Long-term monitoring of a eighty meters high wind turbine steel tower

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Summary

In this paper is described the monitoring system developed for the long term monitoring of a wind turbine steel tower. The measured data include acceleration at various levels, strain on the tower wall, inclination on the upper part and temperature. To correlate with the wind velocity and direction, nacelle position and status and rotor speed the corresponding signals are obtained directly from the nacelle and incorporated in the measurement system. Preliminary results concerning the acceleration measurements and the modal identification are presented.

Keywords: Monitoring, wind turbine steel tower, modal identification.

1. Introduction

The Department of Civil Engineering of the University of Coimbra, Portugal is one of the partners involved in the European research project HISTWIN (High strength steel towers for wind turbines), which aims to ensure high competitiveness of the next generation of steel towers for wind turbines produced in Europe. In this project various aspects of the behaviour of the steel towers are being worked out by partners from 5 countries: LUT Sweden, RTWH Aachen and GLWind, Germany, AUTH, Greece, Repower systems and UC, Portugal and Ruukki, Finland.

This paper presents a part of the ongoing experimental program concerning the on-site long-term measurements to be performed on the steel tower (Fig. 1). The following objectives were established for the information to be extracted from the measured data: i) the dynamic behaviour of the tower and an accurate modal identification of the system during operation; ii) the section loads acting on the top and bottom of the tower and on two intermediate levels, iii) the performance of the assembling joints and the behaviour of the thin walled section in the vicinity of those joints.

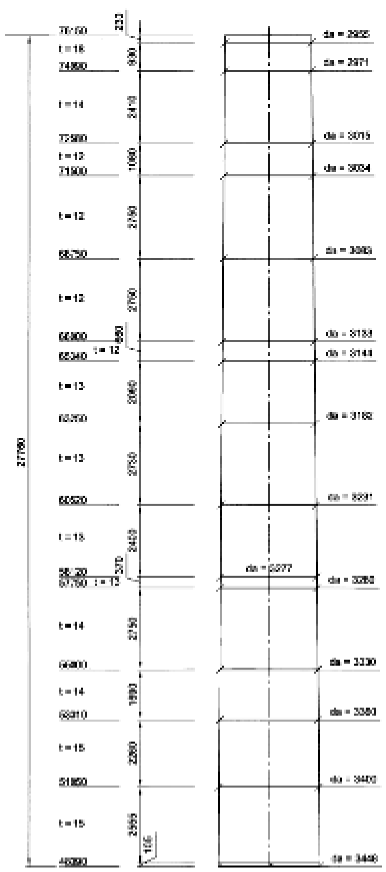
In order to obtain as much information as possible data will be acquired during about two years. The physical quantities to be measured are the strains on the inner surface of the steel cylinder and inside some of the bolts used in the connections, the accelerations at various levels, the inclinations in the upper part of the tower and the surface temperatures at a fixed level.

