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Vibration-based fault diagnosis of spur bevel gear box using fuzzy technique

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Abstract

To determine the condition of an inaccessible gear in an operating machine the vibration signal of the machine can be continuously monitored by placing a sensor close to the source of the vibrations. These signals can be further processed to extract the features and identify the status of the machine. The vibration signal acquired from the operating machine has been used to effectively diagnose the condition of inaccessible moving components inside the machine. Suitable sensors are kept at various locations to pick up the signals produced by machinery and these signals are very meaningful in condition diagnosis surveillance. To determine the important characteristics and to unravel the significance of these signals, further analysis or processing is required.

This paper presents the use of decision tree for selecting best statistical features that will discriminate the fault conditions of the gear box from the signals extracted. These features are extracted from vibration signals. A rule set is formed from the extracted features and fed to a fuzzy classifier. The rule set necessary for building the fuzzy classifier is obtained largely by intuition and domain knowledge. This paper also presents the usage of decision tree to generate the rules automatically from the feature set. The vibration signal from a piezo-electric transducer is captured for the following conditions – good bevel gear, bevel gear with tooth breakage (GTB), bevel gear with crack at root of the tooth (GTC), and bevel gear with face wear of the teeth (TFW) for various loading and lubrication conditions. The statistical features were extracted and good features that discriminate the different fault conditions of the gearbox were selected using decision tree. The rule set for fuzzy classifier is obtained by once using the decision tree again. A fuzzy classifier is built and tested with representative data. The results are found to be encouraging.

Keywords: Feature selection; Statistical features; Decision tree; Gear box; Fuzzy; Fault detection

1. Introduction

A faulty gear system could result in serious damage if defects occur to one of the gears during operation condition. Early detection of the defects, therefore, is crucial to prevent the system from malfunction that could cause damage or entire system halt. Diagnosing a gear system by examining the vibration signals is the most commonly used method for detecting gear failures. The conventional methods for processing measured data contain the frequency domain technique, time domain technique, and time–frequency domain technique. These methods have been widely employed to detect gear failures. The use of vibration analysis for gear fault diagnosis and monitoring has been widely investigated and its application in industry is well established (Cameron & Stuckey, 1994; Gadd & Mitchell, 1984; Leblanc, Dube, & Devereux, 1990). This is particularly reflected in the aviation industry where the helicopter engine, drive trains and rotor systems are fitted with vibration sensors for component health monitoring. The raw vibration signal in any mode from a single point on a machine is not a good indicator of the health or condition of a machine. Vibration is a vectorial parameter with three dimensions and requires to be measured at several carefully selected points.

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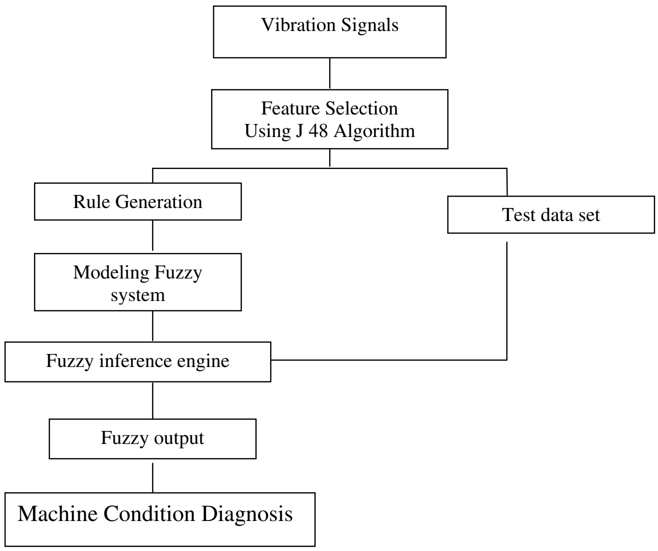

Fig. 1. Flowchart for bevel gear box health diagnosis.

