# A Review on Condition Monitoring and Fault Diagnosis of Rolling Element Bearing

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***Abstract***

*Rolling element bearings (REB) find widespread domestic and industrial applications. Proper function of these appliances depends on the smooth and quiet running of the bearings. In industrial applications these bearings are considered as critical mechanical components and a defect in such a bearing, unless detected in time, causes malfunction and may even lead to catastrophic failure of the machinery. Defects in bearings may arise during the manufacturing process as well as over using and weathering of the bearings. The defect in rolling elements may lead to serious catastrophic consequences resulting in costly downtime. Therefore detection of these defects is important for condition monitoring as well as quality inspection of bearings. Different methods are used for detection and diagnosis of bearing defects; they are classified as vibration and acoustic measurements, temperature measurements and wear debris analysis. For monitoring the condition and diagnosing the fault that may occur in rolling element bearing, the vibration analysis technique is widely used because it is most reliable and accurate defect detecting technique.*

***Keyword:*** REB, bearings, mechanical components, bearing defects.

## 1. Introduction

A bearing is a machine element that allows one part to support another and the main function of a bearing is to reduce the friction between the two or more machine components. The rolling element bearing is a bearing which carries a load by placing rolling elements like balls or rollers between two bearing rings called races. Rolling element bearings are the most crucial part in any of the appliances weather it may be any small domestic appliance like mixer grinder or washing machine or any heavy industrial machine. Proper function of these appliances and machineries depend on smooth and proper functioning of these bearings. Defects may cause a huge loss in industries and may get dangerous for mankind too. When the defect in a rolling element comes in contact with another element surface, an impact force is generated which is results in an impulsive response of the bearing. A defect at any element of the REB transmits to all other elements such as outer race, inner race, ball and train cage of the bearing. An analysis should be made to identify the bearings defects before they become catastrophically fail with the associated downtime costs and significantly damage to other parts of rotating machineries. Intensive research has been done in recent years for the REBs defect diagnosis to ensure the performance and extend the bearing life. The fault analysis techniques are discussed below. [2]

## 2. Fault Analysis And Condition Monitoring Techniques:

The art of machine condition monitoring is knowing what to look for, and successful diagnosis is having the ability to measure it and to correlate the results with known failure mechanisms. The four different techniques used for fault analysis and condition monitoring of a rolling element bearings are vibration analysis techniques, temperature analysis, wear and debris analysis and acoustic analysis.[3]

### 2.1. Vibration Signal Analysis:

The vibration signal analysis is the analysis of vibration monitoring data to monitor the characteristic changes in rotating machinery caused by imbalance, misalignment, bent shaft, mechanical looseness, fault in gear drives, defects in rolling element bearings and defects in sleeve bearings. The factors which influence the bearing vibration includes different machine types, bearing types and modes of failure. Condition monitoring can be divided up into three main areas, detection, diagnosis and prognosis. Detection can often be as simple as determining that a serious change has occurred in the mechanical condition of the machine. Diagnosis in effect determines the location and type of the fault, while prognosis involves estimation of the remaining life of the damaged bearing. So the key factor involved in analysis of vibration signal is underlying the science of bearing vibration, bearing kinematics and dynamics, bearing life, vibration measurement, signal processing techniques and prognosis of bearing failure.[1]

### 2.2. Temperature Analysis:

The temperature analysis is defined as a group of methods based on the determination of changes in physical properties of rolling element bearings as a function of temperature in a controlled atmosphere. The expected bearing operating temperature is important for designing the bearing arrangement, lubrication and scaling, and for determining the proper bearing setting and fitting practice. Excluding extraneous heat, the operating temperature of a rolling element bearing under medium speed and load conditions is relatively low. The principle of temperature analysis is based on the law of energy conservation, known as the first law of thermodynamics, and on the rate equations of heat transfer. The two basic elements being used for bearing temperature analysis are heat generation and heat transfer which includes conduction and convection.[9]

### 2.3. Wear Debris Analysis:

Fault detection using vibration analysis is difficult in very low speed – high load noisy machines. In the case of slow speed bearing the vibration generated by damaged components is very low, usually close to the floor noise and difficult to identify. In these situations, the wear debris analysis has proven useful in providing supporting evidence on the bearing or gear status. It also provides information on the wear mechanism, which is involved. The wear is caused by the relative motion between metallic parts. The motion is accompanied by friction and wear on the surfaces, which are in contact with one another. Lubricant plays a vital role in analyzing, controlling and causing the wear in the elements. This technique of wear debris analysis is based upon the systematic collection of oil samples from an oil lubricated machines. The method identifies, isolate and classify wear particles from machine parts. A magnetic field is used to sort the wear particles in the flowing oil. This technique was used to monitor the condition of military aircraft engines, gear boxes and transmission.[8]

