Application of laser vibrometers for dynamic characterisation of ropeways components

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ABSTRACT

In this work applications of laser Doppler vibrometers to typical problems of mechanics and possible applications in the field of ropeway transportation are discussed. Benefits have been found because of the new possibility opened up to perform, at considerable distance and without any contact, motion and vibration measurements on components during plant operation and also on moving parts (rope, bull wheels, rotating shaft, etc.) for prototype optimisation, maintenance or plant working condition monitoring with possible improvements in reliability and safety.

Some case study are presented:

- the application of a laser scanning vibrometer for measuring tangential movements of a rope on a sheave assembly on the chair lift ropeline,
- for measuring of sheave vibrations in axial direction,
- and for measuring flexural vibration of a portal line support.

All the measurements have been performed while the plant was normally working and carrying people. The results obtained are discussed and possible benefits highlighted.

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1. INTRODUCTION

The importance of vibration and stress control applied to ropeways transportation is known to every technician operating in this field. The ropeway is a match including mechanical and electrical components and civil structures. Some defects show themselves often through anomalous and unusual vibrations. If we can detect and analyse these vibrations, we are often able to go back swiftly and exactly to the causes of this defect. Vibration measurements techniques did not have a great develop on ropeways transportation because it is very difficult to diagnose the defects using traditional methods. In fact, we can rarely control a ropeway plant during the working season, loaded of people, when, as a rule, the syntoms of defects are very definite because the measurement, using the traditional systems (accelerometers, amplifiers, cables, recorder etc.), needs a physical and intrusive approach directly on the plant components. Consequently, to perform the measurements, stops can be frequent and this fact is intolerable. A laser Doppler vibrometer is a non intrusive measurement system and it can solve this problems because the measurements are made on plant components from remote place using a laser beam only.

A laser Doppler vibrometer allows to measure, without any contact and at considerable distances, linear and rotational displacement, velocity and acceleration on points of vibrating structures. The measurement principle is based on the Doppler effect that occur when a laser beam is back-reflected by a vibrating surface . As consequence of the instantaneous vibration velocity value v (component along the incident laser beam) the back-reflected light changes its frequency of $\Delta f=2v/\lambda$, being λ the wavelength if the incident laser beam. An interferometer inside the head of those instruments and photodiodes provide the electrical signal of frequency Δf. An electronic demodulator converts those frequencies into a proportional voltage output that can be acquired with a spectrum analyser to obtain time histories or spectra of the surface vibration velocity. A Bragg cell is also used to detect velocity sign.

Using two mirrors, and relative control systems, it is possible to automatically move the laser beam in order to measure vibration, sequentially, on many points of the surface (laser scanning vibrometers). Providing a reference signal to the laser scanning vibrometer it is possible to obtain a matrix of Frequency Response Function (FRF), sequentially acquired, without contact, on up to 512x512 measurement points on the surface. The measurement grid definition is made easy by a camera integrated on the system that takes a picture of the surface and makes it possible to design the grid directly on the image shown on the computer screen. Once the grid, the sample frequency of the reference and velocity electrical signals and other system parameters have been defined, the system performs automatically the measure in all the points of the grid. Using two interferometers it is also possible to measure torsional vibration (changes of rotational speed) of a rotating shaft in order to analyse dynamics of rotating parts (torsional vibrometers).

Other optical configurations allow to measure tangential velocity (and its changes in time) of a moving surface with typical applications to belts and transmission systems and possible applications to analyse rope dynamic during operation and typical effects when it wraps around pulleys, bull wheels, sheaves etc. Also for detachable attachment plants the knowledge of tangential velocity changes of grip or rope, measured without contact during the acceleration of the carrier , could be very useful.

Some application of vibration measurements by laser techniques have been developed to analyse for example belt vibrations to predict noise emission and to obtain dynamic models of the belt [1]. The use of laser scanning vibrometers has demonstrated in many field that very accurate dynamic modelling of mechanical components by experimental modal analysis techniques can be obtained in very reduced times and can be used to optimise dynamic (Finite Element Model) FEM models of mechanical components [2]. Also the possibility of performing such measurements when the component is working in field [3] opens up new possibilities in order to optimize its design and performances. In the field of ropeways such measurement techniques can be used, for example, to obtain mechanical models of components such sheaves and their suspension systems, carriers, chairs, towers, bull wheels, station structures etc. It can also be used to measure their motion in terms of vibration velocity or displacements during operation for maintenance or security purposes. Vibration of a mechanical component is, as well known, related to the mechanical integrity, if there are changes of vibration parameters they can be used to identify defects [4].

