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Vibration Condition Monitoring Techniques for Fault Diagnosis of Electromotor with 1.5 Kw Power

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Abstract: Vibration analysis is the main conditions monitoring techniques for machinery maintenance and fault diagnosis. This technique has its unique advantages and disadvantages associated with the monitoring and fault diagnosis of machinery. When this technique is conducted independently, only a portion of machine faults are typically diagnosed. However, practical experience has shown that this technique in a machine condition monitoring program provides useful reliable information, bringing significant cost benefits to industry. The objective of this research is to investigate the correlation between vibration analysis and fault diagnosis. This was achieved by vibration analysis and investigating different operating conditions of an experimental electromotor. The electromotor was initially run under normal operating conditions as a comparative test. A series of tests were then conducted corresponding to different operating condition. Our varieties were speed of electromotor at three levels, respectively 500, 1000 and 1500 rpm. We did three faults in our electromotor; there were misalignment, looseness and bad bearing. We coupled our electromotor to the variable blade fan and applied several load on that by changing the number of blade of fan. We have chosen 2, 6 and 10 blades fan to apply three different loads on our electromotor. Vibration data was regularly collected. Numerical data produced by vibration analysis were compared with vibration spectra in normal condition of healthy machine, in order to quantify the effectiveness of the vibration condition monitoring technique. The results from this paper have given more understanding on the dependent roles of vibration analysis in predicting and diagnosing machine faults.

Key words: Vibration analysis, machine condition monitoring, electromotor, predicting, diagnosing machine faults

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INTRODUCTION

Traditional preventative maintenance not only leads to wasteful machine downtime but also premature replacement of parts. Successfully implementing a condition monitoring program allows the machine to operate to its full capacity without having to halt the machine at fixed periods for inspection (Carter, 1996).

It has been known for many years that the mechanical integrity of a machine can be evaluated by detailed analysis of the vibratory motion (Eisenmann, 1998). Many mechanical problems are initially recognized by a change in machinery vibration amplitudes. In addition, the frequency of vibration, plus the location and direction of the vibratory motion are indicators of problem type and severity. Vibration characteristics can be distinctively divided into two types: forced vibration and free vibration. Typical forced vibration relates to problems such as mass unbalance, misalignment and excitation of electrical or mechanical nature. Free vibration is a self-excited phenomenon that is dependent on the geometry, mass and damping of the system and typically caused by structural, acoustic resonance and by aerodynamic or hydrodynamic excitation.

Vibration signals carry information about exciting forces and the structural path through which they propagate to vibration transducers. A machine generates vibrations of specific color when in a healthy state and the degradation of a component within it my result in a change in the character of the vibration signals (Williams *et al*., 1994).

Lindh (2003) provides a comprehensive overview of bearing defect detection methods and different condition monitoring schemas. The condition based maintenance

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and predictive condition monitoring are becoming an important issues, since up to one third of all maintenance cost was wasted as a result of unnecessary or improperly carried out maintenance during the last years.

The implementation of the signal processing algorithms can be done using different computation techniques. These techniques include but are not limited to Fast Fourier Transform (FFT), Neural Network and Wavelet analyses which have been applied to vibration monitor and detection in industries systems.

Condition monitoring provides information on the health and maintenance requirement of industrial machinery and is used in a wide range of industrial applications. Parameters such as vibration, temperature, lubricant quality and power consumption can be used to monitor the mechanical status of equipment (James *et al.*, 2004). Machine condition monitoring has long been accepted as one of the most effective and cost-efficient approaches to avoid catastrophic failures of machines. The most effective and cost-efficient group is vibration analysis (Barron, 1996). However, recent evidence shows that vibration condition monitoring techniques provides greater and more reliable information, thereby resulting in a more effective maintenance program with large cost benefits to industry (Mathew and Stecki, 1987; Maxwell and Johnson, 1997; Troyer and Williamson, 1999).

