Bearing Condition Monitoring for Rotating Equipment

Alwi Abidin
Master of Mechanical Engineering
Swiss German University
Tangerang City, Indonesia
alwi@intitech.co.id

Hanny J. Berchmans
Master of Mechanical Engineering
Swiss German University
Tangerang City, Indonesia
hanny.berchmans@lecturer.sgu.ac.id

Henry Nasution
Master of Mechanical Engineering
Swiss German University
Tangerang City, Indonesia
henry.nasution@sgu.ac.id

***Abstract*— In industries, high maintenance cost is one of the main concerns. Most of the budget for maintenance is spent ineffectively. Many of them still use run-to-failure and preventive strategies as their concept of maintenance strategy, and they still don't have the proper tools to identify the condition of the machine. Bearings are one of the most critical elements for rotating equipment in the machineries. Establishing a predictive maintenance method by monitoring the current situation of the bearing will maximize the life span of the path and reduce the total cost of maintenance. In this work, to know the condition of a bearing, it is necessary to capture the vibration at high-frequency range. By analyzing the vibration pattern, the bearing failure in an earlier stage can be properly identified.**

***Keywords*—bearing condition monitoring, vibration, rotating equipment, predictive maintenance.**

I. INTRODUCTION

In industries, high maintenance cost is one of the main concerns. Most of the budget for maintenance is spent ineffectively. There are some reasons or causes for the maintenance cost ineffectiveness. Identification of these causes is used to define the methodology and strategy for better and effective maintenance in many industries to reduce the cost. Fig.1 shows that the main maintenance strategy is divided into four categories: run to failure, preventive, proactive and predictive [1].

In this work, we aim to exhibit the method analysis of vibration of rotating equipment, especially the bearings, by collecting the vibration data, so that an operator can identify the latest condition of the bearings and when the overall vibration limit is exceeded, the operator could take corrective action to reduce the unscheduled shutdown.

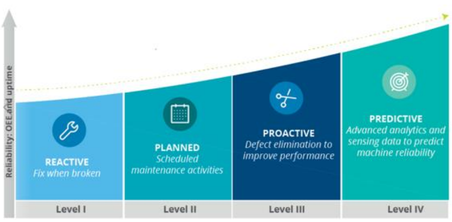

Fig.1. Level of maintenance strategy

A. Vibration Analysis

Vibration analysis is the most popular approach for condition monitoring inspection. At normal condition, a rotary machine will run at low vibration. But when a problem occurs and a dynamic process is affected in a rotary machine, the vibration pattern will change. The most reliable approach to assess the health of rotating machinery is by monitoring the vibration condition.

B. Bearing Problems

Bearings are generally applied in rotating equipment. 50% of all machine malfunctions are due to bearing failures. High-resolution spectral analysis can be used to discover bearing faults. If a bearing has a damage, then it causes the system to vibrate more. The unusual vibration can also cause unplanned shutdown and shorten the life of the other component. Therefore, it's important to monitor the vibration of this bearing.

C. Condition Monitoring

The main purpose of a condition monitoring system is to protect and warn the user if the machine is malfunctioning [2]. The condition-based maintenance system is implemented by monitoring vibration data of rotating equipment. The vibration data are taken from the sensors that are attached in the bearings and compared to acceptable vibration levels regularly. In industry, online monitoring techniques with time and frequency domain can be utilized to monitor vibration.

II. METHODOLOGY

A. Rolling Elements Bearings

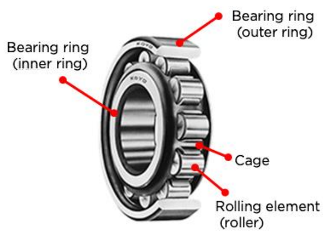

Fig. 2. Bearing elements

As shown in Fig. 2, bearing inner ring, outer ring, rolling element, and cage are the essential components of a bearing. The outer ring is usually fixed on the housing, while the inner circle is attached to a rotating shaft. Depending on the load-carrying capability, the rolling parts may be ball or roller. The cage isolates the rolling elements to keep them from colliding [3].

Ball bearings are the most frequent type of rolling-element bearing utilized for high-speed applications. However, roller bearings are more commonly used for applications requiring great load-carrying capability [4].

B. Bearing Fault Frequencies Characteristic

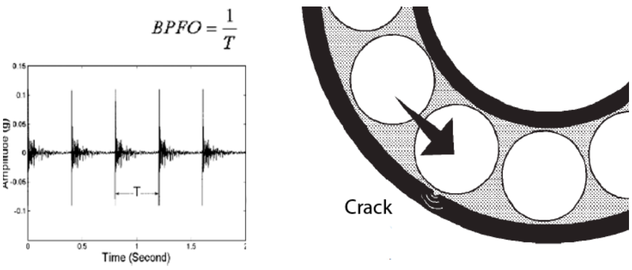

Fig. 3. Bearing fault frequencies

As shown in Fig. 3, bearing failure can be caused by various issues, including cracks, wear damage, incorrect lubrication, and corrosion. If the outer race of a bearing dented or cracked, then impulsive force is incurred each time one of the balls rolls over, causing the bearing to vibrate and the bearing rings its inherent frequency in response [5]. This is the basic frequency of interest in bearing defect detection. There are four frequency characteristic equations for bearings in which the inner race rotates while the outer race remains stationary:

