

MULTI FAULT DIAGNOSIS OF BALL BEARING USING FFT AND WAVELET ANALYSIS

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ABSTRACT

Most of the machinery used in the modern manufacturing industry operates by means of bearings, gears and other rotating parts that may probably develop faults. The bearing faults reduce the efficiency of the machine and other parts connected to bearing also gets damaged. Thus, it is necessary to establish a method to detect faults in order to keep the systems running properly. This paper deals with a new scheme for the diagnosis of localized defects in ball bearings based on the wavelet transform. The bearing fault diagnosis using wavelet technique is to be determined from the motor driven experimental setup using the vibration signals from Fast Fourier Transform (FFT) analyzer and DAQ card using Lab VIEW. The wavelet Transform was used to process the vibration signals and to generate impulse depending upon characteristic defect frequency. Mother wavelet is selected based on the energy to Shannon entropy ratio of vibration signals. These signals are very useful for fault diagnosis. The wavelet de-noising technique is to be applied for the signals to decompose the signals and to remove the noises in the signal. Finally the results from two methods of wavelet analysis are compared and the method with accurate value is specified.

Keywords: FFT, Bearing fault diagnosis, Wavelet.

1. Introduction:

Bearings are one of the most important and frequently encountered components in rotating machinery. Fault identification of rolling element bearings using condition monitoring techniques has been the subject of extensive research in the last two decades. Vibration based condition monitoring technique has been the most used. Bearing failures can be caused by several factors, such as faulty design and manufacturing, poor lubrication, spalling and plastic deformation. During fault bearing operation, high impulses are generated when rollers pass over the defect at a frequency determined by shaft speed, bearing geometry, and defect location (outer race, inner race, or roller). The difficulty in the detection of defects in bearings lies in the fact, the signature of a defective bearing is spread across a wide frequency band and hence can be easily masked by noise and low frequency effects.

2. Problem definition

Sometimes bearings are getting failure earlier than expected. When the bearing failure occurs, it gradually propagates to surface generating detectable vibrations and increasing noise levels. On the basis of failure mechanism, the defective rolling element bearings are producing vibrations at the rotational speed of each component. In present work, analysis is proposed to be performed for multi-fault diagnosis in such systems by using wavelet and FFT analyzer. The multiple defect combinations are made on ball bearing through EDM artificially. Wavelet selection criteria based on Maximum Energy to Shannon Entropy ratio is used to select an appropriate wavelet for analysing vibration signals.

3. Experimental setup

The experimental setup shown in Fig 1 made for acquiring bearing vibration signals using piezo electric sensor. The bearing used for testing is ball bearing of 6205 z type. Two bearings are mounted on a 25mm diameter shaft of length 1600mm by bearing housing. The distance between two bearings is 600mm. The rotors are mounted on the shaft for applying load to the bearing. The mass of rotor is 2kg and the shaft is coupled to a 1hp motor running.

