Early Detection of Cracks in a Gear Train System Using Proper and Smooth Orthogonal Decompositions

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Abstract. Machine learning is broadly used as an efficient approach to fault diagnosis and defect detection in gear-train systems. However, the complex nonstationary dynamics and the high nonlinearity in its faults inhibit the effectiveness of machine learning techniques, particularly in feature extraction. In this paper, we leverage Proper Orthogonal Decomposition (POD) and Smooth Orthogonal Decomposition (SOD) methods to more efficiently extract the features for machine learning algorithms. A mock-up gearbox is used as the experimental platform to validate the proposed method. Results demonstrate the effectiveness of the proposed techniques in capturing the nonlinear behaviors and optimally detecting early cracks with 100% accuracy.

Introduction

Condition Based Maintenance (CBM) relies on implementing online assessments of the current machine condition without interrupting the normal machine operation. Gear-train faults are the most common causes of the failure of transmission systems, which makes gear fault diagnostic technology a significant factor in reducing casualties and economic losses. This study develops a CBM strategy to detect early tooth cracks in a gear-train of a helicopter engine, which is a 5m-long large-scale machine consisting of a motor, dynamometer and four gearboxes as shown in Figure 1.And a triaxial accelerometer is mounted on the gearbox to record the vibrational signals of the gearbox and test gears while a crack of length 2 mm was introduced.

Figure 1: Gear-train experimental setup

Diagnostic Approach

In the field of vibration monitoring of rotating machines, various feature extraction techniques have been explored for gear fault detection and diagnostics. In earlier work, we introduced the Phase Space Topology (PST) method to describe and distinguish the topology of the phase space trajectory with quantitative measures[1]. In this study, we extract features by using Proper Orthogonal Decomposition (POD), and a newly developed method called Smooth Orthogonal Decomposition (SOD) [2]. POD and SOD are techniques used to map multi-dimensional data into basis vectors. POD, also known as principal component analysis (PCA), finds orthogonal basis vectors such that the projection of the data onto these basis vectors has maximum variance. SOD can be viewed as an extension to POD, which alters these basis vectors in a way that the evolution of data, or in other word the dominant flow, has the maximum smoothness, which release the condition of basis orthogonality. For each data sample, the POD and SOD are performed to extract a feature set including (1) the angle lying between each proper orthogonal mode and the positive x-axis, (2) each proper orthogonal value, (3) the angle lying between each smooth projection mode and the positive x-axis, (4) each smooth orthogonal value, and (5) the proper and smooth orthogonal modes. Then, these selected features extracted from nonstationary vibrational signals can be mapped onto different health conditions by developing appropriate machine learning algorithms. The results show remarkable performance of the POD and SOD techniques with 100% accuracy in detecting early stage cracks.

References

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