Identification of Bearing Faults using Wavelet Transform

Ajay Sharma, Prem Narayan Vishwakarma

ABSTRACT : This research is concerned with description of a scheme for bearing's localized defect detection based on wavelet packet transform (WPT). WPT provides a high resolution time-frequency distribution from which periodic structural ringing due to repetitive force impulses, generated upon the passing of each rolling element on the defect, are detected. The objective of this work is to emphasis on the outer race defect, inner race defect and ball defect. In modern industrial scenario, there is increasing demand for automatic condition monitoring that reduce the gap between digital model and actual product. With reliable condition monitoring, faults such as machine element failures could be identified in their early-stages and further damage to the system could be prevented. Successful monitoring is a complex and application-specific problem, but a generic tool would be useful in preliminary analysis of new signals and in verification of known theories.

Keywords: Bearings, Condition Monitoring, Diagnosis, Fault Detection, Wavelet Packet Transform (WPT), Root Mean Square Value (rms) and Machine Health Condition Monitoring (MHCM).

I. INTRODUCTION

The prevention of potential damage to machinery is necessary for safe and reliable operation of process plants. Failure prevention can be achieved by sound specification, selection and design audit routines. When a failure occurs, then finding the absolute root cause of that failure is the main requirement to the prevention of future failure events [1, 4 and 5]. A low-cost set-up and simple design was develop [17] machine fault simulator for rotating elements to identify fault diagnosis and vibration analysis. The extensive research has been carried out in the area of machine health condition monitoring (MHCM) and the work is still going on. During the last decade, Machine Health Condition Monitoring has evolved from breakdown maintenance to the developing stages of diagnosis of machinery and its components..

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The future of MHCM is the design of smart machinery with the built-in diagnostic capabilities. The machine health condition monitoring is based on a systematic engineering approach of data acquisition, signal processing, fault pattern recognition and classification of fault's features [15]. Condition based maintenance can significantly cut routine maintenance costs

Machinery condition monitoring covers distinctive disciplines such as mechanical measurements, electrical measurements, performance and process measurement and tribology. Therefore, it is very important to find out the defects of bearing that create different types of vibration characteristics. Vibration signals are captured from the bearing housing with either healthy or one of the faulty bearing and decomposed the each signal using wavelet packet transform up to six level and obtained 62 nodes are then compared for the rms value of the transformed signal coefficients at each node and taken as a characteristic to describe fault [3,6 and 7].

In the present work, focus is on the wavelet decomposition of time signal as an alternative of the Fourier Transform. This technique provides better analysis for non-stationary signals as permitting analysis of frequency bands to sort out our desired frequencies and rejecting other as considering noises. In this study, we compared rms values of the frequency bands of our interest with the rms values of the healthy bearing considering it as a baseline. There are various vibration signatures such as sound, temperature and vibration amplitude but the sound and temperature are not showing their significant variation when compared to our three bearings.

II. MACHINE HEALTH CONDITION MONITORING

Condition monitoring is a valuable preventative maintenance tool to extend the operating life of a machine. The Prevention of potential damage to machinery is necessary for safe and reliable operation of process plants. When failures do occur, accurate definition of the root cause is an absolute prerequisite to the prevention of future failure events. Equipment downtime and component failure risk can be reduced only if potential problems are anticipated and avoided. Often, this is not possible if we apply only traditional methods of analysis .It is thus appropriate to employ other means of precluding or reducing consequential damage to plant, equipment, and personnel. This leads to the way of new concept that is Machine Health Condition Monitoring. Traditional preventative maintenance not only leads to wasteful machine downtime but also premature replacement of parts. This needs the proper diagnosis of the machinery .The condition monitoring is new development in this field of maintenance.