Fig. 1 *Instrumented tower in Algarve, Portugal*

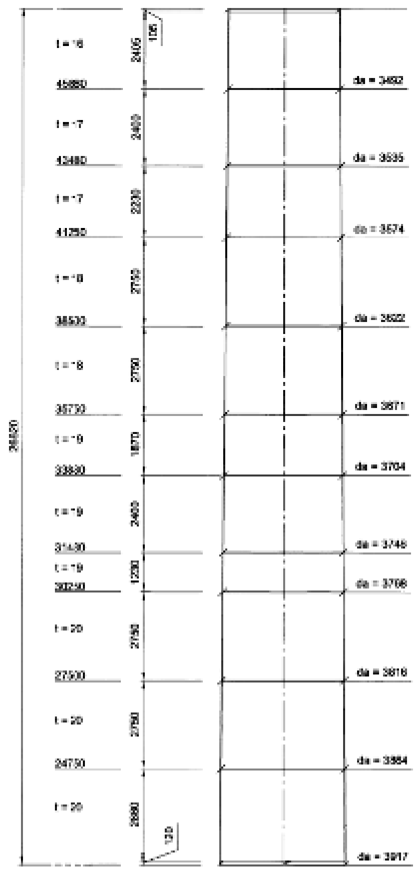
2. Steel tower

2.1 Description

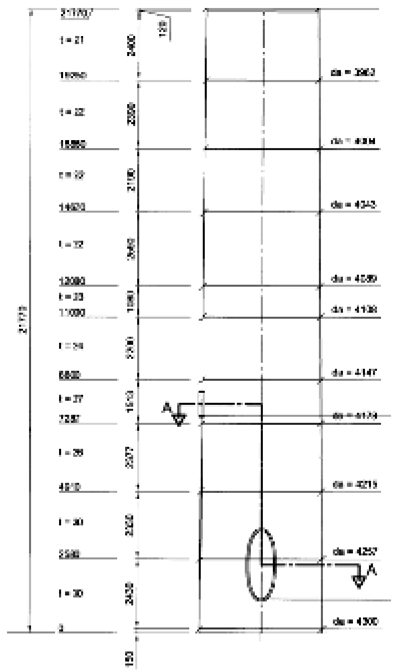
The structure of the wind tower is a free standing steel tube with varying diameter and tube thickness throughout height. The tower is divided in three parts to enable transportation to the construction site and is assembled on site (Fig. 2).



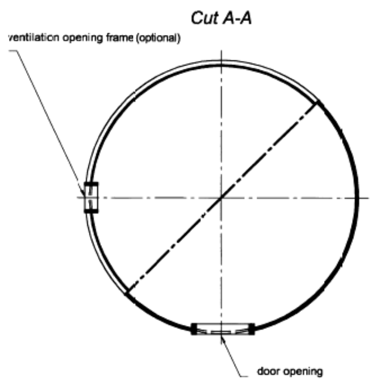
a) Tower upper part



b) Tower middle part



c) Tower bottom part



d) Cut A-A

Fig. 2 *Steel wind tower composed by three parts; Cut A-A (d) shows the ventilation opening (optional) and the door opening*

The diameter varies between 2.955 m at the tower top up to 4.30 m at the tower bottom. The thickness varies between 12 and 30 mm at the same sections. The connections between modules is achieved using very stiff end rings welded to the tower tubes and M36 e M42 class 10.9 bolts are used to connect the rings.

3. Monitoring Methodology

Four types of signals are measured and recorded:

1. accelerations at different levels of the tower, which will allow the identification of the modal parameters and will give information about the loads acting on the tower by solving the

inverse problem;

2. strains along the inner perimeter of the thin walled sections located near the top of the tower and near the assembling joints; strains inside the bolts of the assembling joints as well;
3. inner temperature variation of the steel section caused by the direct effect of the sunlight on the face of the tower; this will allow for the estimation of its static position;
4. inclination of the tower in x and y directions at two different levels, which will permit the estimation of the lateral displacements of the tower through the cross check with the displacements obtained from the time integration of the accelerations

Efforts were made in order to get access to the information available in the monitoring system running under the responsibility of the tower manufacturer. Information about the turbine position (azimuth), wind velocity and direction, blade velocity of rotation and pitch are very important for the estimation of the wind loads acting on the turbine and for the correlation estimation between tower response and operating loads.

Following signals are obtained from the nacell monitoring system and are included in the measurement system developed by the research project team:

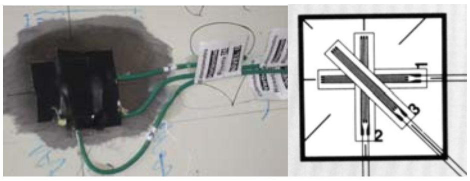
1. Wind speed and direction
2. Nacell position
3. Operation status and Rotor speed
4. Blade angle

4. Measurement system

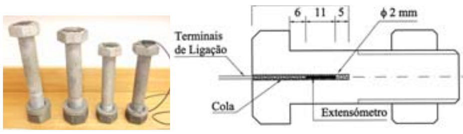
4.1 Sensors type and location

4.1.1 Accelerometers

The position of the accelerometers used for operational vibration measurements correspond to those defined for levels 0, 1, 2 and 3 in Fig. 4. A total of 9 accelerometers and a maximum sampling frequency of 50Hz is used. The accelerometers are of the type PCB393B04 and have a dynamic frequency range starting from about 0.1Hz.



a) Strain rosettes on the inner side of the tower



b) Strain gauges inside the bolts

Fig 3 – Details of strain gauges application

4.1.2 Strain gauges, inclinometers and thermocouples

The strain gauge rosettes type TML PFR-20-11 (three directions) and bolt gauges type TML BTM-6C were placed according to Fig. 3 and 4. A total of 96 strain gauges are used.

Four thermocouples were placed at level 2 to measure the temperature in the inner surface of the steel

Two inclinometers were placed at each of the levels 2 and 3 to measure the inclination of the tower and to calibrate the displacements obtained from the double integration of the accelerations.