3 MEASUREMENTS OF SHEAVE ASSEMBLY VIBRATIONS

In order to demonstrate the feasibility of in field measurements by a laser scanning vibrometer the axial movements of a support sheave assembly have been analysed. A laser scanning vibrometer has been installed inside and off-road vehicle as illustrated in fig. 1 near the chair lift station.

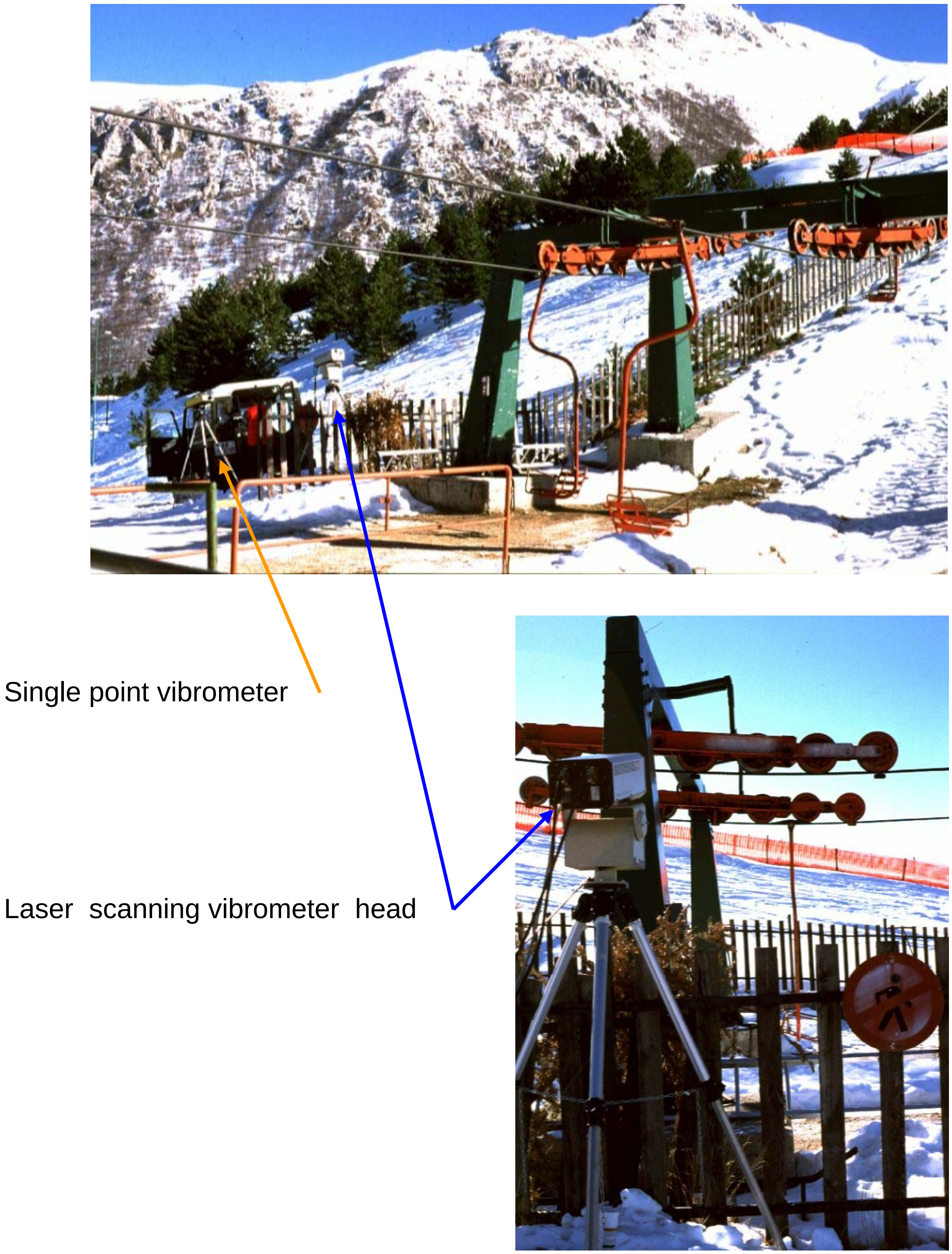

Fig. 1: Laser scanning vibrometer set-up and the sheave assembly analysed

The laser vibrometer head has been placed on a tripod support on a side of the first portal tower of the chair lift at a distance of about 10 m from the sheaves. Another