Condition monitoring is a valuable preventative maintenance tool to extend the operating life of a machine. Successfully implementing a condition monitoring programs allows the machine to operate to its full capacity without having to halt the machine at fixed periods for inspection. Condition monitoring provides a powerful weapon in the maintenance armory. It provides early warning of many potential problems allowing planned maintenance and avoiding unscheduled outages. Condition Monitoring is most frequently used as a Predictive or Condition-Based Maintenance technique. However, there are other Predictive Maintenance techniques that can also be used, including the use of the Human Senses (look, listen, feel, smell etc.), Machine Performance Monitoring, and Statistical Process Control techniques.

Machine Health Condition Monitoring includes every area of a plant whether it is inspection, process, quality, design and material.

In the past decade, industrial facilities around the world have come to recognize that condition monitoring is a cost-effective way to avoid unanticipated downtime. More recently, facilities have discovered the importance of integrating collected information into a plant-wide system that can be shared by everyone with a key role in plant productivity. This trend has demonstrated that through a collaborative effort, maintenance, operations, engineering and management have been able to achieve productivity levels that were previously out of reach.

Condition monitoring of a machine or equipment can be easily compared to the health monitoring of an individual by diagnostic test /checks/instruments. For example, the annual medical check-ups which executives undergo each year is in reality a boon for them because they are told by doctors if they are perfect fully fit medically ,or certain symptoms are indicative of a malfunction and there is a need for corrective surgery or medication to control these. Machine health Condition Monitoring involves surveillance, That is ,obtaining of data specific to the machine to coming to certain conclusions known through 'diagnosis' by analyzing data. Thus, it will be seen that condition monitoring checks can indicate where problems are causing trouble and provide precise information on the machine health conditions and thus enable one to arrive at certain decisions well in advance of the actual breakdown.

III. VIBRATION SIGNATURE ANALYSIS

Monitoring, by definition is an act of extracting information from specific system by means of appropriate observation of instruments. The machine health may predict by several techniques (such as temperature, sound, oil contamination etc) the vibration signature monitoring is the superior one. Vibration monitoring thus consists of acquiring signals and using them as information carriers. Vibration signature responds much quickly to any deterioration in the machine components. A vibration signature measured at the external surface of a machine or at any other suitable place contains a good amount of information to reveal the running condition of the machine. Vibration monitoring is the technique of measuring vibration parameters e.g. Displacement, velocity or acceleration at suitable locations on the machinery (in this case it is bearings).

The word signature has been coined to designate signal patterns which characteristics the state or condition of a system from which they are acquired. Signatures are extensively used as a diagnostic tool for mechanical system. In many cases, some kind of signal processing is undertaken on those signals in order to enhance or extract specific features of such vibration signatures. Signature based diagnostic make extensive use of signal processing techniques involving one or more methods to deal with the problem of improvement in the signal to noise ratio, says identification, data production and transformation etc. These techniques have been broadly classified in three areas namely:

1. Time Domain Analysis
2. Frequency Domain Analysis
3. Quefrency (or Cepstrum) Domain Analysis

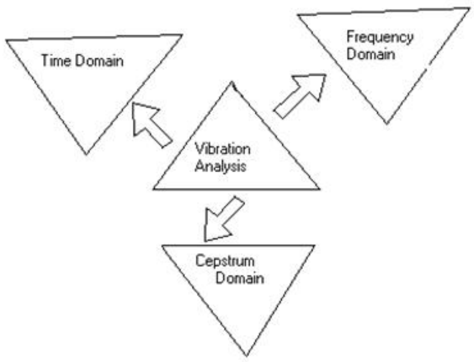

FIGURE 1 Vibration Analysis Techniques

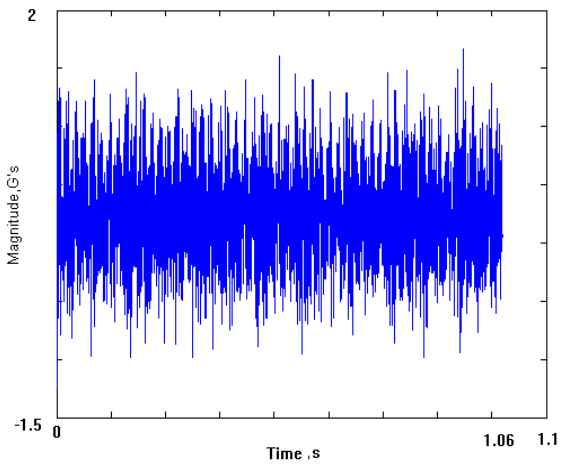

Figure 2 Time domain signal of healthy bearing

IV. WAVELET TRANSFORM ANALYSIS

A wavelet is a waveform of effectively limited duration that has an average value of zero. Compare wavelets with sine waves, which are the basis of Fourier analysis. Sinusoids do not have limited duration — they extend from minus to plus infinity. And where sinusoids are smooth and predictable, wavelets tend to be irregular and asymmetric.

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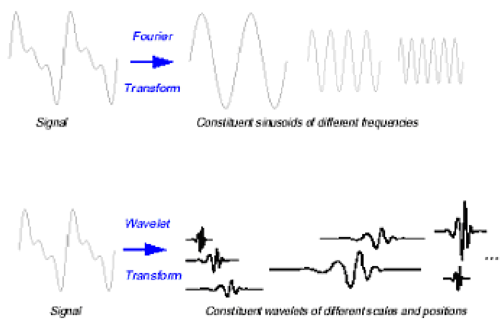

Figure 3 comparision of fourier with wavelet

Just looking at figure 3 of wavelets and sine waves, we can see intuitively that signals with sharp changes might be better analyzed with an irregular wavelet than with a smooth sinusoid, just as some foods are better handled with a fork than a spoon.

Wavelet analysis is capable of revealing aspects of data that other signal analysis techniques miss aspects like trends, breakdown points, discontinuities in higher derivatives, and self-similarity.

Furthermore, because it affords a different view of data than those presented by traditional techniques, wavelet analysis can often compress or de-noise a signal without appreciable degradation. Wavelet analysis represents the next logical step: a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information.

In wavelet analysis filtering algorithm yields a wavelet transform — a box into which a signal passes, and out of which wavelet coefficients quickly emerge. The details (cD) are the low-scale, high-frequency components. While doing analysis one can go up to several level decompositions, forming a branched (or tree like) structure.

V. FOURIER BEARING VIBRATION ANALYSIS

To evaluate vibration frequencies due to the bearings defects, with the help of rotor speed and bearing geometry for each type of defect characteristic frequency varies simultaneously[18,19].

The outer race defect frequency is given by:

$$FOD = (n/2)(N/60)\left[1 - \frac{bd * \cos\phi}{pd}\right] \quad (1)$$

Where:

ϕ is the contact angle, pd is the pitch diameter, bd is the ball diameter, n is the number of balls and N is the rotational speed in rpm.

The inner race defect frequency FID or the ball pass frequency of the inner race is given by

$$FID = (n/2)(N/60)\left[1 + \frac{bd * \cos\phi}{pd}\right] \quad (2)$$

The ball defect frequency (or ball spin frequency) is given by

$$FOD = \left(\frac{pd}{2bd}\right)(N/60)\left[1 - \left(\frac{bd}{pd}\right)^2 * \cos^2\phi\right] \quad (3)$$

Fast Fourier Transform Method is utilized to transform time domain signal into frequency domain, so that from the frequency domain signal it can be analyzed, that on which fault frequency peaks of amplitudes are present in the signal. Then, supposed to know the outcome and predict the fault presence in the ball bearing [16]. But the limitation of this approach is that Fourier analysis was limited to stationary signals and what time this peak is coming.

Presently, there are many advance approaches, which are evolving for vibration analysis and prediction of occurrence of faults in machine health condition monitoring and the results of these approaches are further going towards the making of intelligent system [8-9].

