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REDUCING WEAR OF THE MINE ROPEWAYS COMPONENTS BASING UPON THE STUDIES OF THEIR CONTACT INTERACTION

To improve the durability of the rollers of supporting and guiding devices as well as traction ropes of ropeway facilities based upon the analysis of their contact interaction. Theoretical studies of a mathematical model of contact interaction of mine ropeway components to determine regularities of the formation of dynamic efforts within the contact area and experimental studies of the plant under mine conditions. Based upon a mathematical model, contact stresses within the zone of contact of traction rope with guiding rollers and drive sheaves of mine ropeways under real operating conditions have been determined. The obtained results are validated experimentally under mine conditions. Innovative patent-protected design solutions have been proposed; the solutions make it possible to considerably increase the durability of the ropeway components.

It has been determined that methods of surface increase in the strengthening of a roller working surface do not have proper effect as the strengthened layer on a soft base cracks and delaminates due to high contact loads; maximum angle of rope bending on rollers of supporting devices (6º – in operation manual; 15º – in safety rules) recommended for GRW is overstated. It shouldn't be more than 1.5º in terms of values of contact stresses for standard plants; development of prestressed compression state in the material of elastic lining of a drive friction sheave allows increasing considerably (by two times and more) its service life.

Ropes with reduced diameters of external layer wires (Ukraine's regulatory document – DST 2688) being used currently on mine ropeways do not meet the operating conditions and have a short period of service life due to their corrosive and fatigue breaking. To lengthen the service life of GRW traction ropes, it is required to change for the ropes with increased diameters of the external layer wires with preliminarily clamped strands.

(Ukraines regulatory documents: DST 3077, DST 3081, DST 7668, DST 7669 and TU 14-4-1070).

Keywords: rope, roller, friction sheave, ropeway, contact stresses, durability

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1. Introduction

A ground ropeway (GRW) and rope monorails occupy a considerable segment among the facilities of auxiliary transport of coal mines in Ukraine. They are used to transport equipment, material, and people within the mine workings characterised by diverse road cross-sections where it is impossible to use locomotive or rope haulage for safety reasons [1-3]. Recently, the authors have contributed to widening the sphere of ground ropeways in terms of transporting rock mass, material, and people, while driving mine workings [4]. It has resulted in the growth of loads within the facilities components, road velocity, and, as a result, the development of new structures of heavy roads [5].

According to Singh, R.P. et al. [6], the consideration for the reasons for the destruction of wire ropes operating at high-stress levels and are almost invariably subject to load fluctuations.

In [7], the failure of the rope used on the drilling rig was investigated. The analyses were performed using the finite element method. In [8], an analysis of failures of a broken stranded wire rope from a marine platform crane was performed.

A ground ropeway (Fig. 1) is a complex of the equipment providing movement of towing trolley 2 with the reserve of haulage rope and car batch 3, connected to it along rails 5 of a mine working with the help of closed rope 1. Haulage rope is driven with the help of a drive with friction sheave 4. The road equipment also includes a tension station with loads 6, supporting devices 8, ending block 9, and a block of reverse branch 7.

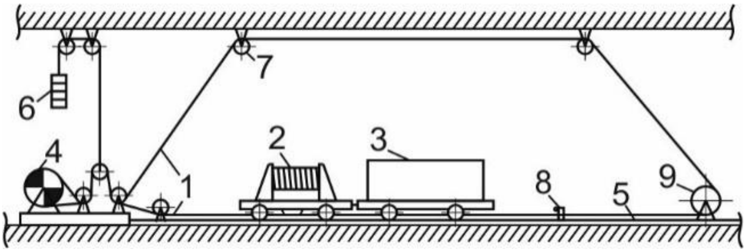

Fig. 1. Ground ropeway: 1 – traction rope; 2 – towing trolley; 3 – load-carrying car; 4 – drive; 5 – rails; 6 – tension loads; 7 – guiding block; 8 – supporting device; 9 – end block

A drive station is meant for driving a closed haulage rope; it may be used in several variants: it may include electric drive, hydraulic clutch, reducing gear, and multi-wrap friction sheave, or a hydraulic clutch may be replaced with the hydrostatic transmission or frequency converter for a motor. The drive is equipped with a safety brake of shoe type with a spring-controlled blocking which interacts immediately with the brake rim of a friction sheave.

The towing trolley is aimed for transporting a rolling stock, accumulating haulage rope reserve, and catching the stock in case of breakage of a haulage rope or exceeding the admissible velocity of motion.

