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Research Paper

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Development of Fault Detection System for Ball Bearing of Induction Motor Using Vibration Signal

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ABSTRACT

Induction motors are the most important and significant component of any industry. Induction motor faults results in motor failure causing loss of production time and cost of repairing. Vibration analysis is one of the most successful technique used for condition monitoring of rotating machines. This paper describes a new condition monitoring method for induction motors based on vibration signal analysis. A robust bearing fault detection scheme has been developed by time domain feature extraction from vibration signals of healthy and faulty bearings. The statistical parameters such as peak value, RMS value, crest factor, kurtosis, skewness, impulse factor, shape factor, clearance factor, upper bound and lower bound value of histogram are used for feature extraction.

Introduction

Induction motors are the most important and significant component of any industry and there breakdown cause great loss due to shutdown of industry and also increases the running cost of machine with reduction in efficiency [1]. Thus detection and diagnosis of incipient faults in induction motor is desirable for product quality assurance and improved operational efficiency. Motor failures in industries cannot be tolerated because it leads to losses in production time and cost of repairing.

Condition based maintenance is most widely used basic maintenance approach, during which inspection of machine is carried out at variable time interval instead of fixed time period. Condition monitoring is carried out to evaluate the lifetime or to find out the health condition of motor and to calculate the degree or grade of detoriation [2]. Correct determination limit saves the unnecessary repair time and cost.

When a fault takes place, some of machine parameters are subject to change [3]. The change in machine parameter depends upon the degree of faults and the interaction with other parameters. Thus by the measurement of machine parameters like terminal voltage, current [4-7], temperature of stator[8,9], rotor speed, torque [10,11], stator frame vibration[12], bearing vibration[13-15], information about development of fault can be obtained and accordingly maintenance can be planned for next available shutdown.

To study the nature and severity of bearing fault vibration signals were considered since they carry the most relevant information about all the types of bearing faults. Vibration signals were considered for four types of bearing conditions namely healthy bearing, defective ball, defective inner race and defective outer race in a 5hp motor three phase induction motor.

Experimental Setup

The monitoring system used for experimental purpose is shown in figure 1. Main components of this system are a 5H.P. induction motor, accelerometer MMA2201EG and data acquisition card. For study bearings (SKF6206) having artificial defect on outer race way, inner race way and rolling element were used.

Figure 1 Monitoring System

Vibration signals were recorded for healthy as well as defective bearings analyzed in the time domain using signal processing techniques. Characteristics features as well as statistical parameter such as rms level, peak level, crest factor, skewness, kurtosis, clearance factor, impulse factor, shape factor, standard deviation, upper wound value of histogram and lower wound value of histogram were also studied for each type of bearing fault.

Computation of Features

Accuracy of interpretation of results has been ascertained by recording the signal by a number of times for a given state of the bearing (healthy as well as defective). Each vibration record consists of 60,000 sample points which is segmented into sets of 2000 data points. These small recorded data sets were then analyzed using MATLAB. Time domain features were extracted for each vibration signal. Study of thirty vibration records for healthy bearing condition was done to obtain time features. Similarly, thirty vibration records each for defective ball case, defective inner race case and defective outer race case were studied to obtain time features of each condition. The time domain features considered in this research work were calculated as [16]:

(a) Standard Deviation

$$SD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - \overline{X})^2}$$

(b) Root Mean Square Value

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i)^2}$$

(c) Peak Value

$$P_v = \max(X_i)$$

(d) Crest Factor:

$$Crf = \frac{Peak\ Value}{RMS\ Value}$$

(e) Kurtosis:

$$K_V = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{X_i - \overline{X}}{RMS\ Value}\right)^4$$

(f) Skewness:

$$Sw = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{X_i - \overline{X}}{RMS\ Value}\right)^2$$

Volume : 2 | Issue : 5 | May 2013 • ISSN No 2277 - 8179

(g) Clearance Factor

$$Clf = \frac{Peak\ Value}{\left(\frac{1}{N}\Sigma_{i=1}^{N}\sqrt{|X_i|}\right)^2}$$

(h) Impulse factor:

$$Imf = \frac{Peak\ Value}{\frac{1}{N}\Sigma_{i=1}^{N}|X_i|}$$

(i) Shape Factor

$$Shf = \frac{RMS\ Value}{\frac{1}{N}\Sigma_{i=1}^{N}|X_i|}$$

(j) Upper Bound Value of Histogram

$$UB = \max(X_i) + 0.5\left(\frac{\max(X_i)-\min(X_i)}{N-1}\right)$$

(k) Lower Bound Value of Histogram

$$LB = \min(X_i) - 0.5\left(\frac{\max(X_i)-\min(X_i)}{N-1}\right)$$

Result and Discussion

The time domain vibration signals considered for the analysis are collected for four different conditions of the bearing: healthy bearing (HB), defective ball (DB), defective inner race (DIR) and defective outer race (DOR). For faulty bearing probability distribution of vibration acceleration showed a non Gaussian distribution with a dominant tail as compared to normal distribution in case of healthy bearing. The vibration signature for a healthy bearing is shown in figure 2 Vibration signals for bearings with faults located in rolling element, inner race and outer race are shown in figure2, 3, 4 and 5 respectively.

