Spall Evolution in a Rolling Element Bearing

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Abstract

Rolling element bearing (REB) is one of the basic mechanical components in rotating machinery. It is common to divide the REB wear into two stages, damage initiation and damage propagation. There has been a growing awareness of the need to understand the damage mechanism during the propagation phase. The current work includes a discussion on the ongoing research and the methodology for the development of the prognostic method for damage propagation. The methodology integrates experiments, diagnostic methods, and physics-based models. Endurance tests were conducted in order to learn about the damage propagation process and model validation. Furthermore, Finite Element model of the spalled bearing was developed and validated. The FE model aims to investigate and simulate the damage propagation process. The simulation results are in good agreement with the experimental observation.

1 Introduction

Failure prognosis of rolling element bearings (REBs) is crucial in rotating machinery PHM. The damage evolution in REBs consists of two main phases: damage initiation and propagation. The conventional REB life models address the lifetime of the bearing to the damage initiation, i.e. first spall formation [1]. However, after the first spall formation, the bearing might be fully operational for millions of cycles. After the first spall formation, it propagates in the circumferential direction of the raceway, until the bearing becomes non-operational [2].

Many diagnostic tools have been developed in order to monitor the spall propagation. However, there is lack of reliable prognostic of the remaining useful life (RUL). Physic-based prediction of the damage propagation in the REB, after the first spall generation. The difficulties in prognosis of the propagation stage necessitate deep understanding of the damage mechanisms, the stochastic nature of the spall propagation process, and its modeling [3, 4]. The main goal of the current work is to develop a physics-based prognostic method for the spall propagation in REBs. Herein, we present a methodology for the development of the prognostic method, which combines experiments, diagnostic methods, and physics-based models.

2 Methodology

The proposed methodology for prognostic of the RUL is based on a combination of physics-based models, diagnostic methods and experiments [7]. The concept is presented in Figure 1. This section includes a description of the objectives that need to be reached in order to achieve the main goal, RUL prognostics.

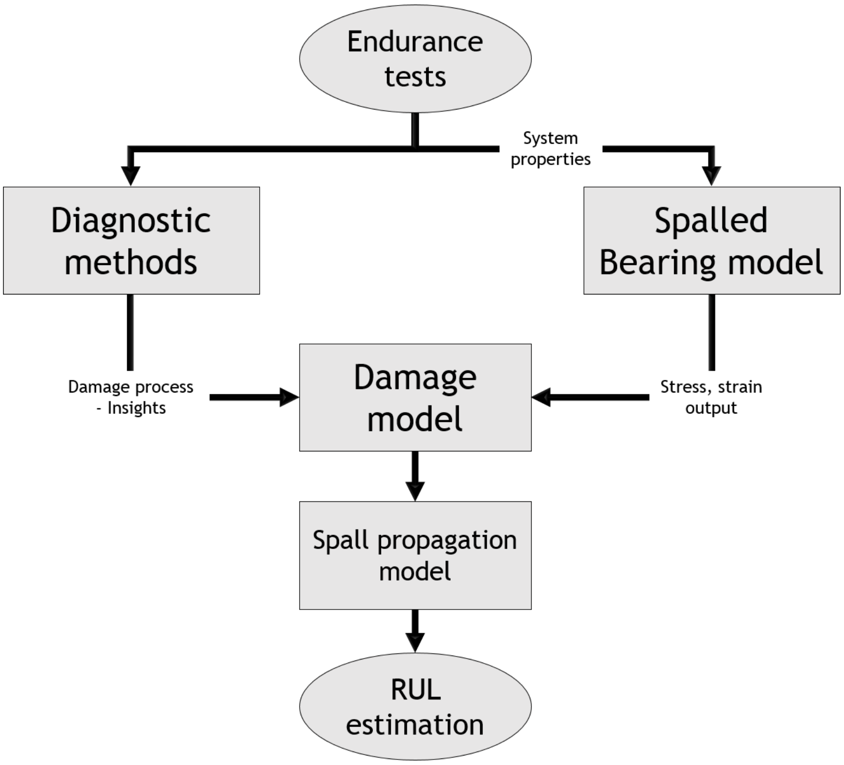


Figure 1: Research flow chart describing the steps toward the development of the prognostic method.

