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Dynamic loads effects on the characteristics of compressive monocable chairlift towers

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Passage of the grip over chair lift compression battery is followed by a series of tower trembles. On that very moment grip has contact with the wheel, passing under the wheel and then lost the contact. The consequences of this phenomenon on the tower structure are not researched well.

This paper research the behavior of not real, but pre-installed structures in real operational conditions. In laboratory conditions, initiative load represents a combination of several basic types of signals. In the research carried out under real conditions, the initiative load was very complex. The possibilities of modeling complex nature of real initiative with satisfy acceptability, were used. The passage of the chair causes a forced damped vibration, which can have stress implications.

The paper describes complex identification of initiative, analysis of the oscillation types of the tower structure, as well as correlated relations of the initiative excitation and tower stress response.

Keywords: Compression tower, monocable chairlifts, impact, modal analysis, the FE model, validated model, oscillation, frequency range, stress consequence.

0 INTRODUCTION

Many authors have studied the problem of the passage of chair under the compression sheave assembly on monocable chairlifts. In [1] to [3] we have investigated the influence of impact load on the behavior of sheave assembly itself, without response of the tower.

Fig. 1. *The consequences of energy exchange*

Passage of the grip over chairlift compression sheave assembly is characterized by energy transfer. Part of kinetic energy that comes from the movement of the vehicle connected with a rope, is transferred to the sheave assembly. Then, part of the kinetic energy that is transferred to the sheave assembly causes the movement of the its components, rotations and displacements of sheave assembly in a vertical direction. The second part is transformed into energy of deformation of the sheave assembly and tower. The author of this paper was interested on the consequences of such energy exchanges on the tower structure, Fig. 1.

1 PASSAGE OF THE GRIP UNDER COMPRESSION SHEAVE ASSEMBLY

In the case of negative sheave assembly, the grip arrives facing the bottom of the rope. Passing under the sheave assembly top surface of the grip, which has the geometry resulted from the calculation of strength, is *n* times in contact with the wheel and the same number of times the contact is lost (*n* - number of wheels in the sheave assembly). The passage of grip, it is usually followed by a series of tower trembles. Driving on the chairlift the passenger has the feeling of driving on the road full of

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small holes. Details [4].

On the Fig. 2. we clearly recognized contact of two elements the grip and the wheel as a collision of two objects. Grip has multiple weight (reduced mass of passenger and chairs M>> m), and also there is a difference in speed at the point of collision. There is also a difference in materials. The cover of the wheel is made of rubber, and the grip was made of wrought steel. During the impact moment a impact pulse occurs, which by its intensity could be several times bigger than static force on one single wheel. But according to time velocity it is defined as the instantaneous value.

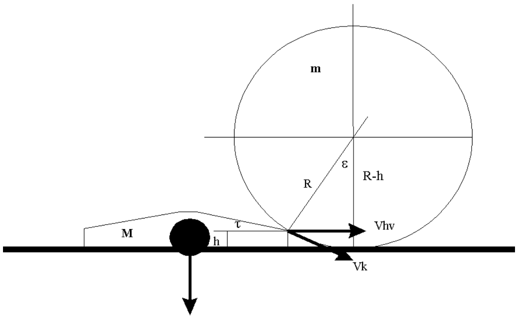

Fig. 2. *Grip and wheel contact*

Load redistribution is the consequence of the appearance of the impact pulse. At the moment of impact, impact pulse is transmitted to the rope through the second wheel, the pair of the hitteed wheel, Fig. 3.

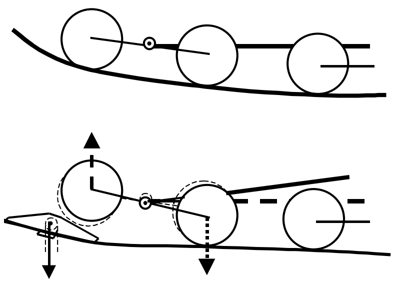

Fig. 3. *The transfer of the impact pulse*

The frequency of this occurrence can be calculated:

$$f = \frac{1}{\frac{l}{v}} \quad [Hz] \tag{1}$$

where: *l – the distance between wheels*
v – line speed of the chairlift

For dimensional relations that are most frequent, for the chairlifts with a fixed grip, it is in the range of *f* = 4 to 12 Hz. The frequency of occurrence is relatively low and there is danger of their coinciding with its own tower frequency. In the static considerations of the construction, this phenomenon are includes by increasing the vertical force for double velocity of the vehicle mass.