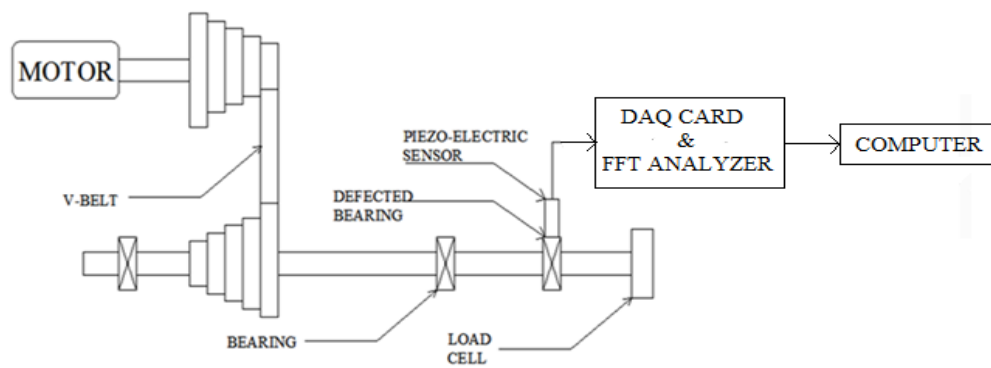


Fig 1: Experimental Setup

The piezo electric sensor is placed on the bearing housing and is connected to the DAQ card. The DAQ card converts the analog signals from the sensor into digital signals. A computer is used to acquire the signals from the DAQ card using LabVIEW software and using FFT Analyzer. This experimental setup is used for acquiring vibration signals from good and defective bearings. The driven end bearing is good bearing and drive end bearing is defective bearing changed for acquiring signals. Each time the drive end bearing is changed with other defect bearing for acquiring signals.

4. Test Bearings

An impact impulse is generated every time a ball hits a defect in the inner raceway or outer raceway. The ball bearing with faults is operating will producing this impact impulse depends upon the severity of defect. In this research, three defect combinations of various defects are used as shown in the following Table 1.

Table 1. Bearing Defect Combinations

Bearing Combinations	Inner Race	Outer Race	Ball	Cage
Combination 1	✓		✓	✓
Combination 2	✓	✓	✓	
Combination 3	✓	✓		✓
Combination 4		✓	✓	✓

5. Wavelet selection methodology

The following steps explain the methodology for selecting a base wavelet for the vibration signals under study:

1. In this study, healthy bearings, bearings with defect in outer race, inner race, ball and cage with combined component defects (CCD) are considered. Vibration signals in time domain analysis are obtained in defective bearing at different speed at 900rpm, 1200rpm, 1500rpm and 2100rpm under loader and no loader conditions.
2. Select one Type of Wavelet for Vibration Signal processing.
3. For healthy and faulty bearings, Discrete wavelet coefficients of vibration signals are calculated using six different mother wavelets in which three are real valued as Meyer, Coiflet2, Symlet3 wavelets and other three are complex valued as Daubechies 9, complex Morlet and Haar wavelets.
4. The Total Energy to Shannon Entropy of DWC is calculated for vibration signals at different rotor speed 900rpm, 1200rpm, 1500rpm and 2200rpm and for different loading conditions using healthy and faulty bearings.
5. The wavelet having Maximum Energy to Shannon Entropy ratio is considered for fault diagnosis of rolling element bearings.

The flowchart for above mentioned procedure is shown in Fig2. The Energy to Shannon Entropy ratio is obtained maximum for Daubechies 9. Hence, Daubechies 9 is considered as the base wavelet to extract features for fault diagnosis.

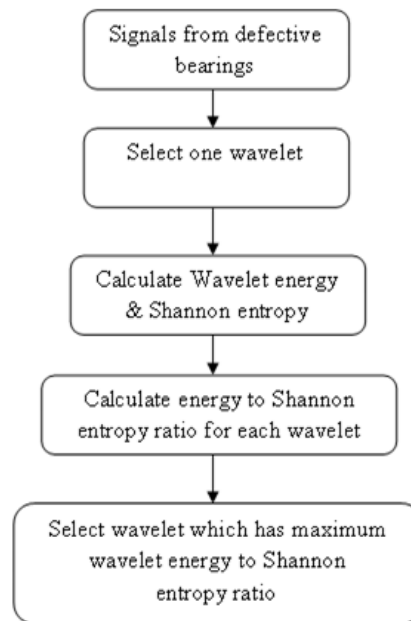


Fig 2: Flowchart for wavelet Selection Criterion

6. Wavelet analysis

A wavelet is a wave-like oscillation with an amplitude that starts out at zero, increases, and then decreases back to zero. The wavelet transform has emerged as an efficient tool to deal with non-stationary signals such as vibrational signal Waveforms. It offers simultaneous interpretation of the signal in both time and frequency domain. Wavelet transform can be Continuous Wavelet transform (CWT) or Discrete Wavelet transform (DWT). The continuous wavelet transform reveals more details about a signal but its computational time is enormous. For most applications, the goal of signal processing is to represent the signal efficiently with fewer parameters and less computation time. The discrete wavelet transform (DWT) can satisfy these requirements.