single point laser vibrometer has been used as phase reference for the FRF measurements on different points.
A typical spectrum of the vibration velocity obtained is illustrated in fig. 2.

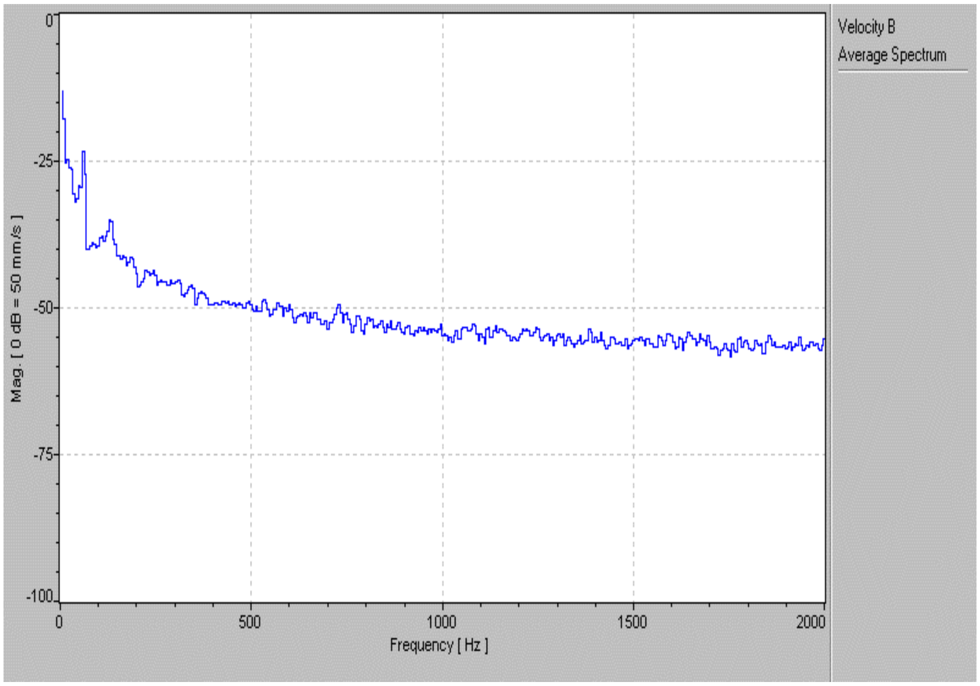

Fig. 2: Typical spectrum of axial vibration velocity of the sheave assembly support

From this result it is possible to detect the lateral movements of the sheave. In this spectrum a first component, at about 5 Hz, can be due to the first vibration mode of the rope between the sheave assembly situated between the last tower , on the descent arm, and the drive bull wheel. In fact, considering the rope's natural frequencies

$$f = \frac{1}{2l}\sqrt{\frac{\tau}{\rho}}$$

where:
l = the free length of the rope = 16 m
τ = the rope tension = 57.400 N
ρ= the rope mass for meter = 2,24 Kg/m
we obtain a frequency of about f = 5 Hz.
In fig. 3 a picture of the analysed area and a 3D mesh illustrating how the sheaves move at this frequency are illustrated. In the spectrum of fig. 2 another relevant frequency component can be identified at about 65 Hz, due to the periodic lateral forces caused by the strands winding of the rope. The rope velocity is 2 m/s, the rope is

composed of 6 strands with a pitch of 175 mm (the rope is one Seale ϕ 25 mm.) Therefore excitation frequency is 6*2000/175 = about 68 Hz