### 2.4. Acoustic Measurement:

Acoustic measurement is the technique of measuring the sound variations that occur in the bearings while they are in work. It includes measurements of the values that describe sounds and noises in terms of their intensities and various qualitative features, such as their spectra or the growth and decay of the sound over time. The principle values measured in acoustics are sound pressure, sound intensity, vibration velocity and particle displacement, the frequency and period of vibrations, propagation velocity, damping factor and others. The most important characteristic is sound pressure, because the human ear responds to the sound wave pressure. The changes in bearing's alignment and defect in them causes the variation in the sound wave be it pressure, intensity, frequency etc. The difference in the normal values and the deviated value is calculated then, and preventive measures are taken reduce the risk of failure and damage.[7]

## 3. Signal Processing Techniques:

### 3.1 Fast Fourier Transform:

A Fast Fourier Transform (FFT) is an algorithm that samples a signal over a period of time (or space) and divides it into its frequency components. These components are single sinusoidal oscillations at distinct frequencies each with their own amplitudes and phase. An FFT algorithm computes the Discrete Fourier Transform of a sequence, or its inverse (IFFT). Fourier analysis converts a signal from its original domain to a representation in the frequency domain and vice versa. An FFT rapidly computes such transformations by factorizing the DFT matrix into a product of sparse (mostly zero) factors. As a result, it manages to reduce the complexity of computing the DFT. Fast Fourier Transforms are widely used for signal spectral analysis.[5]

### 3.2 Wavelet Transform:

Wavelets are mathematical functions that cut up data into different components, and then study each component with a resolution matched to its scale. These basis functions are short waves with limited duration, thus the name wavelets is used. The basis wavelets (transforming function) of the wavelet transform are scaled with respect to frequency. There are many different wavelets that can be basis functions, a few of them are shown below:[4]

### 3.2.1 Daubechies Wavelets: dbN

In dbN, N is the order. Some of them are used as 2N instead of N. These wavelets have no explicit expression except for db1, which is the Haar wavelet. The support length of Ψ and Φ is 2N-1. The number of vanishing moments of Ψ is N. Most dbN are not symmetrical. For some, the asymmetry is very pronounced. The regularity increases with the order. Certainly, this asymptotic value is too pessimistic for small-order N. Note that the functions are more regular at certain points than at others. The analysis is orthogonal.[12]

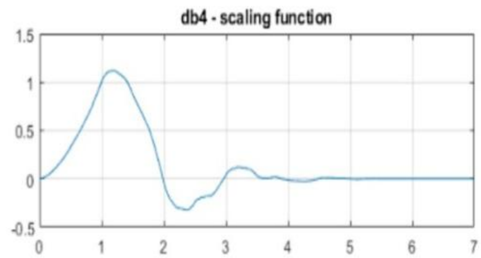


*Fig.1 Daubechies Wavelet*

### 3.2.2 Symlet Wavelets: symN

In symN, N is the order. Some of them are used, as 2N instead of N. Symlets are only near symmetric. The symlet wavelets are the modified version of Daubechies wavelets with increased symmetry. The idea consists of reusing the function m0 introduced in the dbN, considering the modulus of $m_0(\omega)^2$ as a function W of $z=e^{\omega}$ . Then we can factor W in several different ways in the form of W(z)=U(z)U, because the roots of W with the modulus not equal to 1 go in pairs. By selecting U such that the modulus of all its roots is strictly less than 1, we build Daubechies wavelets dbN. The U filter is a “minimum phase filter”.[11]

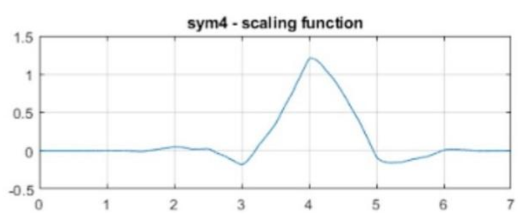


*Fig.2 Symlet Wavelet*

### 3.2.3 Haar Wavelet:

This family includes the Haar wavelet, written db1, the simplest wavelet imaginable and certainly the earlies. The wavelet function of Haar wavelet is as follows:

$\Psi(x) = 1;\ 0 \le x < \frac{1}{2},$

$-1;\ \frac{1}{2} \le x < 1,$

$0;$ otherwise.

The scaling factor of Haar wavelet is, $\Phi(x) = 1;\ 0 \le x < 1,$

$0;$ otherwise.

