UDC 621.86.065.3
https://doi.org/10.23947/2541-9129-2019-4-19-23

# ON THE TORSION OF TRACK CABLES OF JIG BACK ROPEWAYS

***Korotkiy A. A., Khalfin M. N., Ivanov B. F., Panfilov A. V., Kalanchukov I. A.***

Don State Technical University, Rostov-on-Don, Russian Federation

korot@novoch.ru
xalfin@km.ru
ivanov@ikc-mysl.ru
panfilov@ikc-mysl.ru
ilyaskalanchukov@gmail.com

Observations of the operation of jig back ropeways allowed us to suggest the presence of torsion of track cables of a closed structure under the influence of operational loads. In this case, the total weight of the cable and the car is a transverse load, and the cable itself is loaded with longitudinal resistance forces in its individual sections. The paper provides theoretical substantiation and experimental confirmation of the presence of torsional deformations of track cables of jig back ropeways under the influence of friction between the cable and the rocking saddles. A new method of rejection of such cables based on the control of torsional deformations is proposed.

**Keywords**: track cables, jig back ropeways, torsional deformations, method of rejection of cables, rocking saddles, rolling stock, safety margin, experimental studies of torsion, laser beam

УДК 621.86.065.3
https://doi.org/10.23947/2541-9129-2019-4-19-23

# О КРУЧЕНИИ НЕСУЩИХ КАНАТОВ МАЯТНИКОВЫХ КАНАТНЫХ ДОРОГ

***Короткий А. А., Хальфин М. Н., Иванов Б. Ф., Панфилов А. В., Каланчуков И. А.***

Донской государственный технический университет, Ростов-на-Дону, Российская Федерация

korot@novoch.ru
xalfin@km.ru
ivanov@ikc-mysl.ru
panfilov@ikc-mysl.ru
ilyaskalanchukov@gmail.com

Наблюдения за эксплуатацией маятниковых пассажирских канатных дорог (МПКД) позволили авторам предположить наличие деформаций кручения несущих канатов закрытой конструкции при воздействии эксплуатационных нагрузок. При этом суммарный вес каната и вагона является поперечной нагрузкой, а сам канат нагружен продольными силами сопротивления на его отдельных участках. Выполнены теоретическое обоснование и экспериментальное подтверждение наличия деформаций кручения несущего каната МПКД под действием силы трения между канатом и башмаками линейных опор. Предложен новый способ отбраковки таких канатов, основанный на контроле деформаций кручения.

**Ключевые слова:** несущий канат, маятниковая пассажирская канатная дорога, крутильные деформации, способ отбраковки канатов, башмаки линейных опор, подвижный состав, запас прочности, экспериментальные исследования кручения, лазерный луч.

**Introduction.** In works [1-6] it is noted that during operation of jig back ropeways the track cable is subjected to tensile loads. At the same time, there are attempts to substantiate the presence of torsional deformations caused by the influence of the friction force from the slip of the cable on rocking saddle [7, 8].

**Theoretical justification of torsion of the jig back ropeways track cable.** According to Federal Norms and Rules [9, 10], the ratio of the minimum tension of the track cable $T$ to the weight of the loaded rolling stock $M_в$ of jig back ropeways must meet the following conditions:

for the cable with tensioner $\frac{T}{M_{в}} \geq 10$;

for the cable with anchored ends $\frac{T}{M_{в}} \geq 8$.

The friction force when moving the car on the rocking saddle can be determined by the formula:

$$P = cG_n + \mu g(g_0 + m_{в})L + \varepsilon T, \tag{1}$$

where $G_n$ — the weight of the counterweight; $m_в$ — the mass of the car, per one meter of the track cable; $g_0$ — the mass of one meter of the cable; μ — the coefficient of sliding friction of the cable on the rocking saddle, μ = 0.2; $c$ — the loss factor on the stiffness of the track cable, c = 0.035; ε — the coefficient considering the angle of inclination of the track cable, ε = 0.17; $L$ — the length of the stretched section of the cable; $T$ — track cable tension; $g$ — acceleration of free fall.

The expression for the tension of jig back ropeways track cable has the form [2]:

$$T = G_n + 0{,}5 g_0 g l,$$

where $l$ — the length of the tension part of the cable.