2 METHODOLOGY

We used an experimental modal analysis and validated FE model of the tower to investigate the consequences of this described phenomenon on the dynamic behavior of a tower structure. It is common that modal analysis researches are carry out in the laboratory on prototype models. In that case it is necessary to solve the problem by fastening the structure, in a way that coinsided to real conditions. Depending on the type of structure, this step is the most common source of disagreement with the actual experimental conditions.

This paper examines the behavior of installed structures in real operational conditions. In the researches carried out under real conditions the initiative load is the one which in all its complexity affects the structure. When we research the tower of the chairlift we have to consider their behavior over the influence of stiffness of the rope. This research was done for the established operational regime, were inertia forces have no significance.

2.1 Initiative load

Acceleration sensor is attached to the chair structure, and the figure shows the acceleration signal measured in the vertical direction. The figure clearly shoves arrival moment of a chair on the sheave assembly (650) and moment when the grip losing contact with the sheave assembly (1600). Fig. 4.

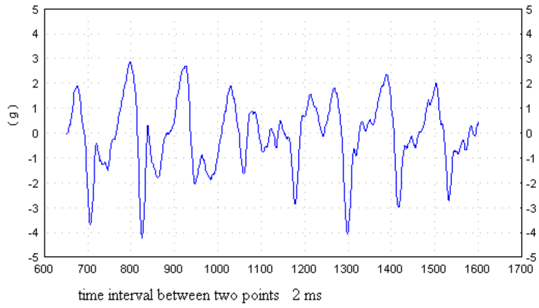

Fig. 4. *The vertical component of chair acceleration on the assembly of 8 wheels*

There is isolated segment, which is used for modeling of dynamic excitation approximating to 12 points. Fig. 5.

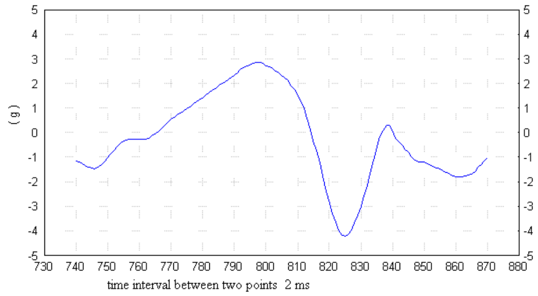

Fig. 5. *Segment acceleration functions used to model load*

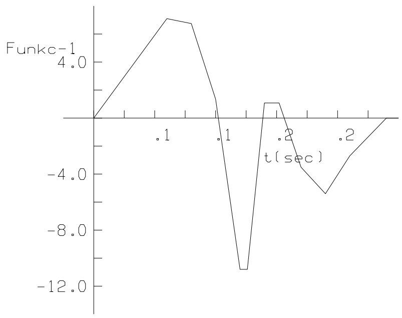

Fig. 6. *Model of the excitation load*

Fig. 6. shows the shape of the excitation load, force [kN] in a function of time [sec]. Thus modeled load included the total time were the grip is in contact with the wheel. If there are *n* wheels on the sheave assembly, this type of load will appear *n* times in calculated model. Performed spectral analysis of real and modeling load, shows a correlation higher than 80%, which justify our assumption of the model with 12 interpolation points.

2.2 Validation of the numerical model

Plate girder model was formed for research purposes. The model is formed with a kinematics freedom of all elements of the sheave assembly. Model validation was performed in a manner that compared the real mode shapes of the structure and mode shapes of a numerical model with a given modeled excitation. Measuring points are shown in Fig. 7, and also they are response points of the model.

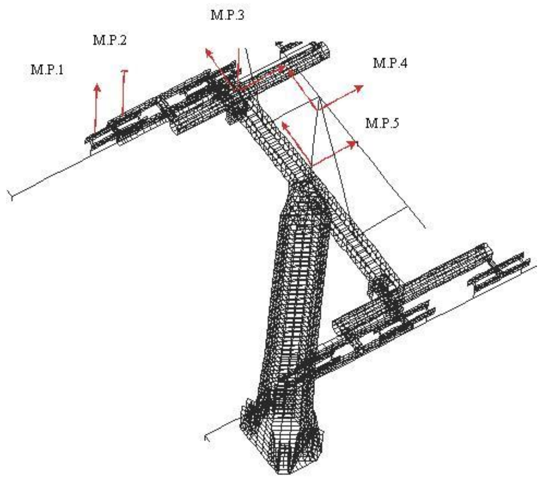

Fig. 7. *Measuring points*

Correlation data degree was estimated higher than 80%. (Example M.P.1 and M.P.5.). For this type of testing in real environment conditions, it can be considered sufficient. Fig. 8.

