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Original Research Article

BEARING FAULT DETECTION IN ROTATING ELECTRICAL MACHINES USING WAVELET TRANSFORM

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Abstract: In almost all the industrial drive systems induction motors plays a vital role because of their simple, efficient and robust nature. Detection and diagnosis of faults while the system is running can minimise all kind of losses.Bearing problems are one major cause for induction motor drive failures. Motor failure due to bearing defect is an issue that has drawn an increasing industrial interest over recent years. Commonly-used signal analysis techniques, based on spectral approaches such as the fast Fourier transform, are powerful in diagnosing a variety of vibration-related problems in induction motor drives. Although these techniques provide powerful diagnostic tools in stationary conditions, they fail to do so in several practical cases involving non-stationary data. Wavelet transform tools are considered superior to the fast Fourier transforms as they can effectively analyze non-stationary signals. This work proposes the use of wavelet transform to analyze vibration data in motors affected by bearing defects. These wavelet tools are applied here, with a suitable choice of a mother wavelet function, to a vibration monitoring system to accurately detect and localize faults occurring in the system.

Keywords*:* Induction motors; bearings; fault detection; wavelet transform

Introduction: Induction motors with a squirrel-cage rotor are widely used in many industrial processes, and they play important roles in various processing industries. Due to their advantage of low cost, reliability and robustness induction motors have the disadvantage of getting sudden failure owing to their exposure to a variety of manufacturing defects or rough environments. These sudden failures and gradual deterioration can lead to motor disordering if not recognised earlier. Fault generally occurs when a motor faces sudden stresses or abnormal condition. Fault in an induction motor can be either internal motor faults (e.g., ground faults, leads and inter-turn short circuits, bearing and gearbox failures, cracked rotor end-rings and broken rotor bars),

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as well as external motor faults (e.g., phase failure, asymmetry of main supply and mechanical overload), are expected to happen sooner or later [1].Based on the analysis of the origin of induction motor failures, the bearing fault is the major source of most internal faults. Since most of the phenomenon occurring in the bearing assembly of motors is in some way represented as motor vibration, therefore one of the most important signals to consider in most motor fault detection scheme is motor bearing vibration [2].Contamination of lubricant, loss of lubricant, over-loading, and excess heating are also the common causes of bearing faults. Therefore, the bearing fault detection in the early stages will decrease the cost of unwanted shutdown .Bearing faults are categorized as inner faults and outer faults by their location. Further bearing defects [3] may be categorized as “distributed” or “local”.

The distributed defects include surface roughness, mismatched waviness and off-size rolling elements. A localized defect consists of flakes, pits and cracks on the rolling surfaces. Another problem caused by the bearing fault results in improper installation caused due to the unbalanced alignment of the bearing onto the shaft. This produces false brine ling of the raceways thereby damaging the motor physically. Therefore correct diagnosis and early detection of faults result in short down time for the machine under consideration and helps to reduce financial loss. A major revolution in the signal processing techniques is brought by the introduction of wavelet analysis as it is capable of revealing aspects of data that other signal analysis techniques could not. [4]. Diverse techniques are largely investigated and applied for the fault detection in the machine. The first methods were based on noise, temperature, and vibration analysis .However, these methods are quite expensive and the mechanical installation is sensitive to the noise. The second technique, named as motor current signature analysis (MCSA), the philosophy of this approach assumes that each type of defect is characterized and classified by an own spectral signature. The current signature analysis has overcome these drawbacks and gives good performance even in noisy atmosphere [5]. These methods are based on straightforward signal processing techniques such as Fast Fourier transforms (FFT), bispectrum, wavelets etc. for motor fault diagnosis. In this paper bearing fault detection is performed by wavelet transform to overcome the shortcomings of Fourier transformation.

Signal processing techniques: The Fourier Transform produces comprehensive frequency information of a waveform. It produces excellent effective results when the waveforms examined are stationary or periodic. The Fourier transform is, however, not appropriate for a signal that has transitory characteristics such as drifts, abrupt changes, and frequency trends. As compared to this the Wavelet decomposition is a superior method of signal analysis in time varying situations due to spatial data retention. Analysis using wavelets produces both frequency and spatial information providing a robust solution for motor fault detection.

Wavelet transform and its application for bearing fault detection: The wavelet transform or wavelet analysis is apparently the most contemporary solution to overcome the shortcomings of the traditionally used Fourier transform [6, 7]. Wavelets have the ability to scrutinize non-stationary signals. Wavelet Transform can be implemented using Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT). In this work, the application of Discrete Wavelet Transform (DWT) is given more emphasis.

