A review on various signal processing techniques used in bearing fault detection

Manpreet Singh*, Rajeev Kumar*, Piyush Gulati*, Jaiinder preet Singh*, Sumit Shoor*, Harpreet Singh**

*School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab-144411

**Department of Planning and Quality, Nettbuss AS, Oslo, Norway.

Abstract

Bearing is an important element in any machine as most of the failures in the machine are happening due to bearing failure. Therefore, bearing needs to be inspected for its faults regularly to verify its health so that shutdown of the machine should not occur during its repair. This paper aims to review the trending techniques used in the detection of bearing faults using signal processing of the vibration signal. The main advantage of using these techniques is that one needs not to dis-mental the bearing for the purpose of inspection. The paper is mainly structured in three parts, in the first part the bearing nomenclature along with types of bearing are discussed. In second the most common faults in the bearing are discussed and in last overall view of detecting these faults is presented.

Introduction of Bearing

Bearing is a machine element made of highly precision which enable to take extremely high speed and for taking high load's at good efficiency for machine component. It generally supports rotating shaft with high precision and reliability. Therefore, bearing is having vast number of applications such as construction machinery, automobiles, machines, turbines, motors and many more applications [1].

1.1 Function of bearing

The main function of bearing is to ensure stability of rotating shaft with having various loads acting in different directions. In addition to this bearing has to provide frictionless rotation of shaft without slip. Let's discuss these functions in detail below

1.1.1 Supporting the load

Load on the bearing may be from any of the direction across. Sometimes bearing may bear loads from multiple directions too. For instance, bearing of axle can be predicted to bear load from all the directions. The prime objective of the bearing is to bear the load without failure however, the every type of bearing is having its own set of applications for the load. The type of loads incur on bearing are as follows

- **Radial Load**

  When the direction of load is across the radius of the bearing it means load is acting perpendicular to the supported shaft. This type of load will try to push the bearing in the downward direction. Most suitable bearing for radial load is roller bearing.

- **Thrust load**

When the direction of load is parallel to the supporting shaft then this type of load is called as thrust load. In this type of load bearing must be having high strengths on the both sides to prevent the failure. Most suitable bearing for thrust load is thrust bearing.

- **Angular load**

If the load is neither perpendicular to supporting shaft nor parallel to the supporting shaft then the load is known as angular load. In this bearing requires combined radial and thrust strength the bear the load without failure. The different types of loading conditions are shown in Figure 1.

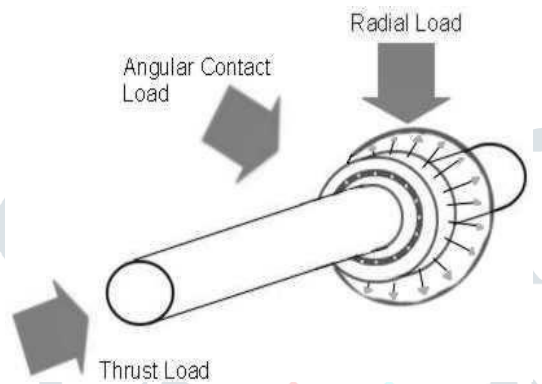

Figure 1: Different type of load on bearing

1.1.2 Reducing friction

Another bearing objective is to reduce friction between components that are moving during mating. By reducing friction, shaft movement within bearing housing will be reduced and the required effort and energy could be saved. The surface is very smooth of inner and outer race of bearing that help to decrease the friction and we can also use lubricant for reducing the friction.

1.2 Bearing parts

Bearing is basically assembly of outer race, inner race, ball/ roller and cage [2]. Inner race in general fits on the rotating shaft, Outer race fits inside the bearing housing and Balls or rollers are rolling between the surfaces of two races to provide rolling action. Cage separates the balls or rollers rolling between two races. The schematic diagram of roller bearing is shown in the Figure 2. Rolling contact area that includes outer race, inner race or ball/roller are the main failure elements in bearing because this part is under load conditions. There are many fine types of bearing these are designed accordingly to different application are classified in details.

