A tribological study in the perspective of vibro-electric analysis

S.S. Erol [a], C. Meran [b],*

[a] Mechanical Engineering Departement, Kilis 7 Aralik University, 79000, Kilis, Turkey

[b] Mechanical Engineering Departement, Pamukkale University, 20160, Denizli, Turkey

* Corresponding e-mail address: cmeran@pau.edu.tr

ABSTRACT

Purpose: In this case study, oil starvation failure that is a common problem for mechanical constructions has been studied within perspective of vibro-electric analysis. The purpose of this research is testing material properties of a ball bearing under the oil starving failure and condition of resonance for inspecting predictive maintenance approaches.

Design/methodology/approach: A test setup construction designed, built and placed in a laboratory location. An electrical motor has been selected for collecting electrical and vibrational data over a bearing by making tests. Test has been implemented under the electricity frequency of 63.8 Hz that was induced the rotation of electrical motor in order to set rotational speed.

Findings: Respect to results of the analysis, inspecting of oil starving failure and resonance problem has been detected more clearly and informative by vibration analysis.

Research limitations/implications: This research study is limited with some experience and data from case companies, data from relevant scientific literature and theories through scientific databases.

Practical implications: Implementation of condition monitoring technologies on mechanical systems brings similarities with the health systems of the human beings. Such as developments in technologies of human health management, consultation of the mechanical systems should be practised in order to prevent breakdowns which cause unplanned stoppages. Vibrational and electrical monitoring techniques can be applied at enterprises in order to ease and reach higher accuracy for detection of symptoms cause from mechanical fault initiations.

Originality/value: The originality of this research receive resources from comparison of traditional condition monitoring tool vibration analysis and more recently developed electrical consumption analysis used for predictive maintenance.

Keywords: Electrical consumption; Vibration; Resonance; Tribology

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PROPERTIES

1. Introduction

Engineering materials are widely used in construction of machines and mechanical systems. Some failures such as mechanical looseness, misalignment, unbalance, oil starvation are the root causes of high magnitude vibrations through different frequencies. Resonance is one of the reasons responsible for deterioration in engineering materials and caused from natural frequencies excited by vibrational forces through rotation of shaft, rotation of bearing elements and mechanical failures. In the condition of oil starvation through ball bearing, it is expected frictional surfaces get increase and consequently failure frequencies of the bearing element may appear more eminently. Respect to the increasing frictional forces, speed of wear or corrosion features may gain acceleration. Electrical consumption and vibration analysis are some of the methods in predictive maintenance in order to detect deterioration levels caused by root factors of mechanical failures.

Mechanical faults of the bearing elements mainly occur randomly during the usage. According to the researches, %43 of these faults of the bearing is related with the lubrication issue [1]. The techniques of vibration analysis is used commonly for inspection of bearing failures [2]. Vibration monitoring is commonly accepted by the maintenance authorities and related with characteristic vibration features that rolling bearings face with rolling surfaces degrade [3]. Many researchers used motor current signal analysis in order to detect anomalies on bearings of electrical motors [4]. At the initiation level, damaged rotor bars, slightly damaged bearing elements and possible misalignments may consequence in induce of the electrical consumption [5]. Electrical Signature Analysis (ESA) is the main word in order to monitor electrical machine condition among the inspection of electrical signals for instance current and voltage. These methods are: Voltage Signature Analysis (VSA), Current Signature Analysis (CSA), Instantaneous Power Signature, Extended Park's Vector Approach (EPVA) [6]. Mechanical problems of the mechanical systems that have rotational elements generally causes reflect vibrational symptoms. These kind of mechanical problems are inspected mainly by vibration analysis [7].

2. Materials and method

The test setup built as consists of double inlet fan, AC induction motor, five feet of flexible coupling and frequency inverter. The test setup construction is built on a steel plate and a steel tripod. The test setup is placed on a double-decker rubber sheet that was located between the test setup and the tripod; also, a vacuum rubber below feet of the tripod has been placed on the floor. This structure with a data acquisition card and an electrical motor is associated to monitoring system with a computer. Testing structure in Figure 1 presents an real view.
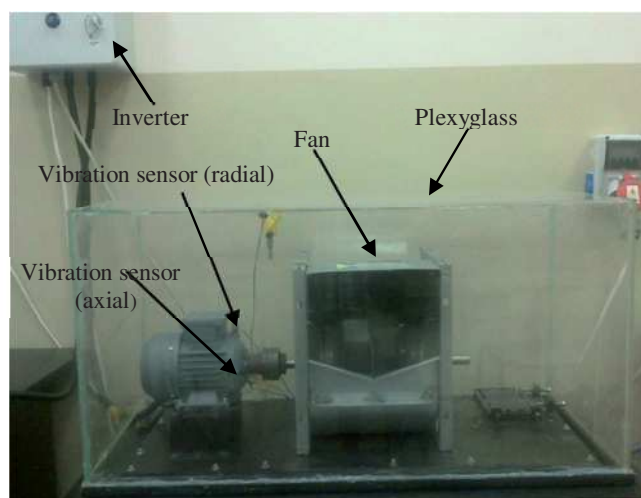