Vibration analysis in particular has been used as a predictive maintenance procedure for some time and as a support for machinery maintenance decisions (Barron, 1996). As a general rule, machines do not break down or fail without some form of warning, which is indicated by an increased vibration level. By measuring and analyzing the vibration of a machine, it is possible to determine both the nature and severity of the defect and hence predict the machine's failure. The overall vibration signal from a machine is contributed from many components and structures to which it may be coupled. However, mechanical defects produce characteristic vibrations at different frequencies, which can be related to specific machine fault conditions. By analyzing the time and frequency spectrums and using signal processing techniques, both the defect and natural frequencies of the various structural components can be identified.

In view of the growing need for multi-skilled graduates and the importance and benefit of skill-based courses to industry, teaching in this area is still limited. Project learning is becoming popular and beginning to appear in recent conferences, such as project-based leaning in structural engineering (Mills, 2001). Tan and Tang developed a vibration simulation rig that permitted students to perform practical tasks, which could then be related to theory studied in class (Tan and Tang, 2002).

In machine health monitoring, Roylance was one of the few researchers who combined tribology and condition monitoring in undergraduate design projects (Roylance, 1994). His work covered a review of bearing failures, failure detection and the analysis methods used to track faults in industrial machinery, particle counting comparison for wear debris analysis technique and the effect of volume flow or wear-debris deposition utilizing a modified Ferro graph analysis. Daabdin and Wang reported four separate vibration monitoring techniques and their application to rolling element bearings (Daabdin and Wong, 1991). Their project involved developing a computer program for data acquisition and analysis techniques involving spectra analysis, kurtosis, shock-pulse metering and the spike energy method.

MATERIALS AND METHODS

Test rig design: The rig design incorporated an undamaged bearing, damaged bearing, a coupling disk system to impose shaft misalignment and looseness. The photograph of the set-up is shown in Fig. 1.

The coupling discs can be adjusted to create an angular misalignment. All exams have been done for 2, 6 and 10 blades fan to apply three different loads on our electromotor but the results of 10 blades were shown in this study. The test rig assembly used for the experimentation consisted of an electromotor have been coupled to a blade fan. The power of electromotor was 1.5 kW (2 hp), three phase, variable rpm. Details of the electromotor are shown in Table 1.

Vibration data was collected on a regular basis after the run in period. The experimental procedure for the vibration analysis consisted of taking vibration readings

Fig. 1: Photograph of set-up

Table 1: Detail of electromotor

Electromotor	Description
Electromotor capacity (kW)	1.5 (2 HP)
Motor driving speed (rpm)	Variable
Voltage	380 v
Phase	Three phase
Ambient air temperature (°C)	≈25
Non driven end bearing	FAG 6205
Driven end bearing	FAG 6205

at two select locations over the electromotor. There were taken on the drive end (DE) and non-drive end (NDE) of electromotor.

Vibration measurements were taken on the DE and NDE of electromotor using an X-Viber (VMI is the manufacturer). Hence, its accelerometer is very suitable for use in dirty field or high temperature environments with little degradation of the signal. The signals from the accelerometers were recorded in a portable condition monitoring signal analyzer. In general, electromotor can be quite difficult to analyze.

Damaged bearing: The test bearings were damaged using a 1 mm wire cutting method. The wire cut removed a section of the first bearing outer ring through to the outer race track and also a section of the inner race of second bearing. The damages were intended to create outer race and inner race types of defects. These could generate impulsive types of signal, as the rolling elements rolled pass the damage.

Shaft misalignment: A coupling disc system was designed to impose shaft misalignment onto the undamaged bearing. The coupling system consisted of two discs: one attached to a short driven shaft, the other attached to a longer shaft enabling considerable angular misalignment on the support bearing by moving the discs apart. The disks are moved relative to each other by tightening/loosening a grub screw, which pushes onto a key.

Misalignment produces a bending moment on each shaft and this generates a strong vibration at 1x rpm, but only some vibration at 2x rpm in the axial direction at both bearings.

Looseness: The base screws of electromotor have been loosed for losing the electromotor.

RESULTS AND DISCUSSION

The most basic form of vibration analysis is called an overall vibration measurement. This reading provides a single number that describes the total amount of vibration energy being emitted by a machine. The idea is that more vibration indicates a problem. A number of standards and guides have been developed to explain what levels are acceptable for various machine types.

In the field of machinery vibration monitoring and analysis, a variety of relevant standards are developed and published by ISO (International Organization for Standardization).