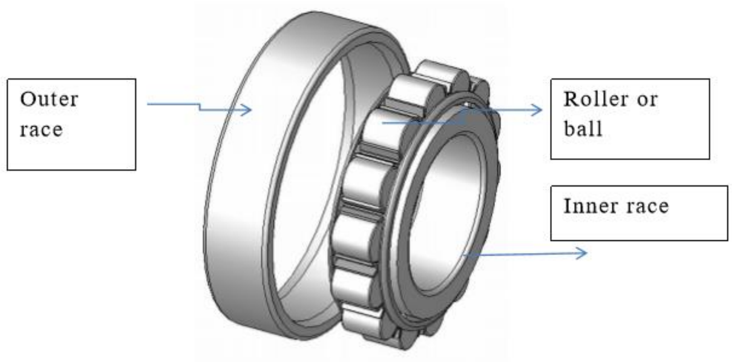

Figure 2: Schematic diagram of roller bearing

1.3 Bearing classification

Different types of bearing are having different applications and suitability [3-6]. Most commonly used bearing are ball bearings, roller bearings and thrust bearings which are further classified below

1.3.1 Ball Bearings
1.3.2 Roller Bearings
- a. Needle Roller Bearing
- b. Taper Roller Bearing
- c. Spherical Roller Bearings

1.3.3 Thrust Bearings
- a. Thrust ball bearings
- b. Cylindrical thrust roller bearings

1.4.1 Ball Bearings

Ball bearings are most common type of bearing used in the vast applications of automobiles [7-12]. These bearings are specially designed to handle both low level radial and thrust loads. These are also known as self lubricating bearings as rolling action is being provided by metallic or ceramic spheres. In case of overloading, high stress will be produced on the rolling surfaces and it can even breakdown the bearing. The schematic diagram of ball bearing is shown in the Figure 3. Ball bearing is having vast application in the automobile, shipping and aviation industry.

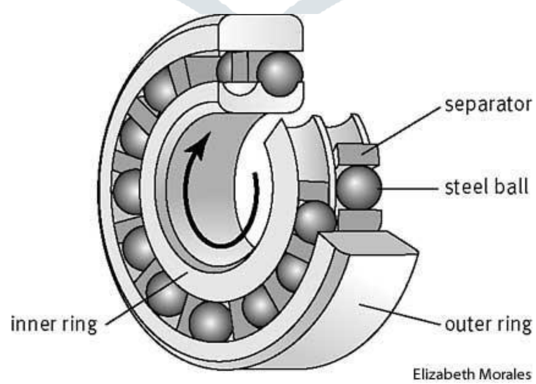

Figure 3: Ball bearing

1.4.2 Roller bearings

Instead of spheres, roller bearings use cylinders which rolls over inner race and outer race of the bearing to make a contact between. Due to its line contact with inner and outer race it has higher capacity to handle higher loads then that of ball bearing. The schematic diagram of roller bearing is shown in the Figure 4. Roller bearings can further be classified broadly on the basis of type of roller used such as needle roller, taper roller and spherical roller.

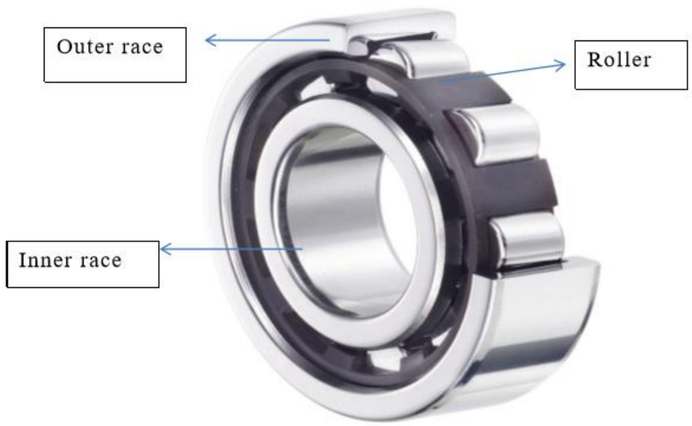

Figure 4: Roller bearing

a. Needle Roller Bearing

This type of bearing using roller with very small diameter. This type of bearing is not suitable for high speed applications but it has capacity to handle high radial loads. These bearings are manufactured for the applications where radial space is very limited and they can be built up of small sizes. These types of bearing are not able to handle axial loads. In this bearing needles are generally parallel to the supporting shaft.

