23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

COMPARISON BETWEEN FRAME AND SPATIAL SETUP OF WIND MILL TOWER USING OMA ANALYSIS

Edilson Alexandre Camargo
Faculdades ENIAC, Guarulhos, São Paulo, Brazil
edilsoncamargo@globo.com

Jens Peder Ulfkjær
Aarhus University, Aarhus, Denmark.
jpu@eng.au.dk

Jorgen Hangel
Conelto Aps, Denmark.
jha@conelto.com

Abstract. *The purpose of this article is to investigate the dynamic properties of new concrete wind turbine tower concept using operational modal analysis. Two different methods were used to make measurements, the first method uses a single measurement, called frame, which is simple and fast. The second method uses a more elaborate technique, called spatial, where the sensors are moved through the DOFs in the structure allowing a more detailed view of mode shapes. The main goal is comparing the different setups and finds out if The DOFs were sufficient to obtain good estimation of the shape mode in the single measurement and validate the frame setup for monitoring purpose. The measurements were conducted using six tri-axial geophone sensors distributed throughout the structure in the X, Y and Z axis. The identification of modal parameters of structure was performed in the frequency domain using modal analysis software ARTeMIS® Modal 3.0. Through the results it can be concluded that single measurement of the structure are sufficient for monitoring purposes because it allows to identify the main vibration modes, but if further details are required, the spatial measurement is the best choice.*

Keywords: *Concrete Tower, Wind Turbine, OMA.*

1. INTRODUCTION

In recent years there have been strong initiatives across the world to enhance the utilization of wind power for electricity generation (Saidur, R. et al, 2010). The negative effects of consumption of fossil fuels are forcing countries to invest in research and looking for new alternatives for energy production from renewable sources for sustaining the increasing demand for energy. All types of renewable sources of energy except solar, it is believed that wind energy have the lowest environmental impact. Wind energy becomes, nowadays, the most affordable and clean of all other known renewable sources, is expected to lead the shift from fossil fuels to renewable energy sources all over the world (Kaldellis, J. K et al, 2011). Much of the renewable energy is expected to come from wind turbines (EWEA, 2014).

In recent years, there have been growing interests in concrete towers for wind turbines, the rise in interest is mainly due to the fact, either an easily transportable solution or in-situ production is desired – both of these can be full filled by concrete towers. The concept aims to optimize several processes at once. Firstly, the production line of a traditional steel tower requires ~250 men, where 20-25 men may produce an equal amount of concrete tower elements. Secondly, steel tower production ties up a lot of capital and have a very long production line with a lead time of 18 weeks. Concrete tower production has a lead time of one week and ties up less investment. This fact makes it a possibility that a lightweight concrete factory may be built close to a future wind park.

Today, the common belief is that hybrid towers are more economical than pure concrete ones (Umut, O. et al, 2011). However, when factoring lead costs, capital binding, increasing hub heights, etc., it may very well become more economical to build pure concrete towers. An additional benefit of using concrete over steel is that it consists of a universal product and therefore has a stable price. This paper demonstrates how the modal properties of the tower can be found using operational modal analysis and in order to achieve this goal two different configuration setup were used and compared.

2. DESCRIPTION OF THE TOWER

The prototype of concrete tower is 31.25 meters high with a steel base and ten high-strength fiber-reinforced post-tensioned concrete rings as can be seen in Fig. 1. The foundation is an octagonal reinforced concrete with a thickness of

1.2 meters and a diameter of 10.2 meters and it is approximately one meter below the surface. Sitting on top of the foundation is a 3.15 meters high steel cylinder base with a diameter equal to the outer diameter of the concrete rings. The steel base is fastened to the foundation with embedded threaded bars. The top of the steel section is a thick metal ring, which serves as an anchor for the post-tensioning cables. The tension cables are dropped down at different levels and fastened in the base plate.

Figure 1. The prototype of concrete tower.

The soil stratifications where the tower is standing have been estimated and the layer immediately under the foundation is moraine clay with occasional gravel until eight meters deep, where the layering changes to marine deposits, mainly sand and some organic material.

3. METHOD

The measurements were made using six tri-axial geophone sensors. The geophone is a highly sensitive sensor capable of precise measuring in a wide frequency band. The measured signal has been processed by the software ARTeMis Modal 3.0 using Frequency Domain Decomposition (FDD). In the Operational Modal Analysis technique, the testing is performed by measuring the responses under natural conditions, in this case the wind was used as the excitation of the tower structure, this means that the data can be acquired in a non-invasive way and no large-scale excitation equipment is needed.