The DWT employs a dyadic grid and orthonormal wavelet basis functions and exhibits zero redundancy. The DWT computes the wavelet coefficients at discrete intervals of time and scales. The dilation function of the DWT can be represented as a tree of low pass filters and high pass filters, with each step transforming the low pass filter into further lower and higher frequency components. The original signal is successively decomposed into components of lower resolution and higher resolution, while the high frequency components are not analysed any further. The lower frequency components of the signal are called approximations and the higher frequency components are called details.

7. Fast Fourier Transform

A **Fast Fourier Transform (FFT)** is an algorithm to compute the discrete Fourier transform (DFT) and its inverse. There are many different FFT algorithms involving a wide range of mathematics, from simple complex-number arithmetic to group theory and number theory; this article gives an overview of the available techniques and some of their general properties, while the specific algorithms are described in subsidiary articles linked below. The DFT is obtained by decomposing a sequence of values into components of different frequencies. This operation is useful in many fields (see discrete Fourier transform for properties and applications of the transform) but computing it directly from the definition is often too slow to be practical. An FFT is a way to compute the same result more quickly: computing the DFT of N points in the obvious way, using the definition, takes $O(N^2)$ arithmetical operations, while an FFT can compute the same DFT in only $O(N \log N)$ operations. The difference in speed can be enormous, especially for long data sets where N may be in the thousands or millions. In practice, the computation time can be reduced by several orders of magnitude in such cases, and the improvement is roughly proportional to $N / \log(N)$. This huge improvement made the calculation of the DFT practical; FFTs are of great importance to a wide variety of applications, from digital signal processing and solving partial differential equations to algorithms for quick multiplication of large integers.

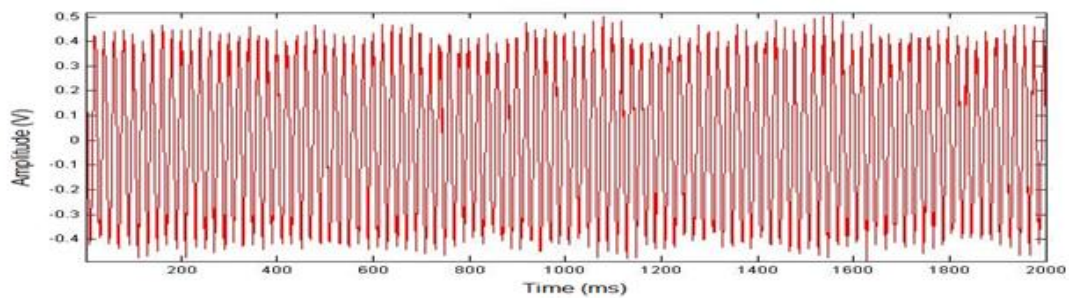
8. Results and discussion

The time domain and frequency domain signals are acquired from DAQ card using piezoelectric sensor and FFT analyzer as shown in Fig 3 & Fig 4. These signals were obtained under various speeds and it contains noises in it. For effective fault analysis, these noises were eliminated using wavelet technique. The signals are processed by using Daubechies wavelet and then denoising is performed. The Energy to Shannon Entropy ratio values of different wavelet types are listed in the Table 2.

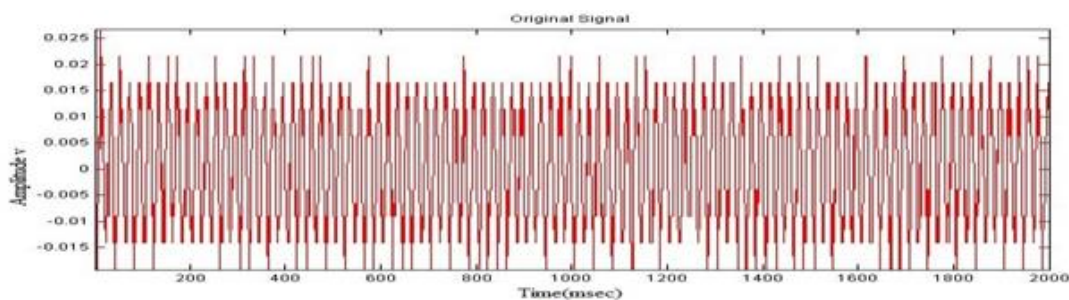
Table 2. Parameters for Wavelet Selection