Load-type tension device is meant for automatic tension of a haulage rope running off the friction sheave branch; the device is mounted near the drive.

Supporting and guiding devices, blocks, and rollers are used to support and guide branches of a haulage rope within a mine working.

The practice of GRW operation indicates low reliability of haulage ropes as well as the supporting and guiding of devices (their service life is not more than several months, while costs for their replacement reduce the equipment efficiency considerably). In the process of operation, both haulage ropes and rollers are subject to intense wear caused by constant high stresses. Furthermore, haulage rope wears down additionally due to bending, coil friction, and cross slipping over the working parabolic surface of a traction sheave as well as processes of fretting corrosion.

2. Objectives and method

In terms of high rope axial load (up to 50 kN) and instability of GRW operation mode due to changeable track cross-section, the zone of roller-rope contact is constantly affected by normal and tangential constants as well as impulse dynamic loads. Studies [9,10] demonstrate that the most intense conditions for contacting bodies are developed near the border of the contact contour.

Periodic opening of the joints of the contacting surfaces favours the development of contact corrosion. Processes of elastic crushing take place within the contact zone under the effect of changeable axial force in terms of mutual slipping with the constant availability of abrasive particles within it. That results in mutual wear of the contacting surfaces. Thus, theoretical determination of contact stresses and experimental verification of the obtained results are rather topical.

The objective of the study is to increase the durability of rollers of both supporting and guiding devices and haulage ropes of GRW.

To reach the objective, it is required to solve the following problems: theoretically study the stresses within the contact zone; develop technical solutions for reducing the wear of working surfaces of rollers and haulage rope; experimentally test the proposed solutions under operating conditions.

3. Theoretical study of the elements contact interaction of GRW

Modern ground ropeways apply cylindrical supporting rollers of diameter (80-150 mm). ropes with fibre core are used as haulage ropes; the ropes are of parallel (sometimes of a cross) lay of 18-26 mm in diameter, with the diameter of rope wires in the external layer being 0.8-2.0 mm. Analyse force interaction of rope wires with a roller surface (Fig. 2).

The scheme shows: Q is funicular force; P is a normal force pressing a rope wire to the roller surface; $T = fP$ is a tangential force directed along the rope axis; f is coefficient of friction; r is the radius of wire cross-section; $r1$ is the radius of wire curvature in a rope; $R1$ is the radius of a roller groove (if it is available); R is the radius of working surface of a roller. First, simple problems in terms of contact stresses and deformations [10] were solved by H.H. Herz with the help of the elasticity theory. Then the solution was complemented by O.M. Dynnyk and M.M. Beliaiev in terms of the following assumptions:

- stresses within the contact zones do not exceed elasticity limits;
- contact areas are small compared to the surfaces of contacting bodies;
- pressure forces distributed over the contact surface are normal to the surface, and there is no rope deformation during the interaction.

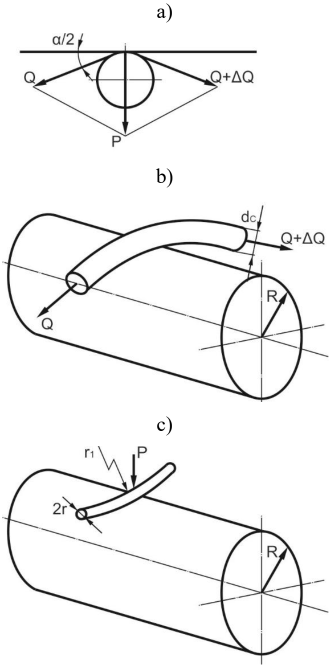

Fig. 2. Scheme of a force contact: a, b – rope with a roller; c – rope wire with a roller

Undeformed surfaces of two bodies near the contact point (Fig. 3a) may be replaced rather accurately with two surfaces of second order being described by equation:

$$Z_1 + Z_2 = Ax^2 + By^2$$

where Z_1, Z_2 is distance between points on surfaces of the bodies; x, y are coordinates of points lying within the plane of a contact area; and A, B are constant coefficients depending upon the value of basic curvatures and the angle between the planes of basic curvatures of tangential bodies.

$$\begin{aligned} A + B &= \frac{1}{2}\left(\rho_{11} + \rho_{12} + \rho_{21} + \rho_{22}\right) \\ B - A &= \frac{1}{2}\left[\left(\rho_{11} - \rho_{12}\right)^2 + \left(\rho_{21} - \rho_{22}\right)^2 + 2\left(\rho_{11} - \rho_{12}\right)\left(\rho_{21} - \rho_{22}\right)\cos 2\psi\right]^{\frac{1}{2}} \end{aligned} \tag{1}$$

where $\rho_{11}, \rho_{12}, \rho_{21}, \rho_{22}$ are maximum and minimum curvatures of surfaces respectively; ψ is angle between the planes of curvatures ρ_{11} and ρ_{21}.

