In-situ measurement of bearing load from a field wind turbine gearbox bearing

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Piezo-ceramic sensors were fitted onto a field wind turbine gearbox bearing. Ultrasonic waves were transmitted through the raceway and reflections from the raceway-roller interface were recorded and analyzed to deduce individual roller and bearing load. Variation in roller load incurred by each individual rollers across a full complement was found to be more prominent compared to that caused by the same roller across successive revolutions. The measured loads were also compared with multi-body modelled values and found mostly to agree well, apart from high and low load outliers theorized to be from transient events not simulated by the model.

Keywords: ultrasound, in-situ measurement, bearing load, wind turbine, bearing condition monitoring

1. Introduction

A large proportion of wind turbine gearbox failures is a consequence of bearing degradation [1]. The ensuing turbine downtime causes significant loss of revenue to the operator [2] and thus the need for in-situ monitoring to better understand the bearing's actual operational conditions. This study aims to show the capabilities of ultrasound for in-situ monitoring of bearing load and was part of a project funded by the Department of Energy and Climate Change UK in collaboration with Ricardo Ltd, University of Strathclyde and Scottish Renewables. Load measurements from a field operational wind turbine gearbox bearing retrofitted with piezo-ceramic sensors were presented. Measurements were subsequently compared with modelled results for validation.

2. Methods

2.1. Background

The variation in time of arrival, Δt of an ultrasonic wave propagating through the raceway thickness is dependent on the stress which the individual rollers impart on the raceway as it traverses across the sensor. The two primary contributions to this includes raceway deflection, δ and acoustoelasticty which denotes the variation in speed of sound when sound waves travel through a stressed material. The latter contribution can be accounted for through measurement of 2nd and 3rd order elastic constants of bearing steel. Consequently, measurement of time of arrival or time shift can be directly related to raceway deflection and subsequently roller and bearing load utilizing elastic contact models. Equation (1) shows the relationship in mathematical form where Q is the roller load, K_{PC} is a constant function of geometry of bearings [3], $(c_{zz})_0$ is the speed of sound in an unstressed material and L_{zz} is the acoustoelastic constant (-2.24 for bearing steel [4]).

$$Q = K_{PC} \cdot \left(\frac{(c_{zz})_0}{(1 - L_{zz})} \Delta t \right)^{1.5} \qquad (1)$$

2.2. Results

Figure 2 compares the ultrasonic load measurements obtained from the field to the values generated by the multibody model for CH1 and 2 (edge and center of the bearing maximum loaded region). Both CH1 and CH2 ultrasonic measurements show reasonable agreement with the multibody model predicted loads, albeit some amount of scatter.

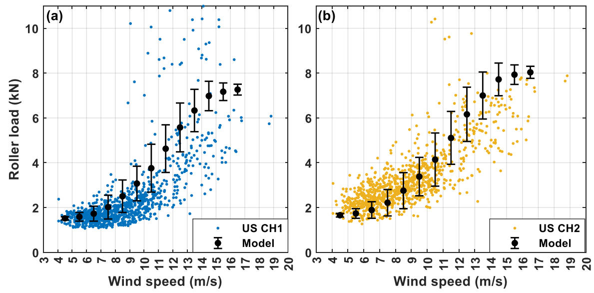

Figure 2: Comparison between ultrasonically measured roller load and multibody model load values for two bearing locations at (a) 241° (CH1) and (b) 201° (CH2) clockwise from bearing TDC.

3. Discussion

As observed in Figure 2, both high and low value outliers were present in the measurements. One possible explanation would be that bearing loaded zone may be potentially shifting. This would result in higher loading experienced at CH1 and consequently lower loading on CH2. Such an occurrence was observed during NREL's dynamometer testing [5] where the bearing loaded zone shifted due to an emergency braking event. For the outlier measurements, values exceeding the modelled results are a cause for concern. These can exceed more than 60% (CH1) or 150% (CH2) of the predicted loading under steady operation. The 60% increase in load will result in a 5-fold reduction in L_{10} bearing life whereas the 150% increase will cause a 21-fold decrease in life.

4. References

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