Application of Acoustic Emission signature for the Assessment of Wind Turbine Drive Train

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Abstract

Current wind turbine condition monitoring methodologies can be time-consuming, costly and fail to achieve the reliability and operational efficiency required by the industry. For these reasons existing vibration-based Condition Monitoring System usually fail to detect defects until they become critical. The application of Acoustic Emission technique as well as more advanced methods of signal analysis, focused on trends of representative signals or combination of signals, can help to detect changes in turbine behaviour at an early stage.

Acoustic Emission technique has been used for the development of a baseline that indicates the behaviour under normal operation of two different components of the wind turbine drive train: the high speed shaft and the low speed shaft. Acoustic Emission data have been collected for a period of time and this initial data has served as a training process. The features extracted during this initial period have been used to create a baseline (or signature) that defines the behaviour of the low and high speed shaft of the wind turbine under normal operation.

A range of maximum and minimum values for these features have been calculated using statistical methods. Using this approach, the shafts monitoring processes can be performed by comparing each new set of data acquired to the original baseline created during the initial stage.

1 Introduction

Three different techniques have been used for the development of a baseline method that indicates the behaviour under normal operation of the critical rotating components in wind turbines: MCSA on the generator, OMA on the drive train (including gearbox) and AE on the high speed shaft. In this paper the results from the AE data are presented. Data was acquired for a period of time and this initial data has served as a training process. For each technique, different signal processing methods have been used to extract the features of the wind turbine components under study. The features extracted during this initial period have been used to create a baseline (or signature) that defines the behaviour of the generator, gearbox and high speed shaft of the wind turbine under normal operation. A range of minimum and maximum values for these features have been calculated based on trends (average ± standard deviation).

In the future, the monitoring process can be performed by comparing each set of new data acquired to the original baseline created during the initial stage.

The necessary hardware for the signal acquisition of the three techniques has been tailor made for the project needs. The system architecture uses multiple sensor modules. The AE module has the added capability to transfer data wirelessly and samples the analogue sensors at rates of up to 2MSPS. Each module samples the sensor(s) for a specified time window, stores the samples temporarily and transmits them to the server. Special development was required for the AE Module as the mandatory requisites was a small size. After acquisition, the signals were processed by each module and the baseline strategy applied.
2 Acoustic Emission

Acoustic emissions (AE) are defined as transient elastic waves generated from a rapid release of strain energy caused by a deformation or damage within or on the surface of a material. Sources of AE in rotating machinery include impacting, cyclic fatigue, friction, turbulence, material loss, cavitation, leakage, etc.

The wave generated by the source is of practical interest in methods used to stimulate and capture AE in a controlled way, for study, process monitoring and others.

The frequency bandwidth of acoustic emission (AE) measurement method is typically in the range 1 kHz to 1 MHz. In that range, vibrations occur in a material by fracture of crystallites, crack nucleation and growth, several mechanisms involving dislocations, phase transformations in materials, boiling and electrical discharges. Each of these mechanisms is characterized by a rapid collective motion of a group of atoms.

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CMSWind is a project that will show the applicability of an advanced condition monitoring system enabling the prompt detection of defects by merging the three novel monitoring techniques mentioned above. There are several limitations and difficulties in application of AE to machinery, in particular to the rotating shaft. This challenge is directly related to the coherent environmental vibration that can become embedded in the spectra of the AE signals.

3 Initial Tests

An integration process was put in place to incorporate the wireless data acquisition hardware. Various tests were conducted in the laboratory, in order to initialize and set up the system. At this stage, it was discovered that the sensor signal was too small to be read from the acquisition boards. This incompatibility lies in the sensor’s signal which has amplitude of µV (+/- 20µV) and the acquisition boards start reading signals on the order of mV (+/- 0.1mV), so a preamplifier was introduced to make AE readings with the correct voltage range. Finally, pencil lead break tests [10] were performed on the surface of a steel plate in order to record the waveform and analyse its features.