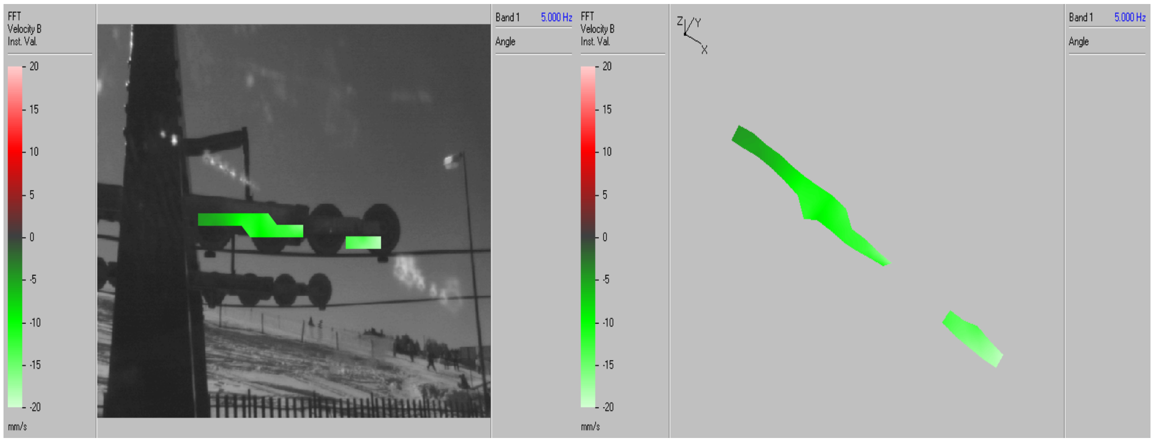

Fig. 3: The analysed surface and sheaves support movement at 5 Hz

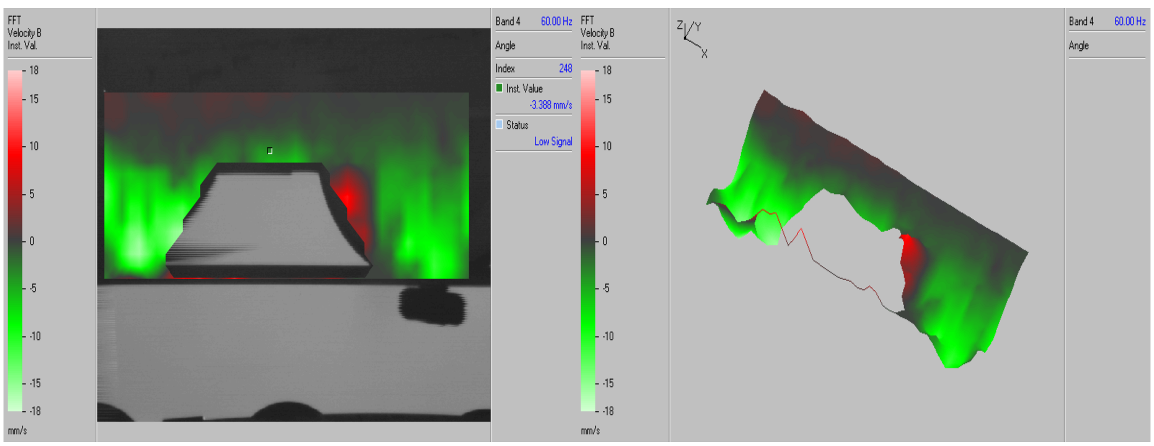

Fig. 4: The analysed surface and sheaves movement at 65 Hz

It is also possible to see, from fig. 4, that the rope moves out of phase with respect to the sheaves. This generates dynamic friction and a relative motion that can decrease the life of the rubber coating of the sheaves.

Therefore, considering the distance, obtained from the altimetric plant profile, between the first tower and the second tower both including depression sheave assemblies, and the distance existing between the sheaves of each sheave assembly (50 cm) and the rope constraints present between the two towers with respect to lateral movements, it can be supposed that a stationary wave, of 1 m wavelength, arises on this rope section. Therefore a frequency of about 85 Hz can be calculated from the above mentioned formulas on the rope natural frequency.

