Wind Turbine Blade Loading

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Abstract

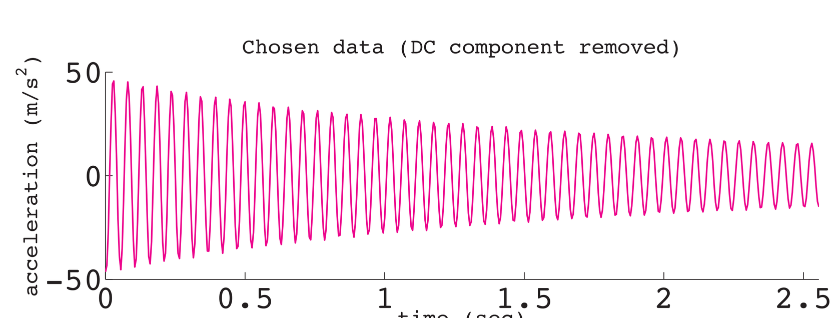
With the aim of measuring and describing the forces on a wind turbine's blade, we have inserted a digital accelerometer into an extruded aluminium blade. The tip's response to an impulse force was characterized as a second order system with a natural frequency of 19 Hz. When the blade was placed on a turbine and allowed to spin freely, the dominant frequencies were multiples of the number of blades time the turbine's rotational speed, without any sign of a 19 Hz component, indicating that the blade's characterized response was a minor component of tip acceleration.

Background

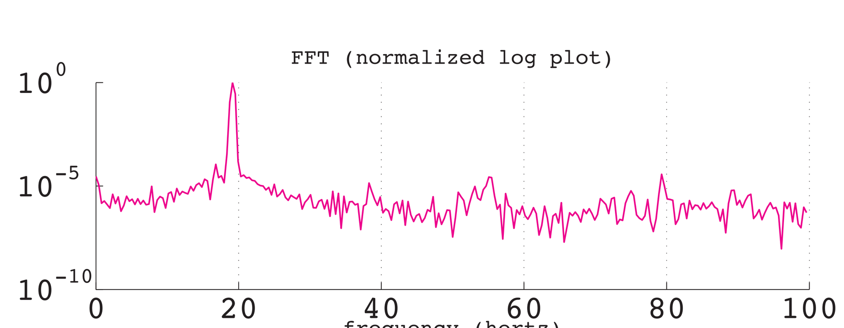
A wind turbine's goal is to make electricity as cheaply as possible, and for modern turbines this objective has led to larger turbines each generation. Recently, a great deal of attention has been paid to offshore wind power, a realm with even more incentives for making bigger turbines; but as turbines increase in size, torques on the blade root (see diagram at right) increase in proportion. Since mechanically stronger blades would increase the cost of energy production, there has been much research into alternatives like active ways of pitching of blades fast enough for them to be able to react either to forces currently felt or to incoming winds. So far this research has focused on theoretical modeling of the blade, but this project is going towards the design of a controller that uses machine learning methods to discover (without theoretical approximations) how best to reduce forces on the blades.

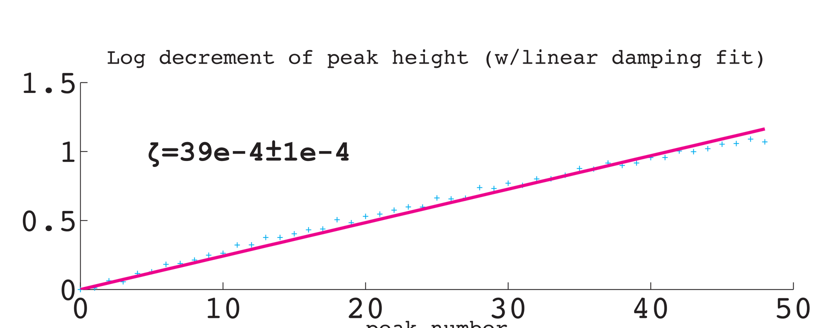
Clamped Blade Vibration

The alumuminum blade was clamped down before being hit with an impulse of force. After a couple of seconds, the acceleration was cleanly sinusoidal, and data was selected for sampling (as seen below).