The FDD technique was developed as an extension of the classical frequency domain approach often referred to as the Basic Frequency Domain (BFD) technique, or the “peak picking technique”. It uses the Fourier Transform (FT), and makes use of the fact that well separated modes can be estimated directly from the power spectral density (PSD) matrix at the peak (Brincker, R. et al, 2001). The FDD technique differs from the BFD in that it uses Singular Value Decomposition (SVD). For the FDD method to be exact, three important criterions have to be fulfilled. If this is not the case, the FDD is approximate, but results are in most cases still adequately accurate and significantly more accurate than the BFD (Brincker, R. et al, 2000). The three criterions are:

- ✓ Loading is white noise
- ✓ Structure is lightly damped
- ✓ Close modes are geometrically orthogonal

The responses are governed by the dynamic characteristics of the system and the forces exciting it, the acquired data contains information about both, and since no input forces are known, assumptions about these need to be made. In OMA, the forces acting on a structure could be ambient forces such as wind, waves or operational forces from machinery, pedestrians, cars etc. These forces should have approximately Gaussian white noise characteristics or at least have an all flat spectral density (Brincker, R. and Ventura, C.E, 2015).

As the tower structure have more degrees of freedom as the number of the sensors available, therefore, it was necessary to apply the principle of roving. This was done by using two of the sensors as reference, remaining at the same place for all measurements, and the other sensors were moved through the desired DOFs in order to obtain sets of time series containing information of all the DOFs of interest. By using this procedure, a larger, more detailed dataset was collected and its enables estimation of more modes with higher accuracy. The placing of the sensors on the structure should be done so that the sensors are able to record the desired modes whether a planar or a spatial analysis are used.

Two different approaches were used in order to compare the results. First, planar frame measurements were carried out with the purpose of determine the possibilities for identification using a limited number of measured DOFs (Fig. 2a). The second measurement setup was carrying out using the spatial setup (Fig. 2b).

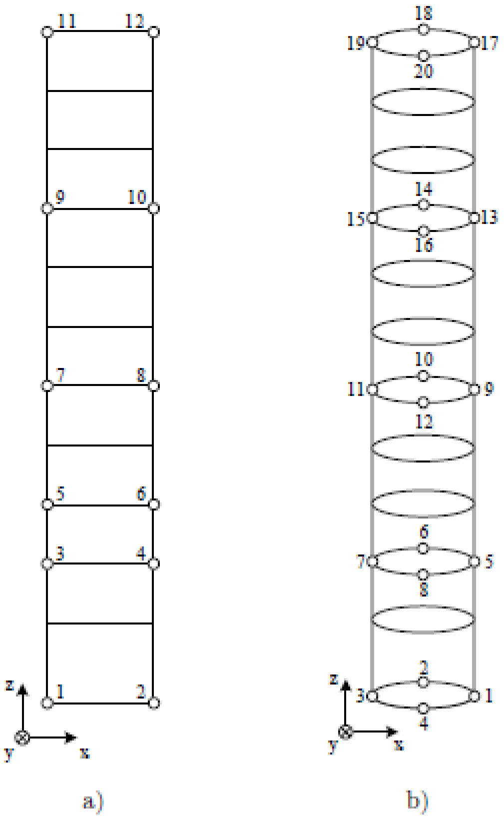

Figure 2. a) Frame setup, b) Spatial setup.

4. RESULTS

The results of the identification from ARTeMIS Modal 3.0 are presented in the form of natural frequencies and the mode shapes. The results of each setup are presented in Table 1 and were obtained from the SVD plots presented in Fig. 3.

