Analysis of the Haulage Ropes on Ropeways in Case of Accidental Loads

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***Abstract* – The proven safe operation and the high availability of aerial ropeways is mainly thanks to their design. This is based on the manufacturer's extensive experience as well as the strict application of the relevant rules and norms.**

In that regard, this paper describes an analysis of the haulage ropes on ropeways in case of accidental loads. In solving this problem, analyzed ropeway system with sufficient accuracy was modeled as a system with three degrees of freedom. For solving differential equations we have used the software "*Wolfram Mathematica*".

At the end of the paper, we discuss the results of the dynamic forces in the haulage ropes in a certain time interval, and the results of the safety factors which in this case are sufficient to ensure reliable operation of the system.

***Keywords* – bi-cable ropeway, haulage ropes, accidental loads.**

1. Introduction

Ropeways are a means of transport with more carriages which are hung on steel wire. Ropeways are widely used for public transport as well as for transportation of goods in mountain resorts and also in urban areas.

For passenger transportation different types of ropeways are used since various technical systems and their combinations have evolved over many years. They can be grouped by two main criteria: the number of ropes with different functions (mono-, bi- and multi-cable ropeways) and the type of motion (continuous (circulating), reversible and pulsed operation) [2].

To cover longer distances and higher elevations using less number of intermediate supports, bi-cable ropeways constitute a feasible technical solution, optionally with circulating or reversible operation system (Figure 1).

As we can observe, due to the great variety of considered systems it is difficult to formulate a universal model and common computational procedure to investigate static and dynamic behavior of such structures. Then scientific publications often handle cases of certain type of load acting on individual type of ropeway (already built and being in use), especially when authors undertake the research of dynamic load [4–8] which usually concern selected problems, e.g. dynamic behavior of carrying and hauling rope [4], [7] or carrying-hauling rope [8], rope and carriers reaction to lateral wind [6], etc.

The speed of cabin while moving like a pendulum is much greater than the speed of freight circulating ropeways and often is (8– 10)m/s, in special cases, at longer transport distances even 2,5m/s.

Therefore, in these types of ropeways, special attention is paid to the safety and security during movement, and the ropes that are applied in these ropeways are calculated with a higher degree of security.

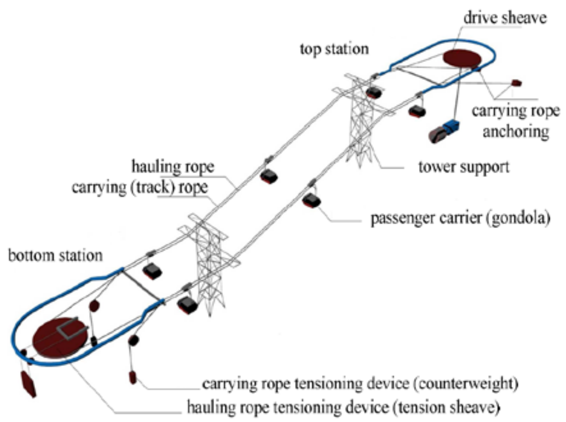

Figure 1. Bi-cable circulating detachable gondola ropeway [3]

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2. Model of the analyzed ropeway system

In this type of ropeway, transfer of two cabins is performed so that the drive station simultaneously runs at one cabin and continues to move like a pendulum. Such a movement of cabins is performed with a system of haulage ropes, whose calculation must include the case of accidental loads generated by breaking one of the two haulage ropes.

With the calculation of accidental loads can be determined values of the safety factor of haulage ropes in relation to the maximum dynamic forces that appear in them, and whether in a particular case, the degree of safety of the haulage rope is sufficient to ensure reliable operation of the system, including delivery of the cabin to the drive station. It is assumed that the cabins with passengers are located on the section of the route with the highest slope (above the corresponding towers) and that the drive unit is turned off. In solving this problem, analyzed ropeway system with sufficient accuracy can be modeled as a system with three degrees of freedom.

For generalized coordinates of the system were adopted displacements X_i and mass m_i , where i = 1,2,3. The masses m_1=6000 kg and m_3=8000 kg are the reduced mass of cabins with passengers, hangers and ropes, and mass m_2=12300 kg is the total mass of counterweights.