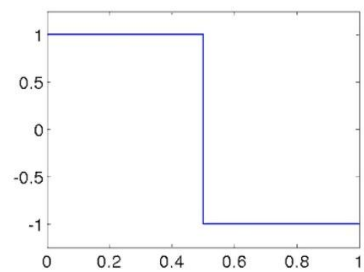


*Fig.3 Haar Wavelet*

**3.2.4 Coiflet Wavelet: coifN**

In coifN, N is the order. Some of them are used 2N instead of N. The function Ψ has 2N moments equal to 0 and the function Ψ has 2N-1 moments equal to 0. The two functions have a support of length 6N-1. The coifN Ψ and Φ are much more symmetrical than the dbNs. With respect to the support length, coifN has to be compared to db3N or sym3N. With respect to the number of vanishing moments of Ψ, coifN has to be compared to db2N or sym2N.[10]

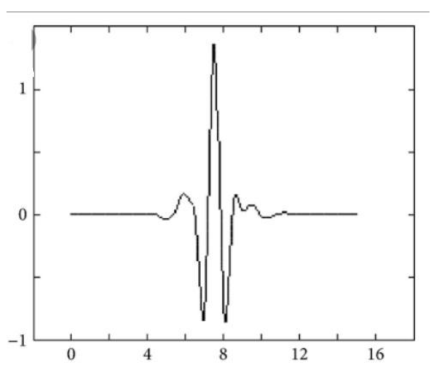


*Fig.4 Coiflet wavelet*

**3.2.5 Biorthogonal Wavelet: biorNr.Nd:**

The new family extends the wavelet family. It is well known in the sub band filtering community that symmetry and exact reconstruction are incompatible (except for the Haar wavelet) if the same FIR filters are used for reconstruction and decomposition.[10]

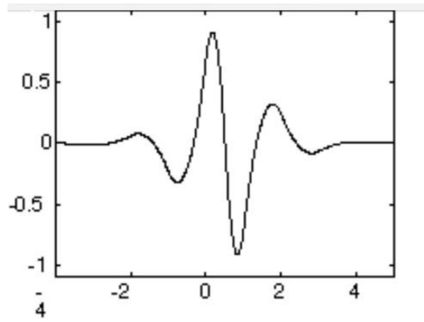


*Fig.5 Biorthogonal Wavelet*

### 3.3 Numerical Methods of Signal Analysis:

Numerical methods of signal analysis were the basic stepping stone towards the field of signal analysis. The scope of signal processing far exceeds the capability of any single book or paper to contain it. Signal processing is that area of applied mathematics that deals with operations on or analysis of signals, in either discrete or continuous time, to perform useful operations on those signals. Signal processing covers a large territory of applied mathematics. However, there is a common thread among all the areas mentioned: they all involve a fair degree of mathematical sophistication and in both theory and practice assume an analytical and a computational component. Depending on the type of signal analysis several mathematical tools can be applied in the process to get the desired result. Some of them are mentioned here probability and stochastic processes, calculus and analysis, vector spaces and linear algebra, numerical methods, functional analysis, linear signals and systems and transform theory, optimization, statistical decision theory etc.[5]

### 3.4 Artificial Neural Network:

An artificial neural network is an interconnected group of nodes, akin to the vast network of neurons in a brain. Here, each circular node represents an artificial neuron and an arrow represents a connection from the output of one artificial neuron to the input of another. In ANN implementations, the signal at a connection between artificial neurons is a real number, and the output of each artificial neuron is calculated by a non-linear function of the sum of its inputs. Artificial neurons and connections typically have a weight that adjusts as learning proceeds. The weight increases or decreases the strength of the signal at a connection. Artificial neurons may have a threshold such that only if the aggregate signal crosses that threshold is the signal sent. Typically, artificial neurons are organized in layers. Different layers may perform different kinds of transformations on their inputs. Signals travel from the first (input), to the (output) layer, possibly after traversing the layers multiple times.[9]

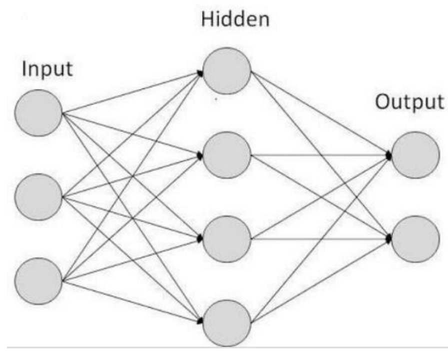


*Fig.6 Artificial Neural Network*

## 4. Conclusion

Rolling element bearings play a very significant role in machineries as their function is to support another moving and rotating mechanical elements as well as to reduce friction between them. The REBs are used in rotating machinery under high load and high rotational speeds. Defects in these bearings may cause a huge loss in industries, machineries and for humans too. Using one of the above discussed method of fault analysis and condition monitoring faults can be detected and repaired on time to prevent losses and accidents.

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