4.2 Architecture of data acquisition and transmission system

The data acquisition is achieved using three dataloggers (NI cRio 9012) that can digitalize dynamic data and one datalogger (NI cFP1808) for static data. A computer inside the tower assures the synchronization of all dataloggers using TCP-IP protocol, stores all measured data in a local database and sends it periodically to a remote system using GPRS. Separately, all signals can be visualized remotely in real time in order to detect malfunctions of the system. A dedicated application was developed in LabView, which controls all the data acquisition and stores the data in the database.

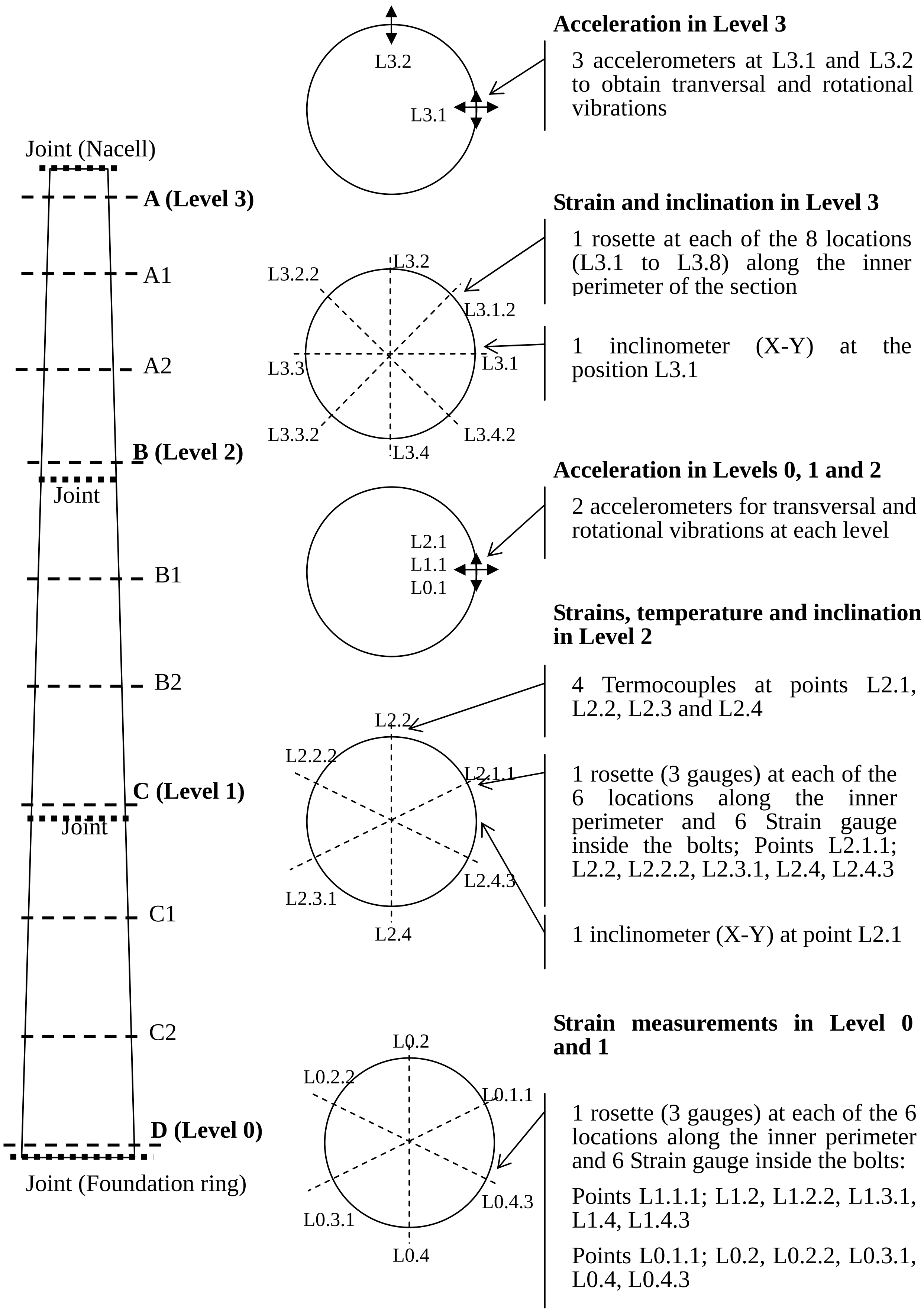


Fig. 4 *Sensors locations.*

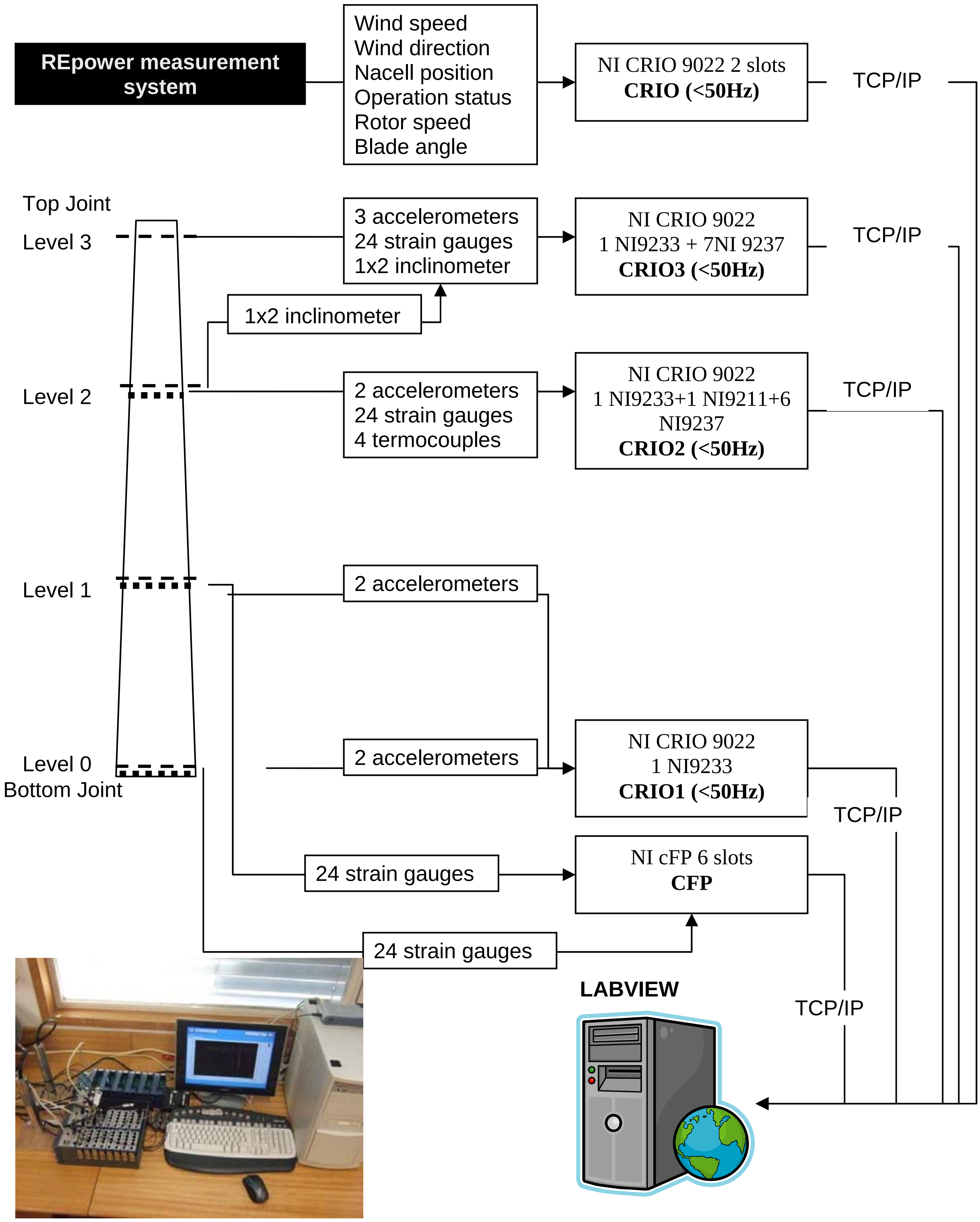


Fig. 5 – *Layout of the communications inside the tower.*

The dynamic signals measured at levels 2 and 3 can be recorded at a rate of up to 50 samples/second. This will allow the unbiased estimation up to about 25Hz of the frequency content of the measured signals. Triggering levels will be established according to ongoing collected information in order to record signals only above pertinent levels of the structural response.

5. Preliminary modal identification

After erection of the tower and before operation starts a preliminary modal identification was performed. The methodology used relies on output-only methods and ambient vibration response analysis. The three accelerometers on the top of the tower (level 3) and two at each of the levels 1 and 2 were used.