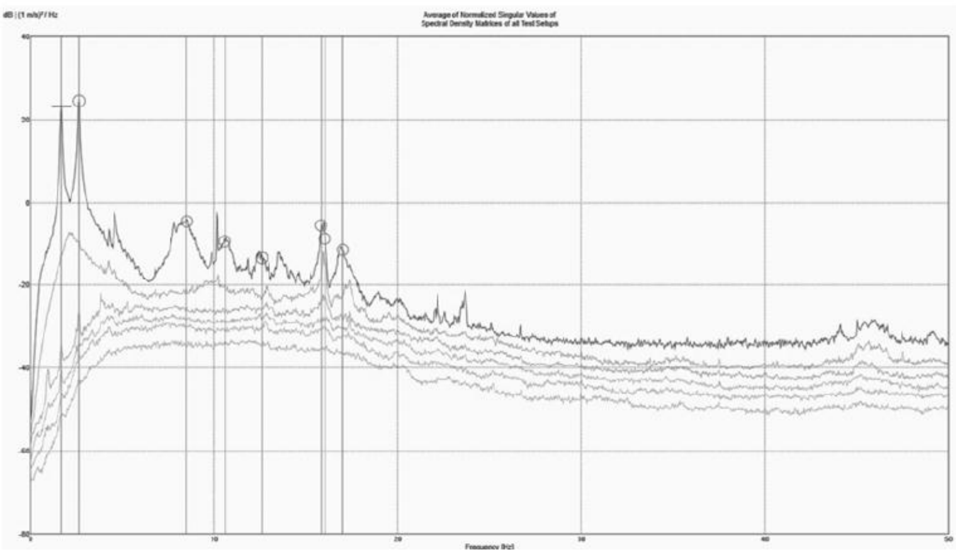

Figure 3. Singular Value Decomposition of the measured points

The corresponding mode shapes corresponding the frame and spatial setup are presented in Fig. 4 and Fig.5 As it can be seen, the frequencies of the different setups are similar to each other witch means that for the monitoring propose, the frame setup full fill the requirements and there no necessity of use more degrees of freedom on the measurements. Therefor if more detail is required, the spatial setup is recommended.

4.1 Frame vs. Spatial sensor setup

From an economic point of view, it would be interesting to see how many sensors are necessary to detect which of the modes. Moreover, there are many instances where it is desirable to be able to analyze a complex engineering structure as a set of simpler components or substructures. For example, the theoretical analysis of a large structure can often be made more efficient if this is broken down into its component parts, each of them then analyzed separately and the entire assembly reconstituted in terms of models each individual component.

Another way to view the process in terms of matrix, it is noted that the spatial model of a large structure typically tend to have large regions mass and stiffness populated with zeros. Thus, this type of structure, the analysis focuses on the sub arrays centered in the main diagonal of the complete matrix system, which does not involve the control of these void areas, which leads to consider the use of simpler models (Ewins, 2000).

The purpose of this study was to comparing the measurement called a frame configuration where it was used only six tri-axial sensors placed in three fixed points of the structure, with the configuration called spatial, where twenty tri-axial sensors were placed on the structure using the roving measurements where the sensors were moved through the five rings on the tower structure as described in Fig. 2.

As can be seen in Fig. 4, the mode shape for the first bending mode can be easily identified as well the torsion, however for the second bending mode shape and the radial-circumferential flexural modes called in this article as ovalization mode shape, is very difficult to identify.

1st Bend. Y 1.68 Hz	1st Bend. X 2.61 Hz	2nd Bend. Y 8.47 Hz	2nd Bend. X 10.82 Hz	1st Torsion 12.45 Hz	1st Ovalization 15.92 Hz