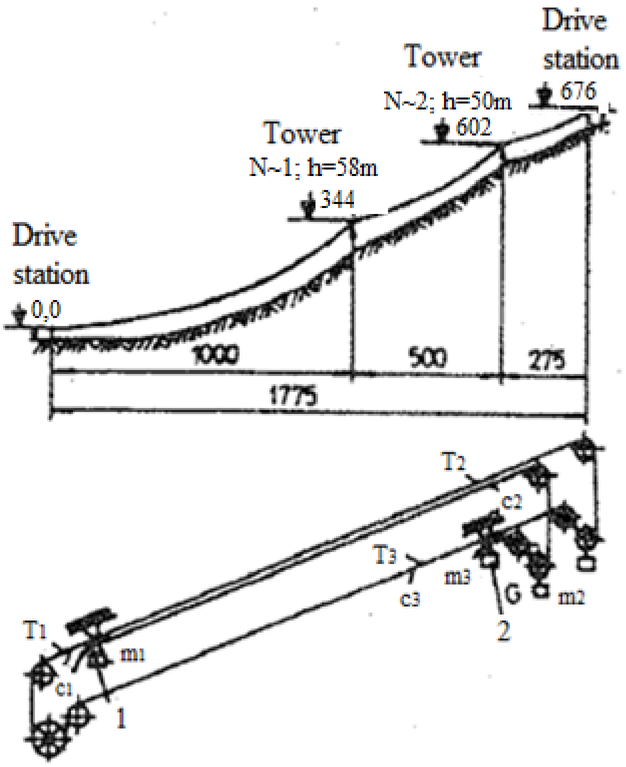

Figure 2. Model of the analyzed ropeway system [1]

Applying D'Alembert's principle leads to the system of equations:

$$\begin{aligned} m_1\ddot{x}_1 &= 2T_2 - T_1 - m_1 g sin\gamma_1 - F_{w1} \\ m_2\ddot{x}_2 &= G - 2T_2 \\ m_3\ddot{x}_3 &= 2T_2 - T_3 - m_3 g sin\gamma_2 - F_{w3} \end{aligned} \quad (1)$$

where:

$$\begin{aligned} T_1 &= 0{,}5(G - F_{w1}) + c_1 x_1 \\ T_2 &= 0{,}5\,G + c_2(2\,x_2 - x_1 - x_3) \\ T_3 &= 0{,}5(G - F_{w3}) + c_3 x_3 \end{aligned} \quad (2)$$

(T_1, T_2, T_3) forces in the haulage and track ropes, $F_{w1} = m_1 g f_0 cos\gamma_1 = 334$ N and $F_{w3} = m_3 g f_0 cos\gamma_2 = 455$N static resistance to movement of the cabin by track ropes, $\gamma_1 = 25°$ and $\gamma_2 = 30°$ slopes of the route track rope, c_i (i = 1,2,3) reduced coefficients of stiffness ropes (resilient connections in the system).

Reduced stiffness coefficients of resilient connections depend on the elastic properties and character of changes shape "curve of descent" ropes.

The coefficient of stiffness is determined by a famous phrase:

$$c_u = \frac{EA}{L} = \frac{EAcos\beta}{l} \quad (3)$$

where:

E - modulus of elasticity,

A - cross sectional area of rope,

L - lengthof rope,

l – distance endpoints rope measured horizontally,

β – slope of the route part

In determining the coefficient of flexibility when changing the shape "curve of descent", two rope positions should be considered:

1. The initial value of the horizontal component of tension force H, and
2. The increase in intensity of the horizontal component of tension force for ΔH, and length of the rope for ΔL.

The above-mentioned coefficient is determined from the expression:

$$\frac{1}{c_f} = \lim_{H_1 \to H} \frac{\Delta L}{\Delta H} = \lim_{H_1 \to H} \frac{q_u^2 l^3}{24} \frac{H^{-2} - H_1^{-2}}{H - H_1} cos\beta = \frac{q_u^2 l^3 cos\beta}{12H^2} \quad (4)$$

where :

q_u - unit weight of rope.

Reduced stiffness coefficients of the rope are:

$$c = \frac{c_u c_f}{c_u + c_f} = \frac{12HEAcos\beta}{l(12H^3 + EAq_u^2 l^2 cos^2\beta} \quad (5)$$

respectively: $c_1 = 816000\ \mathrm{Nm}^{-1}$, $c_2 = 3570\ \mathrm{Nm}^{-1}$ and $c_3 = 6340\ \mathrm{Nm}^{-1}$.