Fig. 1. A view from the test setup

Frequencies determined in the test theoretical (T) and measured (M) are shown in Table 1. Theoretical frequencies are the values determined on the digital frequency converter; according to evaluation of data collected during the tests, real frequency value had some losses. 1x is known as a frequency that is determined as fundamental frequency; 2x, 3x,…. are upper harmonics of fundamental frequency. In Table 1, frequencies is shown with the mark of f for frequency converter and harmonics presented with mark of h.

Measurements were made during the tests at electrical frequency 63.8 Hz and rotational period was detected as 3510 min^{-1}. Frequencies of failures and harmonics are used for calculation of the bearing and fan caused vibrations of the test structure.

Equations of bearing elements with basic failure frequency calculations and respect to insspections are given in Table 2.

In order to create condition of oil starving failure, oil is fully cleaned from the tested bearing; unsufficient quantity of 0.55 g oil was used for bearing in order to supply speedy deterioration. Tested bearing is represented in Figure 2.

Table 1.
Harmonics

(h)	1x		2x		3x		4x		5x	
(f)	T	M	T	M	T	M	T	M	T	M
63.8	63.8	58.59	127.6	117.18	191.4	175.77	255.2	234.36	319	292.95

Table 2.
Fault frequencies

f, Hz	ω_s, Hz	ω_{bpf}, Hz	ω_c, Hz	ω_{bpfo}, Hz	ω_{bpfi}, Hz	ω_{bsf}, Hz
63.8	58.59	585.9	24.24	193.95	316.45	125.26

ω_{bpfo}: Outer ring passing frequency (Hz), ω_{bpfi}: Inner ring passing frequency (Hz), ω_{bsf}: Ball spin frequency (Hz), ω_c: Cage frequency (Hz), ω_s: Shaft frequency (Hz), ω_{bpf}: Fan blade passing frequency (Hz).
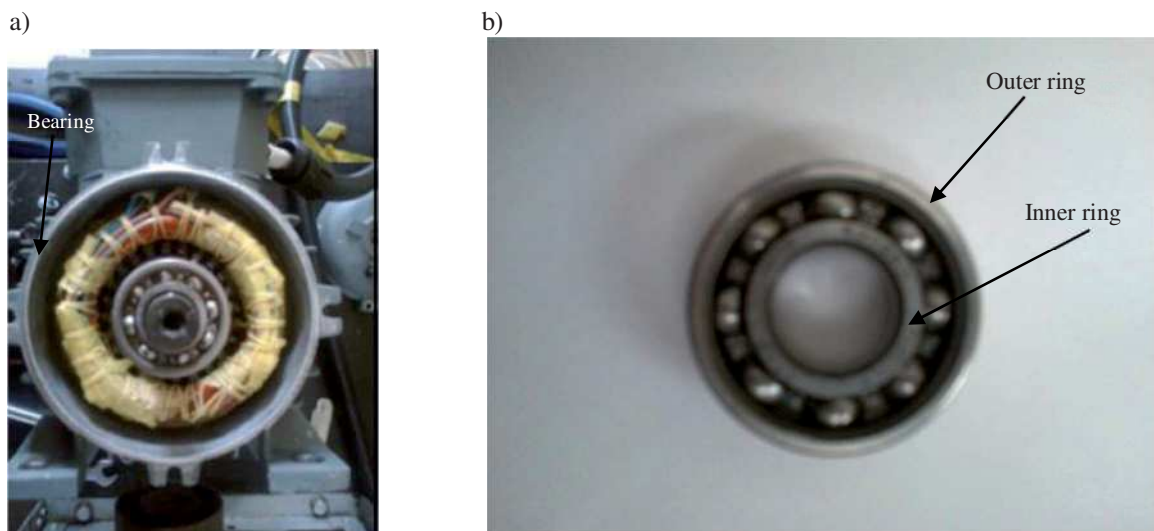
a)

b)

Fig. 2. a) Tested bearing, b) non-lubricated bearing

In order to evaluate the data gathered, the raw data through vibrational techniques has been studied with FFT (Fast Fourier Transform) method and data has been processed for making analysis. Electrical consumption data is collected with a monitoring device and processed with its software on computer as given in trend and power spectrum density (psd) analysis in order to evaluate the data gathered.