A methodology in the frequency domain was used to identify the modal parameters, which consists of simply picking the peaks of the spectral estimates of the measured signals to identify the eigenfrequencies. Although the modal damping can be obtained using, for instance, the half-power bandwidth (Bendat and Piersol, 1993) a more advanced technique, the Enhanced Frequency Domain Decomposition (EFDD) (Brincker et al, 2000) implemented in a software package for system identification (SVS, 2007) was used to extract the modal information from the ambient free vibration.

Using the EFDD technique the modal parameters shown in Table 1 were extracted from the measured time series. The corresponding average of the normalized singular values of the spectral density matrices are shown in Fig. 6. The marked peaks correspond to the flexural mode shapes of the tower. The peaks in the region 1Hz and 4 Hz correspond most probably to thel modes of the blades.

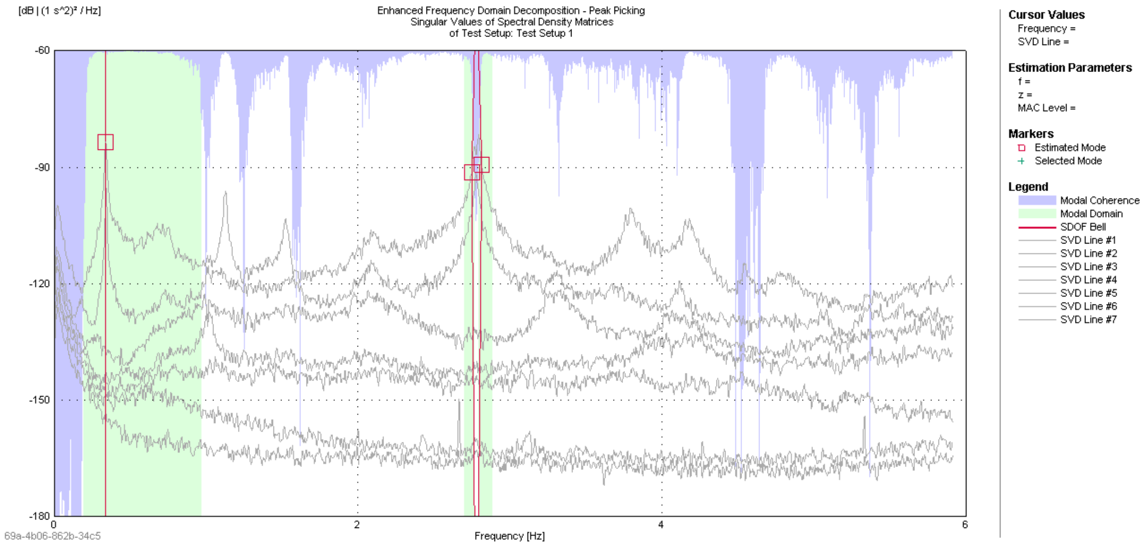


Fig. 6 – *Singular values of the spectral density matrices.*

TABLE 1: Natural frequencies and damping from preliminary measurements

Mode	Frequency [Hz]	Damping Ratio [%]	Mode type
Mode 1	0.340	1.32	1st Bending Nacell direction (x-x)
Mode 2	0.343	0.96	1st Bending Transversal to Nacell direction (y-y)
Mode 3	2.767	0.13	2nd Bending Nacell direction (x-x)
Mode 4	2.794	0.23	2nd Bending Transversal to Nacell direction (y-y)

Results are shown in Table 1 for the lower modes. The viscous damping identified in the first and second mode may is higher than expected for this type of structure. The aero elastic damping induced by the interaction with the wind is probably the cause for the increase in the damping ratio.

6. Conclusions

With constantly increasing demand for wind turbines, driven by the need to use renewable energy sources, cost optimization of the steel tower becomes important and commercially justified. The aim of the research project is to give an integrated view on the steel tower optimizing the performance of the whole structure. Optimization of the tower geometry and innovative solutions for assembly joints are planed to remedy existing limits.

The main objective of the ongoing research project is to improve competitiveness of steel towers used to support multi mega-watt wind turbines. For instance, a better knowledge of the real load distribution along the tower height and the stress distribution nearby the steel connections will help to review stability issues related to more slender shell and detailing such as door openings and number and stiffness of stiffening rings.

The monitoring system developed for the current steel tower aims to allow the updating and calibration of advanced FE model, which will be used to improve next generation of steel wind towers.

Preliminary results are promising. Nevertheless, improvement of the data transmission by reducing the amount of data and automatic evaluation are still issues that will be addressed in future works.

7. Acknowledgements

The collaboration of all project partners and specially Repower Portugal is warmly thanked.

8. References

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