Standards for evaluation of vibration severity are considered one of the most important activities of ISO/TC108. ISO/10816 series (6 parts) Mechanical vibration-Evaluation of machine vibration by measurements on non-rotating parts.

ISO 10816-1 is the basic document describing the general requirements for evaluating machinery vibration using casing and/or foundation measurements. Subsequent parts of each series of documents apply to different classes and types of machinery and include specific evaluation criteria used to assess vibration severity. So we have been used standard ISO 10816-1 for our testing.

Signal data was acquired for machine conditions, including a healthy electromotor, damaged bearings, shaft misalignment and looseness of these machine conditions at operating speeds of 500, 1000 and 1500 rpm. Data analysis required comparing the plots obtained for each test condition to those expected for the specific machine faults simulated.

Prominent frequency spikes determined from the time and frequency domain graphs were also compared to the theoretical vibration fault signatures.

Healthy machine: The results showed that the RMS values for healthy electromotor at 1500 rpm (500 and 1000 rpm were the same) were on acceptable status and also bearing condition values. Mean of overall vibration was 1.76 and standard deviation of that was 0.27. The critical overall vibration recommended value in ISO 10816-1 for this electromotor is 2.8 mm sec^{-1} and measurement values and mean of them were lower than standard value. It indicated that electromotor was in good condition. Mean of bearing condition was 0.37 and standard deviation was 0.10. According to the results the bearings of electromotor were in acceptable condition (Table 2).

Table 2 have been shown measuring date, mm sec^{-1} RMS, Bearing Condition (BC) and alarm status for overall vibration and BC for DE of electromotor also that showed mean and standard deviation of overall vibration and bearing condition.

Electromotor looseness: The results showed that the RMS values for loosed electromotor at 1500 rpm (at 500

Table 2: Overall vibrations and bearing condition of driven end (DE) of electromotor

Test	Measuring date	RMS (mm sec^{-1})	Alarm status	BC	Alarm status
1	16-12-2006	1.84	Ok	0.25	Ok
2	17-12-2006	2.27	Ok	0.31	Ok
3	19-12-2006	2.09	Ok	0.33	Ok
4	20-12-2006	1.62	Ok	0.19	Ok
5	22-12-2006	1.54	Ok	0.49	Ok
6	23-12-2006	2.10	Ok	0.33	Ok
7	23-12-2006	1.41	Ok	0.44	Ok
8	24-12-2006	1.85	Ok	0.23	Ok
9	25-12-2006	1.52	Ok	0.36	Ok
10	26-12-2006	1.73	Ok	0.37	Ok
11	28-12-2006	2.09	Ok	0.37	Ok
12	30-12-2006	1.54	Ok	0.58	Ok
13	30-12-2006	1.60	Ok	0.43	Ok
14	31-12-2006	1.57	Ok	0.36	Ok
15	01-01-2007	1.57	Ok	0.48	Ok
Mean		1.76		0.37	
SD		0.27		0.10	

Table 3: Overall vibrations and bearing condition of driven end (DE) of electromotor at looseness condition

Test	Measuring date	RMS (mm sec^{-1})	Alarm status	BC	Alarm status
1	11-01-2007	5.86	Danger	0.09	Ok
2	11-01-2007	5.87	Danger	0.18	Ok
3	12-01-2007	6.66	Danger	0.20	Ok
4	14-01-2007	4.32	Warning	0.18	Ok
5	16-01-2007	3.09	Warning	0.20	Ok
6	17-01-2007	6.88	Danger	0.26	Ok
7	18-01-2007	4.42	Warning	0.19	Ok
8	18-01-2007	3.57	Warning	0.19	Ok
Mean		5.08		0.19	
SD		1.43		0.05	

and 1000 rpm) were on critical status but bearing condition values were on acceptable status. Mean of overall vibration was 5.08 and standard deviation of that was 1.43.

The critical overall vibration recommended value in ISO 10816-1 for this electromotor is 2.8 mm sec^{-1} and measurement values and mean of them were higher those standard value and the RMS value of electromotor in healthy electromotor. It indicated that electromotor was in bad condition and this condition was looseness. Mean of bearing condition was 0.19 and standard deviation was 0.05. According to the results, the bearings of electromotor were in acceptable condition.

