omega x)\right)$$

then

$$\tanh(\omega l) = \frac{\exp(\omega l) - \exp(-\omega l)}{\exp(\omega l) + \exp(-\omega l)}$$

Substitute these expressions into formula (10) and get

$$y = \frac{l\tan(\gamma)}{\tanh(\omega l) - \omega l}(0.5 \cdot \tanh(\omega l) + \\ +0.5\cosh(\omega x) \cdot \sinh(\omega x) + \omega x) \qquad (12)$$

The limit value of the angle γ is found from the condition that the bent rope will not touch the groove of the block, while

$$tg\beta \geq \left(\frac{dY}{dZ}\right)_{x=0} = \left(\frac{y'}{z'}\right)_{x=0} = \\ = \frac{D\omega l\tan(\gamma)}{4\left(\omega l - \tanh(\omega l)\right)} \qquad (13)$$

Conclusions

Many scientists have long been studying the issue of increasing rope durability, but not all factors are taken into account in calculation practice. When solving the problem of the boundary angle of deflection of a rope on a drum, some assumptions were made that reduced the accuracy of the calculation. The article presents new dependencies that take into account such important factors as the angle of deflection of the rope and the distance between the blocks. This makes the calculation more accurate. The experiments carried out confirmed the obtained analytical solutions.

Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Визначення факторів, що впливають на міцність канату

Анотація. Проблема*. При роботі канату в його перетинах викликає напруження розтягнення від кінцевого вантажу, згину при проходженні блоків і барабана, кручення і контактні напруження. Навантаження, які прикладені до канату, можуть носити статичний і динамічний характер. При розрахунку кранових канатів статичні розтягуючі навантаження визначаються без урахування напружень згину та кручення. Такий підхід недооцінює напружений стан мотузки і може призвести до зниження довговічності мотузки.* ***Метою*** *дослідження було визначення факторів, які фактично впливають на довговічність кранових канатів. Під час намотування каната на барабан або під час згинання каната на поліспастах відбувається відхилення канатів від площини обертання блоків. Зі збільшенням кутів відхилення можуть виникнути дуже негативні аспекти через те, що відхилений канат ковзає по борту паза блоку, що саме зношується та призводить до зносу паза блоку.* ***Методологія****. Реальні умови роботи канату дуже відрізняються від умов їх роботи на пробній машині. Але експериментальні дослідження, проведені вченими, дозволили змінити вплив різних факторів на довговічність каналів Для визначення впливу кута прогину каната було виготовлено машину з рокерним механізмом для дослідження довговічності каната. Водночас, роботу каната досліджували при різних кутах прогину від 3 до 7.* ***Результати*** *Проведені* *дослідження дозволили отримати нові залежності, що враховують відстань між блоками, що, у свою чергу, уточнює розрахунок. Експериментальні дослідження повністю підтвердили отриманий уточнений розрахунок.* ***Оригінальність*** *Отримані формули дозволяють враховувати відстань між блоками і тому є більш точними. Практична цінність. Результати, отримані в статті, дозволяють отримати більш точний розрахунок довговічності каната з урахуванням впливу кута прогину мотузки на блоці.*

Ключові слова: *канат, кут прогину, канатний блок, довговічність каната, міцність, експериментальний стенд.*

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