S No	Wavelet Type	Energy to Shannon Entropy ratio
1	Meyer	29.1275
2	Coiflet 2	31.135
3	Symlet 3	13.139
4	Daubechies 9	31.831
5	Morlet	28.124
6	Haar	11.701

Based on the maximum Energy to Shannon Entropy ratio criterion, the db9 (Daubechies at level9) posses the highest values, thus is considered as the most appropriate wavelet to analyze the vibration signal. The original signal is first decomposed using db9 wavelet at level 3 and the decomposed signal is further denoised. The denoised signal has eliminated the noise in original signal when compared with the plot of original signal. The mother wavelet is selected based on the Energy to Shannon Entropy ratio of the signals.



(a)



(b)

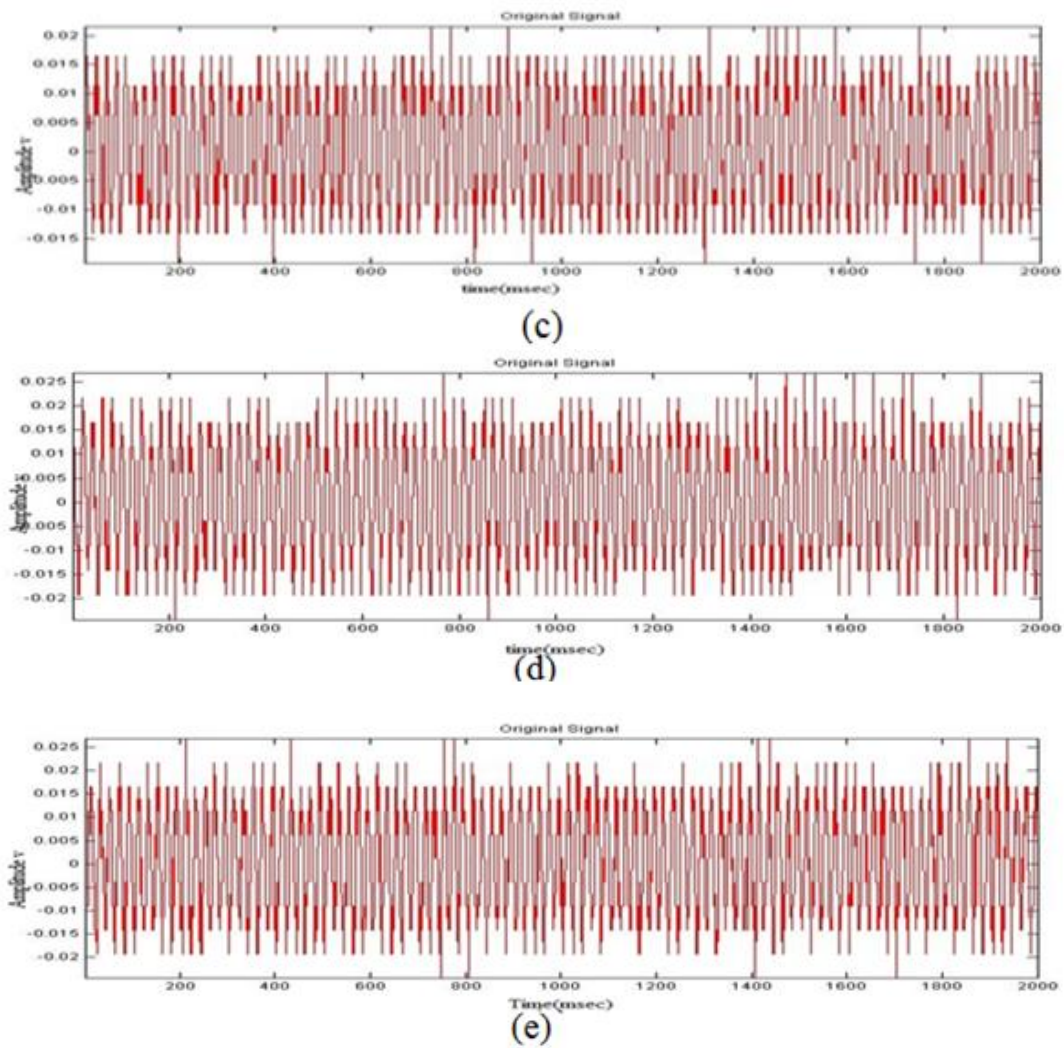
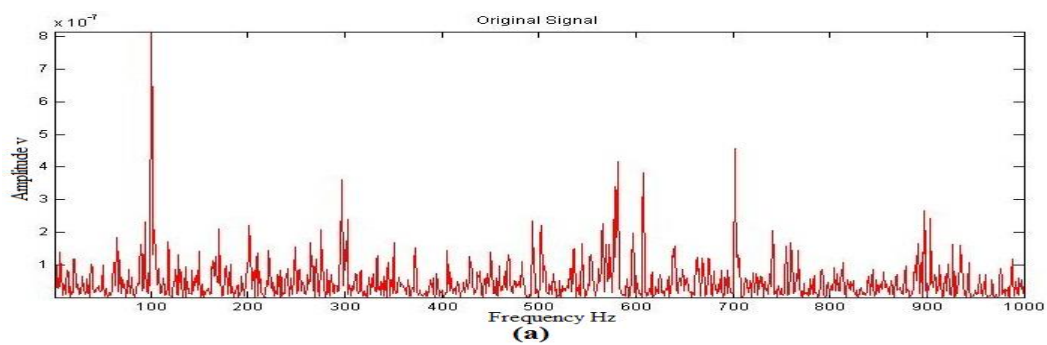