VI. BEARING FAULT SIMULATOR

The vibration simulator is designed, so that it is both easy to operate and multipurpose. The test rig consist double row, self-aligning bearings mounted on a shaft driven by a 3-phase electric motor (0-55KW, 220-240V) of a vibration simulator, all of which make it easy to remove and replace various components for specific types of tests. The bearings housing of the simulator has a facility for the placement of sensors on it. The motor connected with the shaft, rated maximum up to 310 rpm.

The experimental setup for vibration based bearing fault diagnosis of rolling element bearings is classified into two categories: Fault Generator and Vibration analyzers. Fault Generator is the bearing Fault Simulator (MFS) unit.

In most cases, prototypes are built, and stringent experimental testing is carried out. Progressively, engineers rely on modelling techniques to obtain knowledge of the structure's behaviour in the operating environment. The constructional parts of vibrational simulator are precision machined to high tolerances.

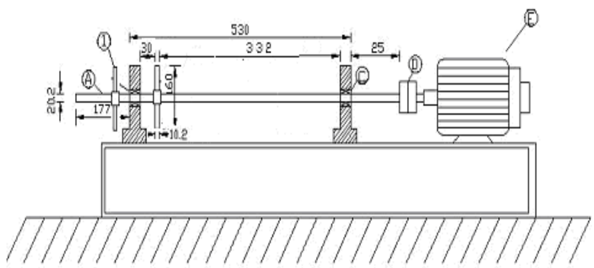

Fig 4 View of bearing fault simulator

As shown in figure 4, it unravels that; accelerometer is placed on the upper side on the bearing which is housing in radial position for sensing the vibration produced by the bearing to be tested. This accelerometer is connected with the FFT analyzer DL 2400 with LCD display and this is connected with a DOS based computer system10, 11.

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VII. BEARING USED IN EXPERIMENT

The bearings that are used in the experiment, are double row self-aligning by SKF, and have 13 balls in a row. There are three types of faulty bearings used in our experiment and one healthy bearing for the comparison. The details of these faulty bearings are tabulated in table (1).

Table 1 Details of Bearings used

Bearing Name	Bearing Defect	Location of defect Number of defects	Defect size
Faulty-1	Ball Defect	2 balls in one row, one by one	1*1mm,0,1 mm, deep
Faulty-2	Inner Race defect	3 defects at each row. 3 mm distance, both rows with defects	1*1mm,0,2 mm, deep
Faulty-3	Outer Race defect	3 defects at each row. 3mm distance, both rows with defects	1*1mm,0,2mm, deep

In this study, the vibration signature analysis using wavelet packet decomposition is used to detect the ball bearing flaw.

First the rms data using accelerometer as pickup is collected. The FFT of this data do not have further perspective, so might be shifted towards the wavelet transform.

In this, the signal is decomposed in to wavelet packets using debauchee's db8 filter in to six levels. The selection of db8 was based on the result of analysis, as previous to db8 all were not giving significant difference12, 13. Wavelet Packet Coefficients (WPC) of the nodes is used to compute the rms values. The nodes which have been reviewed for our analysis are 62, which presents up to fifth level of decomposition.