When the equation(2) is introduced to the system of equations (1) then we get the differential equation of oscillation system:

$$\begin{aligned} m_1\ddot{x}_1 + (c_1 + 2c_2)x_1 - 4c_2x_2 + 2c_2x_3 &= \\ = 0{,}5(G - m_1 g sin\gamma_1 - F_{w1}) & \\ m_2\ddot{x}_2 - 2c_2x_1 + 4c_2x_2 - 2c_2x_3 = 0 & \\ m_3\ddot{x}_3 + 2c_2x_1 - 4c_2x_2 + (2c_2 + c_3)x_3 &= \\ = 0{,}5(G - m_3 g sin\gamma_2 - F_{w3}) & \end{aligned} \tag{6}$$

The forces in the ropes are determined when the solutions of differential equations (6) are included in the expressions (2).

The system of differential equations (6) we have solved using “Wolfram Mathematica” software package, which gives us plenty of opportunities. First, we determine the exact solution, which depended on the six indeterminate constants, because we did not have given initial conditions.

This exact solution from the point of application is pretty useless, and therefore we access the determining unspecified constants. We used a technique that offers a software package and we got pretty satisfactory results compared with the results obtained by other methods.

3. Results

Figure 3. shows diagrams of changes force T_1, which occurs in the haulage rope for a time interval of 12s.

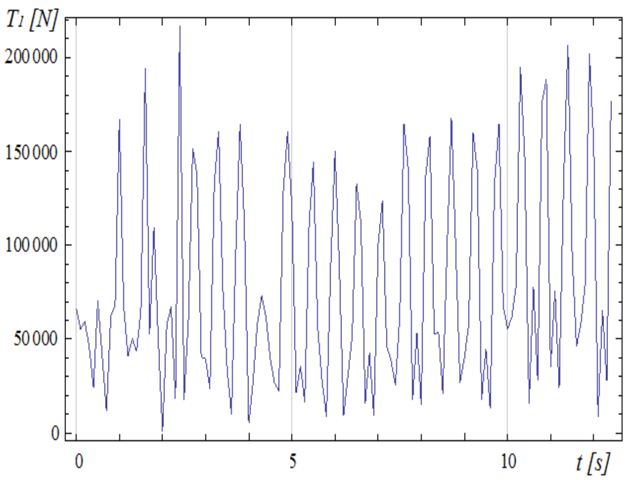

Figure 3. The force T_1 in the haulage rope

Figure 3. shows that the largest intensity of the force $T_1 = 216.767\ N$ occurs at the time of 2,4seconds.

Since the haulage ropes dimensioning to withstand the maximum load of$T_{1max} = 343.000\ N$, then the degree of safety of the haulage rope in relation to the maximum force $T_1 = 216.767\ N$ will be:

$$S_1 = \frac{T_{1max}}{T_1} = 1{,}58 \tag{7}$$

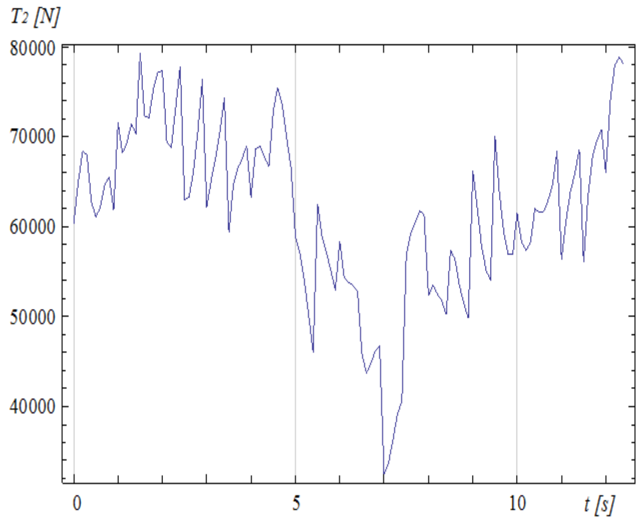

Figure 4. – The force T_2 in the track rope

Figure 4. shows diagrams of changes force T_2, which occurs in the track rope for a time interval of 12s. The largest intensity of the force $T_2 = 79.276$ N occurs at the time of 1,5s.