Table 3 have been shown measuring date, mm sec^{-1} RMS, bearing condition (BC) and alarm status for overall vibration and BC for DE of electromotor also that showed mean and standard deviation of overall vibration and bearing condition. Table 3 showed numerical data of overall vibrations and bearing condition of driven end (DE) of electromotor in this position.

According to the results (Fig. 2), the velocity frequency spectrum of the electromotor DE showed a dominant frequency corresponding to the triple of shaft speed (75 Hz). In some velocity spectrum were observed sub harmonics at 0.5, 1.0 and 1.5 of speed frequency of electromotor that showed looseness.

Table 4: Overall vibrations and bearing condition of driven end (DE) of electromotor at 1500 rpm (shaft misalignment)

Test	Measuring date	RMS (mm sec^{-1})	Alarm status	BC	Alarm status
1	17-01-2007	4.52	Danger	0.44	Ok
2	18-01-2007	3.59	Warning	0.37	Ok
3	19-01-2007	3.29	Warning	0.45	Ok
4	20-01-2007	5.10	Danger	0.35	Ok
5	21-01-2007	3.90	Warning	0.33	Ok
6	22-01-2007	5.12	Danger	0.32	Ok
7	23-01-2007	4.74	Danger	0.40	Ok
8	24-01-2007	4.60	Danger	0.51	Ok
9	25-01-2007	5.29	Danger	0.55	Ok
Mean		4.46		0.41	
SD		0.71		0.08	

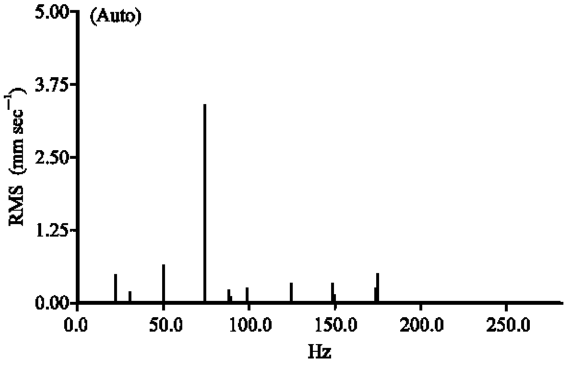

Fig. 2: Frequency spectrum result of DE of electromotor at looseness condition

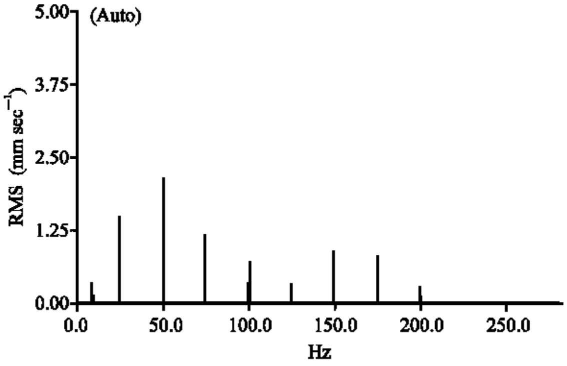

Fig. 3: Frequency spectrum of DE of electromotor at 1500 rpm (misalign status)

Shaft misalignment: When testing for shaft misalignment faults, predicted frequencies were exemplified at the various rotational speeds. The frequency components for shaft speed at 1500 rpm shown in Table 4. Figure 3 shows the prominent frequency peak (shaft speed of

Table 5: Overall vibrations and bearing condition of driven end of electromotor in inner race bad bearing position

Test	Measuring date	RMS (mm sec^{-1})	Alarm status	BC	Alarm status
1	06-03-2007	3.29	Warning	0.23	Ok
2	07-03-2007	3.00	Warning	0.40	Warning
3	08-03-2007	3.48	Warning	0.49	Warning
4	09-03-2007	2.74	Ok	0.42	Warning
5	10-03-2007	2.58	Ok	0.44	Warning
6	11-03-2007	2.53	Ok	0.40	Warning
Mean		2.94		0.40	
SD		0.39		0.09	

