Application of Acoustic Emission for Incipient Fault Detection of Industrial Pilot Plant Machinery

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Abstract—Numerous condition monitoring techniques and identification algorithms for detection and diagnosis of faults in industrial plants have been proposed for the past few years. Motors are one of the common used elements in almost all plant machinery. They cause the machine failure upon getting faulty. Therefore advance and effective condition monitoring techniques are required to monitor and detect the motor problems at incipient stages. This avoids catastrophic machine failure and costly unplanned shutdown. In this paper the acoustic emission (AE) monitoring system is established. It discusses a method based on time and frequency domain analysis of AE signals acquired from motors used in chemical process pilot plant. A real time measurement system is developed. It utilizes MatLAB to process and analyze the data to provide valuable information regarding the process being monitored.

Keywords- Process Plan; Rotating Machines; Acoustic Emission; Time Domain Analysis; Frequency Domain Analysis; Motors; MATLAB.

I. INTRODUCTION

In recent years, the rapid growth of industry automation has motivated the need for advanced machine condition monitoring systems. To reduce the losses due to production intermission and costly machine failure, it is necessary to monitor and diagnose the machine status in real time by means of resourceful condition monitoring technique to provide appropriate information for maintenance and production decision making [1-3].

Generally, condition monitoring entails the study of machine health condition using periodically sampled dynamic response measurements such as vibration signals, acoustic emission signals, etc. which are obtained from various sensors mounted on the machine housing [1-4].

Condition monitoring is the process of monitoring a parameter of condition in machines, such that a significant change is indicative of a developing failure. It is of great practical significance in manufacturing industry since it provides updated information regarding machine status on-line and thus allows maintenance to be scheduled in order to avoid accidental outages that may lead to a catastrophic machine failure that causes the production loss.

Although the technology and application of condition monitoring is continually evolving, its conceptual basis can be traced back to the earliest development of machinery. The use of human senses to monitor the state of industrial equipment is still valid, although currently augmented by scientific advanced instrumentation. The use of such instrumentation permits to quantify the health or condition of industrial equipment, so the problems can be diagnosed early in their development, and corrected by a suitable maintenance before they become serious enough to cause a plant shutdown.

Condition monitoring therefore involves the design and use of sensing arrangements on industrial plants, together with data acquisition and analysis systems in addition to predictive and diagnostic methods, with the objective of implementing equipment maintenance in a planned way using actual condition knowledge [2, 3].

A. Vibration Monitoring Techniques

Several condition monitoring techniques are available, but the most commonly used method for rotating machines is called vibration analysis. The level of vibration can be compared with historical baseline values such as former start-ups and shutdowns, and in some cases established standards such as load changes, to assess the severity.

Interpretation of vibration signals is a complicated process that requires advanced techniques. One commonly employed method is to examine the individual frequencies present in the signal. These frequencies correspond to specific mechanical components such as bearing elements, motor faults or due to a certain malfunctions such as shaft unbalance or misalignment. By analyzing these frequencies and their harmonics, the location and type of the problem can be identified.

Vibration signals in the form of frequency and amplitude are generated due to problems occurred in the moving parts and structure of the machinery. Vibration sensors such as accelerometer, displacement, and velocity are quite common. The frequency range of these sensors is 10 KHz. [5-10].

B. AE Monitoring Techniques

AE is defined as transient elastic waves generated by a rapid release of energy from a localized source within a material under stress. These elastic waves are generated due to mechanisms such as crack, deformation, damage, friction, impact and etc. AE frequency range is 100 KHz - 1 MHz.

Defects in rotating machinery generate a phenomenon in the form of crack growth, wear and tear, etc. This phenomenon
produces elastic waves or seismic signals. AE sensors are capable for detecting these elastic waves. Therefore machine deterioration and malfunction can be detected using AE at much at early stages compared to vibration [11-14].

This study discusses the AE monitoring techniques established to acquire acoustic signals at the motor housing in a chemical process pilot plant. The Physical Acoustic Corporation AE sensor of a wide band with 1 meter integral cable is used to provide the high frequency analysis of the AE signals. The sensor operating frequency range is 100-1000 kHz. The wide band sensor is housed in stainless steel with ceramic face material and a BNC connector located at a side. A sufficient thin layer of couplant grease is applied between the sensor face and the motor housing to fill the gaps caused by surface roughness and to eliminate air gap to ensure good acoustic transmission. MATLAB is used to get the information regarding the process being monitored. The acquired AE signals are processed and analyzed using MATLAB and Lab VIEW to provide information regarding the process being monitored.

II. EXPERIMENTAL SETUP

A. Design Flow Diagram

The design flow diagram of the experimental setup is shown in Figure1.

![Figure1. Measurements on industrial process plant, design flow](image-url)
B. Industrial Plant Experimental Setup

In order to verify the effectiveness of the proposed AE monitoring technique for the detection of rotating machine faults in industrial plants, the technique is implemented on different type of motors and pumps which are used in the industrial process pilot plant located in ground floor building 23, Universiti Technologi PETRONAS (UTP). Figure 2 illustrates the block diagram for the proposed experimental setup.

