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Damping Estimation of an Offshore Wind Turbine on a Monopile Foundation

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Abstract

Many large scale offshore wind farm projects use monopile foundation to realize a cost effective design. During the design of these monopile structures fatigue due to combined wind and wave loading is one of the most important problems to face. The damping significantly influences the dynamic response of the wind turbine reaction and thus also the predicted lifetime. The work presented in this poster describes a comparative study between different techniques aimed at identifying the damping values of an offshore wind turbine on a monopile foundation.

Damping Effects

The overall damping of the first bending mode of an offshore wind turbine consists of a combination of

- **aerodynamic damping**
- **material damping of steel**
- **damping from wave creation**
- **damping due to inner soil friction**
- **damping due to hydrodynamic drag**
- **damping due to constructive devices**

The main goal of this campaign was to identify the damping ratios of the first fore-aft (FA) and side-side (SS) bending mode excluding the aerodynamic damping and damping due to constructive devices.

Offshore Measurements

The measurement campaign was performed at the Belwind wind farm, which consists of 55 Vestas V90 3MW wind turbines. The wind farm is located in the North Sea on the Bligh Bank, 46 km off the coast.

Figure 1: location Belwind wind farm (left) park layout Belwind wind farm (right)

The tests were performed on the BBCO1-turbine. The actual water depth at the location of BBCO1 is 22.9m and the monopile has a penetration depth of 20.6m. The soil is considered stiff and mainly consists of sand.

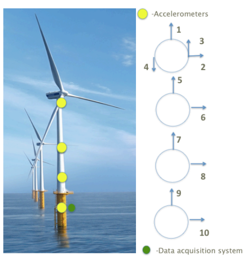

Figure 2: measurement locations on BBCO1

Measurements are taken at :

- **9 locations using 10 accelerometers.**
- **4 levels at 67m, 37m, 23m and 15m above sea level.**

Approach Damping Estimation

For the determination of the offshore damping two tests have been performed. First an emergency stop with vanishing aerodynamic damping has been examined for estimating the damping. Afterwards damping has been estimated using ambient excitation from the wind and waves, while the pitch angle was above 80 degrees in order to minimize the effect of aerodynamic damping

Both during the overspeed test and during the ambient excitation test the tuned mass damper was switched off.

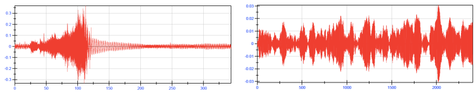

Figure 3: Example measured accelerations during overspeed stop (left) and ambient excitation (right)

Results Overspeed Stop

Time domain analysis

In the time domain damping can be obtained by fitting an exponential function to the decaying time series and extracting the damping ratio from the parameters of the fitted expression. This method assumes that the decay has only the contribution of a single mode and therefore proper filtering might be required.

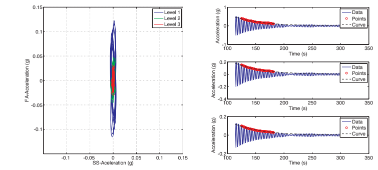

Figure 4: Movement seen from above (left) and exponential fitting on FA acceleration on 3 levels after applying a band-pass filter of 0.3-0.5Hz (right)

The method was applied to the measured accelerations of the highest 3 levels in the direction of the wind. The data was pre-filtered using 3 different band-pass filters.

Band	0.01-1.5Hz	0.1- 0.8Hz	0.3-0.5Hz
Level 1	**1.10%**	**1.12%**	**1.04%**
Level 2	**0.98%**	**1.15%**	**1.05%**
Level 3	**0.86%**	**1.16%**	**1.05%**

Frequency domain analysis

One can also obtain an estimate for the damping using an operational modal analysis approach to the Fast Fourier Transformations of the free decays measured during the overspeed test. This approach fits a polynomial function with multiple modes and therefore the results are not affected by the fact that multiple modes are present.

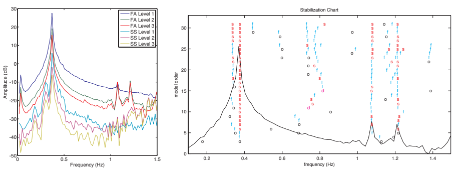

Figure 5: Fast Fourier transformation of the accelerations obtained on the 3 different levels in both the FA and SS direction (left) Stabilization diagram after applying operational modal analysis to the Fast Fourier Transformations.

Damping ratio FA-Mode
1.05%

Results Ambient Excitation

Ambient vibration tests have the strong advantage of being very practical and economical, as they use the freely available ambient wind wave excitation.

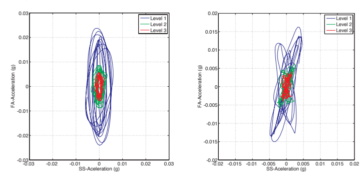

Figure 6: Movement seen from above on 3 levels in FA and SS direction during ambient excitation at 2 different moments in time

Correlation driven analysis in the time domain

By fitting an exponential function to the relative maxima of the auto-correlation functions of the measured accelerations the damping ratio can be extracted.

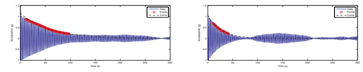

Figure 7: Exponential fitting of an autocorrelation function of a sensor in the FA direction (left) and SS direction (right)

This approach only provides good estimates for the damping when the decay consists of 1 mode. During the ambient tests this is not the case as there is strong coupling between the FA and SS mode, and therefore this approach fails.

Correlation driven analysis in the frequency domain

The Fast Fourier Transformation of the decaying auto-correlations can be used as input for the operational modal analysis methods in the frequency domain.

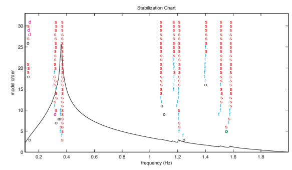

Figure 8: Stabilization diagram after applying operational modal analysis to the Fast Fourier Transformations of the auto-correlations

Damping ratio FA-Mode
1.07%

This approach fits again a polynomial function with multiple modes and therefore the results are not affected by the fact that multiple modes are present.

Periodogram driven analysis in the frequency domain

The periodogram driven approach uses the power spectrum matrix from the measured accelerations as input data for performing operational modal analysis in the frequency domain.

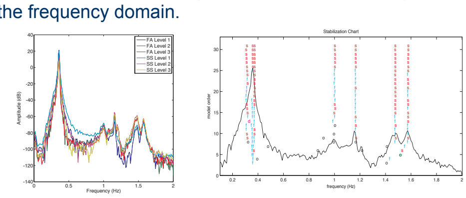

Figure 9: Auto and cross spectra with reference sensor 1 in FA direction (left) Stabilization diagram after applying operational modal analysis to the spectrum matrix (right)

Note that this approach clearly identifies both the FA mode (0.358Hz) and SS (0.345Hz) mode.

Damping ratio FA-Mode	Damping ratio SS-Mode
1.05%	1.27%

Conclusions

We can conclude that the ambient vibration tests together with the application of state-of-the-art output-only identification techniques can provide good estimates of the damping ratios of an offshore wind turbine. The results have been compared with the ones obtained from the commonly used over-speed tests.

Acknowledgments

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