Discrete wavelet transforms parameters considerations: The DWT analyses the signal at different frequency bands with different resolutions. It employs two sets of functions which are termed as scaling and wavelet functions, associated with low pass and high pass filters, respectively. Some of the considerations have to be done regarding the different parameters of the DWT decomposition, such as the type of mother wavelet, the order of the mother wavelet, and or the number of decomposition levels. An important step is the selection of the mother wavelet. The selected mother wavelet is related to the coefficients of the filters used in the filtering process inherent to the DWT [8]. During the earlier researches several wavelet families with rather different mathematical properties have been developed.

Infinite-supported wavelets (Gaussian, Mexican Hat, Morlet, Meyer, etc.) and wavelets with compact support (orthogonal wavelets such as Daubechies, Coiflet and biorthogonal wavelets) have been proposed [9]. After the wavelet family is selected, it is suggested to carry out the DWT analysis using a high-order mother wavelet. It is a type of mother wavelet which is associated filter with a large number of coefficients. If a low-order wavelet is used, the frequency response gets worse, and the overlap between adjacent frequency bands increases. Daubechiesor Symletare type of wavelets which shows satisfactory high orders results. The DWT is then followed by the specification of the number of decomposition levels. It is determined by the low frequency components to be traced. The lower the frequency components to be extracted, the higher the number of decomposition levels of the DWT [10].

Experimental set up: The bearing fault signal b(n)can be expressed as approximation coefficients and detail coefficients using DWT, which represents low and high frequency components respectively [11]. In this work, Daubechies wavelet is taken to calculate the approximation and detail coefficients in each level using below expressions [11]. First of all the vibration signals are recorded from the motor under considerations and signal pre-processing is being conducted.

The specifications of the proposed induction motors used in our experiment are summarized in Table 1. The test is carried out for a healthy motor and a motor with faulty bearing. A 3 phase,4 pole induction motor with a rated frequency of 50 hertz is taken for the test. The rated speed is maintained for about 1440 rpm and voltage is maintained at around 414 volts. For this the mat lab Wavelet toolbox is used to decompose the acquired time domain signal into time-frequency domain. Then fault features frequency band is extracted from all specified wavelet transform level. Finally, the individual diagnosis results are used to validate the developed model. The tests are carried out on a healthy motor and a motor with faulty bearings both at full load. The proposed idea of the application of DWT is the dyadic band pass filtering process carried out by DWT transformation. Provided a certain sampled signal S = (i1, i2, . . . ,iN), the DWT decomposes it onto several wavelet signals (an approximation signal an and n detail signals dj) [8].The approximation and details coefficients at next level can be obtained using A_1, $D_1$from the below equation

$A_1(m) = \sum_n L(-2m)b(n)$……………..………..(1)

$D_1(m) = \sum_n H(-2m)b(n)$……………….……..(2)

Where A_1, $D_1$are the approximate and detail coefficients at level 1 and L, H are the low and high pass filters respectively. Similarly the *j*th level coefficients can be obtained from $j-1$th level coefficients as below.

$A_j(m) = \sum_n L(n-2m)Aj-1(n)$………… (3)

$D_j(m) = \sum_n H(n-2m)Dj-1(n)$ ……… (4)

Table-1 Induction motor characteristics used in the experiment

Description	Value
Power	3.7KW
Rated Voltage	414 V
Rated current	3A
Rated Frequency	50Hz
Number of poles	4
Number of phases	3
Rated Speed	1440 rpm

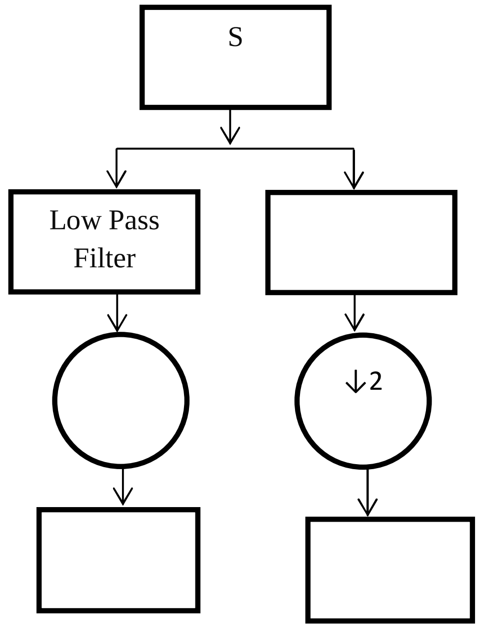

Fig.1 DWT decomposition of a signal

The DWT involves two sets of functions known as scaling functions and wavelet functions. These sets of functions are associated with low pass and high pass filters respectively. With multi resolution analysis (MRA), a wavelet-based technique, a signal S can be decomposed and reconstructed by means of two components: approximation (A_1) and detail (D_1), where approximation can be interpreted as a high-pass filter and detail as a low-pass filter [12]. Fig. 1 demonstrates the decomposition of the signal into different frequency bands which is obtained by successive high pass and low pass filtering of the time domain signal.

