INTELLIGENT FAULT DIAGNOSIS OF GEARBOX UNDER RUNNING-UP CONDITION

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Abstract

In this research, a Fuzzy Inference System (FIS) based on features extracted from Gabor order analysis is proposed for detection and classification of faults in the gearbox under running-up condition. The complexity of detecting gear faults at early stages in run-up condition is due to the non-linearity imposed by dynamic signature of gearbox vibration in which non-stationary fault symptoms are present. Therefore, based on a novel idea, a pre-processing step is utilised on extracted features in order for dimension reduction and selection of most sensitive features to the faults. Gabor transform as a utensil of time-frequency analysis is used for detecting non-stationary periods induced by local faults in gearbox. Moreover, time-variant filtering scheme based on Gabor transform-expansion pair is implemented for revealing the problem of speed-varying phase analysis in the gearbox. By applying Gabor transform with relatively high over sampling rate, exact TF representation is achieved. Proper masks for slew orders reconstruction are defined on the obtained Gabor lattice. These masks posses the potential of extracting important and sensitive features. Template scatter matrix would be formed using extracted features on statistical vibration signals for each working condition of the system. Using PCA and Discriminant Analysis, scatter matrix dimension would reduce while good separability between gearbox working conditions is guaranteed. Consequently, FIS is designed based on projected features. The proposed scheme offers high inference ability and alleviation in complex numerical cost. The implementation of proposed method attenuates the number of fuzzy rule sets and results in higher classification performance. Meanwhile, the computation cost decreases without missing crucial information for fault diagnosis. Eventually, experimental investigations of proposed method on statistical data of Yamaha motorcycle gearbox indicates the efficiency of proposed method for classification of impact and wear defects in gearbox.

1. INTRODUCTION

Gearboxes are an important class of rotating machineries in mobile and aeronautical industries. As a result, fault prognosis and diagnosis of gearboxes have been of great importance in recent decades. Studies show that gear faults include 60 per cent of gearbox failures while incorrect maintenance is just responsible for 24 per cent of gearbox failure cases [1]. Thus, condition monitoring of gearboxes is one of the most crucial items for attenuating failure and guaranteeing ideal work of gearbox. Moreover, an expert fault diagnosis and condition monitoring system with potential of automatic detection of abnormal conditions in
the system could reassure longer life of effective use of a gearbox.

Pattern recognition and statistical techniques, which make use of feature selection and extraction techniques for fault diagnosis, are known as an applicable area for gearbox fault diagnosis [2]. Since local gear faults cause a non-stationary period in gearbox vibration, Joint Time-Frequency Analysis (JTFA) has been widely applied for detecting non-stationarity in gearbox vibration in recent decade [3]. As representation dimension increases in all JTFA transformations, the analysis of fault symptoms becomes a complex problem and mostly dependent on operator. Thus, in recent years, expert systems based on human knowledge with the ability of self-learning have drawn researchers' attention [4]. Among expert systems, Fuzzy Logic Inference (FIS) has been paid attention for its inference ability and simple modelling of complex problems common in classic pattern recognition approaches in the area of rotating machinery fault diagnosis [5].

In 2005, Wu et al. [6] proposed a method based on FIS for gearbox fault diagnosis. Fuzzy rules are defined using feature vectors obtained from gear meshing orders by variable step size affine projection algorithm. Convergence of the method is guaranteed by changing adaptive filter coefficients during the process. In 2005, Bai et al. [7] utilised the combination of signal analysis techniques and a condition inference algorithm based on FIS for fault diagnosis of a rotor system and a 4-cylinder engine with one or two simultaneous faults. Signal analysis algorithm are implemented using a recursive least square and Kalman filter for extracting slew orders. Besides, accurate inference of system condition is achieved using a fuzzy inference engine. Their results show good performance in classification of major faults. In 2006, Xu-hong and Yi-hong applied a novel method based on Takagi-Sugino and Genetic Algorithm (GA) for online fault detection of induction motors. Two fuzzy models, one for fault detection and the other for determining the exact number of winding turns are used. The parameters of the proposed fuzzy model are optimally estimated by GA in each step. They demonstrated that their method possesses higher detection performance for early faults in comparison with a feed-forward neural net. In 2007, Wu et al. [9] used linguistic variables for fault classification in presence of one or two faults in a geared system. In their method, fault classification is based on the exact transformation of frequency spectrum to order spectrum. In this way, Adaptive Kalman filter along with a fuzzy condition inference system is applied for fault diagnosis in a scooter gearbox. In 2007, Tian et al. [10] proposed a neuro-fuzzy approach for fault detection in oil pumps. Due to the non-linear and complicated relation between faults and vibration signature of the pump, by benefiting from the learning ability of neural network classifier and the inference ability of FIS, an expert classifier is designed. They showed that the combination of both utensils results in perfect classification. In 2008, Saravanan et al. [11] utilised a fuzzy classifier for fault diagnosis of bevel gears. Time domain moments of vibration signals are extracted as features. Best features are selected by decision trees. FIS system is used for condition classification and evaluates the performance of proposed method on experimental test data on bevel gears.

In this article, we introduce a Fuzzy Inference System for fault classification of gearboxes under running-up condition. Based on an idea and before the implementation of FIS, a pre-processing step is performed on the sensitive features to the faults extracted by Gabor Order Analysis (GOA). This pre-processing step is performed in order for dimension reduction of initial feature vectors and finding most sensitive mapping for means of final classification. Thus, perfect discrimination between working conditions is achieved and it would be feasible to design FIS with high accuracy rate in gearbox fault classification. Eventually, the performance of the proposed method in fault diagnosis of impact and wear faults would be studied using a set of statistical acceleration signals on Yamaha motorcycle gearbox.