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Review

A summary of fault modelling and predictive health monitoring of rolling element bearings

Idriss El-Thalji *, Erkki Jantunen

Industrial Systems, VTT Technical Research Centre of Finland, Espoo, Finland

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ABSTRACT

The rolling element bearing is one of the most critical components that determine the machinery health and its remaining lifetime in modern production machinery. Robust Predictive Health Monitoring tools are needed to guarantee the healthy state of rolling element bearing s during the operation. A Predictive Health Monitoring tool indicates the upcoming failures which provide sufficient lead time for maintenance planning. The Predictive Health Monitoring tool aims to monitor the deterioration i.e. wear evolution rather than just detecting the defects. The Predictive Health Monitoring procedures contain detection, diagnosis and prognosis analysis, which are required to extract the features related to the faulty rolling element bearing and estimate the remaining useful lifetime. The purpose of this study is to review the Predictive Health Monitoring methods and explore their capabilities, advantages and disadvantage in monitoring rolling element bearings. Therefore, the study provides a critical review of the Predictive Health Monitoring methods of the entire defect evolution process i.e. over the whole lifetime and suggests enhancements for rolling element bearing monitoring.

Contents

* Corresponding author.
E-mail addresses: idriss.el-thalji@vtt.fi (I. El-Thalji), erkki.jantunen@vtt.fi (E. Jantunen).

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1. Introduction

The rolling element bearing (REB) is one of the most critical components that determine the machinery health and its remaining lifetime in modern production machinery. Robust Predictive Health Monitoring (PHM) tools are needed to guarantee the healthy state of REBs during the operation. The PHM tool indicates the upcoming failures and provides more time for maintenance planning. The PHM tool aims to monitor the deterioration i.e. wear evolution rather than just detecting the defects. There are a number of literature reviews which are related to the condition monitoring of REBs [1–6]. These reviews explain very well the developed signal processing (SP), diagnosis and prognosis analysis methods and their challenges, enhancements, and limitations. Many experiments and studies have been performed to explore the nature of bearing defects with the help of several monitoring techniques such as vibration, AE, oil-debris, ultrasound, electrostatic, Shock-Pulse Measurements (SPM), etc. Some simple signal/data processing techniques have been applied to process the signals such as root mean square (RMS), kurtosis, Fast Fourier Transform (FFT), etc. However, there are several challenges that require more advanced SP methods, e.g. to remove the background noise effect, the smearing effect and the speed fluctuation effect. The most important challenge is to deal with the signal response due to defected REBs. Bearing faults are assumed to generate impulses due to the passing of the rolling element over the defected surface. The difficulty is to detect and track such impulses, specially, in the early stage of wear process where the defect is quite small and can be easily buried by other vibration phenomena. Therefore, most of the PHM studies have concentrated to the development of more advanced SP techniques such as envelope detection, cyclostationary analysis, wavelets, data-driven methods, expert systems, fuzzy logic techniques, etc.

In the field of machinery vibration monitoring and analysis, a variety of relevant standards are developed and published by ISO (International Organization for Standardization). A number of ISO standards describe acceptable vibration limits, such as the ISO/7919 series (5 parts) "Mechanical vibration of non-reciprocating machines—Measurements on rotating shafts and evaluation criteria" and the ISO/10816 series (6 parts) "Mechanical vibration—Evaluation of machine vibration by measurements on non-rotating parts". The standards cover the methods of measurement, handling, and processing of the data required to perform condition monitoring and diagnostics of machines. In the industry, the most commonly used techniques are RMS, crest factor, probability density functions, correlation functions, band pass filtering prior to analysis, power and cross power spectral density functions, transfer and coherence functions as well as Cepstrum analysis, narrow band envelope analysis and shock pulse method. These methods try to extract the expected defect features. The frequency equations of the bearing defects (i.e. for outer-race, inner-race, rolling elements, and cage defects) are the main way to provide a theoretical estimate of the frequencies to be expected when various defects occur in the REB. They are based upon the assumption that sharp force impacts will be generated whenever a bearing element encounters a localized bearing fault such as caused by spalling and pitting. These techniques have continued to be used and have been further developed over the time [1].

The ultimate purpose of the PHM system is to indicate the upcoming failures in order to provide sufficient lead time for maintenance planning. Beside the experimental studies, there are several analytical and numerical models to (1) simulate the faulty REBs; (2) verify the ability of SP and diagnosis methods to extract the defect features; and (3) to predict the remaining useful lifetime of the faulty REBs. Several studies have explored the data-driven and model-based prognosis methods for REBs applications. Therefore, the purpose of this study is to review and discuss the entire PHM procedures i.e. detection, diagnosis and prognosis based on experimental studies and simulation models that have been made available in the literature.

The study begins with presenting the fundamentals of rolling bearing and their modelling techniques. Then, the monitoring techniques, SP, diagnostic methods and prognosis analysis for REB are reviewed. Later, all these issues are critically discussed in order to draw some the conclusions of current research, emerging trends and the areas where more work and research is needed.