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Gear Wear Fault Diagnosis in Tail Gearbox of Helicopter Using K-Nearest Neighbor Recognition Pattern

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ABSTRACT: Application of rotary systems in aerospace, power stations, automotive industries and many others is prevalent. System failures and damaging always force a lot of costs to owners of these industries. In addition, maintenance of rotating system based on traditional logics is very expensive. Therefore, intelligent fault detection of engineering systems, especially mechanical ones, is important and a growing issue in industries all around the world. This paper presents a new intelligent approach to fault detection and diagnosis of gear wear. The proposed method is applied to a power transmission system in tail gearbox of a helicopter. Vibration signals of helicopter tail gearbox are measured at some convenient locations and further processed to determine the significance of these signals. A discrete wavelet analysis is used for feature extraction in addition to conventional statistical features extracted from vibration signals. The principal component analysis is used to obtain dominant features. Then, these features are fed as input for training and testing a K-nearest neighbor classifier. The results of the proposed intelligent diagnosis system are found to be encouraging.

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1- Introduction

In recent years, many studies have been carried out with applying vibrations signals analysis about gear fault diagnosis. Simplicity of vibrations signal analysis highlighted this method as one of main useful tools for gear fault diagnosis. Kang et al. [1] used Bayesian networks and the time-domain statistical parameters of vibration signals for identifying gear fault category of tooth breakage and wear. Saravanan [2] presented an intelligent system for spiral bevel gear fault diagnosis through applying optimal statistical feature extraction of vibration signals with fuzzy inference system. Loparo [3] extracted values of standard deviation from wavelet coefficient and used fuzzy inference system for bearing fault diagnosis.

In this paper an intelligent method for gear wear diagnosis is presented. The remainder of the paper is organized as follows: Section 2 explains experimental setup and vibration signal acquisition in different speeds and loads. In Section 3, various statistical parameters in time, frequency and time-frequency domain are extracted, then the two first principal components are selected as dominant features. In Section 4, a classification of gear faults levels through K-Nearest Neighbor (KNN) method is presented and the performance of classification system is evaluated.

2- Experimental Setup

To simulate the gear wear condition monitoring system, a helicopter tail rotor gearbox consisted of a pair of spiral bevel gear was used. Figure 1 shows the schematic of the test stand. Wear fault was simulated on the input pinion gear in three stages; 20%, 40% and 60% fault. Vibration signals were collected by five triaxial accelerometers mounted on the gearbox. In each fault stage, signals were collected at maximum load and

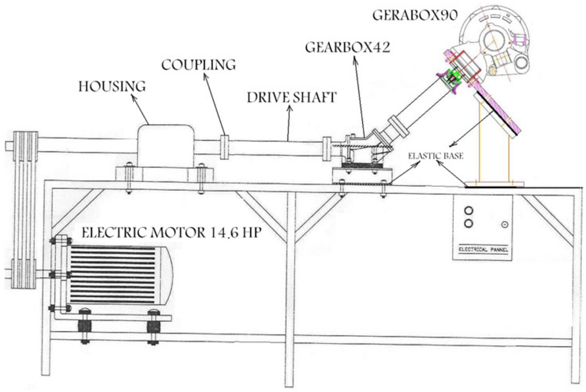

Figure 1. Schematic illustration of the experimental setup

minimum load condition as well as different input rotational speeds of 2250 and 4500 rpm. Therefore, overall 16 tests for data collection were implemented and with considering five triaxial accelerometers 240 signals were obtained.

3- Feature Extraction

In this study, 18 statistical parameters were extracted and applied for gear wear recognition. These parameters were composed of three categories: conventional time-domain parameters, special parameters developed for gear damage and time-frequency domain parameters.

Eight time-domain parameters were root mean square, mean, standard deviation, peak, dkewness, kurtosis, crest factor, and K factor. These parameters are defined in literature [4]. The second category consisted of six statistical parameters specially developed to present gear damage detection and proposed in NASA technical reports [5]. These parameters were FM4, MA6, NA4, N6A, ER and EOP. The third category were consisted of four statistical parameters obtained from

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wavelet coefficients of vibration signals. Applying discrete wavelet transform to a vibration signal decomposes signal to different frequency sub-bands. RSM, Kurtosis, Crest factor, and Energy for frequency bands including the 1st, 2nd and 3rd gear mesh frequency were computed. Since faults in their earlier stages influence the high harmonics of gear mesh frequency, the sub-bands including these frequencies could reveal the transient changes of signal caused by the fault.
All 18 statistical parameters of the measured signals can be used to identify gear faults; however, their regularity and sensitivity in pattern space are different and may vary considerably under different operating conditions. Principal Component Analysis (PCA) is a well-known method for feature extraction. By using PCA, the high-dimensional input vector was converted to two-dimensional vector whose components are uncorrelated.