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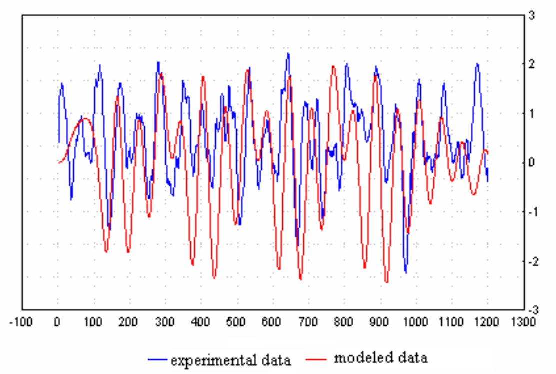

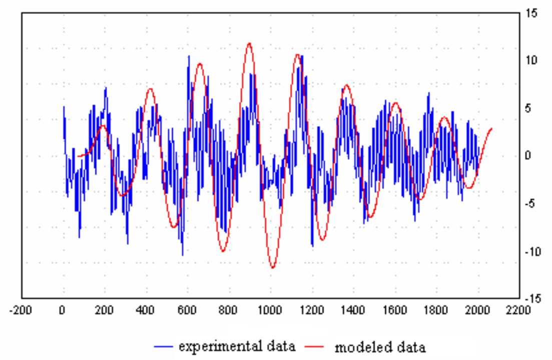

Fig. 8. *An example of correlation of experimental and model data - validation of models*

2.3 Identification of the dynamic behavior of validated model

In the first two modes, on the frequency of ω = 4.25 Hz and ω = 9.6 Hz, the oscillations of the yoke are primary in the longitudinal and lateral direction. The amplitudes of these oscillations are high and at the top of the yoke they move up to 60 mm. In the third mode of oscillation, at frequency of ω = 12.7 Hz, a tower itself and yoke oscillating in the longitudinal plane, with significantly smaller amplitudes of 5.4 mm. The other three modes are oscillations of the sheave assembly, together with the tower itself. Oscillation of the sheave assembly is not a problem because it kinematics allows that, but we can expected that moving of the tower itself has some stress implications.

The proximity of their frequent oscillations in the first three modes of oscillation and the frequent spectrum excitation indicates the possible resonant states.

2.4 Forced damped oscillations in the frequent domain

Anchor structure: studies have shown that the amplitude gain for a given excitation in the vertical direction, measured in the direction of alignment lifts, from 6 - 8 times in the frequency range of 15 - 20 Hz. So, for the last four types of oscillation in which it takes part and tree steps. Significant amplitude enhancement is the still the anchor that is closer to the source of excitation.

The tower itself: if the excitation acts on the return side it show very high values of amplitude states (12-25 times) and the response is monitored at points that are diagonally opposite. Considerably lower but still unacceptably high values are shown if the excitation acts from drafted side. Frequency range of the reported phenomena is from 10 - 20 Hz.

Yoke: The analysis indicates that the yoke oscillates in resonance with the excitation, Fig. 9. The rest of the tower in this process plays the role of the dynamic absorber and this is the main reason that yoke does not separate from cross carrerier. The frequency distribution diagram of the experimental load frequency of 4 - 5 Hz exists with 2 / 3 share in the frequency spectrum.

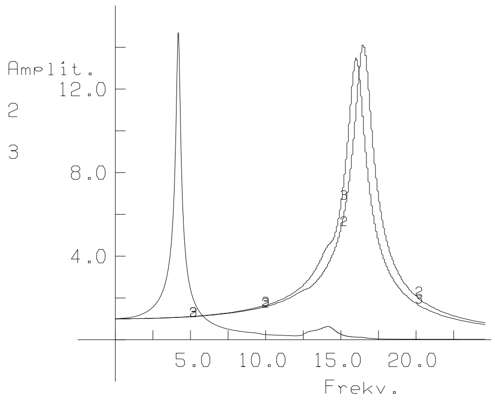

Fig. 9. *Diagram of amplitude intensify of the top of yoke*

2.5 Stress consequences of the passage of seats

Fig. 10. *Measuring poin , strain gauges*

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Tension changes on the tower itself were monitored for the purposes of experimental verification of research results. Strain gauges, Fig. 10, are placed around a light contours on the tower