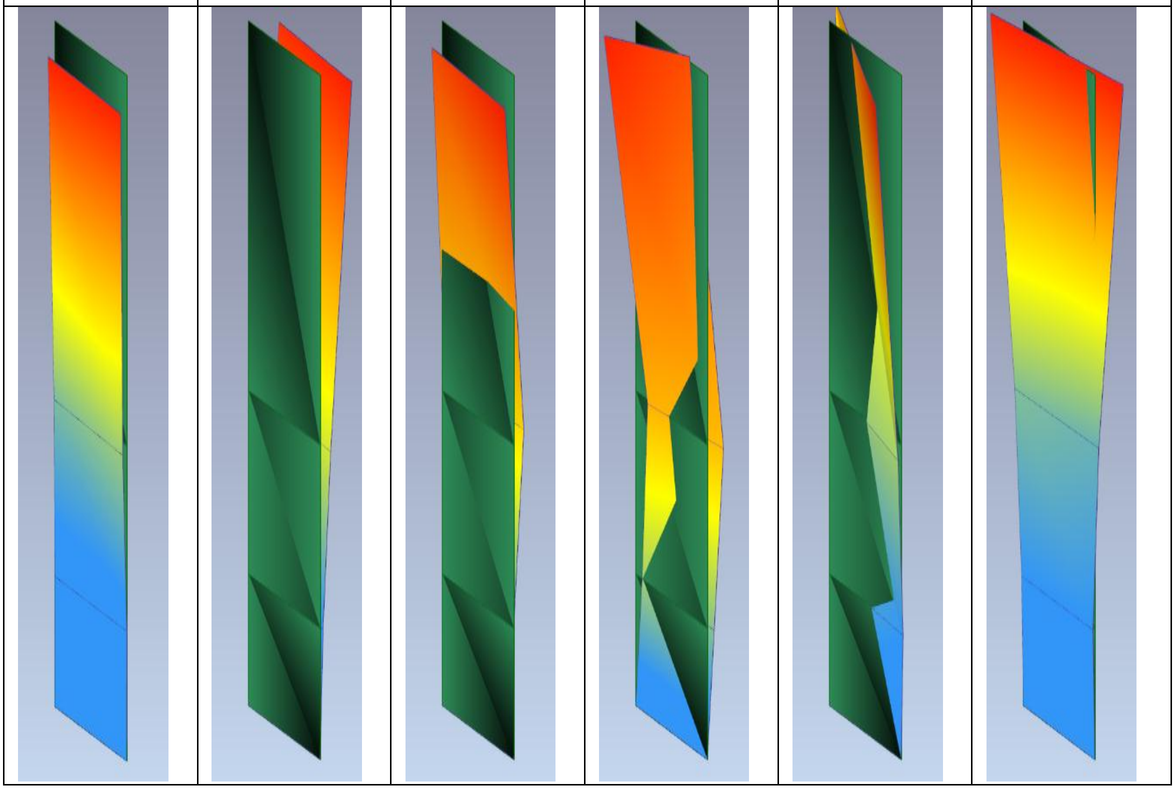

Figure 4. Mode shapes of frame setup

In the analysis of the spatial configuration, a cubic structure was used rather than the circular structure so that there is no need to use slave nodes equation for the non-measured nodes. Fig. 5 shows the mode shapes and can easily notice the mode shapes for all the identified frequencies.