Maximum pressure within the contact area is:

$$p_0 = \frac{3}{2}\frac{P_{\max}}{F} = \frac{3}{2}\frac{P_{\max}}{\pi ab} \tag{2}$$

where $P_{\max}$ is force affecting the most loaded wire; F is area of a contact spot; and a, b are the length of semi-axis of the elliptic contact plane.

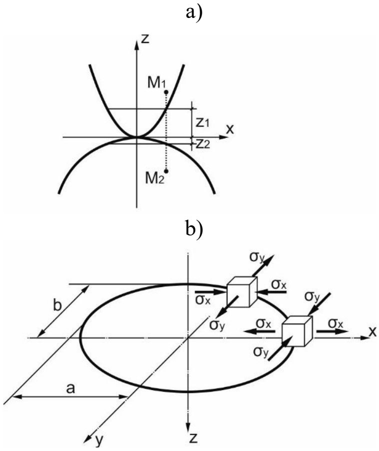

Fig. 3. Parameters of the contact of two bodies: a) – geometric form of the contact; b) – stresses within the contour points

Dimensions of the elliptic contact area are determined according to following expressions:

$$a = n_a \sqrt[3]{\frac{3}{4}\frac{\eta P_{\max}}{A+B}}$$
$$b = n_b \sqrt[3]{\frac{3}{4}\frac{\eta P_{\max}}{A+B}} \tag{3}$$

Coefficients na and nb are determined with the help of table [10] depending upon angle ψ between the planes of main curvatures of both surfaces:

$$\cos\psi = \frac{B-A}{B+A}$$

and elastic constant of tangential forces:

$$\eta = \frac{1-\mu_1^2}{E_1} - \frac{1-\mu_2^2}{E_2} \tag{4}$$

where μ_1, μ_2, E_1, E_2 are Poisson's ratios and elasticity moduli of the bodies being pressed.

Substituting (3) into (2), we obtain:

$$p_0 = \frac{1}{\pi n_a n_b} \sqrt[3]{\frac{6P_{\max}(A+B)^2}{\eta^2}} \tag{5}$$

Expression (1) may be transformed as follows:

$$A+B=\frac{\rho_{11}}{2}\left(1+\frac{\rho_{21}}{\rho_{11}}+\frac{\rho_{22}}{\rho_{11}}+\frac{\rho_{12}}{\rho_{11}}\right)$$

where $\rho_{11}=\frac{1}{r}$; $\rho_{21}=\frac{1}{R}$; $\rho_{22}=\frac{1}{R_1}$; $\rho_{12}=\frac{1}{r_1}$.

To apply haulage ropes and rollers of GRW, the mentioned parameters are within the following limits: $r=0.5\text{-}1.0$ mm; $R=45\text{-}60$ mm; $R_1=\infty$ (there is no groove); $r_1=20\text{-}30$ mm. Considering that $\frac{1}{r}>>\frac{1}{r_1}>>\frac{1}{R}>>\frac{1}{R_1}$, and ratios $\frac{\rho_{21}}{\rho_{11}}$, $\frac{\rho_{22}}{\rho_{11}}$, $\frac{\rho_{12}}{\rho_{11}}$ are close to zero, we may assume (with the degree of accuracy being sufficient for further practical calculations) that:

$$A+B\approx\frac{\rho_{11}}{2}=\frac{1}{2r} \tag{6}$$

Substituting formula (6) into (5), we have:

$$p_0=0,63Cn_p\sqrt[3]{\frac{P_{\max}}{r^2}} \tag{7}$$

where C is coefficient depending upon the materials of a contacting pair.

Since $\mu_1^2<<1$ and $\mu_2^2<<1$, we have:

$$C=\frac{1}{\pi}\sqrt[3]{\frac{6}{\eta^2}}=0,58\sqrt[3]{\left(\frac{E_1E_2}{E_1+E_2}\right)^2},\ n_p=\frac{1}{n_an_b}$$

where n_p is a geometrical parameter characteris ing curvature of contacting bodies [2].