Since the track ropes dimensioning to withstand the maximum load of $T_{2max} = 343.000$ N, then the degree of safety of the trackrope in relation to the maximum force $T_2 = 79.276$ N will be:

$$S_2 = \frac{T_{2max}}{T_2} = 4{,}32 \tag{8}$$

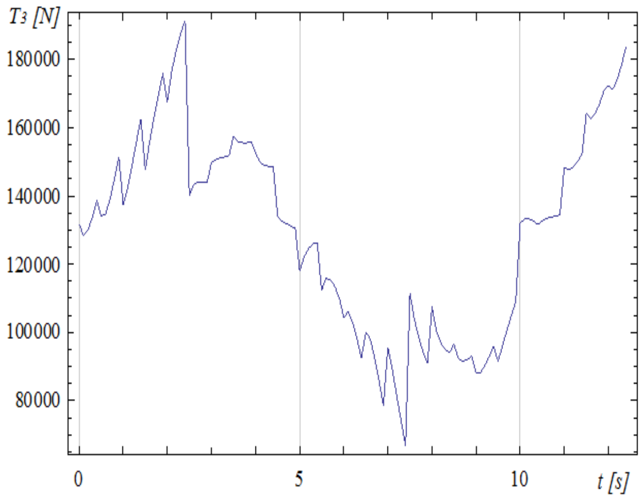

Figure 5. – The force T_3 in the haulage rope

Figure 5. shows diagrams of changes force T_3, which occurs in the haulage rope for a time interval of 12s. The largest intensity of the force $T_3 = 191.337$ N occurs at the time of 2,4s.

Since the haulage ropes dimensioning to withstand the maximum load of $T_{3max} = 343.000$ N, then the degree of safety of the haulage rope in relation to the maximum force $T_2 = 191.337$ N will be:

$$S_3 = \frac{T_{3max}}{T_3} = 1,79 \quad (9)$$

4. Conclusion

Based on the obtained results, we can conclude that the biggest force in the considered case of an accidental loads, achieved in operating the haulage rope1, an increase of 12% of the maximum force in the haulagerope3.

On the other hand, we can see that the minimum force appears in track rope2, which results in the occurrence of the highest degree of safety in that rope and that is about 2.5times higher than the degree of safety in the other two ropes.

Also, when we compare the figures 3, 4 and 5, we can see that the frequency of load changes is the largest in the haulagerope1, while the mentioned frequency in the other haulage ropes are significantly less.

Finally, since the aim of the study was to determine whether the degree of safety with haulage ropes in this case be sufficient for not disturbed the system, we can see that all three degree of safety within the prescribed limits, which means that in this case degrees of safety are sufficient to ensure reliable operation of the system.

References

[1]. Tošić, S.B. (1999). *Transportni uređaji – Mehanizacija transporta*, Mašinski fakultet Beograd, Univerzitet u Beogradu.

[2]. Knawa-Hawryszków, M., Bryja, D. (2014). *Analysis of nonlinear effects in a carrying rope of cableway subjected to moving load*, Proceedings of the 9th International Conference on Structural Dynamics, EURODYN 2014., ISSN: 2311-9020; ISBN: 978-972-752-165-4, Porto, Portugal.

[3]. Hoffmann, K. (2009). *Oscillation Effects of Ropeways Caused by Cross-Wind and Other Influences*, FME Transactions, vol.37, No 4, 175-184.

[4]. Brownjohn, J.W. (1998). *Dynamics of aerial cableway system*, Engineering Structures, vol. 20, p. 826–836.

[5]. Shioneri, T., Nagai, M. (1997). *Study on vibrational characteristics of ropeway transport system*, Proceedings of Asia-pacific Vibration Conference, Korea.

[6]. Petrova, R., Hoffman, K., Liehl, R. (2007). *Modelling and simulation of bi-cable ropeways under cross-wind influence*, Mathematical and Computer Modelling of Dynamical Systems, vol. 13(1), p. 63–81.

[7]. Portier, B. (1984).*Dynamic phenomena in ropeway after a haul rope rapture*, Earthquake Engineering and Structural Dynamics, vol.12, p. 433–449.

[8]. Renezeder, H.C., Steindl, A., Troger, H. (2005).*On the dynamics of circulating monocable aerial ropeways*, In: WILEY-VCH Verlag GmbH & Co.KGaA, editors. PAMM Proceedings of Applied Mathematics and Mechanics, vol. 5, p. 123–124, Weinheim.