Application Paper

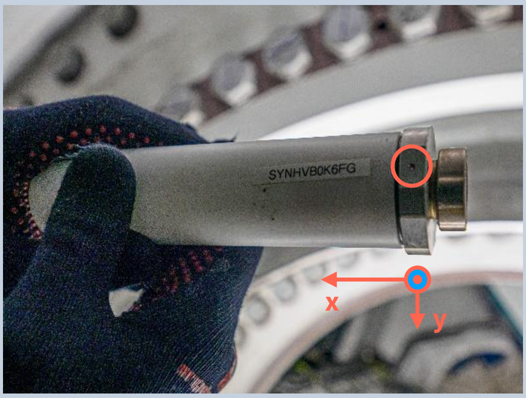
Smart Monitoring of Wind Turbine Main Bearings (MB)

Introduction

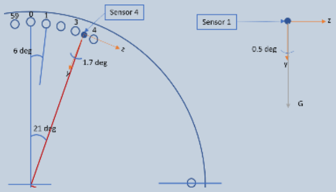
Cost effective and reliable plant operation is the key to success in any competitive industry. In branches of industry where machinery is operated continuously, one aspect of reliable operation is to detect faults in machine components before they lead to failures or affect performance. Cost effective means that a balance must be found between the cost of surveillance and the cost of undetected degradation.
With the wireless, plug&play vibration sensing system LYRA, developed by GradeSens in Switzerland, clockworkX and GradeSens can offer cost effective monitoring in an exclusive partnership. Not just lowering sensor cost, but also installation effort and infrastructure cost, this system makes it possible to monitor far more systems than the current industry standard.
In wind energy, for example, the main bearings of direct drive wind turbines are critical but under-monitored components. The capabilities of the system are demonstrated for such a bearing. Important plots in this case study are void of actual numbers, to anonymize and protect out customers' infrastructure.

System Features

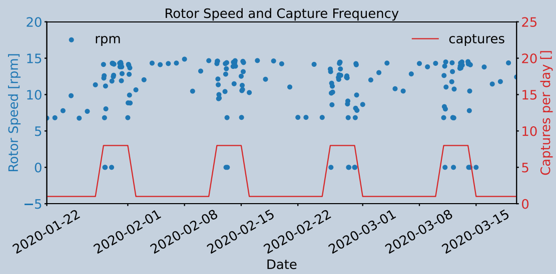
- **LYRASens -** each sensor provides high resolution, raw acceleration signals of up to three axes, as well as temperature data. Detectable frequencies range from 0 to 1500 Hz with a sampling from 4S/s up to 4kS/s. The dynamic range can be configured between ±2g to ±8g with up to 16bit resolution per sample.
- **Plug&Play -** the sensors operate on their built-in power supply for up to five years in typical monitoring applications (recording accelerations of two axes @ 1000Hz/16s with 16bit resolution four times a day). The operating range of the sensors is in the range of kilometers with a direct line-of-sight to the central gateway. They can be positioned freely with different mounts, on static as well as rotating components. Only the central gateway (LYRAGate) requires a power source and internet access, which can be provided through a cellular network, if necessary. A typical installation takes between 30 and 60 minutes and can be easily adapted to the wind turbine design.



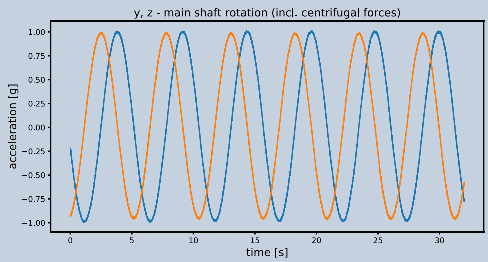
- **Installation effort -** the systems requires no connection to any other system of the wind turbine besides the power supply. Due the wireless data transmission, the sensors can be placed on rotating equipment without the need for a slip ring. This simplicity allows for the system to be installed by non expert personnel. For most applications, the precise position of the sensors is not required, but can be determined from dedicated measurements of the gravitational signal after the installation.



- **Synchronized Acquisition -** one of the key elements of the technology is the synchronized data acquisition ensured by the proprietary radio protocol. The recordings from all sensors are synced to less than 0.1ms.
- **Smart Measurements and Flexibility –** the limited power supply of the sensor is compensated by a smart distribution of measurements over time. In addition to that, all aspects of the measurements are configurable online. The rate can be increased after installation to establish a status zero of the turbine or can be adapted to the wind forecast or incorporate maintenance activities. As a standard, we apply a burst capture scheduling, which allows us to get snap shots over the entire operation range of the turbine with a high correlation in time.



- **Rotating Components -** with sensors on the rotating components, rotational speed and acceleration can be precisely determined. As almost all propagating effects within a wind turbine depend on the rotor speed, this enables us to look in the right places within the data.