Thus, maximum contact stress for a wire-roller pair is:

$$p_0=0,365n_a\sqrt[3]{\left(\frac{E_1E_2}{E_1+E_2}\right)^2}\sqrt[3]{\frac{P_{\max}}{r^2}} \tag{8}$$

Dimensions of a contact area are as follows:

$$\begin{aligned} a&=1,14n_a\sqrt[3]{\left(\frac{E_1+E_2}{E_1E_2}\right)P_{\max}r}\\ b&=1,14n_b\sqrt[3]{\left(\frac{E_1+E_2}{E_1E_2}\right)P_{\max}r}\end{aligned} \tag{9}$$

Stress state within the contour points of the elliptic contact area is characteris ed by the stresses represented in Fig. 3b, where:

$$\begin{aligned}
\sigma_x &= -p_0(1-2\mu)\frac{\beta}{e^2}\left[1-\frac{x}{ae}arcth\frac{ex}{a}-\frac{by}{be}arctg\frac{ey}{b\beta}\right] \\
\sigma_y &= -p_0(1-2\mu)\frac{\beta}{e^2}\left[1-\frac{x}{ae}arcth\frac{ex}{a}-\frac{by}{be}arctg\frac{ey}{b\beta}\right] \\
\tau_{xy} &= -p_0(1-2\mu)\frac{\beta}{e^2}\frac{xy}{ab}\left[\frac{x}{ae}arcth\frac{ex}{a}-\frac{by}{be}arctg\frac{ey}{b\beta}\right]
\end{aligned} \tag{10}$$

where: $\beta=\frac{b}{a}$; $e^2=1-\beta^2$.

Plane stresses can be observed within all the points of the contour ellipse of a contact area. If $x = a$, $y = 0$ (end of a major semi-axis), tangential stress is $\tau_{xy} = 0$, and normal stresses are:

$$\sigma_x = -\sigma_y = -p_0(1-2\mu)\frac{\beta}{e^2}\left[1-\frac{1}{e}arcth(e)\right]$$

It is obvious that within the points of the ends of the ellipsis major semi-axis, one will observe tension in its direction, and compression will be observed in perpendicular direction. Similarly, there is also no tangential stresses within the ends of a minor semi-axis ($x = 0$, $y =$ b), and main stresses are:

$$\sigma_x = -\sigma_y = -p_0(1-2\mu)\frac{\beta}{e^2}\left[1-\frac{\beta}{e}arctg\frac{e}{\beta}\right]$$

In the case of an elliptic contact area, two-axial stress states, called pure shear, will be observed within all the contour points. Maximum tangential stress (if $\mu = 0.3$) is:

$$\tau_{\max} = \frac{\sigma_1-\sigma_3}{2} = 0{,}133p_0$$

According to hypothesis of the greatest tangential stresses, equivalent stress will be:

$$\sigma_{eq} = \sigma_1 - \sigma_3 = 2\tau_{\max}$$

where σ_1, σ_3 are the greatest and the least stress of the three main ones respectively.

Strength in terms of contact stresses is tested, if:

$$\sigma_{eq} = m\sigma_{\max} \le [\sigma]$$

from which:

$$\sigma_{\max} \le \frac{1}{m}[\sigma] = [\sigma]_{cont}$$

where $[\sigma]_{cont} = \frac{[\sigma]}{m}$ is admissible pressure for the greatest stress within the contact point; and m is coefficient depending upon the ratio of semi-axes of the elliptic contact area.

4. Results of the theoretical study

Using formulas by Herz-Beliaiev for the contact of different-configuration bodies and formulas (4), (5), (7), (8) as well as setting the parameters included into them: elasticity modulus is $E_1 = E_2 = 2 \cdot 10^5$ Pa, Poisson's ratio is $\mu_1 = \mu_2 = 0.3$, roller radius is $R_1 = 0.045$ m, rope radius is $r = 1 \cdot 10^{-2}$ m, rope wire radius is $r_1 = 0.5 \cdot 10^{-4}$ m, sheave radius is $R = 0.5$ m, normal force (Fig. 3.2, b) is $P = 2Q \cdot \sin\frac{\alpha}{2}$, and $\alpha = 6°$ is angle of rope displacement on a roller, determine the stresses acting within the contact (Table 1).