b. Tapered roller bearing

This type of bearing is designed to handle both types of loads radial and axial. In this the rollers are of taper type and in case axis of rollers are extended then they all are meeting at the same point. They are self-lubricating and used where loading conditions are not predictable such as axles of the automobile. It can be used for high speed and high load applications. The load taking capacity of the taper roller bearing increases with increase of taper angle of the roller. The researchers are using this type of bearing for the purpose of experimentation because it can be easily be dis-assembled or assembled [7,8,12]. The schematic diagram of taper roller bearing is shown in the Figure 5.

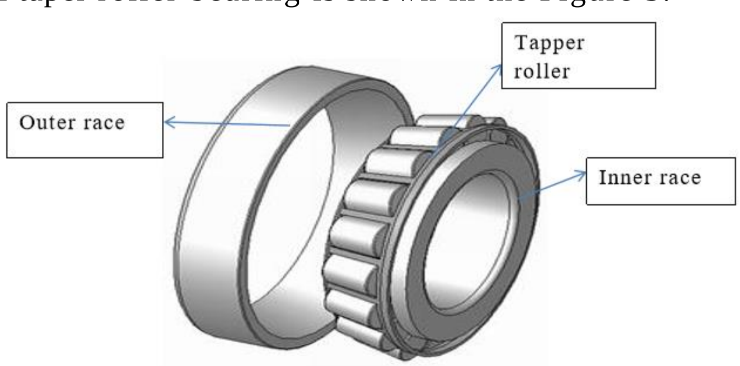

Figure 5: Tapper roller bearing

c. Spherical roller bearing

These types of bearing are having very complex design and difficult to manufacture. Therefore, they are very costly. They are specifically designed to handle very high radial loading conditions. The friction in the rolling is comparatively high due to different speeds of rollers so it cannot be used for high speed applications. The schematic diagram of spherical roller bearing is shown in the Figure 6.

1.4.3 Thrust bearing

These types of bearing are specifically designed to handle axial load. In these bearings both balls and cylinders can be used depending upon the type of applications. These bearings generally support the vertical shaft such as rotating table, gearsets of vehicle transmission.

Figure 6: Spherical roller bearing

1.4 Bearing failure

In any machine bearing failure is highly significant because there may be a complete failure in machine because of it. So, the bearing is highly substantial part to be taken care through predictive maintenance so that we can predict the failure before it occurs [10-12]. The main failure characteristics of the bearing can be in form of a bath tub curve

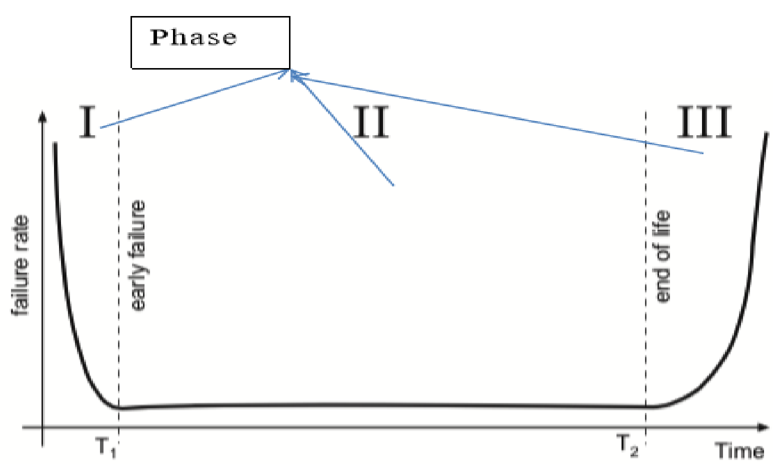

Figure 7: Bath tub curve

There are three regions in this bath tub curve that define the failure rate of bearing according the time.

