Application of Vibration and Acoustic Pressure Monitoring Techniques for Detection of Gear Failures

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Abstract — Manufacturing industry drives the world. Every manufacturing industry is having number of machines and gearboxes, which are used for power conversion, speed, reduction and torque amplification, can control many of them. Any defect induced in gear may costs high at the time of failure. For that early prediction of breakage of gear tooth is essential to avoid stoppage of that machine thereby increase in utilization. Condition monitoring is gaining importance because it can make contribution towards reducing equipments downtime and maintenance expenditure. It can also contribute towards safety in critical application by monitoring an early warning of potential catastrophic failure.

This paper commences with various condition monitoring techniques used for detection of gear failure. It mainly consists of vibration monitoring and acoustic pressure monitoring techniques. Monitoring techniques are discussed with respect to frequency domain analysis. Various faults are induced into the gearbox such as crack on one tooth, broken tooth, wear of teeth, improper lubrication. For these faults detailed analysis were done.

Keywords — Condition Monitoring, Vibration Monitoring, Acoustic Pressure

I. INTRODUCTION

Productivity is a key weapon for manufacturing companies to stay competitive in a continuous growing global market. Increased productivity can be achieved through increased availability. Managing industries into the 21st century is a challenging task. Increasing global competition, fast technological change, consumer’s perceptions towards total quality, reliability, health and safety, environmental considerations and changes in management structure not only provides many companies with considerable opportunities to improve their performance but also the much needed competitive edge to those firms that strategically plan for the future and exploit fully the advantages of modern manufacturing techniques and methods.

Manufacturing productivity is found to be influenced by following major factors:

i) Greater availability of physical resources
ii) Improvements in the quality of the human resources
iii) Improved manufacturing methods and techniques.

Today, most maintenance actions are carried out by either the predetermined preventive- or the corrective approach. The predetermined preventive approach has fixed maintenance intervals in order to prevent components, sub-systems or systems to degrade. The concept of condition monitoring is to select measurable parameters on the machines, which will change as the health or condition of a machine. Regular monitoring is done and the change is detected. Once a change is detected it is possible to make a more detailed analysis of the measurements to determine what the problem is, and hence arrive at a diagnosis of the problem. The parameters most often chosen to detect this change in conditions are either vibration, which tends to increase as a machine moves away from a smooth running condition into a rough mode with development of a fault, or an analysis of machine noise or acoustics, or machine lubricants where samples are tested for items such as wear debris from a developing fault. There are various sensors to detect and monitor the early signals of electrical, mechanical, electronic, pneumatic, hydraulic, etc. and provide an aid to fault diagnosis and to establish an effective maintenance management procedure to predict and prevent system failure just in time. A well-designed condition monitoring strategy reduces production costs, operating costs and labour costs. The cost of people involved in condition monitoring, is an important factor to consider when looking at the total cost of the system, and it often outweighs the cost of technology involved. It is also important to remember that the investment in the system is largely a single, one off cost at the beginning of the program. The amount of time that takes to walk around the plant with such a device, fixing a transducer, or reading a meter cannot substantially be reduced. However software now a day, are helping hands to reduce this time. It allows the reduction of the vast array of often complex measurements into a list of those machines needing maintenance attention, as well as listing the nature of the problem, in a completely automated way.

Gearboxes are often critical components of machine requiring the application of condition monitoring techniques.
Condition monitoring of Gearboxes implies determination of condition of gears and its change with respect to time. The condition of these gears may be determined by the physical parameters like vibration, noise, temperature, wear debris, oil contamination, etc. A change in any of these parameters called ‘signatures’ would thus indicate the change in the condition or health of the gears.

There are certain tools used for condition monitoring:
1. Sound and Vibration
2. Lubricant Analysis
3. Thermography
4. Wear Debris Monitoring

But one of most powerful tool is sound and vibration because sound is ubiquitous. In acoustical analysis technique either sound pressure measurement or sound intensity measurements are carried out.

II. TEST CRITERIA AND SPECIFICATION

A) The specifications of gearbox:
   - Power: 0.25 Hp
   - Input rpm: 1420 rpm
   - Input frequency: $1420/60 = 23.67$ Hz
   - Output rpm: 200 rpm
   - Output frequency: $200/60 = 3.33$ Hz
   - No. of stages: 2 stage
   - Gear Meshing Frequency: 284 Hz (for gear under consideration)

B) Creation of faults on gear tooth:
For creation of artificial faults on gear tooth, four different gears are procured. For that, the spur gear having 48 teeth and module of 1.5 is selected.