1. Train, Cage Frequency (FTF):

$$FTF(Hz) = S(\frac{1}{2})(1 - \frac{B}{P}\cos\Phi)$$

2. Ball Pass Frequency, Outer race (BPFO):

$$BPFO(Hz) = S(\frac{N}{2})(1 - \frac{B}{P}\cos\Phi)$$

3. Ball Pass Frequency, Inner race (BPFI):

$$BPFI(Hz) = S(\frac{N}{2})(1 + \frac{B}{P}\cos\Phi)$$

4. Ball Spin Frequency (BSF):

$$BSF(Hz) = S(\frac{P}{2B})(1 - \frac{B^2}{P^2}cos^2\Phi)$$

C. Bearing Fault Detection Techniques

If bearing vibrations were simple, then bearing defect identification would be simple. However, bearing vibrations are complicated and dominated by high levels of misalignment and imbalance components, as well as random vibration from other sources. The ringing pulse sequence's spectrum components are not fundamental harmonics but rather small amplified harmonics [6].

D. Vibration Analysis 4 Stages Bearing Failure Method

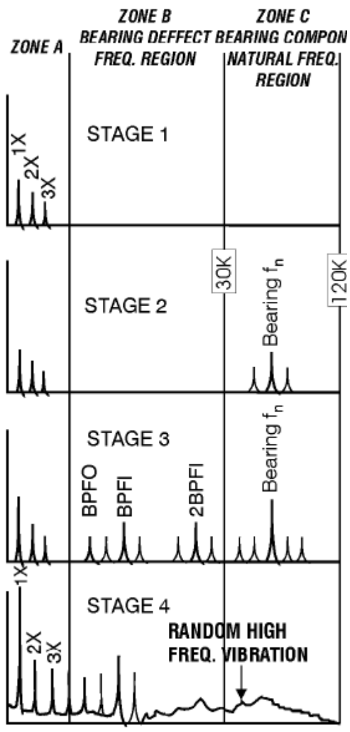

Fig. 4. Bearing failure stages

As shown in Fig. 4, the reasons for bearing failure may be varied as there are different stages of bearing failure, from premature failure to losses despite planning and maintenance. There are 4 stages of bearing failure indication [7]:

- In the first stage, the first signs of bearing difficulties can be found in ultrasonic frequencies ranging from 250.000 to 350.000 Hz. As the bearing wear increases, its vibration usually drops to approximately 1.200.000 to 3.600.000 CPM (20.000 to 60.000 Hz). The only instrument can evaluate the energy for this stage are Spike Energy or shock plus devices. Obtaining high frequency enclosed spectra in first stage will confirm whether the bearing is failing or not.

- Second stage, minor bearing faults begin to “ring” bearing component natural frequencies, which most commonly occur in the second stage in the 30 K to 120 K CPM (500 Hz to 2000 Hz) range. Such as natural frequencies can be due to the resonance of bearing support structures. Sideband frequencies appear above and below the natural frequency peak at the end of this stage.

- Third stage, bearing fault frequencies and harmonics develop. As wear grows, the number of fault frequency harmonics and sidebands increases. High frequency demodulated and enveloped spectra help to confirm the bearing damages, and it is advisable to replace the bearing at this stage.

- Fourth Stage, a random fluctuation of high-frequency vibration has occurred in this stage.

E. Mechanical Looseness Analysis

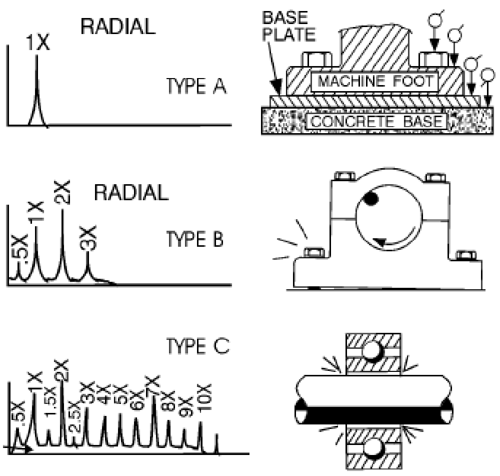

Fig. 5. Type of mechanical looseness

Mechanical looseness (Fig. 5) is indicated by either Type A and B or vibration spectrum.

Type A may cause by structural looseness, machine on soft baseplate or foundation. Type B may generally cause by pillow block bolts or cracks in frame structure. Type C may normally generate by improper fit between component parts which will cause many harmonics due to nonlinear response of loose parts to dynamic forces from rotor, bearing liner loose in its cap, a loose impeller on a shaft, etc. Type C phase is often unstable and may vary widely from one measurement to the next. A looseness will often cause subharmonic multiple at exactly 1/2 or 1/3 X RPM (.5 X, 1.5 X, 2.5 X, etc.) [7].