TABLE 1

Calculated contact stresses

Contact surfaces	**Maximum contact stress, MPa**	**Admissible maximum pressure, MPa**
Steel rope – roller	2600	1000
Rope wire – roller	4700	1000
Steel rope – roller with groove	1200	1000
Plane rope – roller	300	1000
Steel rope – lined roller	30	3.2
Steel rope – lined friction sheave	3	3.2

Comparing calculated values of maximum contact stresses with admissible ones $[\sigma]_{cont} = 1000$ MPa for steel 30 (US equivalent steel: 1030, G10300, M1031), which is used to make a roller tube, following conclusions can be drawn:

- when a rope (as a solid rod) contacts a roller, the stresses within the contact zone exceed the admissible ones by more than 2 times, and in terms of a rope wire-roller contact – the stresses are more than 4 times compared to admissible ones;
- the available groove on a working surface of a roller reduces contact stresses; however, in terms of the available sizes of contact bodies, they are more than admissible stresses by 1.2 times;
- use of a plane rope makes it possible to have stresses being several times less than the admissible ones;
- If rubber lining for a roller is used, then stresses in that lining are 10 times more compared to admissible ones; in the case of a traction sheave, the stresses are less than the admissible ones.

Calculations for the case when the total angle of rope bending on a standard roller is not more than 1.5° demonstrate that maximum contact stresses are not more than the admissible ones.

Detailed classification of the methods to reduce wear, represented in Fig. 4, has been developed based upon the literature sources.

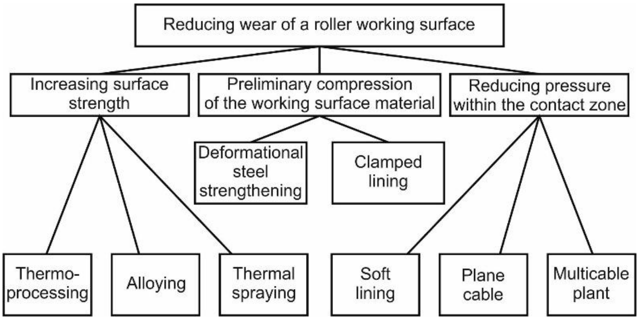

Fig. 4. Methods to reduce wear of a roller working surface

5. Experimental study

Both program and testing methodology have been developed for experimental validation of the obtained theoretical results. Wear tests are usually carried out under laboratory conditions using special machines. In this context, wear is measured either in linear or in weight units. However, such testing gives almost no possibility to represent all the conditions of a real operation of mine plant units (air humidity, aggressive mine waters, the abrasive rock and coal particles etc.). Consequently, if we take into account all the mentioned conditions, the mining experiment carried out within the framework of the study may be considered as the correct one.

Following rollers were used as the experimental ones: with a supporting surface, rubber-lined and steel-alloyed, treated with electro spark doping, electric arc spraying, and shock-wave strengthening.

The rubber of MP 10283 (TU 38-105376-72) grade is used for the soft lining of rollers; the rubber and supporting surface were joined using hot vulcanisation in the laboratory of Dnipropetrovsk Institute of Industrial Rubber Goods.

The surface of another roller was doped with BK8 hard alloy in the laboratory of the Department of the Technology of Mining Engineering of the Dnipro University of Technology, by using a plant for electro spark doping of Elektron type [11]. There are the following electric modes for the treatment: voltage is 200 V, condenser capacity is 200 μF, and short circuit current intensity 3A.

Measuring microhardness of the strengthened alloys shows that the same surface has a different hardness. Hence, we may assume that the surface layer consists of a soft base with inclusions of fine-grained carbides of high hardness.

A favourable combination of soft base and hard inclusions makes the surface highly wear-resistant; however, its quantitative characteristics may be determined only whilst testing the experimental samples under mine conditions.

Nowadays, metal-working often applies shock-wave strengthening with the help of explosions [12,13]. Ammonite of 6 ZHV grade was used to strengthen the metal of rollers. Fig. 5 demonstrates a charging schematic.

In order to prevent deformation of the middle part of a roller tube, a metal rod (1) of 56 cm in diameter was placed inside the tube. The space between the rod and tube wall is filled with water (2). The lower part of a roller is closed with a sealed pan (6) with the help of a bolt; hermeticity is provided by means of sealing the joints with a special mixture. The Roller surface

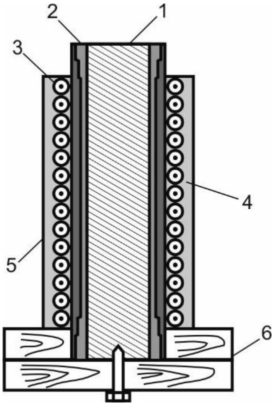

Fig. 5. Shock-wave method to strengthen rollers: 1 – rod; 2 – water; 3 – detonating cord; 4 – ammonite; 5 – casing; 6 – pan

is coated with two layers of detonating cord (3), the ends are brought onto the butt end of the upper roller. Carton casing (5) is mounted at the top; explosive (4) is set between the casing and detonating cord. Charging and sample preparation for an explosion was performed within a special site for blasting operations; the explosion was performed in a specially-equipped armoured pit. As a result of the treatment with the explosion, the maximum decrease in their diameter within the middle part was 1.2 mm, the maximum tube lengthening was 3.5 mm, a change in the diameter of mounting seats for bearings were not observed, and the surface hardness increased compared to the initial one from 132-140 HB up to 150-165 HB.