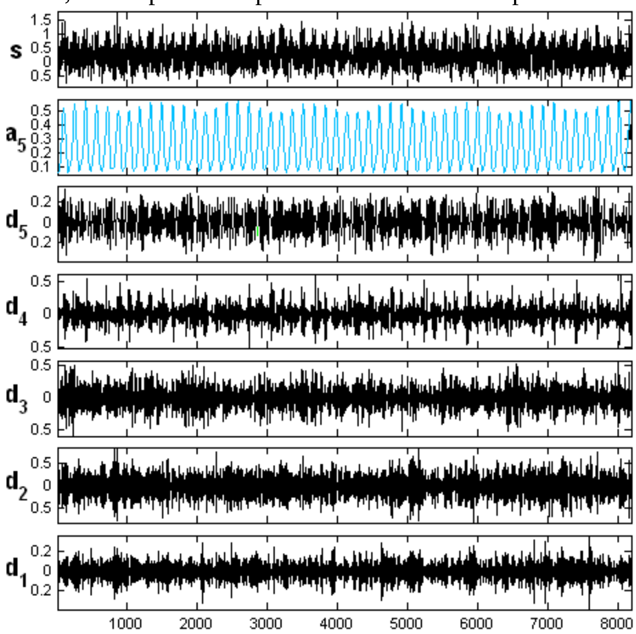

Figure 5. 5 level decomposition of the original signal's'

VIII. RESULT

The paper presents an investigation of flaws and to predict the nature of flaws in the bearings used in the work. The data for all the bearings are analyzed by using wavelet transform. Decomposition has been done up to 62 nodes and then for each node rms value is calculated and analyzed for finding the nodes which is giving significant differences in different faulty or healthy condition. All the 62 nodes are tested for the difference among the value of each node corresponding to different fault nodes and healthy bearing nodes. Out of these, 13 nodes are found with significant differences which are used for classifying faults are shown in table (2) below :

Table 2 Node with significant differences

Sr. No.	Node		Healthy Bearing	Ball Fault	Outer race Fault
1	4	max(rms)	0.42828	0.56803	0.6199
		min(rms)	NA	0.44723	0.54767
2	6	max(rms)	0.19587	0.25084	0.22477
		min(rms)	NA	0.14546	0.19878
3	8	max(rms)	0.48283	0.82885	0.58867
		min(rms)	NA	0.60331	0.47476
4	10	max(rms)	0.42614	0.63278	0.64296
		min(rms)	NA	0.34424	0.57033
5	15	max(rms)	0.13355	0.12292	0.15341
		min(rms)	NA	0.077402	0.18224
6	18	max(rms)	0.49223	0.63146	0.3828
		min(rms)	NA	0.51383	0.54771
7	21	max(rms)	0.3725	0.75651	0.5062
		min(rms)	NA	0.35906	0.46081
8	22	max(rms)	0.4837	0.75651	0.78272
		min(rms)	NA	0.35108	0.669
9	35	max(rms)	0.31199	0.41045	0.43667
		min(rms)	NA	0.2832	0.3598
10	36	max(rms)	0.6175	1.1706	0.82643
		min(rms)	NA	0.9308	0.64784
11	38	max(rms)	0.48063	0.73922	0.58488
		min(rms)	NA	0.56332	0.40832
12	39	max(rms)	0.2202	0.25116	0.33246
		min(rms)	NA	0.13919	0.25187
13	43	max(rms)	0.31584	0.36376	0.5349
		min(rms)	NA	0.25327	0.45345

IX. DESCRIPTION

In the above table each colored bars indicate its differences with the others. These 13 nodes indicate that each type of fault differs in rms value with the other. By using this we can predict our result by making some relations among them.
In the table it is clearly shown that if the maximum rms value for healthy bearing is less than the minimum rms value of the other two faulty bearings, it will clearly indicate the presence of the flaw.

X. CONCLUSION

The bearing fault simulator is an essential tool for analysis, development for vibration. Traditional time domain analysis or frequency domain approaches dictate the compromise of frequency resolution, but wavelet transform have no such limitations and therefore more suitable for the processing of vibration signature.

In this study, wavelet packed decomposition (WPD) that is one of the many wavelet transforms, because it is giving a good difference among all the bearings and enables us for getting optimum results. Studies can be performed on the vibration spectra of common faults, learn fault signatures, vibration based diagnostic techniques, lubricant condition and wear particle analysis. The following conclusions were drawn:

1. The rms value is a significant signature for the fault identification.
2. The Wavelet Packet Decomposition is capable of predicting the presence and the nature of the fault.
3. After generating more rules from this approach, one can easily train the expert system to make the monitoring on line.

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