A Research Study on Vibrating Elements and Consuming Electricity in Predictive Maintenance

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Abstract

Mechanical looseness is one of the common failures detected on machines and mechanical systems. In this research, resonance effect that is a problem for mechanical systems has been studied within perspective of mechanical looseness failure through a bearing. A test setup has been designed, built and located in laboratory environment. A bearing in the electrical motor, that is one of the elements in the test setup construction, has been chosen for acquiring data throught acoustic, vibration and electrical consumption during the test. The purpose of this research is testing condition monitoring of mechanical looseness failure and resonance for studying comparison of different predictive maintenance perspectives. The test was implemented at the electricity frequency of 40.5 Hz that forced the electrical motor through identified rotation speed. According to the analysis results, inspecting of mechanical looseness failure and resonance problem has been detected as the most effectively by vibration analysis.

Keywords: acoustic, electrical consumption, mechanical looseness, resonance, vibration

Introduction

Mechanical failures mainly face with common problems such unbalance, misalignment, mechanical looseness and so on. These failures consequence changes in vibration and electrical consumption behaviour. Common maintenance techniques applied in production industries are breakdown maintenance, periodic maintenance and predictive maintenance. Predictive approach is the maintenance method which is performed on acquiring data about condition of the machine. Predictive technique is based on analysing symptoms of parameters such as acoustics, electrical consumption, vibration, heat, lubrication and etc. Resonance is one of the important problems for mechanical systems and mechanical looseness is an important failure for cause of the resonance problem. In this research, effect of mechanical looseness on resonance problem has been studied in the perspective of acoustics analysis, vibration analysis, electrical consumption analysis and results are given.

If predictive maintenance used with proper techniques, it has limitless benefits for production industries [1]. As using an well designed test setup, precious data can be obtained and as transforming the data from time-domain to frequency-domain by Fast Fourier Transform (FFT) method, it assists for finding root causes in the perspective of prognostics [2]. Some techniques are developed in maintenance diagnosis for linear systems which can be transferred to non-linear systems as well [3]. As compared with an traditional maintenance implementation, 30% cost saving can be gained by vibration based maintenance [4]. It is suggested to make some artificial failure tests on systems before the installation in order to have idea about the sensitivity of the signals [5]. Manufacturing industries goes into more productive maintenance techniques respect to the competitiveness and deacreasing market place. So that, more efficient maintenance techniques get more importance to decrease the unit cost [6].

Materials and Methods

Test setup construction has elements as a double inlet fan, AC induction motor, five feet of flexible coupling and frequency inverter. The test apparatus is located on a steel sheet and a steel tripod. The test apparatus is mounted on a double-decker rubber sheet that is oriented between the test system and the tripod; also, a vacuum rubber located below each foot of the tripod on the floor. This system with a data acquisition card and an induction motor is connected to monitoring system through a computer. Testing design in Figure 1 presents an view.

