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Experimental study on the optimum time for conducting bearing maintenance

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ABSTRACT

Bearings are critical components in the products of many industries, and their failure can result in long downtime and costly maintenance. Prolonging a bearing's service in a safe manner is vital for operators of equipment, and condition monitoring is regarded as one of the best approaches to achieve this. In general practice, condition monitoring does successfully indicate the presence and growth of bearing faults. However, standard condition monitoring techniques do not usually have a proven method to determine the best time to conduct maintenance of a defective bearing. Traditionally, maintenance will be conducted when the measured vibration of a bearing is found to exceed an acceptable vibration level, as defined by an industry standard. However, the industry standard is only a general guideline to the design and operation of the kind of machines/components under certain conditions. The actual dynamic response of a bearing is reliant on a variety of factors, such as lubrication, loading, temperature, and operational and environmental conditions. As a consequence, although the empirical vibration levels suggested by the standard are helpful in ensuring the safe operation of a bearing, they cannot guarantee full utilization of the residual life of a defective bearing. The purpose of this paper is to try and find a feasible solution for this issue, and moreover validate it through a number of experiments conducted under various loading and operational conditions. In the research, four dimensionless condition monitoring criteria: normalized information entropy; *J*-Divergence; Kurtosis; and a composite criterion based on them, are employed to assess the actual health condition of the test bearings with different types and severity levels of failures. Experimental results have shown that in comparison of the industry standard, the proposed method provides an effective and feasible approach for predicting the optimum time to conduct bearing maintenance. It is deemed that the achievements of this work will help operators in further improving their management of assets.

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1. Introduction

Bearings play a vital role in industrial equipment, and failure of them not only results in long downtime and expensive maintenance, but can potentially cause damage to neighboring equipment. Hence, on the one hand operators attempt to ensure the safe operation of bearings; on the other hand the operators pursue to prolong the service-life of the bearings in the meantime for achieving the best financial return. Condition monitoring (CM) has been regarded as an effective way of achieving both purposes. In the past decades, significant effort has been expended in detecting bearing faults [1–8]. However, to date the question, 'What time is the best time to conduct the maintenance of a defective bearing?' has not been satisfactorily answered. Traditionally, the maintenance of a defective bearing will be conducted when its vibration is

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found to reach or exceed an acceptable vibration level suggested by industry standards. Currently, a few international standards have been available for this purpose. For example, ISO IS 7919 suggests the threshold peak-to-peak levels of vibration displacement; ISO 10816/2372, ISO IS 3945 and VDI 2056 suggest the threshold Root Mean Square (RMS) values of vibration velocity. These standards were initially designed for providing general guidelines to the design and operation of the kind of machines/components under certain conditions. However, the actual vibration response of a bearing is reliant on a range of conditions, such as loading, rotational speed and temperature. For this reason, a fault will definitely increase the vibration of bearing, while the increase of bearing vibration does not necessarily mean the presence of a fault. Thereby, the application of these standards could be helpful in ensuring the safe operation of a bearing. They however cannot guarantee the full utilization of the residual life of a defective bearing. The issue still remains to be solved of, “How to determine the right time to conduct the maintenance of a defective bearing”.

Aiming to deal with this issue, two approaches have been tried previously. The first approach is to predict the average life of a bearing through calculating its basic rating life L_{10} [9]. Mathematically, L_{10} is a function of load and rotational speed of the bearing. It indicates 90% of bearing life, although the actual average life of a bearing is usually about five times of the calculation result. L_{10} has been extensively used for predicting the life of rolling element bearings. The limitation of L_{10} calculation is that it does not take into account the influence of lubrication, which has been found having significant contribution to damage of bearings. The recently introduced SKF life equation improves on the traditional L_{10} by taking into account contamination lubrication and moreover introducing a fatigue load limit concept into the calculation. More details about this improved equation can be found in the standard ISO 281:1990/Amd 2:2000. In spite of this improvement, the calculated average bearing life is anyway a suggested value. The actual service life of a bearing could be significantly different from the calculation result. So, although this approach is helpful it cannot fully provide the answer.

The second approach is to determine the time for maintenance based on the statistical failure rate of bearings. The limitation of this approach is that it requires long-term recorded reliability information about the bearing. However, historical reliability data is often unavailable. Moreover, the significant number of occasional factors can result in large differences between predicted and actual values of ‘time-to-failure’. Hence, the second approach is not a perfect solution either for the issue.

In recent years, some other approaches, e.g. neural network [10], are tried for predicting the residual life of defective bearings. However, the extensive application of these methods is delayed due to the challenges in training the network and the uncertainties of predicted results.

For the aforementioned reasons, an experimental study is conducted in this paper in order to find a simpler and more feasible solution for the issue. Firstly, the paper develops the principles for determining the optimum time for conducting bearing maintenance following discussing the relevant issues and challenges; Then, the paper introduces four dimensionless CM criteria as the tools for predicting the approximately optimum time for bearing maintenance; The proposed optimum time approximating method is finally validated experimentally by using the bearing vibration data that are openly published by Case Western Reserve University.

The novelties and contributions of this paper can be summarized as: (1) the paper exposes the long-ignored issues in condition-based maintenance practice and the limited capability of existing industry standards in dealing with the kind of problems; (2) the paper proposes a approach for predicting the optimum time for conducting bearing maintenance; (3) the paper employs four dimensionless criteria as the tools for prediction. Since the criteria are dimensionless, they are less affected by operational conditions. They therefore are more reliable in comparison of those conventional CM criteria; and (4) with the aid of four dimensionless criteria, the paper develops a reliable method for predicting the optimum time to conduct bearing maintenance. Experiments have shown that the proposed approach is extensively applicable to those bearings with different failure modes and subjected to various loading and operational conditions.

2. Principle for predicting the optimum time to conduct bearing maintenance

Bearing maintenance is always not a pure technical issue. It requires the availability of a range of items, for example spare parts, transport and installation tools, the correct people, suitable time and weather conditions, etc. In this paper, all these things are assumed to be available for simplicity. Then, in theory the optimum time for conducting bearing maintenance can be simply regarded as the compromise of safe operation and the utilization of bearing’s residual life. From the point of view of material science [11], the safe operation of a bearing can be indicated by a risk index, γ, i.e.

$$\gamma = \frac{\delta_{\text{actual}}}{\delta_{\text{critical}}} \tag{1}$$

where δ_{actual} and δ_{critical} represent the actual and critical sizes of the defect [11], respectively. The critical size δ_{critical} is the defect size at which the material will fail.

Since the actual defect size δ_{actual} is a function of the service time of the bearing (i.e. the longer the bearing serves, the larger δ_{actual} tends to be), the continued operation of a defective bearing will suffer higher and higher risk (indicated by an increasing value of γ).

The equilibrium equation of bearing life can be expressed as

$$T_{\text{design}} = T_{\text{actual}} + T_{\text{residual}} \tag{2}$$

where $T_{\text{design}} \approx 5 \times L_{10}$ refers to the designed service life of a bearing; T_{actual} stands for the actual service time of the bearing; and T_{residual} represents the residual life of the bearing.

Then, what operator is attempting to do is to maximize the actual service time T_{actual} and in turn to minimize the

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