To study the effect of contact stresses upon the working surface of a roller with high hardness, its tube was made of alloyed steel of 45X (US equivalent steel: 5135, 5140, 5140H, 5140RH, G51350, G51400, H51350, H51400) grade with further thermoprocessing up to the surface hardness of 300 HB.

Apart from the mentioned rollers, the experiment involved the ones whose surface was treated by electric arc spraying; its essence is in coating the surface of a component part with the particles of the arc spraying agent melted by electric arc [14]. In this context, high strength of joint with the base (roller tube) is provided. A roller was strengthened on the industrial plant of UDM-4 type in the scientific and research laboratory of plasma spraying of Prydniprovska State Academy of Civil Engineering and Architecture; the strengthening involved wear-resistant nichrome wire of 1.8 mm in diameter, which melted particles were delivered by pressurised air under the pressure of 0.5-0.6 MPa onto the roller surface, rotating in a turning machine.

The spraying mode is as follows: current rate is 140-180 A, voltage is 38 V, rotating speed of a sample is 50 rev/min, and thickness of the sprayed layer is 2 mm. Such a mode allows having the surface layer hardness up to 48 HRC units.

Since the criteria to measure roller durability may be determined only under real production conditions [15,16], a stand for operating tests has been designed and manufactured (Fig. 6); it includes a frame with the rollers mounted on it. Moreover, the rollers are arranged in such a way so that the rope will bend by 3° on the extreme roller, and the rope bending angle will be 6° on the other ones, which correspond to a maximum angle of roller rope contact according to the rules to operate ropeways.

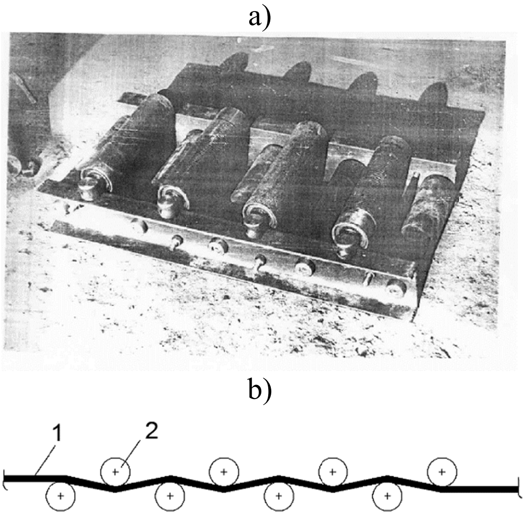

Fig. 6. Stand to test GRW supporting rollers: a) – general view;
b) – scheme of rope bringing (1– rope; 2 – roller)

The operating time of ground ropeway is taken as the input variable; the wear rate of the supporting surface of a roller is taken as the output one. Rollers mounted on the stand are subject to wear due to the effect of the rope load; rope tension changes depending upon the load mass 5-20 kN. In this context, transportation distance is unchangeable (800 m).

The periodicity of measuring is determined based on the analysis of data on the durability of standard rollers; the periodicity is 20-30 days.

The main haulage heading No. 1 of C5 seam of Pavlogradska mine (length is 800 m, the cross-section is 14.5 m^2, supported with arch lining) was selected as the site for the experimental testing stand. Rails inclination is from 5 to 50‰; the mine working is rectangular in plan. The stand was fixed on wooden rail sleepers with the help of bolts at the distance of two meters from a drive; the diameter of haulage rope was 18 mm, maximum tension was up to 30 kN. The facility transports rock mass from the driving of water-drainage roadway and boundary entry; it also delivers material and equipment into those faces.

6. Results and discussion

While testing the rollers for wearing undermine conditions involving special stand, the indices were measured in linear units using micrometre with 0.02 μm scale division.

The roller diameter is to be measured at the point of its contact with traction rope within three diameter sections displaced one from another by 120º. The linear wear of a roller is determined according to the measuring data.

$$\Delta d = d_1 - d_2$$

Where d_1, d_2 are initial roller diameters and the diameter at the testing moment, respectively.