1) Phase-1: Infant mortality (initial running-in) phase 2) Phase-2: Useful (normal operating) phase
3) Phase-3: Wear out phase

Infant mortality phase basically shows the premature failure in the bearing. This is the main phase where the studies the prominently applied. In this region of highly concern for the person doing failure study.

Second phase is basically smooth where rate of failure is minimum but after crossing this phase normally wear and tear occur in bearing and bearing enters in wear out phase. In the wear out phase bearing in general fails after spending its normal life.

1.5.1 Bearing defect causes

There are number of causes due to which defects of different kinds are initiated in the bearing. We are referring few of the significant reasons below

- Excessive load - Excessive load often contributes to premature tiredness. Tight brinelling and inadequate preloading can also lead to early failure
- Overheating – The ball and the inner surface material can be annulled by excess temperature. The resulting loss of the hardness of the bearing
- Normal fatigue failure – Fatigue loss generally referred to as spreading – is the cracking of the running layer and resulting displacement of small individual substance particles
- Contamination – In contamination raceways of the bearing generally erodes and and during operation bearing generates high vibrations. This is happening because of dirt or dust of abrasive material.
- Lubricant failure – If the supply of lubricant is restricted during the operation of bearing then this type of failure occurs. It can also be caused by using degraded lubricant and in this temperature of the surface rises.

1.5 Bearing Defect Frequencies

Bearing when running generates its own set of frequencies while running. When the defect is present on the outer race then every time when the roller/ball passes over the defect will generate an impulse. Theses impulses will be having its own value of frequency depending upon number of rollers, rpm of the shaft, ball diameter, pitch circle diameter and pressure angle. In this section a brief review is given for how to calculate the different defect frequencies. The line diagram of bearing is shown in Figure 8. The notations used are as follows

N_b = number of ball

W_i - Relative speed difference between inner and outer race (RPM)

V_i = velocity of inner race

V_o = velocity of outer race

P_d = pitch diameter $= \left\{\frac{Di+Do}{2}\right\}$

B_d = ball diameter

Ø = contact angle

Di = inner race diameter

Do= outer race diameter

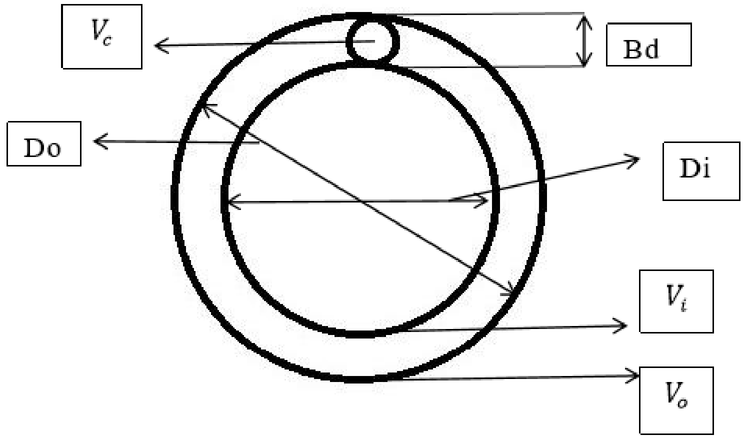

Figure 8: Line diagram of bearing diagram

Fundamental Train Frequency

Linear velocity of each ball center

$$V_c = \frac{V_i + V_o}{2}$$

$$W_c = \frac{V_c}{R} = \left[\frac{\frac{Vi+Vo}{2}}{\frac{Pd}{2}}\right]$$

$$FTF = W_c = \left[\frac{W_i\left(\frac{P_d}{2} - \frac{B_d \cos\emptyset}{2}\right) + W_o\left(\frac{P_d}{2} + \frac{B_d \cos\emptyset}{2}\right)}{P_d}\right]$$

$$= \frac{1}{2}\left[W_i\left(1 - \frac{B_d \cos\emptyset}{P_d}\right) + W_o\left(1 + \frac{B_d \cos\emptyset}{P_d}\right)\right]$$

where $\boldsymbol{W_o} = \boldsymbol{0}$

$$\textbf{FTF} = \frac{Wi}{2}\left\{1 - \frac{B_d}{P_d}\cos\emptyset\right\} \text{......................(EQ 1.1)}$$