3. Experimental

Measurements of vibration are taken in radial (vertical) and axial direction through the tests. Measurements of

electrical data are realized throught electrical motor as associated with the electrical circuits. Vibrational data are received with sensors connected to a DAQ (Data Acquisition Card) and studied with its software. In order to determine natural frequencies for comparison, damping tests are done on test setup when the system is not dynamic.

3.1. Electrical analysis

Respect to the electrical consumption analysis, data interpretation is based on trend values in Figure 3 and power spectrum density values in Figure 4.
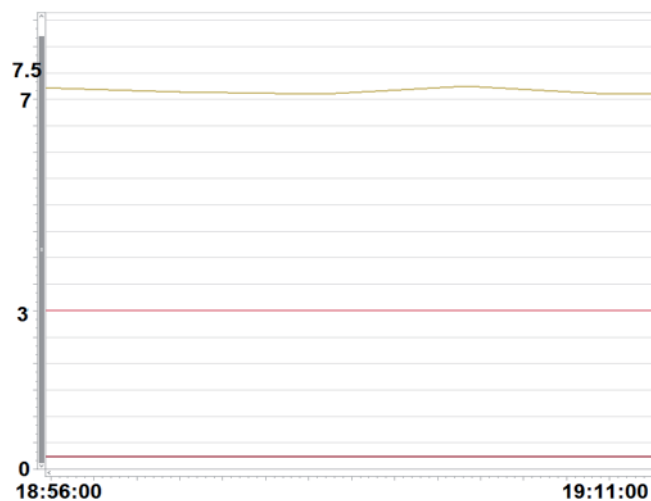
Fig. 3. Electrical consumption trend analysis (std. deviation – time)

Trend values are given through three different parameters as bearing parameter, mechanical looseness and unbalance. In both parameters of bearing (standart deviation: 3) and unbalance (0.2), no change is detected under the condition of oil starvation. Trend values of mechanical looseness condition had change even slightly between standart deviation of 7.3 and 7.5 almost in the middle of the test time.
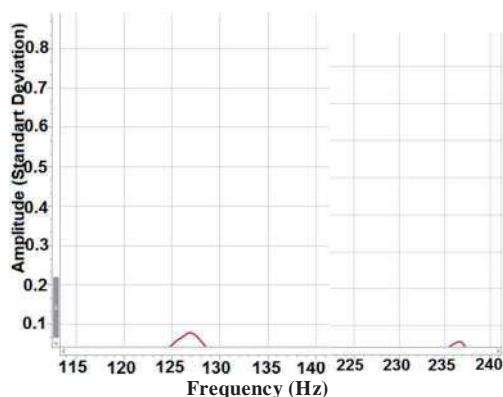

Fig. 4. Electrical consumption psd analysis (std. deviation – frequency)

As trend values are not sufficient enough informative about the condition of oil starvation, examination of PSD values is studied. According to algorithm of the electrical consumption analysis device, some specific failures are categorized on frequency intervals which are called bands. Respect to bands, PSD signal around 127 Hz is categorized

in band of bearing factor 2 and signal around 237 Hz is categorized in band of bearing factor 4. As the bearing is healthy and does not have any damage on its elements, these signals at 127 Hz and 237 Hz signs the effect of oil starving condition. Furthermore, increase of rotor indicator in trend analysis and increase of the psd signal about 63.8 Hz is detected which may lead to symptom of resonance condition.

3.2. Vibration analysis

Harmonic of 2x has been detected as the first dominant signal in radial direction with amplitude of 2.05 m/s^2. Second dominant vibration signal is detected at harmonic of 1x on 58.59 Hz. In radial direction, signal at 175.77 Hz that is the upper harmonic of fundamental frequency (3x) excited a signal at the frequency 179.4 Hz which is a natural frequency and consequently superharmonic resonance has been observed with the signal amplitude as 0.332 m/s^2. Resonance effects has been detected at fourth and fifth dominant signals as well. Fourth signal at 921.06 Hz has been excited by 921.12 Hz ($38x\omega_c$) and fifth signal at 128.2 Hz has been excited by 125.26 Hz ($1x\omega_{bsf}$) in the frequency-domain.

Respect to the Figure 5 and Table 3, oil starvation increased the vibration magnitude of signals at the element passing zone. Respect to the findings, 38th order of cage frequency and 1st order of the ball spinning frequency appeared eminently among five dominant signals. The effect of oil starvation on frictional forces through steel material of the bearing has brought out these signals and excited natural frequencies.
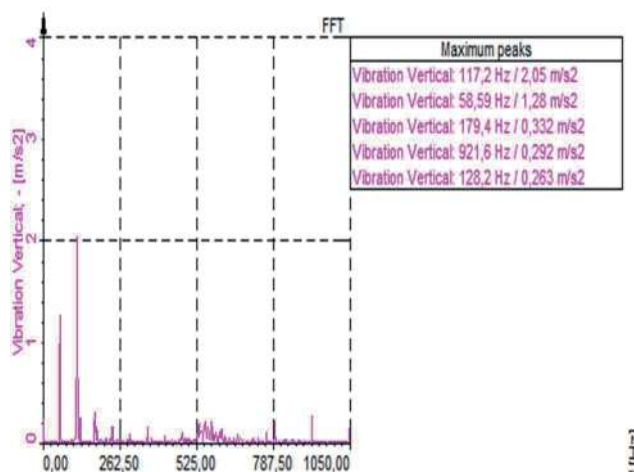