Relative wear values will be:

$$\varepsilon = \frac{\Delta \overline{d}}{d_1}$$

where $\Delta \overline{d}$ is the arithmetic mean value of linear wear.

Fig. 7 shows the results of experimental studies of wear value of the rollers of supporting devices.

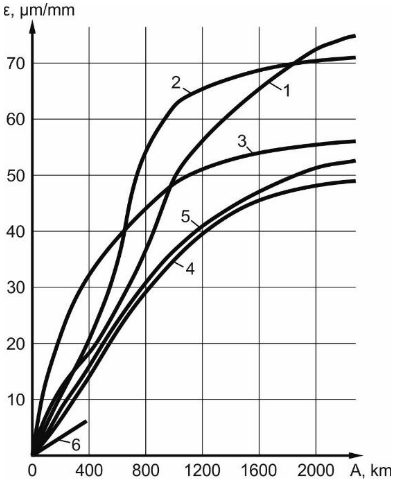

Fig. 7. Curves of the wear of experimental samples of rollers: 1 – standard; 2 – with electrospark doping; 3 – with electric arc spraying; 4 – with shock-wave treatment; 5 – lined with alloyed steel; 6 – rubber-lined

According to the dependences, the wearing process for different rollers is nonuniform.

The rubber lining of the working surface of a roller withstood the distance of more than 200 m being out of order as a result of the rubber delaminating and separating from the base.

Rollers which surface is strengthened with electrospark doping and electric arc spraying wears more intensely until there is a run life of 1800 and 1000 km respectively than a standard roller; then the wear decreases. The phenomenon can be explained by the fact that within the initial period of the rope-roller interaction, in terms of minimum contact area, stresses influence the hard surface layer applied on a softer base. At that point, it becomes deformed, the layer cracks and breaks.

The least wear degree was observed in terms of rollers which surface was treated with the help of shock-wave strengthening technique as well as rollers with a tube of alloyed thermoprocessed steel – after 2000 km of a run life it was about 60% of the standard roller wear.

Similarly, experimental studies were carried out to analyse the interaction of rope and elastic lining of a traction sheave.

The object of the research is the experimental sample of a drive sheave with the increased friction coefficient made at the Department of Transportation Systems and Technologies of the

Dnipro University of Technology; the device is of split design (Fig. 8) with changeable friction lining made of tread rubber (Ukraine's regulatory document – DST 5513-75).

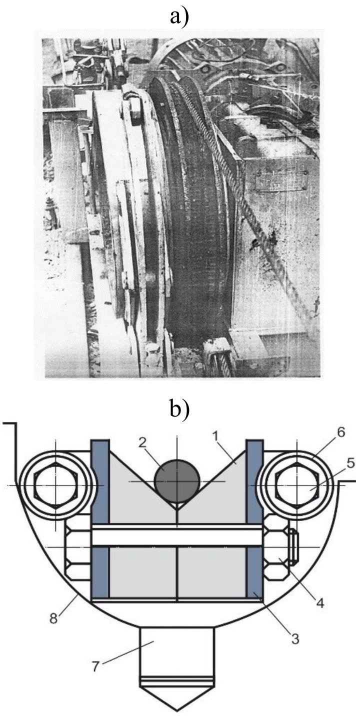

Fig. 8. Experimental sample of a friction drive sheave of ground ropeway of GRWL type:
a – general view; b – cross-section of changeable lining (1 – lining; 2 – rope; 3 – sidewall;
4 – nut; 5 – bolt; 6 – rope-eye; 7 – standoff; 8 – sheave)

Variation of the force of lining precompression to regulate its stress state is provided by clamp bolts.

To interact with the rope, there is a surface of a tread cap; the value of deformation due to lateral precompression is 20 mm.

An experimental sample of a drive sheave is set on a ground ropeway GRWL-1 which is mounted within the zone of a surface complex of Pavlogradska mine. During the experiment, the following parameters were recorded: the tension of a rope branch that is running on a sheave; the tension of a running-off branch; the wear value of the drive sheave lining.

Measurements were performed with the help of a mechanical dynamometer of the DPU-5-2 type (measuring accuracy is ± 100 N), beam compass, and micrometre.

While determining the wear, the following parameters were recorded: distance run of rope (km) involving a sheave revolution counter, forces in branches (N) involving dynamometers of DPU-5-2 type (measuring accuracy is ± 100 N), and absolute lining wear (mm) involving beam compass at three diametric sections being at the distance of 120º from each other. Table 2 represents the measuring results.

