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Case History

Automated diagnosis of rolling bearings using MRA and neural networks

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ABSTRACT

Any industry needs an efficient predictive plan in order to optimize the management of resources and improve the economy of the plant by reducing unnecessary costs and increasing the level of safety. A great percentage of breakdowns in productive processes are caused by bearings. They begin to deteriorate from early stages of their functional life, also called the incipient level. This manuscript develops an automated diagnosis of rolling bearings based on the analysis and classification of signature vibrations. The novelty of this work is the application of the methodology proposed for data collected from a quasi-real industrial machine, where rolling bearings support the radial and axial loads the bearings are designed for. Multiresolution analysis (MRA) is used in a first stage in order to extract the most interesting features from signals. Features will be used in a second stage as inputs of a supervised neural network (NN) for classification purposes. Experimental results carried out in a real system show the soundness of the method which detects four bearing conditions (normal, inner race fault, outer race fault and ball fault) in a very incipient stage.

1. Introduction

All rotating machinery used in the modern world can develop faults. Maintenance plans include analyzing the relevant external information of critical components in order to evaluate their internal state. Therefore, bearing failures are the common cause of rotating machinery breakdown. Realtime on-line monitoring can increase early detection and fault diagnosis automation, but a more reliable and faster mathematical method is required.

Classification of incipient faults in rolling bearings is an open line of research. There is not much work related to this issue. In the two last years, prestigious journals have published only four or five papers related to incipient bearing fault diagnosis [1,2,7]. In these papers, data collected from an experimental lab bench do not include radial load, which is the most important force the rolling bearings are designed for. Probably one of the most important elements in industrial machines are shafts, which transmit energy. Radial rolling bearings are designed to support the loads that the shafts transmit: basically, the radial load provided by the masses of different elements connected to the shaft (gears, cranks, etc.) and their own mass, which in industrial machines is not negligible, and a certain degree of axial loads due to misalignments. In this paper, this consideration of loads applied to the rolling bearing has been included in the experimental setup. This difference from other authors makes the defect classification more difficult due to the increment of the contact ellipse between the ball and the race. As can be seen in the developments carried out by Harris [3], the width

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of the contact surface is directly proportional to the square root of the radial load. That is, the higher radial load that the bearing supports, the more ellipse surface contact exists. In these cases, contact between the ball and the race cannot be considered a point, so incipient faults can go in the contact surface, making it difficult to detect them.

There are two important stages to implement in the fault diagnosis process: the first is signal processing, for feature extraction and noise diminishing, and the second one consists of signal classification, based on the characteristics obtained in the previous stage. Most of the research related to bearing fault diagnosis agrees with the use of vibration signature for this purpose, due to the non-stationary characteristics the signals present when a fault occurs in the rolling element bearing operation [1,4–7].

In recent years, different technologies have been used in order to process signals provided from dynamical systems. Most of the authors classify the analysis of vibration signature in three approaches [5,6]: time domain based on statistical parameters such as mean, root mean-square, variance, kurtosis, etc. [8], frequency domain, where the Fourier transform (FT) [2] and its variations [9] were the most commonly used in the past; and time-frequency analysis such as the wavelet transform (WT) [10]. This last approach is the most commonly used in signatures with non-stationary characteristics.

The most classical approaches are the power spectra density (PSD) and demodulation analysis (based on frequency domain). The first approach gives us an idea of the energy of each frequency peak obtained from fast Fourier transform (FFT). The demodulation approach or envelope analysis consists of obtaining the spectra from the temporal signal envelope (based on the Hilbert Transform). These approaches have been demonstrated to be useful in detecting bearing faults (not in an incipient stage) under laboratory conditions, where all the other sources of faults are reduced or removed. In the case of incipient faults, the amplitude of the spectra is very low and other techniques are needed.

The WT has been successfully applied as a fault feature extractor due to the good energy concentration properties. Peng et al. in [11] carried out a bibliographical review of the WT application in the monitoring and fault diagnosis in machines. The main drawback of WT, apart from the selection of the suitable basis function for performing the transformation, is that it is not able to separate the high frequency bands where the information of the machine operating with failure is presented. This problem is solved by using the wavelet packet transform (WPT) proposed by Liu et al. in 1997 [12]. The WPT is a multiresolution analysis (MRA) technique [9] which gives a suitable frequency-band partition. Whereas most of the authors that use WT in failure diagnosis develop a method to discard the less representative coefficients obtained (for example, with the threshold method as Chen et al. develop in [13]) for the next classification step, the wavelet packet coefficients can be directly used as features, and they possess a high sensibility to failures [1]. In summary, many kinds of fault features can be obtained, principally with wavelet coefficients or wavelet energy. Since wavelet coefficients will highlight the changes in signals which often predict the occurrence of the fault, the Wavelet coefficients-based features are suitable for fault detection. However, because slight changes in signals often have little energy, these changes will be easily masked in the wavelet energy-based features. Therefore, the wavelet energy-based features are often not able to detect early faults.

Signal processing is a relevant item in a bearing fault diagnosis system. Nevertheless, in order to obtain a monitoring system which concludes the real condition of the rotatory element, a classification system is needed. New trends in fault diagnosis try to develop intelligent classification systems. Preliminary research can be found in [14,15]. Lou et al. in [2] used a fuzzy classifier to diagnose faults in bearings, based on the use of the discrete wavelet transform (DWT) as a feature vectors generator. Hu et al. uses an support vector machine (SVMs) ensemble in [1], and the rest of the researchers in the field use genetic algorithms [16] or neural networks [17,18] as a classification kernel.

In the present work, vibration signature from rolling element bearings is processed by means of the WPT and a neural classifier in order to detect four bearing conditions. The flow chart of the monitoring procedure proposed in this manuscript is shown in Fig. 1.

The methodology proposed performs the diagnosis procedure in a direct way, without developing the detection and identification task developed by other authors [2,1]. In this sense, vibratory signals represent the input to the monitoring system, which are going to be processed at once, in order to obtain relevant information about the component condition or state. Subsequently, a previously trained classifier system will provide the diagnosis of the system condition. This methodology reduces the effect of the human factor during the diagnosis process.

2. Experimental setup

Vibratory signals have been obtained thanks to the test lab bench presented in Fig. 2. In this bench, developed by the UNED mechanical department, FAG 7206 B single ball bearings were tested. In the figure, starting on the right hand-side, the following elements are visible: axial and radial pneumatic cylinders, the bearing assembly, a B&K 4383 accelerometer with an 8.5 kHz bandwidth, a phototachometer device for RPM measurement, and a transmission pulley directly connected

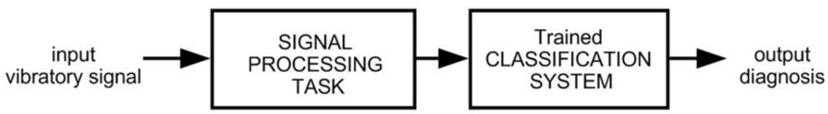

Fig. 1. Diagnosis procedure flow chart.