F. Block Diagram

Vibration is collected by the vibration sensors and then the signal is amplified by the instrumentation amplifier and processed by Data Acquisition system. The result of the vibration spectrum and analysis is processed in computer (PC) as shown in Fig. 6.

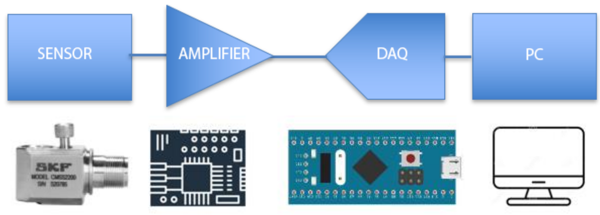

Fig. 6. Block diagram of bearing measurement kit

G. Design Measurement Tool

Fig. 7. Measurement tool

III. SIMULATION AND RESULT

In this simulation, an electric motor is used to drive a shaft using a coupling and pillow block bearing. 3 scenarios cylindrical bearing housing is prepared for this simulation such as normal bearing, outer race defect bearing and looseness bearing (Fig. 7).

Accelerometer piezoelectric sensor, instrumentation amplifier and microcontroller are required to collect the data from the sensor and send the data to the PC for further analysis.

A. Condition Monitoring Run Test on 12 kHz

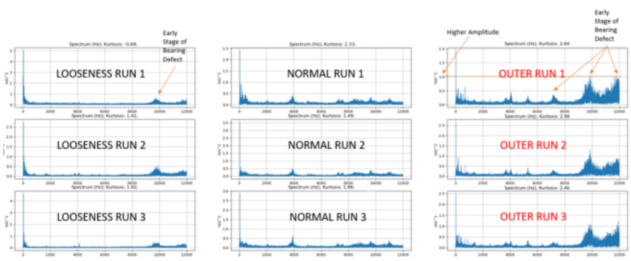

Fig. 8. Vibration data in 12 kHz

B. Condition Monitoring Run Test on 2 kHz

In the 12 kHz range (Fig.8), we focus on outer cage defect detection. The result show that the bearing is still in early stage of failure. The impact is still small, and it is only can be detected well in high frequency. Also, it has the highest amplitude compared to looseness and normal bearing conditions.

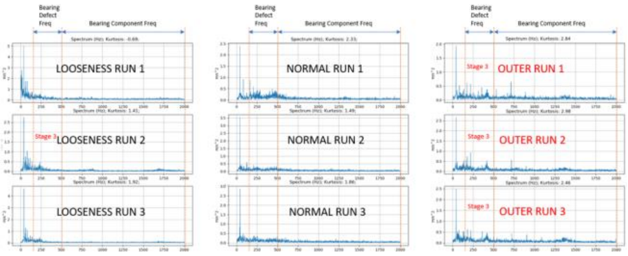

Fig. 9. Vibration data in 2 kHz

Based on the 4 stages bearing failure theory, there are some peaks on the left of the spectrum for outer and looseness bearing, and it is also categorized as stage 3 level, and it is recommended to replace the bearing (Fig. 9).

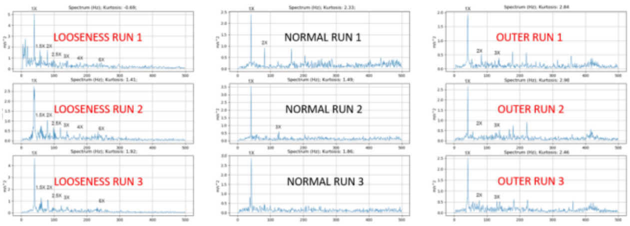

Fig. 10. Vibration data in 500 Hz

As shown in Fig. 10, the chart is zoomed to 500 Hz. The chart shows the velocity area to confirm the looseness indication on bearing 1 time peak, and then it occurs again on 1.5 times, 2 times. 2.5 times, 3 times, 4 time until 6 times. It indicates that there is looseness based on the 4 stages bearing failure theory.

On the normal middle chart. We only see 1 time peak, which is the frequency motor itself, and we can see on the right chart, the harmonic pattern occurs in this spectrum on 1 time, 2 times and 3 times around 40 Hz, 80 Hz, and 120 Hz, this indicates the outer race defect occurs in the bearing.

IV. CONCLUSION

Based on data obtained from several experiments and tests, the following conclusions can be drawn:

1. Vibration data monitoring and analysis show how to implement good predictive maintenance in the rotating machines. By analyzing the trending and history of the vibration data, the operator machine cand find the root cause of the machine failure.
2. The effectiveness analysis for bearing fault is presented in charts or graphs. The machine operator can see the trending and predict the machine condition and plan the right time to replace. With condition monitoring, if the vibration spectrum shows good results, then it will extend the asset lifetime despite the schedule or running hour limit has over. The machine operator may decide to continue to operate the machine without any replacement. Thus, this may benefit and reduce the total cost of maintenance.

In this work, to know the condition of a bearing, it is necessary to capture the vibration at high-frequency range. By analyzing the vibration pattern, the bearing failure in an earlier stage can be properly identified.

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