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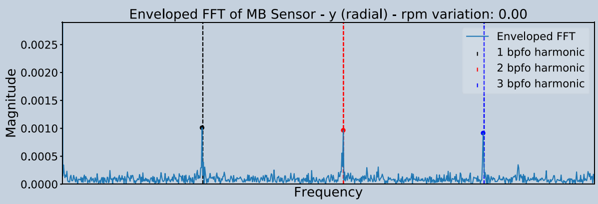
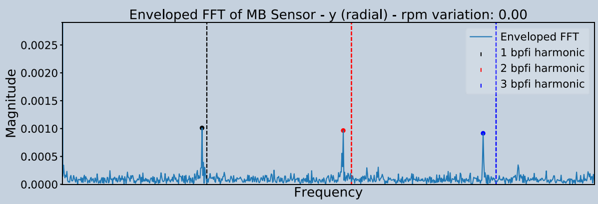
Measurement Set-Up

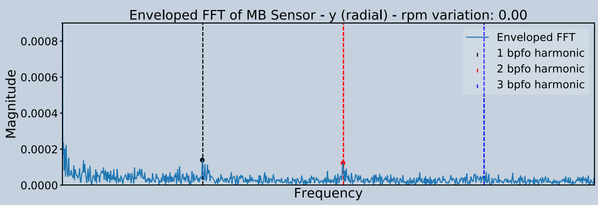
Our Smart Main Bearing Monitoring is based on frequency analyses of acceleration data coming from two sensors installed on the static seat of the main bearing (MB). A third sensor is placed on the rotating seat of the bearing and lets us derive the rotor speed of the turbine, which is crucial for a precise interpretation of the results. A fourth sensor placed near the top of the nacelle provides measurements such as the tower side-side and for-aft motion. We use these sensors to “clean” the vibration data from the MB sensors and isolate the parts of the signal relevant to fault detection, increasing precision and signal-to-noise ratio.
In the following we will present results generated with a simple FFT over the envelope of the cleaned signal of one of the MB sensors. Illustrating the capability in fault and bearing state detection of our system, even when applying a comparatively simple frequency analysis.

Results for Constant Rotor Speed

At constant rotor speed, the FFT of the envelope signal shows very sharp and distinct peaks. The ball pass frequencies over the inner as well as the outer race of the bearing (BPFI & BPFO), as well as the ball spin and fundamental train frequencies (BSF & FTF) can be readily calculated with the bearing dimensions and the rotor speed. Comparing the peaks in the spectrum with the harmonics of these frequencies is a proven method to distinguish peaks corresponding to BPFO and BPFI and detect defects and faults in the respective surfaces. The first plot illustrates how well the peaks in our example can be attributed to the BPFO. The clear distinction to BPFI is shown in the second plot.
Since our measurement of the rotor speed comes from a vibration sensor, its signal can be used to confirm these observations, albeit at a much lower magnitude. To our knowledge, detecting these effects on an encoder signal would not be possible.

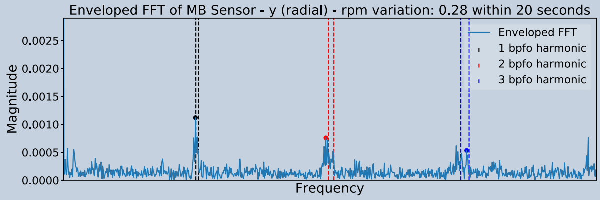






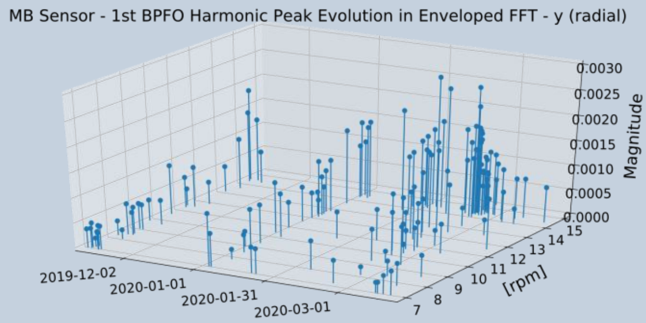
Results for Varying Rotor Speed

When the rotor speed varies during a capture, the frequency analysis of only the vibration signal coming from a MB sensor would become much more difficult. As shown in the plot below, the peaks are spread out, as the ball pass frequencies vary with rotor speed. The signal from the rotating sensor allows us to determine the change in rotor speed and the varying ball pass frequencies with it.



Signal Evolution

In this specific case, we are confident that we are detecting an early onset of damage. In this stage, an individual signal does not convey much about the absolute state. To determine the criticality of the detected issue, the BPFO amplitudes need to be monitored over time. The plot below shows the amplitudes of the first harmonic over four month. The amplitude grows with increasing rotor speed but remains stable along the time axis. We can observe changing amplitudes around rated speed, as rotor speed does not correlate with wind speed and loading from rated speed onwards. Further parts of our monitoring solution analyze the evolution of these peaks along the different dimensions with higher fidelity, in order to distinguish a stable behavior from growing damage.



Conclusions

Our solution allows existing WTs to be retrofitted easily and cost effectively. Our non-invasive sensors provide high quality raw data after only 30 minutes of installation. The overall system is self-sufficient and does not need to interface with the turbine controls. Due to our unique sensor fusion solutions, it is possible to significantly enhance the value of each measurement by combining different sources, ensuring the highest quality of information.
Our Smart Main Bearing Monitoring can detect the onsets of defects early on and our continuous monitoring will warn about changes and trends in the data to enable true predictive maintenance

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