Abstract

Remaining Useful Life Estimation (RULE) for rolling bearings via random vibration signals and a Functional Based model

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In the present thesis, a study on the estimation of the remaining useful life of a bearing on a shaft via vibration signals and a statistical time series method based on Functionally Pooled (FP) models has been conducted. The double-row bearing, designated "Rexnord ZA-2115," has been subjected to a radial load of 27 (kN) under normal operating conditions over a period of 7 days, from February 12 to February 19, 2004. The employed data have been based on acquired signals from an accelerometer mounted on the bearing housing, which recorded at a sampling frequency of $Fs = 20\ kHz$. A total of 984 signals have been available and divided into 4 batches corresponding to 4 simulated experiments/artificial life cycles, each consisting of 246 signals and corresponding to different total operating hours. This division of signals aims at investigating the potential for estimating the remaining life across different total operating time ranges of the bearing, particularly in cases where it approaches the end of its useful life more rapidly. The objectives of this thesis are the proper formulation of a method based on FP models for the effective and comprehensive modeling of the bearing's dynamics throughout its lifetime and, through this, the accurate estimation of the remaining useful life for all different life cycles, using a minimal amount of data for the method's training. Specifically, the methodology followed was based on Functionally Pooled Autoregressive (FP-AR) models of order $na = 91$ with a functional basis of dimension $p = 6$, which successfully represented the bearing's dynamics as confirmed by model residual checks and spectral comparisons. The estimation of the bearing's remaining life commences when the system enters a degraded state, detected through a statistical test based on the acceleration spectrum. The detection of degradation is achieved timely, specifically before half of the total life span, and the estimation of remaining life through the method based on Functionally Pooled models is excellent, deviating by only 0.5% from the actual remaining lifetime, using just 82 signals for its training. The superiority of the proposed method over existing literature is confirmed through comparisons with the Wiener degradation model based on frequency and time domain features, which fail to adequately describe the bearing's dynamics throughout its operation time. The Wiener model's best performance shows a 1.1% deviation from the actual remaining lifetime, which is surpassed by the excellent 0.5% achieved by the proposed method. Finally, the results of this work confirm the applicability of the proposed method for prognostics in bearings, thereby supporting the direction of predictive maintenance, which implies fewer undesirable operational interruptions and, consequently, reduced costs.

Keywords

Remaining Useful Life Estimation, Vibration Signals, Functionally Pooled Models, Statistical Degradation Models, Predictive Maintenance