The values of tensile stresses in the wires of the track cable are determined by the expressions presented in [3]:

- for the section of untwisting of the track cable on rocking saddle:

$$\sigma_p = E \cdot \left( \begin{array}{l} (G_n + \frac{P}{2}) \cdot \frac{1}{2A_{11}} \cdot \cos^2\alpha + \\ + \frac{A_{22} \cdot P}{A_{11} \cdot A_{22} - A_{12}^2} \cdot \cos^2\alpha - \\ - \frac{A_{12}}{A_{11} \cdot A_{22} - A_{12}^2} \cdot \frac{P}{2} \cdot r \cdot \sin\alpha\cos\alpha \end{array} \right); \tag{2}$$

- for the twisting section of the cable:

$$\sigma_p = E \cdot \left( \begin{array}{l} (G_n + \frac{P}{2}) \cdot \frac{1}{2A_{11}} \cdot \cos^2\alpha - \\ - \frac{A_{22} \cdot P}{A_{11} \cdot A_{22} - A_{12}^2} \cdot \cos^2\alpha + \\ + \frac{A_{12}}{A_{11} \cdot A_{22} - A_{12}^2} \cdot \frac{P}{2} \cdot r \cdot \sin\alpha\cos\alpha \end{array} \right), \tag{3}$$

where $E$ is the elasticity modulus; $r$ is the radius of lay of the layer of wires; α — the angle of lay; $A_{11}$, $A_{12}$, $A_{22}$ are the coefficients of stiffness of a track cable of a closed structure [11].

Substituting the value of the friction force, found by the formula (1), in the expressions (2) and (3), it is possible to determine the total stresses from stretching and torsion of the track cable in its sections of untwisting and twisting. For a closed structure cable at safety margins of 2.7 and 3.15 [9] tensile stresses depend on the ratio $\frac{P}{T}$. This ratio is taken in the range of 0.08 ... 0.2. Then the tensile stresses will be in the corresponding range of 90 ... 180 MPa. Such loading of the cable is accompanied by fatigue effect. Under these conditions, when the parameter $\frac{P}{T}$ reaches an abnormal value ($\frac{P}{T}$ > 0.2), the outer shaped wires may break and other defects may develop. This will reduce the service life of a jig back ropeway track cable of a closed structure beyond repair.

**Devices and methods of experiment.** To experimentally confirm the presence of torsion deformation of the jig back ropeway track cable there has been developed a device consisting of a movable and fixed brackets attached to the cable. A screen is mounted on a movable bracket, a laser ruler is mounted on a fixed one. The fixed bracket can be rotated together with the cable when torsional deformations develop. As a result, the angle of rotation of the beam is fixed on the screen of the movable bracket. The experimental study was conducted at jig back ropeway of the Research institute "Gorlesekol", Sochi. Below there are the parameters of this road:

length of the road — 1.1 km;
number of cars — 2;
number of wagon wheels — 8;
number of passengers in the car — 30;
weight of the car — 1.1 tons;
weight of the tension load — 44 tons.

To measure the torsion strain of the track cable, the device was fixed at a distance of 3 meters from the cable attachment at the drive station (Fig. 1).

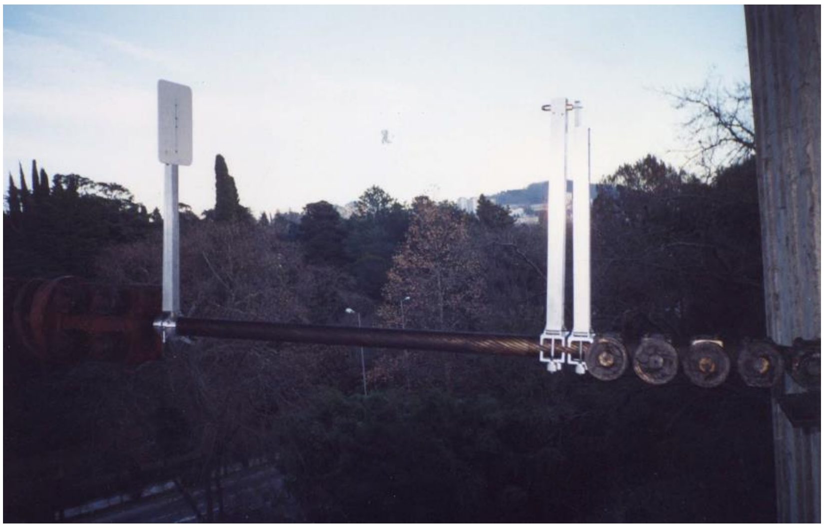

Fig. 1. General view of the device for measuring the torsion of the track cable of a closed structure