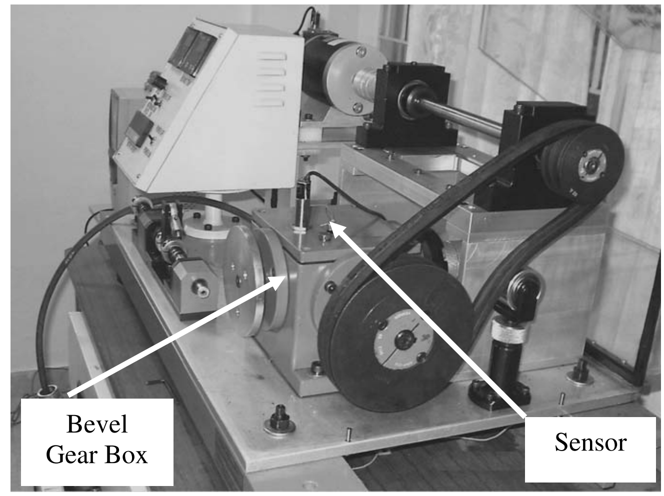

Fig. 2. Fault simulator setup.

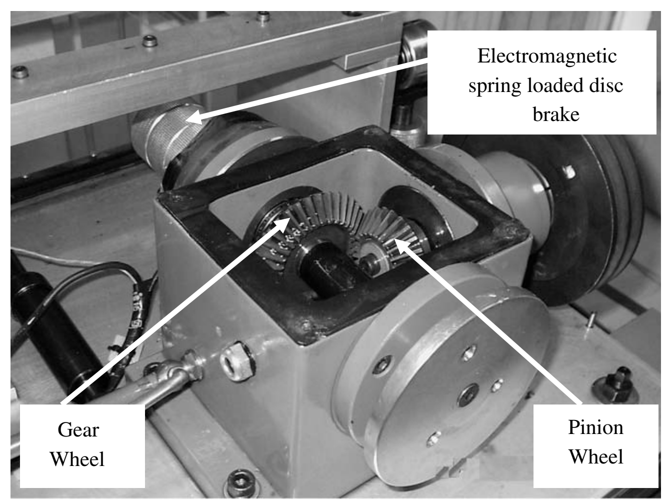

Fig. 3. Inner view of the bevel gear box.

Vibration analysis can be carried out using Fourier transform techniques like Fourier series expansion (FSE), Fourier integral transform (FIT) and discrete Fourier transform (DFT) (Collacott, xxxx). After the development of large-scale integration (LSI) and the associated micro-processor technology, fast Fourier transform (FFT) analyzers became cost effective for general applications. The raw signatures acquired through a vibration sensor needed further processing and classification of the data for any meaningful surveillance of the condition of the system being monitored.

Artificial neural network (ANN), support vector machine (SVM) and Fuzzy classifier are widely used as classification tool and reported in literature (Burgess, 1998; Jack & Nandi, 2000a; Nandi, 2000; Samanta & Al-Baulshi, 2003; Samanta, Al-Baulshi, & Al-Araimi, 2003; Shi et al., 1988). Among them, ANN has limitations on generalization of the results in models that can over fit the data (Samanta et al., 2003). SVM has high classification accuracy and good generalization capabilities for crisp data (Burgess, 1998; Jack & Nandi, 2000a; Shi et al., 1988). In the problem at hand, the nature of the fault itself is fuzzy in nature. Fuzzy classifier models the physical problem under study more closely. The flow chart of the fault diagnostic system is shown in Fig. 1.

1.1. *Different phases of present work*

The signals obtained are processed further for machine condition diagnosis as explained in the flow chart Fig. 1.

2. Experimental studies

The fault simulator with sensor is shown in Fig. 2 and the pinion and gear shown in Fig. 3. A variable speed DC motor (0.5 hp) with speed up to 3000 rpm is the basic drive. A short shaft of 30 mm diameter is attached to the shaft of the motor through a flexible coupling; this is to minimize effects of misalignment and transmission of vibration from the motor. The shaft is supported at its ends through two roller bearings. From this shaft the drive is transmitted to the bevel gear box by means of a belt drive. The gear box is of dimension 150 mm × 170 mm × 120 mm and the full lubrication level is 110 mm and half lubrication level is 60 mm.

SAE 40 oil was used as a lubricant. An electromagnetic spring-loaded disc brake was used to load the gear wheel. A torque level of 8 N-m was applied at the full-load condition. The various defects are created in the pinion wheels and the mating gear wheel is not disturbed. With the sensor mounted on top of the gear box vibrations signals are obtained for various conditions. The selected area on the top of the gearbox for mounting the sensor is made flat and smooth to ensure effective coupling between the sensor and the gearbox. The sensor used is a piezoelectric accelerometer (Dytran model) which is mounted on the flat