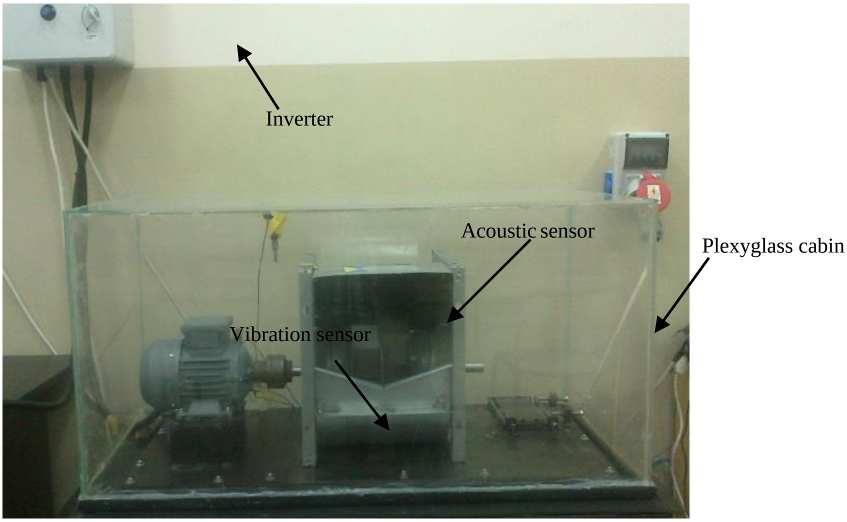


Figure 1. A view from the test setup

Frequencies set on inverter (I) and measured at spectrum domain (S) are shown in Table 1. Theoretical frequencies shows the value set on the digital frequency changer; respect to data during the application, set frequency ranging suffered some losses. Frequency at 1x is a frequency that is fundamental frequency; 2x, 3x and the upper orders are harmonics of fundamental frequency. In Table 1, the frequency is shown with the symbol of f for frequency changer and harmonic order presented with symbol of h.

Table 1. Harmonics

(h) / (f)	1x		2x		3x		4x		5x	
	I	S	I	S	I	S	I	S	I	S
40.5	40.5	39.06	81	78.12	121.5	117.18	162	156.24	202.5	241.56

Measurements were made during the tests at electrical frequency 40.5 Hz and rotational period was measured as 2350 min^{-1}. Frequencies of failures and harmonics are considered during calculation of the bearing and fan-caused vibrations of the test apparatus.

Bearing equations with the fundamental fault frequency calculations and respect to measurements are given in Table 2.

Table 2. Fault frequencies

f (Hz)	ω_s (Hz)	ω_{bpf} (Hz)	ω_c (Hz)	ω_{bpfo} (Hz)	ω_{bpfi} (Hz)	ω_{bsf} (Hz)
40.5	39.06	390.6	14.84	118.74	193.76	76.69

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)

In order to practice condition of mechanical looseness failure, looseness of 0.5 mm is created by using shims under front feet of the electric motor. Tested bearing has been shown in Figure 2.

a) Tested bearing lubricated b) Creating looseness with shim

Figure 2. Tested bearing

In order to decide about the measurements, data from acoustics and vibration methods have been processed with FFT (Fast Fourier Transform) approach and data has been transferred for making analysis. Electrical consumption data has been processed respect to the algorithm of the device software and analysis are made by PSD (Power Spectrum Density) and trend indicators.

Experimental

Vibration measurements are received in radial (vertical) direction in the tests. Acoustic measurements are recieved in omni-directional over the test setup under plexyglass cabin. Vibrational and acoustic data captured with sensors through a DAQ (Data Acquisition Card) and processed with a software. For detection of natural frequencies in order to make comparison, damping tests are practised on test setup when the system is not in rotational movement. Data of electrical consumption has been received through an electronic device connected to electrical circuit of the motor and analyzed with a software.

Acoustic Analysis

Frequencies of acoustic data received based on rotation of shaft and bearing elements has been presented in Figure 3 and the highest five amplitudes are given. The main rotation frequency is 39.06 Hz and the highest amplitude signal has been detected at this frequency with the amplitude of 5.32 Pa. An other order of the main frequency has been detected at 351.6 Hz (9x) that is the third dominant signal in the spectrum domain. Third dominant acoustics signal appeared at 156.3 Hz (4x) with the amplitude of 0.703 Pa. The other two dominant signals have not integer orders of the fundamental frequency. Fourth dominant signal detected at 410.2 Hz is the harmonic 10.5x and fifth signal detected at 253.9 Hz is the harmonic 6.5x.