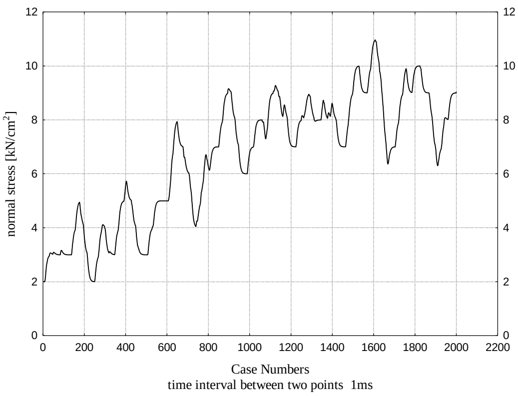

Fig. 11. *Tension signal from the strain gauges*

Passage of the seat is registered by changing of stress and an increase of the stress state, Fig. 11. Comparing the signals in Fig. 4, Fig. 11, it is clear correlative relationship. Stress signal in Fig. 11, represents the relative change in stress. Strain gauges were attached on a tower, which was already loaded with a rope and empty chairs (during maintenance). It is expected that the stress changes are around some constant values. In Fig. 9 it is not that situation, because load distribution along the corresponding suspension bridge and the load on the opposite side, affects the value of stress. For this reason, we can talk about an average increase of stress state caused by the passage of the chair.

For researched structure of the tower average increase in normal stress is 4 kN/cm^2 and tangential 1.2 kN/cm^2, for given measuring point. Alternating stress change nature should be carefully examined

Spectral analysis on Fig. 12, showed grouping of stress states at a frequency of 4 Hz in other words excitation frequency.

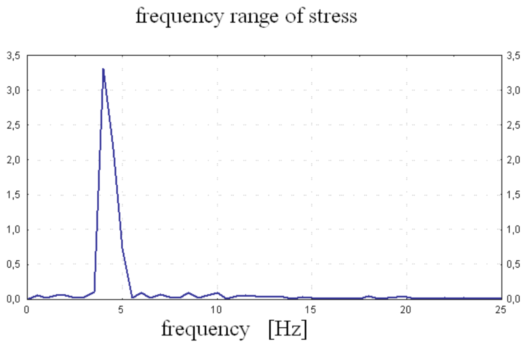

Fig. 12. *Frequency spectrum of tension*

3 OTHER SOURCES OF DYNAMIC EXCITATION

Geometry of the rope were selected depending on the chairlift load. Monocable chairlift ropes are mainly type 6 x (9 +9 +1). Ropes with larger diameter has larger strand diameter, which results in a larger hollow between the strands. Depending of rope step the wheel alternating comes across the top of the strand and then go down of it, Fig. 13. The frequency of this occurrence can be calculated:

$$f_{užeta} = \frac{v}{\frac{\lambda}{n}} \quad [Hz] \tag{2}$$

where: *v – linear velocity of the rope (chairlift)*
λ – rope step
n – number of strands

For the dimensional ratio that are most frequent for the chairlift with a fixed clip, it is in the range f = 50 - 130 Hz.

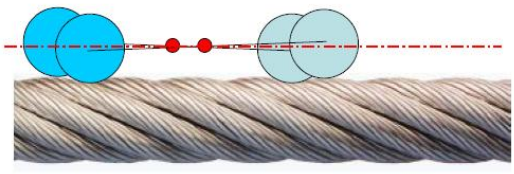

Fig. 13. *Rope as the source of dynamic excitation*

The frequency of this occurrence is high and possibility of resonant states is not a threat. To reduce the consequences to a minimum, it is necessary to take care about the schedule of the wheels within the sheave assemblie.

The next source of excitation may be a line wheel itself and its geometry in terms of oval shape. That shape is a consequence of irregular wear of rubber cover. This phenomenon can be calculated also:

$$f_{toč.} = \frac{v}{2 \cdot \pi \cdot R} \qquad [Hz] \tag{3}$$

where: *v – line speed of the rope (chairlift)*
R – radius of the line wheel

For the dimensional relatios that are most frequent R = 450 mm, for chairlifts with a fixed grip, it is in the range f = 2.8 - 4.2 Hz. Frequency of this phenomenon is relatively low, so its match with tower own frequency is possible.

4 CONCLUSION

Compression towers can not be avoided on the chairlift route. The research presented in this paper aimed to highlight the need for serious analysis of the dynamic behavior of compression towers of monocable chairlifts.

Studies have shown that the frequency spectrum of dynamic loads depends mainly on the structural properties of the sheave assembly. Frequency range of that load is low, which may result in a resonant state of the tower structure. Amplitude values of this loads depends mostly of: chairlift line speed, mass of full and empty chairs and grip geometric characteristics.

Part of the dynamic loading may occur as a result of imbalance between rope structure and disposition of the wheel in the sheave assembly. The frequency and amplitude, themselves, could not provoke problems.

Photos from the introduction part were recorded in the first tower, just before the double sit chairlifts operation section. Chairlifts with a fixed connection during the day has more than 50 stops and starts. Further studies will be extended to the measurement and modeling of these.

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