4- Results and Discussion

After data reduction process and extracting two principal components, classifying was carried out based on the KNN model. The KNN method is a learning algorithm based on observations and samples. In other words, this method is an observation and learning algorithm via analyzing and controlling to classify an object or a new object. Boundaries between different classes, called decision boundaries, are determined based on training sample features.
In this study, from 240 measured signals, calculated parameters from 96 signals, which were gained from sensor #2 (mounted on input Pinion gear) and sensor #3 (mounted on output ball bearing shaft), were used as input of feature extraction process and fault classifier. These two sensors showed a higher sensitivity to the progression of fault. From those 96 signals, 72 signals were used for training and 24 signals were used for test purpose. Figure 2 shows boundaries of classification by KNN method for training stage.

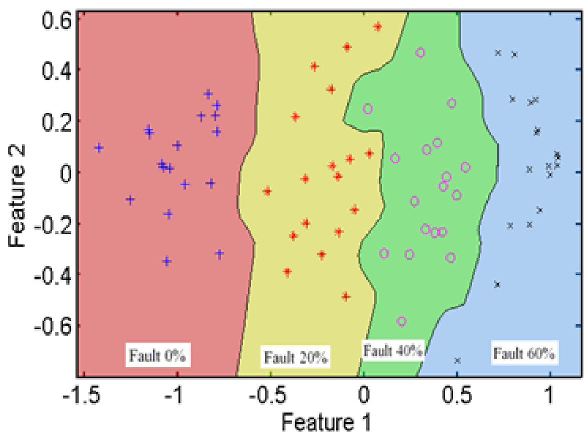

Figure 2. KNN Classification for training data

After classification and boundaries formation processes, 24 test signals were used for classifier. Samples for test stage were selected in a way that including various conditions of testing. Figure 3 shows the results of testing classifier for faulty gear wear.

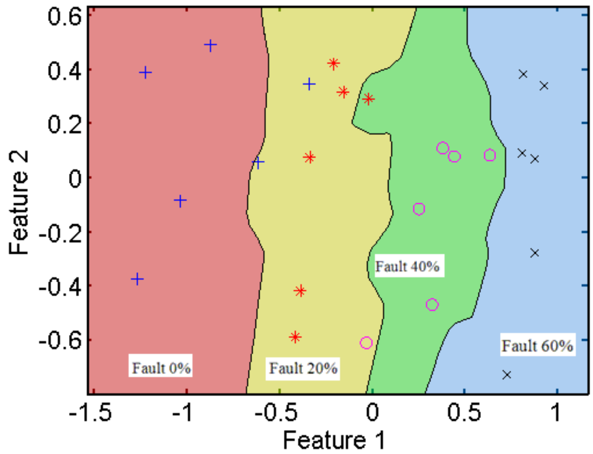

Figure 3. Classifier results for faulty gear wear

As shown in Figure 3, by taking 24 samples, most samples perched within classifier boundaries, 3 samples laid around borders and one sample related to healthy gears was classified out of its category. Consequently, approximate error of the system is 16%. With regard to test system complexity and its extreme similarity to helicopter real system, the proposed method provides promising results.

5- Conclusion

An intelligent method was presented for fault detection and diagnosis of gear wear. The proposed method was applied to diagnosis a tail gearbox of helicopter. Three main stages of this paper included of: signal processing, feature recognition and extraction, and decision-making. Commonly, first step is signal analysis, and then the information gathered in former step will be used for decision making. In this paper capability of KNN method for gear wear diagnosis in tail gearbox of helicopter was verified. Considering the intensive complexity of power transmission of helicopter tail gearbox and high noise percentage in collected signals, results of test are promising. The proposed method not only detects faulty gears but also characterizes fault rate in four categories.

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