Experimental study: Structural resonances in wind turbine's mechanical drive-train

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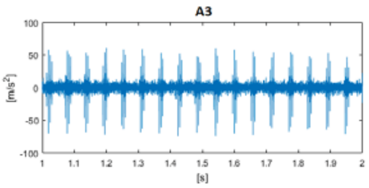
Abstract: What is this about?

This poster gives a review of a real data-set from an offshore wind turbine showing shock impulses. These shock pulses comes from structural resonances, which comes from spalls and cracks in the mechanical drive-train, propagating through the structure and are picked up by inertial acceleration sensors. Low-pass filtering the signal reveals that high-frequency response between 1-10 kHz is what is causing the shock impulses and vibration amplitudes.

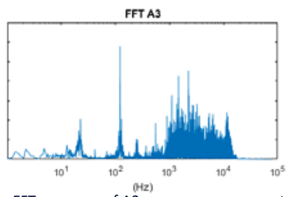
Introduction

The left figure show time-domain sensor measurements of a 2,5 MW, three bladed wind turbine. The mechanical drive-train consist of a two-stage planetary gearbox with a one-stage spur gear. The right figure show the corresponding FFT response.

The given measurement is from an inertial acceleration sensor located at the spur gear of the gearbox.



Time-domain from sensor A3 measurement



FFT response of A3 sensor measurement

Theory

Structural resonances comes from shock impulses when mechanical parts impact each other. This occurs when a spall, crack or other defect develops in any of the mechanical parts.
The phenomenon can be visual detectable as it often appears as signal modulation of the high resonance frequency of the structure and the lower characteristic frequency of the mechanical component.

Structural resonances are often not as obvious as shown here. Then advanced methods (spectral kurtosis and envelope analysis) are utilized.

Method

Characteristic bearing fault frequencies are determined by:

$$BPFI = f\frac{N}{2}\left(1+\frac{B}{P}\cos(\theta)\right) \qquad BPFO = f\left(1-\frac{B}{P}cos(\theta)\right)$$

$$FTF = \frac{f}{2}\left(1-\frac{B}{P}\cos(\theta)\right) \qquad BSF = f\frac{P}{2B}\left(1-\left(\frac{B}{P}\cos(\theta)\right)^2\right)$$

The concept of low-pass filtering is given as:

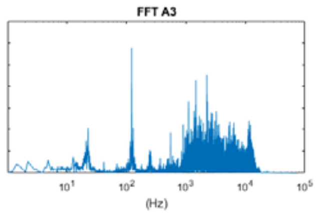
$$b(s) = \frac{\omega_c^2}{s^2+\sqrt{2}\omega_c s+\omega_c^2} \qquad \text{frequency domain}$$

$$\ddot{x}_f + \sqrt{2}\omega_c\dot{x}_f + + \omega_c^2 x_f = \omega_c x \qquad \text{time domain}$$

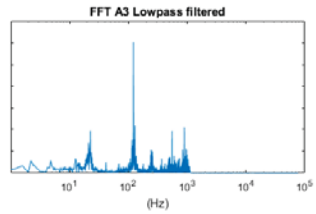
Results and discussion

Applying filtering techniques as discussed in the Method-section, shows how removal of frequencies above 1000 Hz removes the characteristic amplitude peaks.

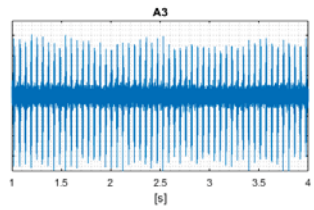
The FFT shows clear amplitude peaks at the characteristic frequency of the HSS pinion (approx. 16 Hz) and the associated BPFI (approx. 180 Hz) of the bearing. In addition, there is a large response in a range of frequencies from 1 – 10 kHz.



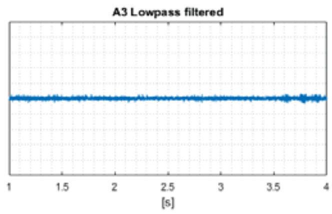
FFT original measurement



FFT after low-pass filtering



time-domain signal



time-domain after low-pass filtering

The results imply that the original measurement's large amplitudes are not caused by the amplitude peaks at the characteristic frequencies from the HSS pinion and BPFI bearing, but rather from the frequency response a much higher range than any of the characteristic frequencies.

Conclusion and further work

Structural resonances has been investigated from a case study of a wind turbine drive-train. Low-pass filtering has been performed on the raw measurement, revealing how the time-domain measurement amplitude shock impulses are created by frequency response between 1-10 kHz.
Further work should look into how these frequency ranges are decided, and if these resonances are affected by the transferring path of the structure. It should also be looked into if these structural resonances actually creates mechanical damage, or are only structure propagations that are picked up by inertial vibration measurement.