Fig. 5. Spectrum in vibration data of radial direction

Table 3.
Harmonics respect to dominant vibration signals of radial direction (S:Signal)

Vibration measurement (Radial)	1.S	2.S	3.S	4.S	5.S
Oil starvation	2x	1x	f_n (3x)	f_n ($38x\omega_c$)	f_n ($1x\omega_{bsf}$)

In axial direction, signals at harmonic of 2x is detected as the first dominant and 1x is detected as the second dominant harmonic same as in the radial direction frequency spectrum. First dominant signal's value as 2.96 m/s^2 in axial direction is higher than the first dominant signal's value as 2.05 m/s^2 in radial direction. Third dominant signal at frequency of 127 Hz has been excited by the $1x\omega_{bsf}$ and subharmonic resonance occurred. Fourth dominant signal is similarly as radial direction excited by the signal at $38x\omega_c$ and subharmonic resonance occurred. Fifth dominant signal is excited by the signal at 3x and subharmonic resonance occurred as well.

Respect to the Figure 6 and Table 4; first two dominant signals are same in the axial and radial direction and other three dominant signals are the natural frequencies which are excited by the same frequencies.
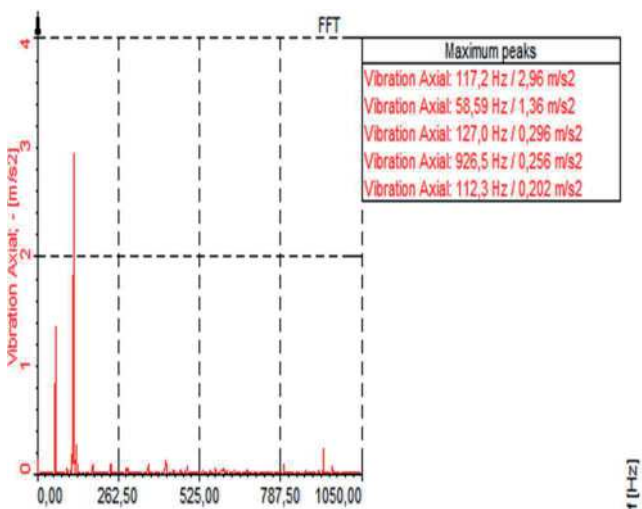

Figure 6. Spectrum in vibration data of axial direction

Table 4.
Harmonics respect to dominant vibration signals of axial direction (S:Signal)

Vibration measurement (Axial)	1.S	2.S	3.S	4.S	5.S
Oil starvation	2x	1x	f_n ($1x\omega_{bsf}$)	f_n ($38x\omega_c$)	f_n (3x)

According to the findings in Table 4; signal at harmonic 2x has been detected with the highest amplitude and 1x has been detected as the second dominant signal which is a characteristic feature of unbalance effect. Bearing frequencies as ball spinning frequency and cage frequency are appeared on the third and fourth dominant signal that is an indicator of oil starvation and they stimulated natural frequencies. Bearing frequencies are eminently detected in axial measurement as well. Fifth dominant signal appeared on a natural frequency stimulated by harmonic 3x.

4. Results and discussion

In this experimental research, tribological and resonance features of a test setup have been studied under the oil starving conditions of a bearing. Approaching with predictive maintenance perspective; techniques of electrical consumption and vibration analysis are studied in order to identify the condition of a tested bearing.

According to analysis results of electrical consumption measurement on effect of oil starving failure; bearing signals and resonance signals are found in the psd data.

Respect to vibration analysis, bearing failure frequencies and resonance frequencies are captured and identified in spectrum data under the condition of oil starvation failure. As the tested failure was oil starvation, detection of this failure succeeded similarly in the radial and axial direction.

In comparison of electrical consumption and vibration analysis results; vibration analysis has been detected as more informative and accurate tool for evaluating resonance features of the inspected system under the condition of oil starvation.

Respect to the increase in quantity of resonance frequencies and magnitude of the deterioration; it may reach to catastrophic failures under the condition of oil starvation. Oil requirement of the bearings may change according to external and internal features; consequently, oil requirement of the bearings should be inspected periodically or predictively and nominal lubrication should be sustained permanently.

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