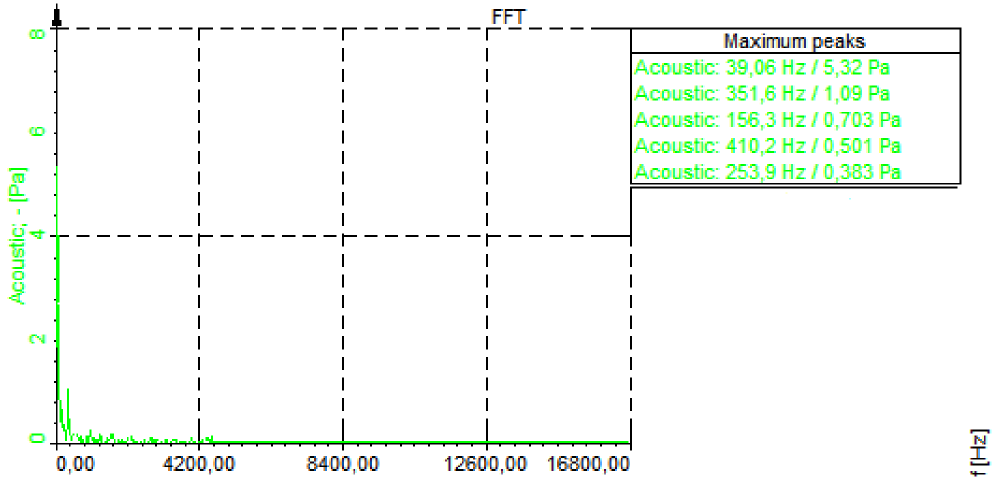


Figure 3. Spectrum in acoustic data

Vibration Analysis

Unbalance harmonic 1x has been detected as the most dominant signal in radial direction with the amplitude of 1.19 m/s^2. In radial direction, signal at 860.72 Hz that is the upper harmonics of cage frequency ($58x\omega_c$) excited a signal at the frequency 866.7 Hz which is a natural frequency and consequently superharmonic resonance has been observed with the signal amplitude as 0.278 m/s^2. The other resonance effects are detected at second and third dominant signal in frequencies of 947.3 Hz and 120.8 Hz. Signal in upper order of cage frequency at 949.76 Hz ($64x\omega_c$) has excited the natural frequency at 947.3 Hz and subharmonic resonance has been appeared with the amplititude of 0.4 m/s^2. Signal at 117.18 Hz (3x) has excited the natural frequency at 120.8 Hz and superharmonic resonance has been detected with the amplitude of 0.298 m/s^2. Signal at harmonic 2x has been appeared as the fourth dominant signal.