The first objective is the quantitative and qualitative understanding of the damage-driven mechanisms, e.g. plastic strains, residual stresses, etc., of the spall propagation process. In addition, it is important to learn, based on the existing literature and experiments, about the effects of the bearing's features (e.g. hardness, ball mass), and operational conditions (e.g. speed, load) on the propagation process and the trend of the spall growth [8, 9]. This objective can be attained by conducting endurance tests. Figure 2 shows an example of a diagnostic indicator evolution, BPFO Z-score distance vs. time. The tests can add insight regarding the spall propagation process and can be used for the physical model validation.

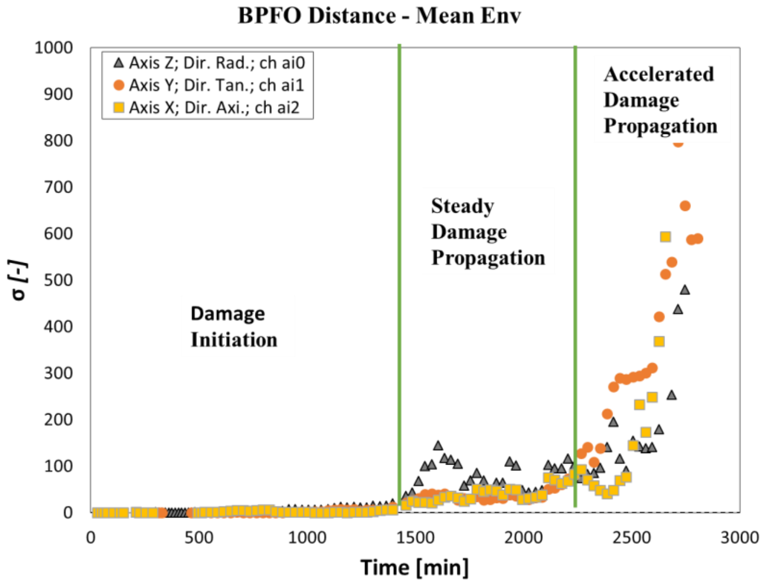


Figure 2: Damage evolution trajectory during the endurance test. Each data point correspond to the vibration measurement during the test.

The second objective is the development of a model for the damage propagation process. First, the material response in the presence of a defect must be analyzed. This analysis, coupled with the endurance test results, will shed light on the mechanism governing the damage propagation process. For this purpose a physics-based model of a spalled bearing has been developed. The model is used for analysis of the material response in the presence of a defect. Moreover, the model was used for damage evolution simulation. Figure 3 shows examples of a simulation result and the metallurgical analysis of a bearing from an endurance test. The accomplishment of this objective will provide a mean estimated damage trajectory. However, the damage propagation is a stochastic process. Hence, dispersed results are expected.