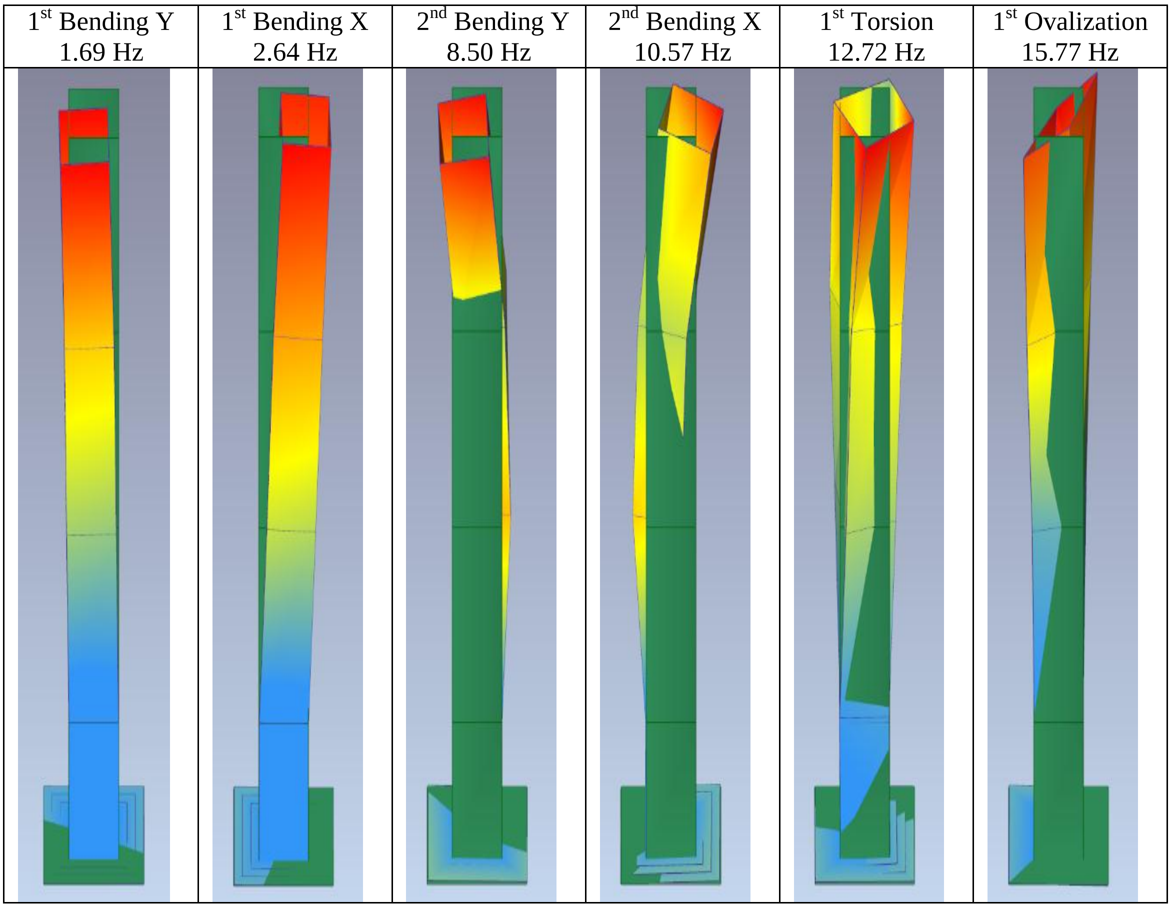

Figure 5. Mode shapes of frame setup

As can be seen in Table 1, the natural frequency found for the two cases are very close, comparing a situation where only a minimum of sensors are used, for example, for monitoring, this information is valuable, there may be a saving of and the time measuring system configuration by keeping the reliability of the frequency information. Where only the first mode needs to be analyzed, one can further reduce the number of sensors to provide these frequencies with a high degree of accuracy. However, it should be considered that the mode shapes can only be determined accurately for the higher modes using more degrees of freedom and in this case the spatial configuration is the most suitable.

Table 1. Comparison between the frame and spatial setups.

Mode	**Setup**		
	Frame	**Spatial**	
	6m 14m 31m	Tower	Tower/Foundation
1st bending, Y	1.68 Hz	1.69 Hz	1.69 Hz
1st bending, X	2.61Hz	2.64 Hz	2.64 Hz
2nd bending, Y	8.47 Hz	8.50 Hz	8.50 Hz
2nd bending, X	10.82 Hz	10.57 Hz	10.57 Hz
1st torsion	12.45 Hz	12.60 Hz	12.72 Hz
1st buckling	15.92 Hz	15.77 Hz	15.77 Hz

In order to illustrate the level of similarity between the different modes, the MAC matrix is extracted from ARTeMIS Modal 3.0, was used and as can be seen in Fig. 6, the frequencies are compatible with the values close to one.

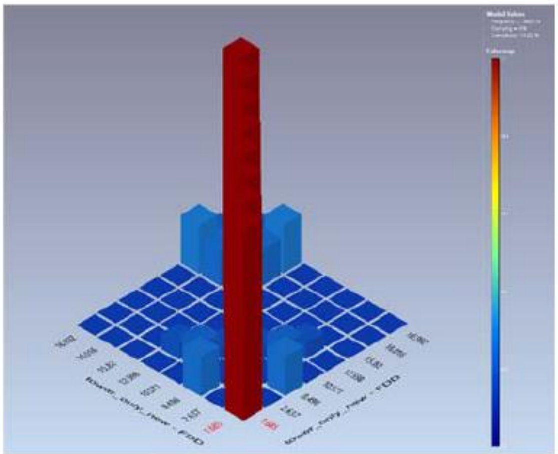

Figure 6. MAC matrix of frame and spatial setup

5. CONCLUSION

This article has shown the use of operational modal analysis to estimate the natural frequencies and mode shapes of a prototype of a concrete tower for use in wind mills. Measurements were performed using two different settings and the results achieved, in terms of frequencies, were very similar; only the mode shapes are easily identified through spatial configuration. If the main objective is the frequency monitoring along the life time of the structure, the frame configuration can be a good choice, since it saves time and number of sensors with very accurate results.

6. ACKNOWLEDGEMENTS

Edilson Alexandre Camargo thanks the financial support received from CAPES, through the Science without Borders Program, for this research. This project was supported by Conelto.

7. REFERENCES

Brincker, R., L. Zhang and P. Andersen: “Modal Identification from Ambient Responses using Frequency Domain Decomposition", *Proceedings. of the 18th International Modal analysis Conference*, San Antonio, Texas, February 7-10, 2000.

Brincker, R., Andersen, P. and Zhang, L., “Modal identification of output-only systems using frequency domain decomposition”, *Smart Material Structure,* Volume 10, 2001.

Brincker, R. and Ventura, C.E., *“Introduction to operational modal analysis”.* Wiley 2015.

EWEA, “Wind energy scenarios for 2020”, *The European Wind Energy Association*, 2014.

Ewins, D.J., *“Modal Testing theory, practice and application”*, 2nd edition, Research Studies Press Ltd, 2000.

Kaldellis, J. K. and Zafirakis, D., *“The wind energy (r)evolution: A short review of a long history”, Renewable Energy*, Issue 36, 2011.

Saidur, R, Islam, M. R., Rahim, N. A. and Solangi, K. H, “A review on global wind energy policy”, *Renewable and Sustainable Energy Reviews*, Vol.7, No.14, 2010.

Umut, O., Akbas, B. and Shen, J., “Design issue of wind turbine towers”, *Eurodyn 2011*, Leuven, Belgium, 2011.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.