Bearing degradation indicator using characteristic frequencies applied on non-stationary vibration signals

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Abstract

The well-known bearing characteristic frequencies (BPFO,BPFI,...etc.) reflect the complex kinematic of operating bearings. Far from the idealised perfect rolling assumptions, the experimental frequencies deviate from their theoretical values. The deterioration of the bearing health is likely to induce changes in the kinematics, materialising by a shift in the characteristic frequencies. However, non-stationary operating conditions are also known to influence these frequencies. In this work, the effect of loading and angular acceleration is assessed to measure the feasibility of a bearing degradation indicator using characteristic frequencies for non-stationary operating machines. The method is applied to the monitoring of industrial wind turbines.

1 Introduction

Rolling-element bearings are wear components in rotating machinery. Usually, their condition is monitored with signal-processing tools tailored for vibration-based surveillance. From cyclostationary theory, angle-time analysis, or sparsity-based approaches, numerous methods have been developed relying on the properties of incipient fault signals. The scalar indicators coming from these techniques are well-suited for detection and localisation, but face difficulties in prognosis.

There is a need to develop scalar indicators dedicated to gravity estimation. We believe that the geometry modification of the fault will induce changes in the kinematics of the rolling-element bearing. Far from the ideal perfect-rolling assumption, the relationship between the races' rotation and that of the fundamental train is the fruit of complex interactions. What is usually summarised in the contact angle in the traditional fault frequency equations conceals various effects of axial-radial load ratio, skidding between the elements, and imperfect transmission. As the fault extends, these interactions may change with a direct impact on the fault characteristic frequencies. Bertoni and Andre [1] proposed to monitor these characteristic frequencies with the BeaFEM method to estimate the most probable contact angle. They showed on an industrial test-bench run-to-failure experiment that monitoring the fault frequencies could be a valuable degradation indicator. The validation was done on stationary conditions with a main focus on instantaneous angular speed measurements where parameters of rotating speed and load were finely controlled. However, under non-stationary conditions, the equivalent contact angle is sensitive to various factors such as loading, angular acceleration, or lubrication [2, 3, 4]. An extension of the method is presented to prove the relevance of the concept applied to industrial cases with non-stationary conditions. The role of apparent contact angle as a scalar accounting for the kinematics is clarified. The effect of load and rotation speed is assessed and the methodology adjusted to emphasise only the contribution of the fault. The method is applied to industrial vibration signals from a damaged wind turbine.

2 A common kinematic for the fault frequencies

Using the characteristic frequencies as a degradation indicator rely on two main assumptions. First, there is a common kinematic between the fault frequencies BPFO, BPFI, and FTF. Second, the presence of a fault induces sufficient changes in the kinematics to detect a drift in these frequencies. Originally, the common kinematic was chosen to be the load angle α which was both an intuitive and readily interpretable scalar. While mainly a cosmetic choice, the following work will rely on the fundamental train frequency as the common parameter. A parameter C is introduced to account for the differences between the FTF, calculated assuming perfect rolling between the Z rolling elements and the races, and the actual fundamental train frequency f_c, $f_c = C \times FTF$. For a fixed outer race, the ball pass frequencies of outer and inner races respectively boil down to: $f_o = Z \times C \times FTF$ and $f_i = Z \times (1 - C \times FTF)$. Using this framework over an equivalent angle integrates the interpretation of a deviation from the perfect rolling assumptions . Similar to the methodology of [1], the idea is to find the parameter C_{opt} that maximises the sum of several spectral components $I(C)$. The carriers, number of harmonics, and modulation side-bands to scan are case-dependent.

3 Effect of non-stationarity on the kinematics of the bearing

The following work is be based on vibration signals acquired from industrial wind turbines of the company Engie Green. The accelerometers are placed in the vicinity of the different bearings to monitor. Each signal lasts 10s and is acquired at a sampling frequency of 20 kHz. The machines are monitored for several months and the signals are accompanied by 1Hz estimations of active power and rotating speed.

A macroscopic estimation of the angular acceleration can be estimated with a linear regression of the 1Hz rotating speed measurements. When scanned with the BeaFEM method on the envelope spectra, the C_{opt} appears to be correlated with the macroscopic acceleration of the machine.

To study the influence of loading on the characteristic frequencies, the active power was used as a reasonable image of the loading. The results show a clear influence of the power on the C_{opt}.

4 Condition monitoring of industrial wind turbine

Given the dependency of the train speed on the loading and the acceleration, one can hope to detect the influence of a fault if these parameters are mitigated. A straightforward approach would be to retain signals acquired in favourable acceleration conditions and similar loading. Figure 1 presents the C_{opt} indicator calculated on signals acquired during the last two months of a severely damaged bearing. A shift can be observed from index 60, indicating a degradation of the condition.

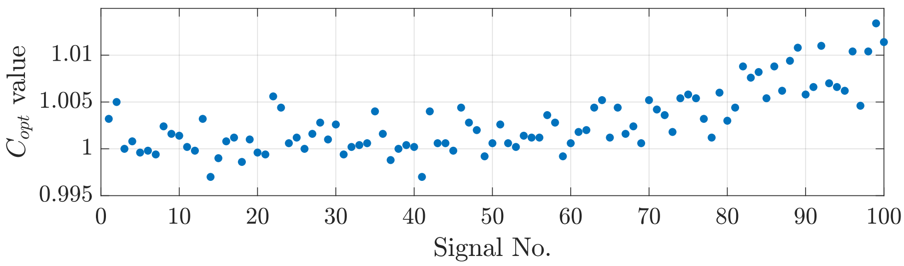

Figure 1: Evolution of C_{opt} for signals recorded during the last 2 months of the bearing before replacement. The index of signals is chronological.

5 Conclusion

In this paper, the potential use of monitoring characteristic frequencies as a bearing degradation indicator was assessed. The goal was to see to what extent the approach proposed by Bertoni and Andre [1] could be used for non-stationary operating machines. The key takeaways are:

- The common kinematic is expressed as a function of fundamental train frequency rather than an equivalent load angle
- Angular acceleration of the races and loading influence the characteristic frequencies and will be shown during the presentation.

- Severe faults induce sufficient changes in the kinematics to be detected and will be illustrated during the presentation.

Further work will focus on the detection of less severe faults.

References

[1] R. Bertoni and H. André. Proposition of a bearing diagnosis method applied to IAS and vibration signals: The BEAring Frequency Estimation Method. *Mechanical Systems and Signal Processing*, 187:109891, March 2023.

[2] P. Borghesani, R. Ricci, S. Chatterton, and P. Pennacchi. A new procedure for using envelope analysis for rolling element bearing diagnostics in variable operating conditions. *rvtMSSP*, 38(1):23–35, 2013.

[3] T. A. Harris. An Analytical Method to Predict Skidding in High Speed Roller Bearings. *A S L E Transactions*, 9(3):229–241, January 1966. Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/05698196608972139.

[4] Paolo Pennacchi, Pietro Borghesani, Steven Chatterton, and R Ricci. An experimental based assessment of the deviation of the bearing characteristic frequencies. In *Proceedings of the 6th International Conference Acoustic and Vibratory Surveillance Methods and Diagnostic Techniques*, pages 1–8. 2011.