In the case of motor experiments, the AE sensor is mounted on the motor housing using cable tie and tape. The sensor is connected to preamplifier. The preamplifier gain is adjusted to 60 dB and its output is connected to amplifier. The amplifier gain is adjusted to 13 dB and its output is connected to oscilloscope. The oscilloscope is used to perform the spectrum analysis for the acquired time domain AE signals.

Averaging, envelope, sample and peak detection acquisition modes are used in the analysis. The spectrum and time domain signals are saved and finally plotted using Mat LAB. Initially, the measurements are established for three motors: AG140, AG130 and AG120. These motors are used in the chemical process control pilot plant.

Figure 3 and Figure 4 show the experimental setup for the chemical process plant. It is observed that AG140 motor has got some defects that include oil leakage and vibration at the coupling side to the mixer which is shown in Figure 3.

III. MEASUREMENTS ON INDUSTRIAL PLANT

The initial measurements are conducted for the motors used in chemical process plant. The motors under tests are named AG140, AG130 and AG120, they are mounted vertically.
steel bar. A stirrer is mounted at the end of the bar to mix the solutions on the tank. Each motor is monitored at a time while running the plant using the proposed AE techniques. The sensor is first mounted on the top of the motor housing and then near the coupling side. It is observed that the AG140 motor is leaking and slight vibration could be seen on the coupling side. At the beginning two tests are carried out on motor AG140. The first measurement is carried out when the sensor mounted on the top of the motor and the second is the coupling side.

The aim is to check the effect of changing the mounting position of the sensor on the AE measurements. The AE signals obtained are saved and plotted using MatLAB. Some of the results obtained are shown on Figure 5. The second measurements are performed on AG130 motor. Sample of the results are shown on Figure 6. The final measurements are conducted on AG120 motor. The corresponding results are displayed in Figure 7.

![Figure 5. AE data of AG140 motor, top side measurements (a) Time domain (b) Frequency spectrum](image5)

![Figure 6. AE data of AG130 motor, top side measurements (a) Time domain (b) Frequency spectrum](image6)

![Figure 7. AE data of AG120 motor, top side measurements (a) Time domain (b) Frequency spectrum](image7)
Table 1 summarizes the AE data obtained from the measurements conducted on the AG140, AG130 and AG120 motors of industrial process plant. There are no distinguishable variation in the amplitudes of AE signals observed in the measurements performed at the two ends of the AG140, AG130 and AG120 motors. This indicates that the mounting position and direction of the sensor are not showing any significant effect on the AE measurements since it is in the vicinity of the part to be monitored. It could be observed that AE signal amplitudes of AG130 and AG120 motors do not exceed 2.5 Vpp. The spectrum analysis of the acquired signals does not show any peak in the whole measuring range of the sensor except the sensor resonance frequency, at a peak of 100 kHz.

On the other hand, the measurements performed on AG140 motor indicate high amplitudes that extended to 14.2 Vpp. The spectrum analysis of the acoustic signals on this case shows peaks at frequencies ranging between 200 to 450 kHz, although a peak at 240 kHz is predominant in almost all the measurements conducted. Using the measurements results of the three motors it could be deduced that: AG130 and AG140 motors are still working in good condition, whereas AG140 motor is having some problems and need to be rectified. It can be concluded that the AE data obtained for the healthy motors are quite similar.. However, the measurements on the faulty motor reveal AE signals that are quite distinguishable from those of the healthy motors.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Sensor mounting position</th>
<th>AG140 motor</th>
<th>AG130 motor</th>
<th>AG120 motor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Amplitude, Volt</td>
<td>Peak Frequency, kHz</td>
<td>Amplitude, Volt</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>5.8</td>
<td>100, 250, 450</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>7.5</td>
<td>100, 240, 450</td>
<td>1.6</td>
</tr>
<tr>
<td>3</td>
<td>On top of the motor</td>
<td>7.6</td>
<td>100, 240</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>9</td>
<td>95, 200, 240</td>
<td>1.9</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>8.4</td>
<td>100, 230</td>
<td>1.7</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>6</td>
<td>100, 240</td>
<td>2.1</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>10.5</td>
<td>90, 240</td>
<td>1.6</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>10.8</td>
<td>100, 250</td>
<td>1.5</td>
</tr>
<tr>
<td>9</td>
<td>On the motor coupling side</td>
<td>14</td>
<td>90, 220, 400</td>
<td>2.5</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>10.5</td>
<td>100, 250</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>11.6</td>
<td>100, 240, 400</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>14.2</td>
<td>95, 240</td>
<td>1.9</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>13.8</td>
<td>100, 240</td>
<td>2.2</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>12.9</td>
<td>95, 240, 450</td>
<td>1.6</td>
</tr>
</tbody>
</table>
IV. MEASUREMENT ON EXPERIMENTAL TEST RIG

The Schematic diagram of the experimental test rig used for this study is shown in Figure 8. It consists of a shaft supported on two bearing assembly. A three phase electrical motor (model A4300) is coupled to the shaft using flexible coupling element. The shaft is driven by the motor. AE sensor (model WB DIFF AE sensor/1m integral cable) is mounted on the roller bearing. A thin layer of couplant grease is applied between the sensor face and the bearing housing in order to fill the gaps caused by surface roughness and to eliminate air gap to ensure good acoustic transmission. This type of sensor is used to get high fidelity and frequency analysis of AE signals as well as providing useful information about the bearing condition and for noise discrimination.