Fig 3: Time domain signals (a) Good Bearing, (b) Inner, Ball and Cage defect, (C) Inner, Outer and Ball defect, (d) Inner, Outer and Cage defect, (e) Outer, ball and Cage defect.



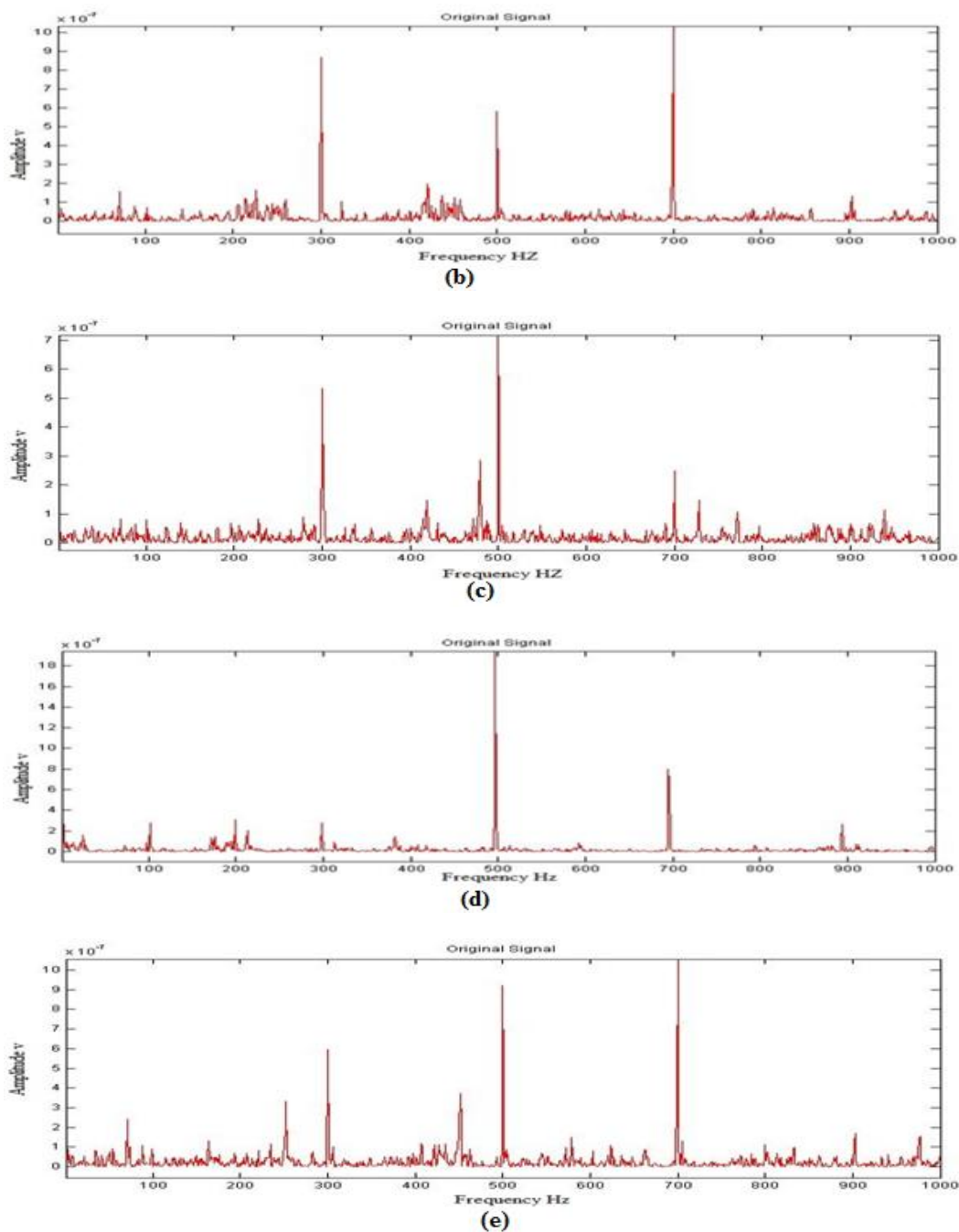


Fig 4: Frequency domain signals (a) Good Bearing, (b) Inner, Ball and Cage defect, (c) Inner, Outer and Ball defect, (d) Inner, Outer and Cage defect, (e) Outer, ball and Cage defect

Rms and kurtosis values of these time signals were found and are shown in the Table 3. The Rms value is low for good bearing compared to defective bearings and the value is high for bearings with multiple faults compared to a single fault. However, one cannot find the location of the defect in the bearing. For finding the location of the defect, the frequency domain approaches are shown in Fig 4 shows the vibration spectra (FFT) of good as well as defective bearings. In all the spectra, a peak at running speed is present. In the case of an inner race, outer race and cage defective bearing, the peak at the characteristic defect frequency is present at 484.93Hz.

Table 3. RMS and Kurtosis Values of the obtain signals

Bearing Defects	RMS values	Kurtosis values
Good Bearing	0.781	0.864
Inner. Ball and Cage defect	1.814	1.257
Inner, Outer and Ball defect	1.957	1.428
Inner, Outer and cage defect	1.567	1.294
Outer, Ball and Cage defect	2.177	1.564

9. Conclusion

This paper shows that wavelet and FFT analyzer techniques can be efficiently used in multi-fault diagnosis of ball bearings. Mother wavelet is selected based on the maximum Energy to Shannon Entropy ratio criterion and db9 (Daubechies at level9) is considered as a base wavelet. The analysis results from ball bearing signals with different faults in various working conditions show that the diagnosis approach based on using wavelet and FFT to extract the root mean square of different time and frequency bands can identify ball bearing faults accurately and effectively.

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