The amplitude relative to that frequency is highlighted in correspondence of the 90 Hz spectral line in the spectrum pictured below. (Fig. 5)

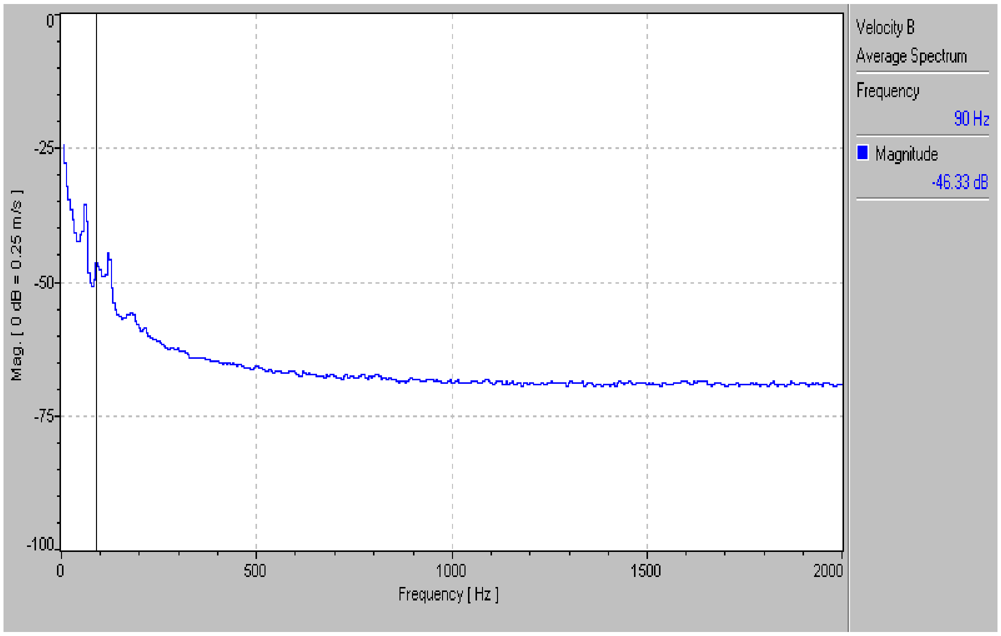

Fig.5: Spectrum of axial vibration velocity of the sheave

It is also possible to see, from fig. 6, that the sheave, where there is contact between the rope and the groove of the sheave, moves out of phase with respect to the other sheave.

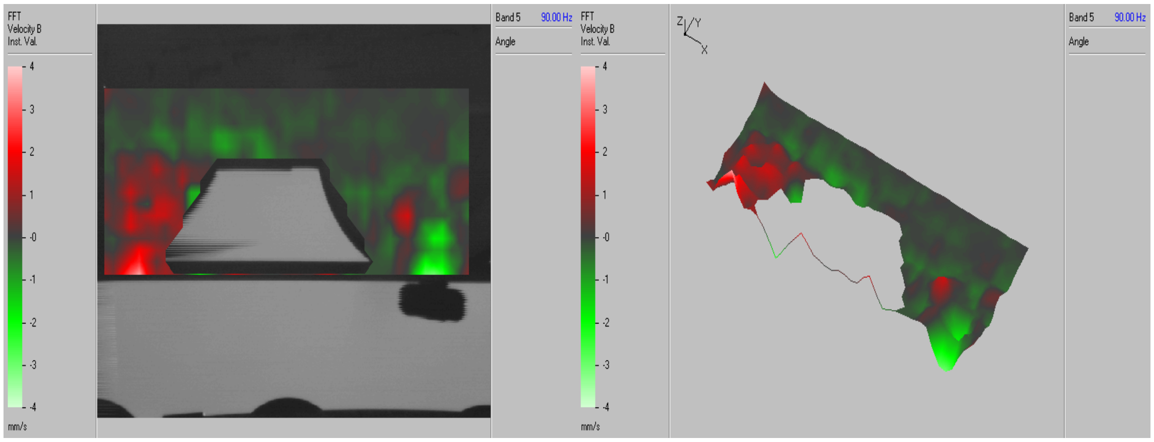

Fig. 6: The analysed surface and sheaves movement at 90 Hz

This and similar results can be used, for example, to detect the fatigue stress on the suspension components from the experimental knowledge of dynamic displacements, at different frequencies, in order to predict the fatigue life of the sheave assembly components. We can utilise the same results, also, in order to optimize the sheave assembly, to analyse the effect of the contact pressure between the rope and the sheave, to reduce the noise minimising vibrations.