This test consists of breaking a 0.5 mm (alternatively 0.3 mm) diameter pencil lead approximately 3 mm (+/- 0.5 mm) from its tip by pressing it against the surface of the plate. This generates an intense acoustic signal, quite similar to a natural AE source that the sensors detect as a strong burst.
One of the purposes of these tests is to ensure that the transducers are in good acoustic contact with the part being monitored. Generally, the lead breaks should register amplitudes of at least $80 \text{ dB}_{AE}$ for a reference voltage of $1 \mu V$.

![Hsu-Nielsen Source](image)

After installing the complete system, including the pre-amplifier, Pencil Lead Breaks (PLB) data was recorded. The picture below shows one of these acquisitions from the Viewer program.

With this application, it is possible to study the amplitude and the frequency of the acquired signal. A zoom can be implemented to appreciate these parameters in detail.

![Initial Acoustic emission waveforms](image)

After achieving the first AE acquisition, a comparison between the wireless transmission and a wired oscilloscope was completed. This test was developed in order to value the data loss using the wireless connection.

To perform this comparison, a wireless and a wired acquisition system was connected by laptop or oscilloscope, respectively.

Finally, an application to read the .hdf5 file generated by the wireless acquisition system in LabVIEW™ was developed and tested. Using this program the options to study the signal greatly increase. Parameters like max/ min values, RMS, frequency, count of acquisitions, etc. were obtained from the software. In addition, a vast range of graphs can be developed to view different signal forms.
4 WINDMASTER 300 Nacelle Test Rig Set Up

A WINDMASTER 300 drive train was integrated in an operation process that allows the investigation of fault signatures in order to characterise a failure deviation from baseline. An schematic of the wind turbine test rig connection is shown below.

![Figure 3. Nacelle test rig working diagram](image)

The specifications for the wind turbine test rig are:

- 30kW rated maximum power output
- 1500 rpm nominal speed for the high speed shaft

The system was designed and installed in the test drive train in order to test and acquire data correspondingly. The final objective is to characterise the fault detection by seeding defects in the machinery.

![Figure 4. AE sensors location in the WINDMASTER 300](image)

a. Baseline Development Strategy

The proposed idea is to generate a baseline for different AE parameters that will therefore be used to determine the safe operational range for the operation of the wind turbine. The drive train test rig control system was programmed to sweep around the full speed operational range provided by the wind turbine manufacturer. The 1500 rpm maximum range was split in intervals of 150 rpm and the variable frequency drive conducted an acceleration process as shown in Figure 5. The data acquisition cards were programmed to acquire 20 data samples per speed interval. At the end of the frequency sweep test, 200 AE data sets were analysed, each of them having been sampled at 2,5 mega samples per second for a period of 1 second.
AE sensors were located in both, low and high speed shafts surrounding areas, in order to compare the results for the two different speed ranges. The areas where the sensors were placed were selected and prepared accordingly. Figure 6 shows the final location of the sensors.

![Figure 6. AE sensor locations. Low speed shaft (left) and high speed shaft (right).](image)

5 Results and Further Work

The AE module has been implemented in a wind turbine in order to validate the system and evaluate the applicability of the technique. The subsystem was tested and a Baseline generated with the purpose of identifying the safe limits of the full operational range of the WINDMASTER 300 drive train.

The AE subsystem generates a Baseline dependent of different evaluable AE parameters so that the operator can identify the most representative in each specific situation.

Figures 7 and 8 show the results from the RMS values of AE activity as a function of rotational speed of the wind turbine. Data was gathered, sensing both the low and high speed shafts of the wind turbine.
The full operational speed range AE-RMS level has been presented. This baseline has been generated in order to identify the safe operational range of the wind turbine. The correct evaluation of data acquired and frequency dependency of the signals will be evaluated in further work. In relation to this, the selection of the different AE parameters will help to identify the most relevant performance indicators in relation to the drive train deterioration.

Further validation tests are expected using different wind turbines typologies covering different machinery architecture and sizes.

6 Acknowledgements

The investigations and results presented have been obtained from CMSWind [1] Project, which is a European Research & Development Project partly funded under the FP7 Framework Research for SME Associations under Grant Agreement Number 286854.
References

[1.] Description of Work (DOW) of the CMSWind Project, 1 June 2012, Grant Agreement Number 286854.