After adjusting the laser beam, a loaded car at revision speed moved in the direction of the drive station to the tension one. The deviation of the laser beam from the center of the screen ranged from 6° to 8° (Fig. 2). The measurement error of the relative torsion of the track cable did not exceed 7×10-3 $mm^{-1}$.

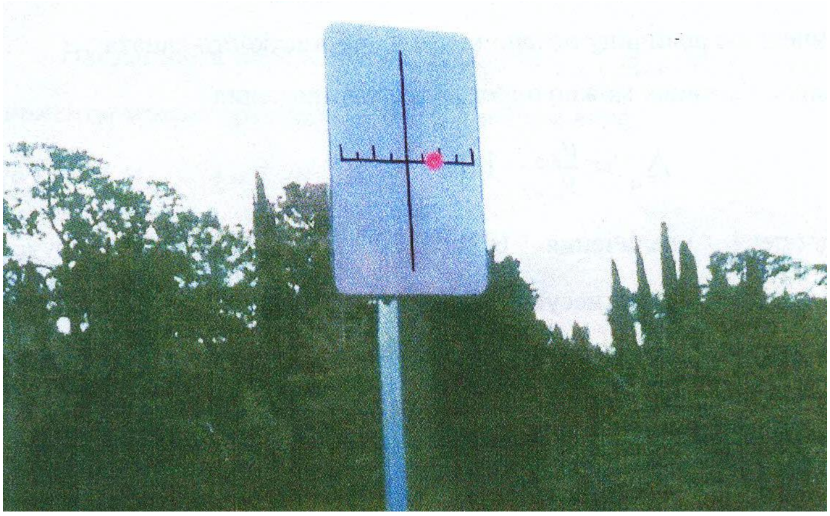

Fig. 2. Fixation of torsion of the track cable

**Analysis of research results.** The obtained results made it possible to propose a method for cables rejection based on the comparison of torsional deformations of their sections located near the place of fastening. During operation, the torsional rigidity of cables is reduced due to wear, corrosion, technological imperfections. The spread of mechanical properties, uneven tension of wires of both outer and inner layers contribute to an increase in torsional deformations. Therefore, periodical measurement of the torsion deformation of the cable can help you control the decrease in its strength.

In [8] the calculation of the relative torsion strain is presented as a complex of deformations caused by technological imperfections and friction of the track cable on the rocking saddle. Taking into account the requirements of Federal norms and rules about necessity of rejection of the track cable of a closed structure at the decrease of the area of cross-section of a wire by 10 % [9, 10], it is possible to write down the formula for rejection index on torsion:

$$\Delta_n = \frac{F_н}{F_u} \cdot 100\% = \frac{100\%}{0,9} = 111\%,$$

where $F_н$ and $F_u$ — the cross-sectional area of the new and worn rope, respectively.

This means that if the torsional strain of the track cable of a closed structure exceeds 11%, it should be replaced.

**Conclusion.** The presence of torsion deformations of track cables of a closed structure due to friction between the cable and the rocking saddle of linear supports was justified theoretically and confirmed experimentally.

A method of rejection of jig back ropeways track cables, based on reducing the torsional stiffness of the worn cable in operation is proposed.

**References**

1. Dukelskiy, A.I. Podvesnye kanatnye dorogi i kabel'nye krany. [Cableways and cable cranes.] Leningrad: Mashinostroenie, 1966, 428 p. (in Russian).

2. Belaya, N.M. Osnovy rascheta nesushchikh kanatov. Stal'nye kanaty. Vyp. 2. [Calculation basis of track cables. Steel ropes. Vol. 2.] Kiev: Tekhnika, 1965, pp. 139-144. (in Russian).