The AE signal is amplified and filtered using 20/40/60 dB, AE PREAMP/100-1200 KHz with band pass filter. The PAC AE5A amplifier is a high performance AE system that amplifies and filters an incoming AE signals from the preamplifier. The resulting high-frequency AE analog signal output is connected to TEKTRONIX TDS3012B digital storage scope in order to view a cause and response relationship. The amplifier AE5A covers the extended AE frequency up to 5 MHz [15-18]. The Tektronix oscilloscope is interfaced to PC using National Instrument general purpose interface bus (NI GPIB 488-2). GPIB is configured using Measurement and Automation Explorer (MAX). In this paper rolling element bearings from NACHI (6203-2NSE) and KOYO (6203ZZCM FG) manufacturers have been used. Electrical discharge machine is used to create different faults on the bearing assembly. Initially a couple of experiments were conducted for a group of healthy bearings [HB]. Each bearing is mounted on the bearing housing of the test rig and the measurement was repeated for various motor speeds and loads. Consequently, significant amounts of AE data were collected. It is essential in relating any AE activity with bearing faults detection afterwards. The spectral analysis of the acquired signals is obtained using Fast Fourier Transform. Figure 9 is an example of the measurement results.

The second measurements were conducted by removing a part of lubrication grease to realize the onset of bearings failure. To control the amount of grease inside the tested bearing, the bearing was first dismantled from the bearing housing, and then immersed in chemical solution to confiscate all of the grease; after that the bearing was greased with a...
small amount of lubrication grease and reassembled in the housing and the tests was started identically to previous operating conditions. Several tests were conducted for different amount of grease supplied to bearings.

Finally the measurement results were collected and recorded for comparison studies. Figure 10 symbolizes the AE data acquired.

In evaluating the effect of bearing faults on AE signatures, problems other than poorly lubricated bearings required to be studied. This time EDM machine is requisite to create faults of different sizes in the bearings assembly. In this paper faults of different sizes created on inner and outer race defects were studied. The previous operating conditions were applied on the test rig to capture the AE for bearings with seeded defects. The AE data obtained for outer and inner race defects were presented on Table 2.

<table>
<thead>
<tr>
<th>Motor speed, rpm</th>
<th>Outer race defect bearing</th>
<th>Inner race defect bearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vpp, Frequency, dBV2RMS</td>
<td>Vpp, Frequency, dBV2RMS</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>11.4, 160, 250</td>
<td>10.5, 250, 400, 525</td>
</tr>
<tr>
<td>2200</td>
<td>14.3, 160, 250</td>
<td>12.3, 100, 400, 525</td>
</tr>
<tr>
<td>2300</td>
<td>19.4, 100, 250</td>
<td>17, 100, 200, 525</td>
</tr>
<tr>
<td>2500</td>
<td>23.2, 200, 250</td>
<td>20.8, 100, 395, 525</td>
</tr>
</tbody>
</table>

To understand the pattern of AE signals for a set of bearings with various defects, several tests were conducted at a motor speed of 2000 rpm, a load of 50 N. SKF bearings were used in the tests. Each test was repeated 40 times. The amplitudes of healthy, poorly lubricated (PLB), inner and outer race defect bearings (IRDB, ORDB) were correlated as shown in Figure 11.
V. CONCLUSIONS

It can be concluded that the AE data collected from the structure of the motors under test will not be affected by the mechanical noise from adjacent machinery, since a typical results are obtained while the other equipment are in operation or idle.

The results of the measurements conducted on chemical process plant signify the capabilities of the proposed AE techniques for detection and diagnosis of rotating machine faults. Under similar operating conditions applied to experimental test rig, it was observed that the amplitudes of healthy bearings do not exceed 3Vpp, that of poorly lubricated are relatively high (reaches 7Vpp). However, the amplitudes of outer race and inner race are quite distinct.

FFT analysis of time domain signals captured from healthy and poorly lubricated bearings shows that no peak signals present for the whole frequency range of the AE sensor. Nevertheless, a peak at 100 kHz persists in all analysis. This peak frequency corresponds to -60 dBV2RMS for most of the measurements conducted. It is noted as the resonant frequency of the sensor.

Unlike healthy and poorly lubricated bearings, spectrum analysis of AE signals obtained in the case of outer and inner race defects confer peaks at frequencies range from 160 to 525 kHz. These frequencies were also observed for bearings with different defect sizes.

REFERENCES


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