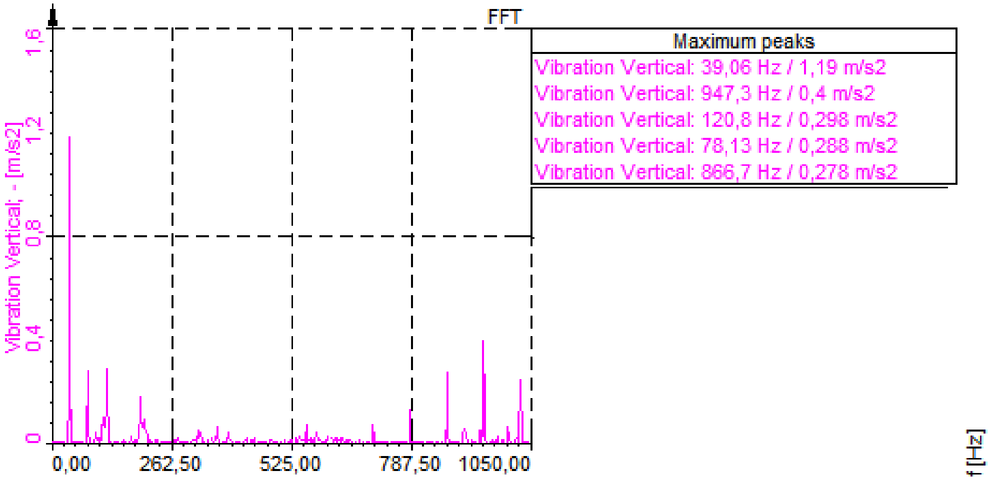


Figure 4. Spectrum in vibration data

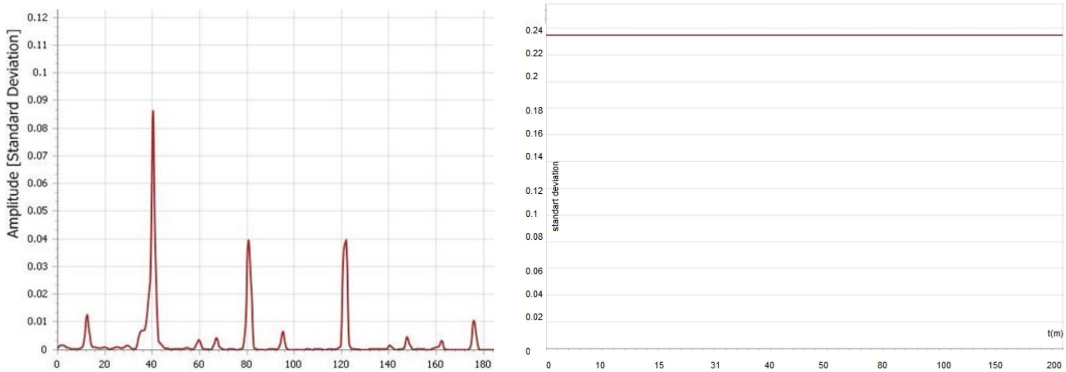
Respect to the Figure 4 and Table 3, mechanical looseness increased the vibration magnitude of signals at the rotor zone.

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

MEASUREMENT	1.S	2.S	3.S	4.S	5.S
Mechanical loosenes	1x	f_n (64xω_c)	f_n (3x)	2x	f_n (58xω_c)

Electrical Consumption Analysis

Standart deviations in measurements are evaluated in perspective of electrical consumption, data is given in PSD analysis and trend analysis. Respect to PSD analysis in Figure 5, peaks can be seen at the orders of 40.5 Hz. Highest three amplitudes are on 40.5 Hz, 81 Hz and 121.5 Hz. According to the methodological approach of device software, band at the main frequency represents the condition of the rotor, band at the second order represents the condition of bearing and band at the third order represents the any other failure. The PSD analysis takes attention to rotor and bearing.



a) PSD data b) Trend data

Figure 5. Electrical consumption data

According to evaluation of trend analysis in Figure 5, mechanical looseness indicator has not detected fluctuation in the condition of the bearing respect to the mechanical looseness failure.

Results and Discussion

In this test based research, resonance features of a test setup have been researched under the mechanical looseness condition effect on a bearing. Focusing with predictive maintenance perspective; methods of acoustics, vibration and electrical consumption analysis are studied in order to detect the condition of a tested bearing.

According to analysis results of acoustic measurement; symptoms are appeared partly on effect of mechanical looseness failure but bearing frequency and resonance frequencies are not found in the acoustic data.

Respect to vibration analysis, bearing failure frequencies and resonance frequencies are detected in spectrum data under the mechanical looseness failure.

Electrical consumption analysis is successful in detection of mechanical looseness failure in PSD respect to the band of rotor, but not in trend analysis.

In comparison of acoustic, vibration and electrical consumption analysis results; vibration analysis has been decided as the most informative and accurate tool for inspecting the resonance features of the tested system in the condition of mechanical looseness failure at the level of 0.5 mm.

References

[1] R.K. Mobley, An Introduction to Predictive Maintenance, Second ed., Elsevier Science, New York, 2002.

[2] Mahmood, S. T.,; Use of Vibration Analysis Technique in Condition Based Maintenance. MSc Thesis, *Royal Institute of Technology, p 63, 2011.*

[3] Margenau, H., Hill, R.A.,; Correlation Between Measurements in Quantum Theory, Theoretical Physics,Vol. 20, pp. 722-738, 1961.

[4] Tlrpude, V., Modak, J., Mehta, G.,2011: Vibration Based Condition Monitoring of Rolling Mill, International Journal of Scientific&Engineering Research, Vo.2., Issue 2,

[5] Velarde-Suarez S., Ballesteros-Tajadura R., Hurtado-Cruz J.P., 2006: A predictive maintenance procedure using pressure and acceleration signals from a centrifugal fan, *Applied Acoustics*, 67, 49-61.

[6] Karsak, E., Tolga, E., Fuzzy multi-criteria decision making procedure for evaluating advanced manufacturing system investments, International Journal of Production Economics 69 (2001) 49–64.