Experimental results

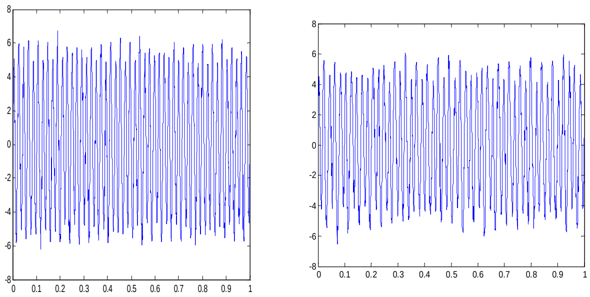

Fig.2 Vibration signal under full load for healthy and faulty motor respectively

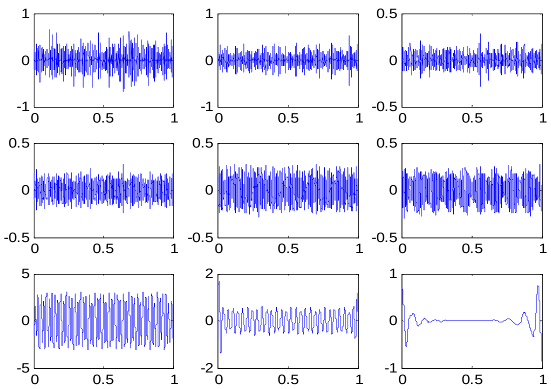

Fig.3 8Level DWT of vibration signal for healthy motor at full load

Table -2 Statistic Computation of RMS Value

	RMS Level Healthy Bearing	RMS Level Faulty Bearing
Mean	0.5964	0.5883
Standard Deviation	1.1409	1.0202

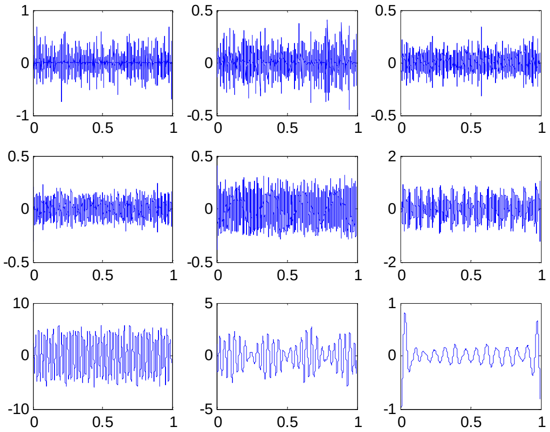

Fig.4 8 Level DWT of vibration signal for faulty motor at full load

Discussion: The vibration signal under full load for healthy and faulty motor respectively has been demonstrated in fig.2.The decomposition levels for vibration in case of healthy and faulty motors were also described in fig.3 and fig. 4 respectively. On the basis of these experimental results, the root mean square values for healthy bearing are compared with faulty bearing. It has been found that the minimum, average and maximum root mean square values of vibration for healthy bearing are slightly greater than faulty bearing. The statistics computation of root mean square value in terms of mean and standard deviation are summarised in figure 2.Consequently, it can be concluded that the wavelet transform based criterion allows to efficiently and automatically detecting bearing defect and its root mean square value gives a measurement of the fault severity.

Conclusion: The bearing fault detection and its prognosis plays vital role in terms of cost effective as well as production losses in industrial application and electrical drive system. In this work we have seen that as compared to Fast Fourier Transform, Wavelet Transform can be effectively utilized for fault diagnosis specially in case of bearing fault due to their peculiar characteristic of detailing signal specific points. Wavelet transform provides flexibility in describing signals that include regions of different frequency contents .paper has presented the incipient state of bearing faults in faulty motor and compared it with the vibration signals of healthy motor. It has been also observed that vibration analysis is the most effective technique for monitoring the health of induction motor under running condition.

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