Outer race pass frequency= N_b.FTF

$$= N_b.\frac{Wi}{2}\left\{1 - \frac{B_d}{P_d}\cos\emptyset\right\} \text{..............................(EQ 1.2)}$$

Inner race frequency

$$= N_b[W_i - W_o]$$

$$= N_b\left[W_i - \frac{1}{2}\left[W_i\left(1 - \frac{B_d\cos\emptyset}{P_d}\right) + W_o\left(1 + \frac{B_d\cos\emptyset}{P_d}\right)\right]\right]$$

$$= N_b\left[\left(\frac{W_i - W_o}{2}\right) + \left(\frac{W_i - W_o}{2}\right)\frac{B_d\cos\emptyset}{P_d}\right]$$

$$= N_b(W_i - W_o)\left(1 + \frac{B_d\cos\emptyset}{P_d}\right)$$

Where $W_o = 0$

$$= N_b\left[\frac{Wi}{2}\left\{1 + \frac{B_d}{P_d}\cos\emptyset\right\}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(EQ 1.3)}$$

1.7 Signal processing techniques used for detection of bearing failure

Bearing is one of the main essential components of machinery because this part is under heavy loads. Bearing is a kind of fault initiation, in bearing is very crucial and it has to be detected before bearing completely fails. From the raw signal it is very difficult to identify the fault at incipient stage. So, signal processing techniques are applied to identify the fault. In our case study we have selected induced outer race defect to be analyzed by using different signal processing technique and hence we will check their effectiveness.

In vibration analysis signal is being captured from the vibrating machine by transducer and with help of data acquisition system (DAQ). Signal is stored in the computer system. Signal processing techniques are then applied on the signal to extract the useful information. The main defect or failure occurs in rotating part in any machinery like in bearings or gears.

The main working of signal-processing based techniques is shown in Figure 9. In this firstly raw signal was recorded using transducer which converts physical signal into voltage. Then signal in the form of voltage goes to Data acquisition (DAQ) device and signal gets converted into readable values format. Then analog signal is converted into digital for the purpose of processing in analog to digital convertor (ADC). After processing signal again gets converted from digital to analog form in digital to analog convertor (DAC). Then signal gets analyzed for final results.