3. Sergeev, S.T. Stal'nye kanaty. [Steel ropes.] Kiev: Tekhnika, 1974, 326 p. (in Russian).

4. Berkman, N.B. et al. Podvesnye kanatnye dorogi. [Cableways.] Moscow: Mashinostroenie, 1984, 264 p. (in Russian).

5. Pataraya, D.I. Raschet i proektirovanie kanatnykh system na primere podvesnykh dorog. [Calculation and design of rope systems on the example of cableways.] Tbilisi: Metsniereba, 1990, 102 p. (in Russian).

6. Mamaev, Yu.D. Optimal'nye usloviya ekspluatatsii nesushchikh kanatov na podvesnykh kanatnykh dorogakh. [Optimal operating conditions of track cables on cableways.] Stal', 1995, no. 1, pp. 44-46 (in Russian).

7. Khalfin, M.N., Ivanov, B.F., Sorokina, E.V. K raschetu na prochnost' nesushchego kanata podvesnoy kanatnoy dorogi. [On the calculation of the strength of the track cable of the cableway.] Interstroymekh-2011: materialy mezhdunar. nauch.-tekhn. konf. [Interstroymekh-2011: proc. of the international sci.-techn. conf.] Mogilev, 2011, pp. 237-240 (in Russian).

8. Khalfin, M.N., Sorokina, E.V., Ivanov, B.F. Kruchenie i volnistost' nesushchikh zakrytykh kanatov podvesnykh kanatnykh dorog. [Torsion and undulation of cableways track cables of a closed structure.] Novocherkassk: Nabla, 2004, 117 p. (in Russian).

9. Pravila bezopasnosyi passazhirskikh kanatnykh dorog i funikulerov: Federal'nye normy i pravila v oblasti promyshlennoy bezopasnosti: [utv. Federal'noy sluzhboy po ekologicheskomu, tekhnologicheskomu i atomnomu nadzoru, 6 fevralya 2014 g. [Safety rules of passenger cableways and funiculars: Federal rules and regulations in the field of industrial safety: [app. by Federal service for environ-

mental, technological and nuclear supervision, February 6, 2014] Konsortsium Kodex. Available at: http: // docs.cntd.ru/ document/ 499077072 (accessed 10.10.2019). (in Russian).

10. O vnesenii izmeneniy v Federal'nye normy i pravila v oblasti promyshlennoy bezopasnosti: [utv. Federal'noy sluzhboy po ekologicheskomu, tekhnologicheskomu i atomnomu nadzoru, 28 aprelya 2016 g. [On modification of Federal norms and rules in the field of industrial safety of passenger cableways and funiculars: [app. by Federal service for environmental, technological and nuclear supervision, April 28, 2016] Kontur. Normativ. Available at: https: // normativ. kontur.ru/ document?moduleId=1&documentId=273818 (date accessed: 10.10.2019). (in Russian).

11. Glushko, M.F. Stal'nye podyemnye krany. [Steel track cables.] Kiev: Tekhnika, 1966, 327 p. (in Russian).

***Autors:***

***Korotkiy Anatoliy Arkadyevich,***
*head of the Department "Operation of transport systems and logistics", Don State Technical University, (1, Gagarin sq., Rostov-on-Don, 344000, Russia), doctor of technical sciences,*
korot@novoch.ru

***Khalfin Marat Nurmukhamedovich,***
*professor of the Department "Operation of transport systems and logistics", Don State Technical University, (1, Gagarin sq., Rostov-on-Don, 344000, Russia), doctor of technical sciences,*
xalfin@km.ru

***Ivanov Boris Fedorovich,***
*professor of the Department "Operation of transport systems and logistics", Don State Technical University, (1, Gagarin sq., Rostov-on-Don, 344000, Russia), candidate of technical sciences,*
ivanov@ikc-mysl.ru

***Panfilov Aleksey Viktorovich,***
*assistant professor of the Department "Operation of transport systems and logistics", Don State Technical University, (1, Gagarin sq., Rostov-on-Don, 344000, Russia), candidate of technical sciences,*
panfilov@ikc-mysl.ru

***Kalanchukov Ilyas Aleksandrovich,***
*student of the Department "Operation of transport systems and logistics", Don State Technical University, (1, Gagarin sq., Rostov-on-Don, 344000, Russia),*
ilyaskalanchukov@gmail.com