4 MEASUREMENTS OF A PORTAL TOWER FLEXURAL MOVEMENTS

With the instrumentation installed as previously described a series of measurements of a portal tower vibration during working of the chair lift has been performed.
A typical vibration spectrum obtained is illustrated in fig. 7

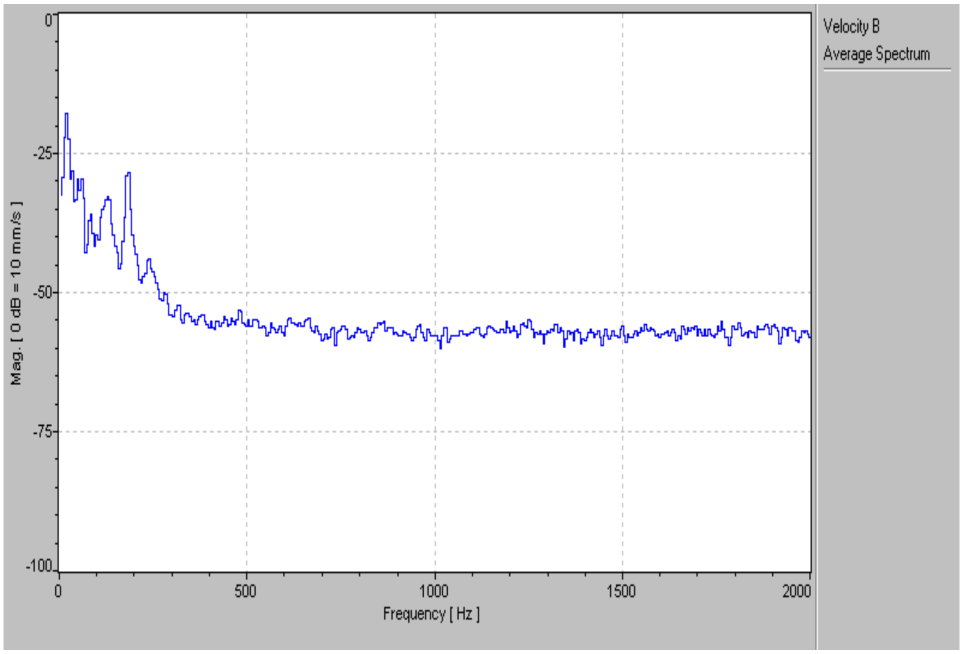

Fig. 7: Typical vibration spectrum of the portal tower structure

This ropeway component vibrates mainly at about 20 Hz as illustrated in fig. 8

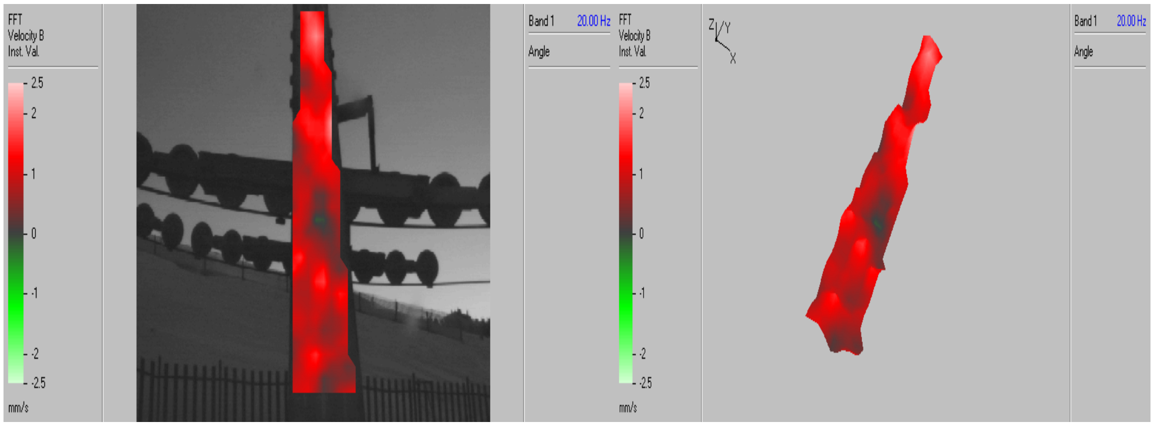

Fig. 8: Mode shape of the portal tower at 20 Hz

This vibration can be identified as a first global mode shape of the whole structure, excited by the dynamic forces transmitted by the rope and sheave assembly.