TABLE 2

Measuring results of sheave lining wear

Force in rope, N	Run life, km	Value of lining wear, mm			
		Cross-section 1	Cross-section 2	Cross-section 3	Average value
8000	10	0.5	0.7	0.5	0.57
	20	1.1	1.0	0.9	1.00
	30	1.3	1.4	1.3	1.33
	40	1.6	1.5	1.4	1.50
	50	1.8	1.7	1.8	1.77
16000	10	0.9	1.0	0.8	0.90
	20	1.2	1.2	1.4	1.27
	30	1.5	1.5	1.6	1.53
	40	1.8	1.7	1.8	1.77
	50	2.1	2.0	2.1	2.07

Based upon the observation results of the plant operation it is determined that the main reason for lining wear is because the parts are torn away with the ends of rope strands due to their unsatisfactory splicing.

Nowadays, the national industry manufactures a substantial number of ropes aimed for the operation on underground transportation facilities; however, manufacturers of modern domestic ropeways recommend using DST 2688-81 ropes with linear wire contact in the structure strand 6×19 (1+6+6+6) with a fibre core. There is the alternation of wires of larger and smaller diameters within the external layer of that rope. For instance, in terms of a rope with a diameter of 15.0 mm, their diameters are 1.1 and 0.8 mm, respectively.

Wires of 0.8 mm in diameter may lose their bearing capacity as early as within several weeks if processes of fretting corrosion and high contact stresses are available.

Analysis of the obtained dependences makes it possible to conclude the fact that the increase in diameters of the external layer wires up to 1.2-2.0 mm allows a considerable decrease in the value of contact stresses (and effect of fretting corrosion), thus, increasing their service life by 1.5-2.0 times. That is why using ropes made according to DST 3077, DST 3081, DST 7668, and DST 7669 with the increased diameters of the external layer wires and preliminarily clamped strands (Ukraine's regulatory document – TU 14-4-1070) should be considered as prospective. The most rational design of the mentioned ones may be determined as a result of separate studies under mine conditions.

7. Conclusions

Following conclusions are made as a result of theoretical and experimental mine studies of contact interaction of the traction rope with supporting rollers and traction sheave of GRW:

1. Stresses within a roller-rope contact zone exceed the limit of constructional steel fatigue;
2. Methods of surface increase in the strengthening of a roller working surface do not have proper effect as the strengthened layer on soft base cracks and delaminates due to high contact loads;

3. Use of soft rubber lining (on the Shore hardness scale up to 50) for rollers cannot be recommended from it breaking under high pressure. It is clear that in this context, polyamide lining will not be durable (admissible polyamide pressure is only by 30% higher than the rubber one);
4. Use of alloyed-steel rollers with further thermoprocessing reduces considerably (up to 30%) the wear of a roller working surface; however, the issue of their effect upon the traction rope wear requires further studies;
5. Development of prestressed state within the working surface of a roller allows increasing its wear-resistance features by 30-40%;
6. Use of plane metal or rubber-coated ropes for GRW are considered to be rather prospective from the viewpoint of the durability of both supporting devices and traction facilities [17]; that will allow decreasing contact stresses for them to be lower than the admissible ones;
7. Maximum angle of rope bending on rollers of supporting devices (6º – in operation manual; 15º – in safety rules) recommended for GRW is overstated, and it should not be more than 1.5º in terms of values of contact stresses for standard plants;
8. Short period of service life of GRW traction ropes is stipulated not only by high contact and bending stresses but also by increased wear due to coil friction on parabolic friction sheave. Rubber lining of a sheave considerably raises the friction coefficient of a rope-sheave pair and makes it possible to use a one-wrap lined sheave that eliminates coil friction of a rope;
9. Development of prestressed compressed state in the lining material increases significantly (by two and more times) its service life;
10. Ropes with reduced diameters of external layer wires (DST 2688) being used currently for mine ropeways do not meet the operating conditions and have a short period of service life due to their corrosive and fatigue breaking;
11. To lengthen the service life of GRW traction ropes, it is required to change for the ropes with increased diameters of the external layer wires with preliminarily clamped strands (DST 3077, DST 3081, DST 7668, DST 7669 and TU 14-4-1070).

Results of the theoretical calculations are validated by experimental studies under mine conditions.

The obtained dependences are true for traction ropes, supporting rollers, and drive sheaves of standard domestic GRW.

The Stress-strain state of supporting rollers and sheaves of GRW within the zone of contact with rope has been analysed; technical recommendations as for life extension of the contacting pair have been substantiated.

Further studies should be carried out towards theoretical substantiation and development of plane spring-controlled traction facilities for ground heavy ropeways.

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