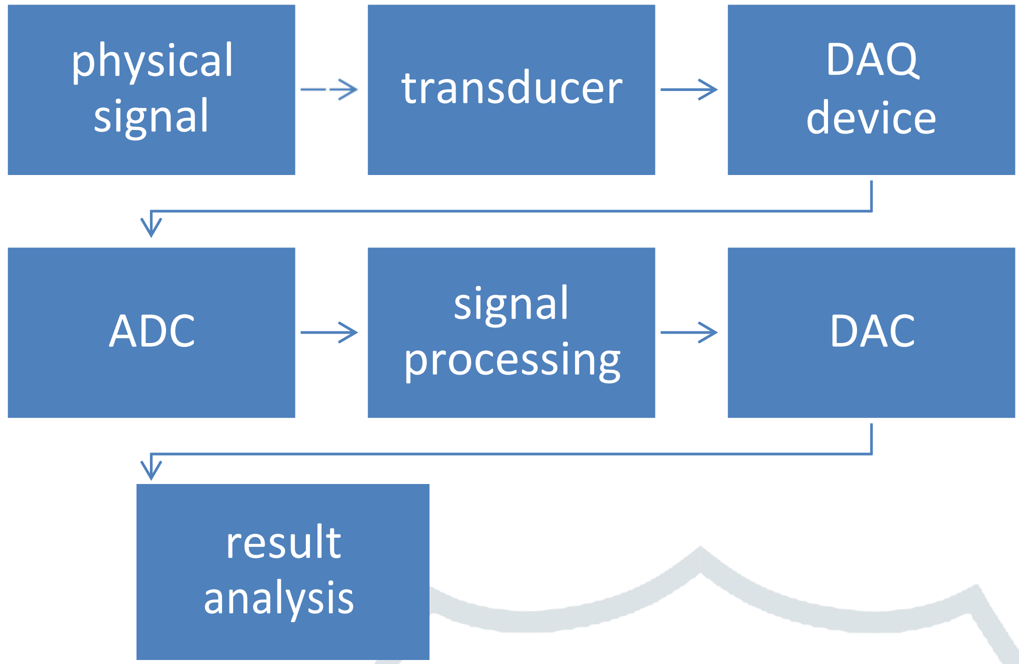

Figure 9: Signal processing technique

Conclusion

The use of signal processing techniques in predicting the health of bearing are widely used. The main advantage of using signal processing for monitoring is that one need not to dis-mental the bearing for the purpose of inspection. Therefore, this paper has presented the bearing nomenclature in detail along with its types. Then about the faults which may incur in bearing and its type of damages. These damages effect on vibration signal are also discussed in detail. At last how the signal processing technique works in detecting the fault in bearing. This paper will be very helpful for those who wants to apply signal processing techniques in the condition monitoring of bearing.

References

[1] Cambow, R., Singh, M., Bagha, A.K., Singh, H.: To compare the effect of different level of self-lubrication for bearings using statistical analysis of vibration signal. Materials Today: Proceedings, 5(14), Part 2, 28364-28373(2018).

[2] Gillich, G.R., Mituletu, I.C., Praisach, Z.I., Negru, I. and Tufoi, M.: Method to enhance the frequency readability for detecting incipient structural damage. Iran J Sci Technol Trans Mech Eng 41(3), 233-242(2017).

[3] Bains, M. and Kumar, R.: Detection of missing ball in bearing using decomposition of acoustic signal. Asian J of Chem 21(10), 143-147(2009).

[4] He, Q., Li, P. and Kong, F.: Rolling Bearing Localized Defect Evaluation by Multiscale Signature via Empirical Mode Decomposition. J. Vib. Acoust 134(6), 061013(2009).

[5] Yan, R., Gao, R.X. and Wang, C.: Experimental Evaluation of a Unified Time-Scale-Frequency Technique for Bearing Defect Feature Extraction. J. Vib. Acoust 131(4), 041012(2009).

[6] Zhu, D., Gao, Q., Sun, D., Lu, Y. and Peng, S.: A detection method for bearing faults using null space pursuit and S transform. Signal Proc 96(Part A), 80–89(2014).

[7] Kumar, R. and Singh, M.: Outer race defect width measurement in taper roller bearing using discrete wavelet transform of vibration signal. Measurement 46(1), 537-545(2013).

[8] Singh, M., Yadav, R.K. and Kumar, R.: Discrete Wavelet Transform Based Measurement of Inner Race Defect Width in Taper Roller Bearing. MAPAN- J of Metrology Soc of India 28 (1), 17-23(2013).

[9] Sawalhi, N., Wang, W. and Becker, A.: Vibration signal processing for spall size estimation in rolling element bearings using autoregressive inverse filtration combined with bearing signal synchronous averaging. Adv in Mech Eng 9(5), 1–20(2017).

[10] Aye, S.A.: Statistical Approach for Tapered Bearing Fault Detection using Different Methods. Proc of the World Cong on Eng Vol III, July 6 - 8, London, U.K., 2112-2115(2011).

[11] Jena, D.P., Singh, M. and Kumar, R.: Radial Ball Bearing Inner Race Defect Width Measurement using Analytical Wavelet Transform of Acoustic and Vibration Signal. Measurement Sci Review 12(4), 141-148(2012).