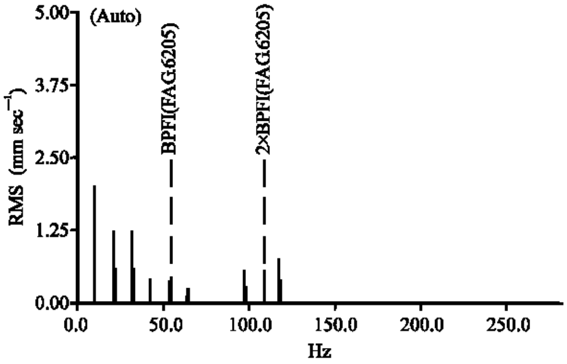

Fig. 4: Frequency spectrum result of electromotor in inner race bad bearing position

1500 rpm), which occurred at 2 shaft speed frequency (SSF) and a smaller spike at 1 and 3 times of shaft speed frequency, indicating misalignment.

Results showed that the mean of overall vibration for looseness did not have significant difference, but their frequency spectrum were quite different, so we used frequency spectrum analyze to find misalignment and looseness of electromotor.

Damaged bearing: According to the results, the mean of overall vibration and bearing condition had significant different another situation and also healthy condition. Table 5 showed the numerical data at 500 rpm rotating speed of electromotor in inner race bad bearing.

When simulating bearing damage only, the experimental rig successfully related the theoretical calculations of ball pass frequencies at each rotating speed. Prominent peaks in Fig. 4 permitted students to easily identify and compare the corresponding frequencies. The spectrum showed spikes corresponding to 1-2 times the BPFI. This is consistent with results obtained by Barkov and Barkova (1995).

Table 6 showed the numerical data for 1500 rpm rotating speed of electromotor in bad bearing position. The results showed that overall vibration and bearing condition have been increased.

Table 6: Overall vibrations and bearing condition of electromotor at 1500 rpm with bad bearing

Test	Measuring date	RMS (mm sec^{-1})	Alarm status	BC	Alarm status
1	06-03-2007	6.47	Danger	0.73	Warning
2	07-03-2007	9.05	Danger	1.66	Danger
3	08-03-2007	9.23	Danger	1.57	Danger
4	09-03-2007	9.64	Danger	1.54	Danger
5	10-03-2007	8.97	Danger	1.16	Warning
6	11-03-2007	9.52	Danger	1.43	Warning
Mean		8.81		1.35	
SD		1.18		0.35	

According to results the overall vibrations of driven end (DE) of electromotor that showed in Fig. 4 were higher than standard values.

The results showed that the RMS values at 500 and 1500 rpm were on critical and warning status. Bearing condition values were also on bad condition. Mean and standard deviation of overall vibration and bearing condition of electromotor was taken in Table 6.

Correlation of vibration and fault diagnosis: Vibration analysis technique has been used to assess the condition of the electromotor and diagnose any problems of that. The results from vibration analysis of our experimental research indicate our defaults those made in our electromotor. Vibration analysis of electromotor discovered the looseness, misaligned and bad bearing in electromotor.

The correlation between the vibration analysis and fault diagnosis was excellent as vibration technique was able to pick up on different issues, thus presenting a broader picture of the machine condition. Vibration analysis detected a continuing motor defect along with a possibility of mechanical looseness of the outer casing from assembly. The vibration analysis confirmed that a three-body rolling action took place and significant life remained in the electromotor. Vibration analysis technique was capable in covering a wider range of machine diagnostics and faults within the electromotor.

CONCLUSION

The experimental results demonstrated that the vibration monitoring rig modeled various modes of machine failure is indeed capable of both independently and simultaneously generate common machine faults. In this case, students were able to perform practical tests on the constructed rig to confirm the expected theoretical frequencies that had been predicted in the classroom.

Student feedback supported a positive view of the vibration monitoring rig as an experimental device for demonstrating preventative condition monitoring theory.

Vibration analysis is the most effective techniques for monitoring the health of machinery. It offers complementary strengths in root cause analysis of machine failure and is natural allies in diagnosing machine condition. It reinforces indications seen in each technology and has unique diagnostic strengths in highlighting specific wear conditions.

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