The above illustrated sheave vibrations at about 65 Hz are also present in the portal tower structure but generate only little movements of the steel panels that act like a loudspeaker diaphragms, so the whole portal tower structure is responsible of considerable noise emission at this frequency. This means that noise at this frequency can be reduced in at least two ways: reducing the vibration energy of the sheave assembly or reducing the movements of the portal tower panels.

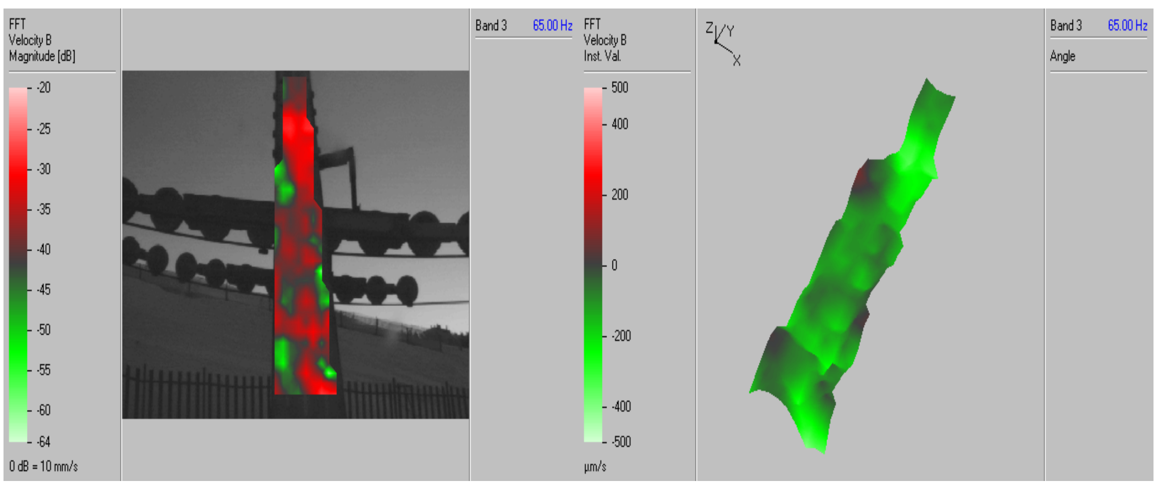

Fig. 9: Vibrations of the portal tower at 65 Hz

CONCLUSIONS

Laser vibrometers can be very useful to obtain experimental dynamic information about mechanical components in very reduced times. Also measurements on mechanical components during operation and in motion are possible due to the non intrusivity of those measurement techniques. In this work it has been demonstrated that the non contact character of those measurement techniques and the very low power of the laser beam allow to perform such measurements also when a ropeway is carrying people, therefore in the effective working condition. The results obtained allow to better understand the working condition of ropeway components and can be used by manufacturers to improve the design and performances of the system in order to increase reliability and reduce noise. The possibility to detect dynamic displacements and deformation of components can be also of help for plant testing before operation or specific controls required by survey authorities. The possibility to perform vibration monitoring during operation can help to identify the beginning of failures in order to increase safety.

These new measurement techniques applied on ropeway transportation can allow to provide also a real help to improve the rules and standards in this field.

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REFERENCES

[1] R. Di Sante, G. Ferri, G. M. Revel, G. L. Rossi, "A method for the indirect measurement of acoustic power emitted by synchronous belts", Int. conference IMAC 1999

[2] G.L. Rossi, C. Santolini, E. P. Tomasini, P. Nava, M. Pinzauti, "Experimental tuning of resonance frequencies of a turbine blade by a laser scanning vibrometer" 16th IMAC Conference, Santa Barbara, CA, USA, 2-5/02/98

[3] G.L. Rossi, C. Santolini, C. Giachi, S. Generosi , " The application of a laser scanning vibrometer for dynamic characterisation of large impellers", Measurement Journal, 1

[4] P. Castellini, C. Santolini, "Vibration Measurements on blades of naval propeller rotating in water", 2th Inter. Vibr. Meas. by Laser Techniques: Advanced and Application, SPIE, Ancona, 186-194, 23-