The common faults of gear tooth are as follows:
1. Wear on one tooth
2. Crack on one tooth
3. One tooth broken or missed
4. Lack of lubrication

1. Wear:
Wear on one tooth of gear is made by filing teeth and removing material from tooth in direction of rotation. The wear is made near the pitch circle.

Fig. No (2) Gear with fault – Teeth Wear

III. CRACK ON ONE TOOTH
A crack is produced on tooth of gear. This is made by cutting the tooth with hacksaw blade at root of tooth in the direction of rotation.

Fig. No (4) Gear with fault – Tooth Crack
IV. BROKEN TOOTH

For making this fault, one tooth of gear is removed by hacksaw blade and original non-defective gear is replaced with this gear.

4. Inadequate Lubrication or No Lubrication:

Many times unsatisfactory operation of gearbox may be caused by failure of lubrication. To enable one to identify this condition an experiment is carried out by completely darning lubrication oil from the gearbox. The gearbox will run for 15 minutes so that exact condition of no lubrication will achieved.

Experimental Procedure

1. The gearbox is run at its rated power (0.25 HP) and speeds (1420 RPM) by applying load on rope break dynamometer having diameter of pulley 71.38 mm
2. The positioning of sound pressure level probe was done properly on the top of the gear under consideration for measuring sound pressure. For vibration measurement accelerometer is kept on the top of gearbox.
3. By making all above arrangements, readings are taken for non-defective gear and good lubrication condition. This data will be stored in FFT for further analysis.
4. Vibration and noise spectrums are taken for gears having various faults and the data is stored in the memory of notebook PC for further analysis. For different condition of faults data was collected.

V. RESULT AND DISCUSSION

The various faults were created deliberately on spur gear of gearbox and acoustic pressure and vibration signatures were obtained. These signatures are compared with good gear signatures and an attempt is made to correlate them with their faults.
Fig. 7, 8, 9, 10 respectively shows comparison of cracked tooth and healthy gear spectrums, Broken tooth and healthy gear, wear of teeth and healthy gear, Improper lubrication and healthy respectively. As the crack was produced on the gear, it reflects the change in vibration spectrum. From above results following characteristics can be associated to fault.

1. The amplitude level increases considerably at gear mesh frequency.
2. The amplitude level increases by considerable margin at side bands.

VII. ACOUSTIC SPECTRAL ANALYSIS

Various acoustic spectrums are taken for healthy and various defective gears and are discussed below

Spectrum of Healthy Gear

Fig. 12 shows the acoustic spectrum of healthy (non-defective) gear. It shows that there is remarkable sound pressure level at gear mesh frequency, which is may be due to the inherent unbalance in gear and manufacturing defects. It is, therefore obvious that, there will be some sound pressure level at gear mesh frequency due to created faults.
Fig. 13, 14, 15, 16 Shows comparison of cracked tooth and healthy gear spectrums, Broken tooth and healthy gear, wear of teeth and healthy gear, Improper lubrication and healthy respectively. As the fault was produced on the gear, it reflects the change in acoustic spectrum. It is observed from figure the amplitude of gear mesh frequency has increased considerably. From above results following characteristics can be associated to fault:

1. The amplitude level increases considerably at gear mesh frequency.
2. The amplitude level increases by small margin at side bands.

Following data gives brief idea about all faults:

<table>
<thead>
<tr>
<th>Type of Fault</th>
<th>Percentage Change in Vibration Acceleration compared with Healthy Gear at GMF</th>
<th>Percentage Change in Acoustic Pressure compared with Healthy Gear at GMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crack on One Tooth</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Gear with Broken Tooth</td>
<td>19</td>
<td>11</td>
</tr>
<tr>
<td>Wear of Teeth</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Improper Lubrication</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

VIII. CONCLUSION

It was shown that various types of gear failures can be detected successfully by both acoustic and vibration signals analysis.
Condition monitoring using acoustics tool is presented in this paper, shows the considerable freedom in positioning of the microphones - distance and plane with respect to the source, and being able to detect the characteristic frequency spectrum of the gearbox and consequently fault detection and diagnosis using advanced signal processing. It is shown that as the fault was produced on the gear; it reflects the change in acoustic and vibration spectrum. It is observed from the amplitude of gear meshing frequency has increased considerably.

REFERENCES