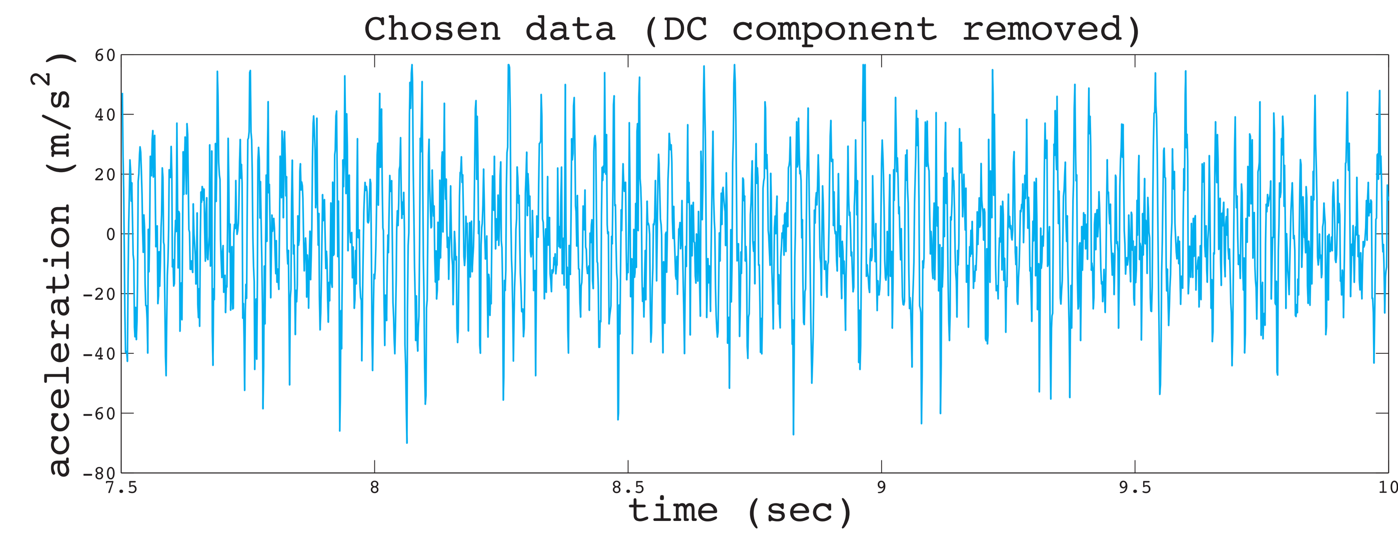
The fourier transform of this signal had an extremely clean peak at 19 Hz (as shown on left), while the plot of logarithmic decrement (on right) showed a linear trend, indicating a constant damping coefficient to be a good fit.



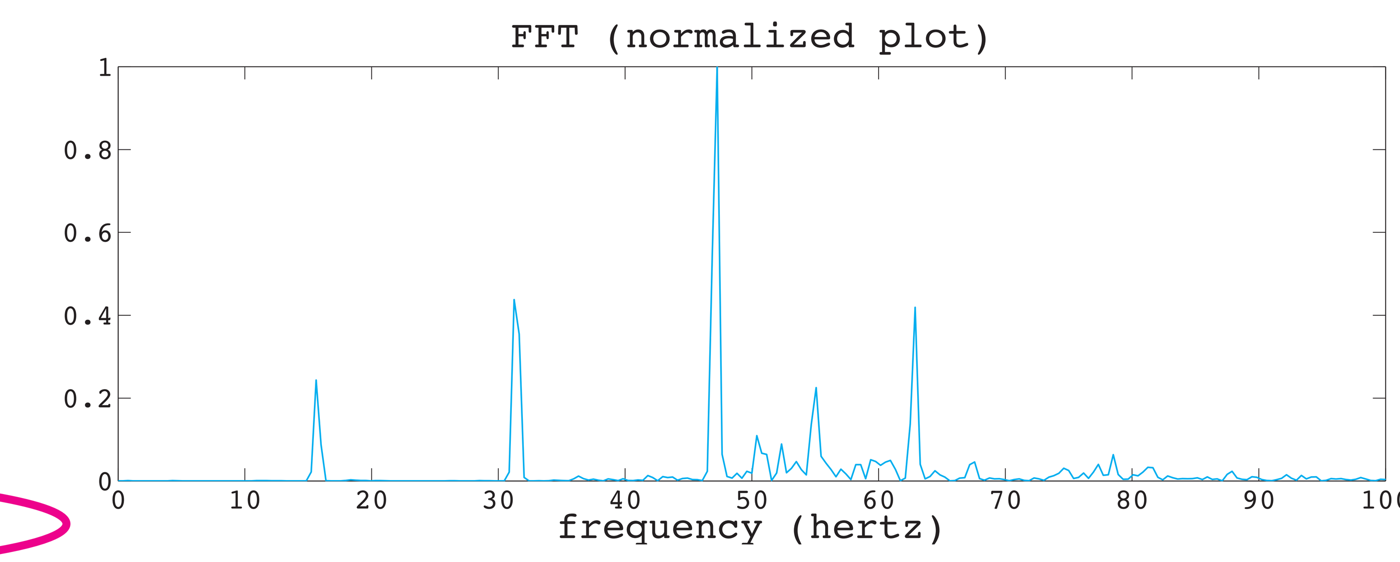


Operating Vibrations

The blade's flapwise acceleration when attached to a turbine spinning at ~300 rpm (~5.2 Hz) is shown below:



Interestingly there is no sign of the blade's 19 Hz primary mode; instead, the FFT shows harmonics at multiples of the turbine's rotational speed (5.2 Hz) times the number of blades (three): the tallest peaks occur at 15.6, 31.2, 47.3, and 62.9 Hz.



These four peaks imply that the turbine's precise speed was 5.24 Hz, matching the speed observed in high-speed camera footage.

Conclusion

That the operating vibrations have no 19 Hz mode corresponding to the blade's natural frequency is a clear sign that the blade's vibration is a minor component of overall tip acceleration. The dominance of modes at three times the turbine's rotational speed point to oscillations in the tower and hub as the primary source of tip acceleration, while the lack of modes corresponding to one times the turbine's speed indicates that effects of gravity, asymnmetric wind, and other factors occuring once in each blade's rotation are also minor compared to turbine-wide vibration in the tower and hub,

Since the acceleration data does not show blade bending, it will not be useful to an automatic controller attempting to minimize bending. However, it may still be useful as a means to minimize overall turbine vibration. It would be interesting to place the accelerometer in the hub and see whether it saw similar vibrations; if it does, then the trouble of a blade-mounted accelerometer can be avoided.

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