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Thermal analysis MLP neural network based fault diagnosis on worm gears

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ABSTRACT

The importance of fault diagnoses, in any kind of machinery, can't be over stated. Any undetected small fault in machinery will most probably rise with time and will cause machinery to shut down thus resulting in both mechanical and more importantly economical loss for the industry. In recent years, researches have been done for the faults diagnosis through the analysis of their vibration and sound signatures. The extraction of those characteristic signatures is a complicated process because complexities in modern day machineries can results in many vibration and sound generating sources. This paper presents a condition based fault diagnoses technique to detect the condition of gear. An experimental setup, consisting of a worm gear driven by an electric motor, was setup to conduct tests under different working conditions. The vibration and sound signature signals of worm gear were examined for normal and faulty conditions under different speeds and oil levels. The collected data was then used for feature extraction, by using Fast Fourier Transform to filter background noise signals and to collect only the signature of the gearbox vibration and sound signals. An MLP (Multilayer Perceptron) Artificial Neural Network Model has been developed to classify the signature signals. A thermal camera is also used to observe the heating patterns for all those working conditions. With the help of MLP Artificial Neural Network it is possible to predict the speed and oil level of the gearbox and hence a possible fault diagnoses is also feasible.

1. Introduction

Rotating machinery, is one of the most basic and important equipment, that plays a very important role in any kind of industry [1,2]. The majority of these machines are operated by means of gears, bearings and other parts, which can become faulty during their use and can affect the performance of the machine and can even result in the breakdown of the machine [3]. Machine downtimes results in loss of production, upon which the whole industry relies on.

In almost every kind of industry, there are, several machinery consisting of a most basic yet one of the most important rotating element, gear. Gearboxes are considered to be one of the earliest machine parts. It has been in use for thousands of years. It is a fundamental part on most types of machinery in order to change the shaft speed, the torque and the power. In current era, the existence of gearbox is believed to have control over the economics of the industries and in fact nations. As all the industry's economy is based on those important machineries, the role that those tiny little mechanical elements become extremely important as any kind of failure in them

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may lead to the machine failure affecting the production of the industry and hence the economy. Also, in some types of machinery as helicopter or aircraft, the role of gearbox is extremely important as its failure may lead to the loss of human life besides the loss of assets [4].

Nowadays, the modern rotating machinery is getting more complex which requires the system to operate in a much more reliable, safe, low cost production and maintenance [5], for which an accurate fault diagnosis of machine failure is a necessity. Therefore this topic of condition monitoring has attracted the attention of the researchers and many different techniques have been put forward to address such situation beforehand.

Several researches have been dealing with vibration [6,7] and sound [8] signatures of gears, and changes in their relative oil temperatures with time for diagnostics of different faults. But a few of those researches are focused on worm gears.

Vibration signals of a good and faulty helical gearbox component were examined by using naïve Bayes and Bayes net algorithms [9]. In another research [10], the most efficient oil to use in a worm gearbox was determined by means of the vibration signals and processed by an Artificial Neural Network for classification purposes. A predictive maintenance technique, combining both the oil analysis and the vibration analysis, was proposed for a worm gearbox [11].

The nonlinearity between a gear pair leading to a faulty condition, has been studied [12]. Their findings show that an increase in fault factor will generate more clear sidebands on the meshing frequency levels. They also claim that sub-harmonics from the vibration of gearbox aren't solely related to the fault only.

A combination of Hilbert and wavelet packet transforms based model for the gearbox fault detection has been proposed for effective detection of different levels of fault in a gearbox [13]. For worm gear acoustic emission [14], vibration based signal processing techniques [15], oil analysis [16] were researched. In this studies, neural networks were not used to make decisions. For this systems, educated persons are needed for interpreting the signal processing results. Neural networks made work automatic.

Yesilyurt presented the applications of four time-dependent parameters (e.g. the instantaneous energy, mean and median frequencies, and bandwidth) based upon the use of spectrogram and scalogram, and compared their abilities in detection and diagnosis of localized wear related gear failures [17].

In wind power industry, vibration monitoring is used routinely to detect faults in bearings and gears. Sensors are mounted on the bearing housing to detect the unique characteristic of vibration signatures for each gear mesh or bearing, which depends on the geometry, load, and speed of the components [18].

A fault can be recognized by the vibration signal obtained from a gearbox [19] and later analysis with different signal processing techniques [20].

An approach combining both the vibration and wear debris analysis was proposed for condition monitoring [20]. Polyshchuk et al. presented a novel approach for detection of gear damage based on time–frequency analysis and the energy change of the vibration signal [21]. The use of vibration analysis for the condition monitoring of a gearbox was shown in a study conducted by Choy et al. [22].

A research based on the thermal analysis of contact properties of cylindrical gears has concluded that the high speed and heavy loading on the gear teeth results in a rise in temperature gradient [23].

A novel approach for gear and bearing fault diagnosis by means of wavelet signal processing, using vibration signals, was presented [24]. A vibration analysis system (VES) for fault diagnosis, has been developed to analyze oil, debris and vibration for the condition monitoring of fixed plant [25]. Adaptive neuro-fuzzy inference system (ANFIS), applied to the information extracted from the vibration signals to diagnose abnormalities in bearings has been developed [26]. Continuous wavelet transform was used for fault diagnoses of a gear-set by acquiring both vibration and sound signals and Artificial Neural Networks based classification algorithm was developed yielding 98% accuracy [27].

The aim of this paper is to introduce a technique to be used for accurate and effective identification of working condition of a worm gear using its vibration and sound signals and thermal patterns. Sound signals, vibration signals and also infrared thermography are used to increase the reliability of this research, which has been done in early studies. Overall there is very little research available for worm gears making this research unique. A Data Acquisition Module was used to collect raw vibration and sound signals. This data was then pre-processed for signal processing, by taking the mean of the raw data and then subtracting it from the original raw signal, resulting in a much more refined signal. After conversion to frequency domain using Fast Fourier Transform, the data was used for feature extraction. Artificial Neural Networks (ANN) have been chosen as a candidate MLP technique because of their generality and ability to learn complex relations. Furthermore, this algorithm is fast and simple structure. In order to classify the faults, a back propagation MLP Artificial Neural Network, was designed after choosing the optimal parameters. A total of 16 different oil levels and rpm related conditions were observed for worm gear in normal and faulty conditions. Each experiment was repeated 10 times, resulting in a total of 160 experiments, to assess the performance of the developed system.

2. Theoretical background

2.1. Gears

Gears permit the transfer of energy between two shafts. The process is important in that components of a system can be designed for maximum efficiency, with the gears acting as the interface between the components. Specific uses for gears are to change speeds, change direction of rotation, and transmission of power [17] in a system.

Worm gears can be used to drive spur or helical gears and allow two nonintersecting and perpendicular shafts to mesh. An important aspect of worm gear meshes is their