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Vibration monitoring for defect diagnosis of rolling element bearings as a predictive maintenance tool: Comprehensive case studies

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Abstract

Vibration monitoring and analysis in rotating machineries offer very important information about anamolies formed internal structure of the machinery. The information gained by vibration analysis enable to plan a maintenance action. In this study, the vibration monitoring and analysis case studies were presented and examined in machineries that were running in real operating conditions. Failures formed on the machineries in the course of time were determined in its early stage by the spectral analysis. It was shown that the vibration analysis gets much advantage in factories as a predictive maintenance technique.
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1. Introduction

The failures of rotating machineries can be very critical because these lead to machinery damage, production losses and personnel injury. So, a very important duty of the maintenance department is to prevent these failures when they are in its initial stage. The predictive maintenance by vibration analysis is the best tool for this purpose. The vibration analysis is a technique, which is being used to track machine operating conditions and trend deteriorations in order to reduce maintenance costs and downtime simultaneously [1]. The vibration analysis technique consists of vibration measurement and its interpretation. Firstly, vibration signals are collected by means of the vibration analyzer equipped with a sensor in the time domain then, these signals are converted into frequency domain by processing FFT, and the information gained from the vibration signals can be used to predict catastrophic failures, to reduce forced outages, to maximize utilization of available assets, to increase the life of machinery, and to reduce maintenance costs related to health of machinery [2]. The vibration measurements are taken periodically, one time per month in general and vibration is monitored by comparing previous measurements to new ones. The vibration monitoring is based on the principle that all systems produce vibration. When a machine is operating properly, vibration is small and constant; however, when faults develop and some of the dynamic processes in the machine change, the vibration spectrum also changes [2]. There are many studies on the vibration monitoring of the rotating machinery. Great amount of them concentrate on ball or cylindrical element bearing vibration monitoring [3–6]. In these studies a test rig, includes ball or cylindrical roller bearing, is used and either an artificial defect is formed on bearing parts or the test rig is running until a desired defect arise on the bearing in laboratory conditions. These studies were partly realized by ideal condition assumption. However, under conditions of real environment there are many factors that affect the actual running state of the machinery. Thus, these factors must be taken into consideration. Studies related to real operating conditions of machineries were quite few. Gluzman [7] monitored vibration of motor-generator system supported by ball and cylindrical roller bearings to predict impending bearing failures. He successfully identified impending failures of the bearing outer and inner races. Al-Najjar [8] observed many bearing vibrations in paper mills for many years to predict remaining bearing life accurately. He also investigated effectiveness of vibration-based maintenance and proposed some findings.

In this study, the application of vibration monitoring and analysis was carried out on the machineries in a petroleum

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refinery. The vibrations of the machineries were monitored for a certain period and diagnosing of defects arised on the bearings of the machineries during this period was aimed. The study includes three different case studies that were obtained from the machineries, which run under real operating conditions.

2. Vibration measurement

Vibration data were gathered and processed using CSI 2110 [9] machinery analyzer. It is well known that a machinery analyzer generally consists of a sensor, a memory in which the signals are stored, electrical circuits that convert time domain signals to frequency domain signals (FFT process) and a port by which vibration signals were transfered into a computer. The sensor used was an accelerometer (CSI 350) with a sensitivity of 0.1 V/EU. Parameters for collecting of vibration signals were given in Table 1. Vibration was measured in axial, horizontal and vertical directions. Obtained data from the vertical direction was dominant compared with the other two directions so the vibration data measured in the vertical direction was used to characterize the health of the machinery.

3. Defect frequencies of rolling element bearings

The rolling element bearing defect produces certain frequencies that depend on rolling element bearing geometry, which is shown in (Fig. 1), number of rolling element, and shaft speed. These frequencies are expressed in Eqs. (1)–(4).

$$w_c = \frac{n}{2}\left[1 - \frac{d}{D}\cos(\alpha)\right] \quad (1)$$

$$w_b = \frac{n}{2}\left(\frac{d}{D}\right)\left[1 - \left(\frac{d}{D}\right)^2 \cos^2(\alpha)\right] \quad (2)$$

$$w_{bp} = \frac{n}{2}N_b\left[1 - \frac{d}{D}\cos(\alpha)\right] \quad (3)$$

$$w_{bpi} = \frac{n}{2}N_b\left[1 + \frac{d}{D}\cos(\alpha)\right] \quad (4)$$

where n, N_b, w_c, w_b, w_{bp}, w_{bpi} represent shaft speed, number of rolling elements, cage frequency, rolling element spin frequency, rolling element pass frequency outer race, rolling element pass frequency inner race, respectively. Sometimes the defect frequencies computed by above equations deviate to some amount from obtained-ones by measurement. This is because equations use shaft speed by declared manufacturer but real speed of the shaft may be different from this speed in the moment of vibration measurement.

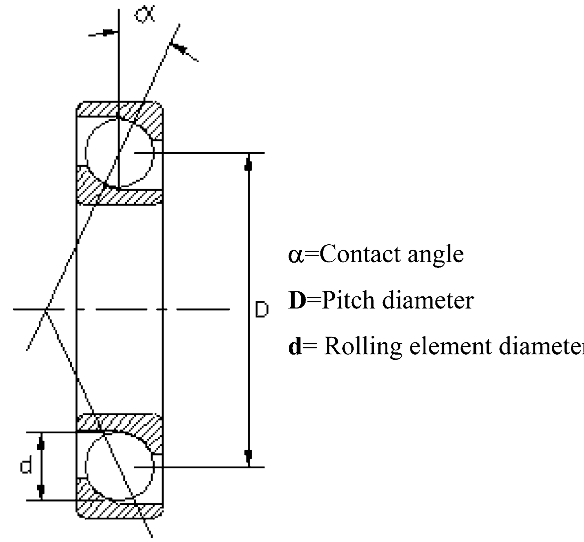

Fig. 1. Rolling element bearing geometry.

When a defect is formed on one of these parts of the bearing, related frequency, its orders, its sidebands, etc. may arise in a spectrum graph. Sometimes these frequencies may exist for healthy rolling element bearing due to some manufacturing errors. The defect frequencies of rolling element bearings used in this study were given in Table 2.

Table 1
Parameters for vibration measurement

Number of spectral lines	400
Number of average	6
Number of gathered data	1024
Window type	Hanning
Spectral average mode	Normal
Frequency range	60–3000 Hz

4. Case study I

The vibration of a huge centrifugal pump with nine vaned was monitored. The power and revolution of the pump motor are 160 kW, 2975 rpm, respectively. The reference measurement was taken on 17 October 2001 (Figs. 2 and 3). As shown from reference measurement, vibration behaviour of the pump inner bearing composes of multipliers of the shaft rotation in the spectrum graph and irregular impact signals in the time domain waveform graph.

This situation indicates that rotating equipment, namely ball bearing, is looseness on the housing [10,11]. The vibration amplitudes are in low level. For this reason, maintenance of the pump is not required in this stage. The vibration monitoring was continued and after three weeks, vibration amplitude increased suddenly (Figs. 4 and 5). This situation shows that ball bearing looseness developed. The maintenance was planned and then ball bearing was pulled out on 13 February 2002, finally it was shown that the housing was worn out and the outer race of ball bearing was corroded (Fig. 6). After

Table 2
Defect frequencies of rolling element bearings

Bearing type	Shaft speed (Hz)	N_b	w_c (Hz)	w_b (Hz)	w_{bp} (Hz)	w_{bpi} (Hz)
SKF NU 224	12.35	17	5.385	43	91.55	122.14
SKF 6222	16.41	10	6.78	43.56	67.82	98.48

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