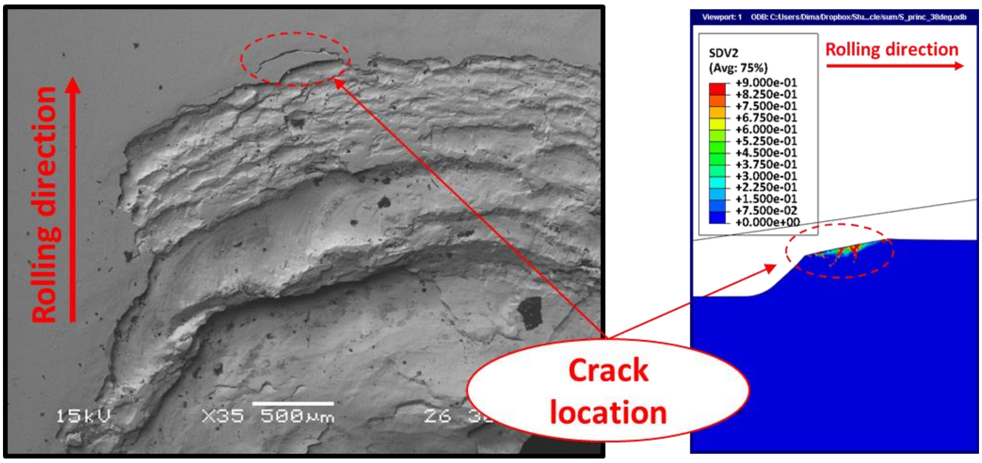
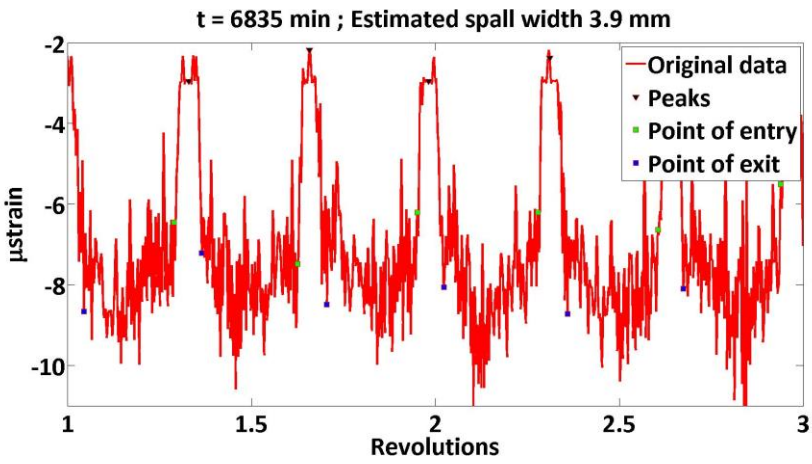
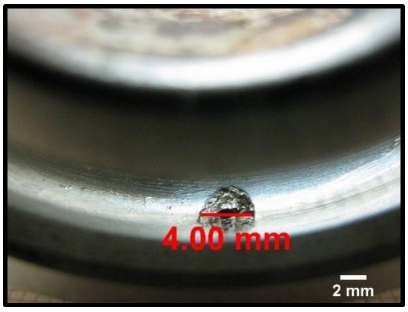


Figure 3: SEM Image of the spall trailing edge and simulated cracks.

The third objective of the research, and probably the most challenging, is to model the stochastic nature of the damage propagation. The propagation of the spall in the REB is a stochastic process. Even under well controlled experimental conditions, using allegedly identical bearings, the results of the endurance tests vary [2]. The prognostic method must consider the uncertainties and the progress of the probability distribution. One of the common methods is to use diagnostic condition indicators in the early stages of the damage in order to monitor its propagation, e.g. oil debris, vibration level, etc. For this purpose, methods for the spall width estimation via time domain analysis were developed [10]. The spall width is estimated based on the acceleration and strain signatures, Figure 4. The spall width and vibration based CIs will be used for the estimation of the damage model parameters by the trend identification of the spall propagation process. The accomplishment of this goal will complete the development of the physics-based prognostic method.



(a)



(b)

Figure 4: Strain data vs. cycle, based on which the spall size was estimated. The (a) estimated size is 3.9 *mm*, and the (d) measured size is 4.0 *mm*.

3 Summary and Conclusions

The remaining useful life (RUL) estimation using physics-based prognostic method is schematically illustrated in Figure 5. The calibration of the damage model can be implemented by comparing the simulations results with the data extracted from endurance tests. For example, a diagnostic method for the defect severity estimation (fault size, vibration level, etc.) can be implemented during the first stages of the tests. The results obtained by the diagnostic method can be used for the estimation of the damage model parameters and their uncertainties. The integration of the prognostic and the diagnostic methods, has the potential for reliable online estimation of the RUL including probability distribution of the result.

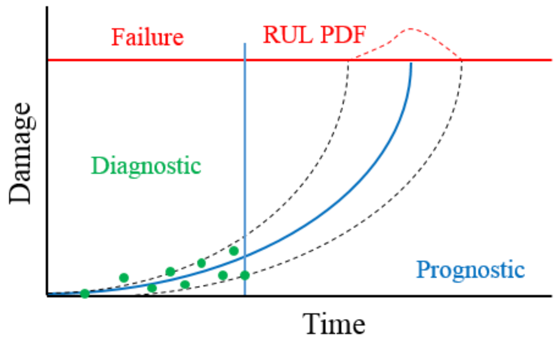


Figure 5: Bearing prognosis - first the damage propagation process is monitored; next, the model parameters are estimated; and the RUL is calculated [7].

Acknowledgments

The authors would like to express their deepest appreciations to Pearlstone Center for their support and funds of this work.

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