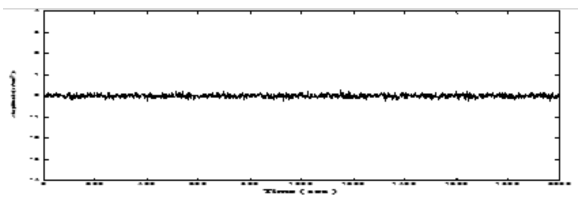

Figure 2: Vibration Signal of Healthy Bearing

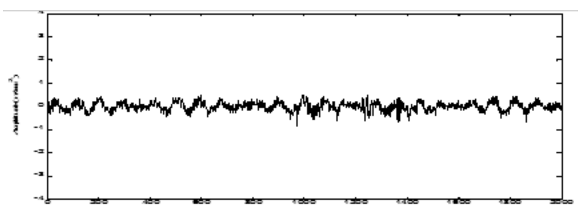

Figure 3: Vibration Signal of Defective Ball

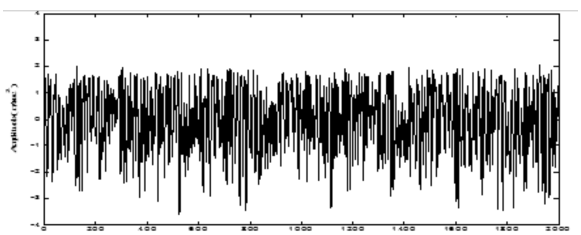

Figure 4:Vibration Signal of Defective Inner Raceway

The time domain analysis features are extracted from vibration signals of healthy and faulty bearings for fault classification. The statistical parameters such as peak value , RMS value, crest factor, kurtosis, skewness, impulse factor, shape factor, clearance factor, upper bound and lower bound value of histogram are used for feature extraction. Feature extracted from vibration signals are shown graphically in figures 6-16.

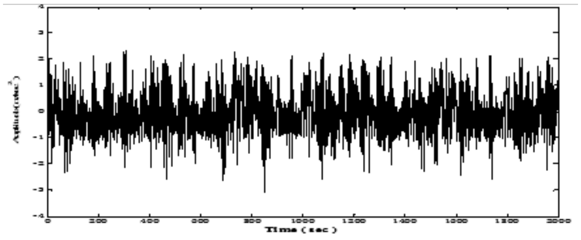

Figure 5: Vibration Signal of Defective Outer Raceway

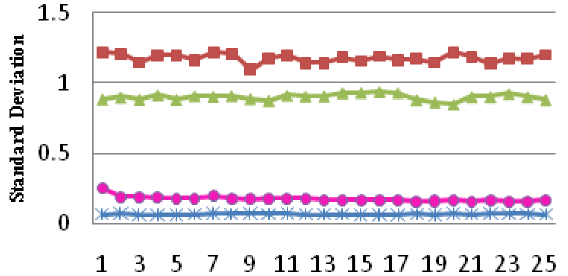

Figure 6: Variation of Standard Deviation

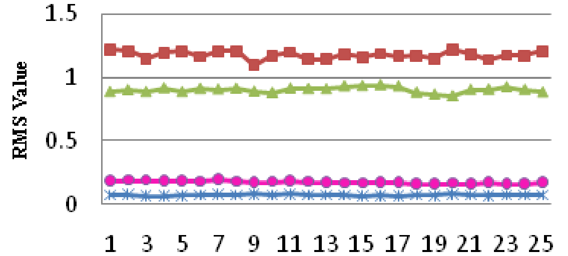

Figure 7: Variation of RMS Value

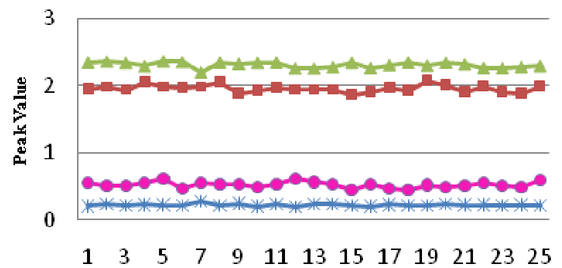

Figure 8: Variation of Peak Value

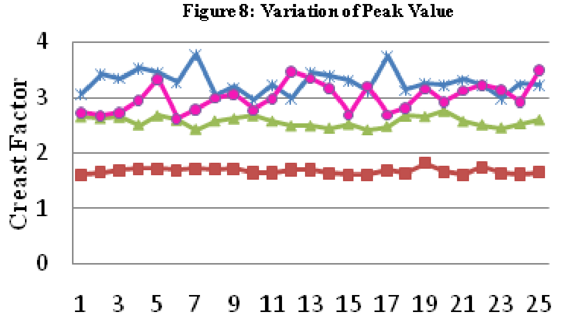

Figure 9: Variation of Crest Factor

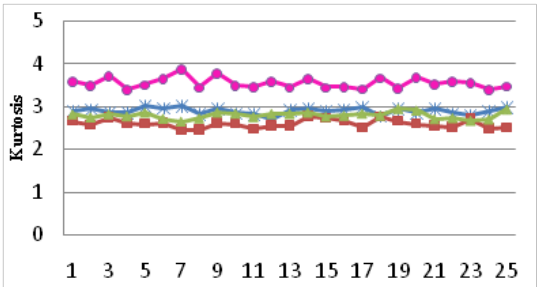

Figure 10: Variation of Kurtosis

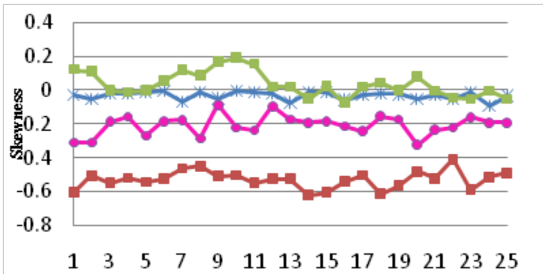

Figure 11: Variation of Skewness

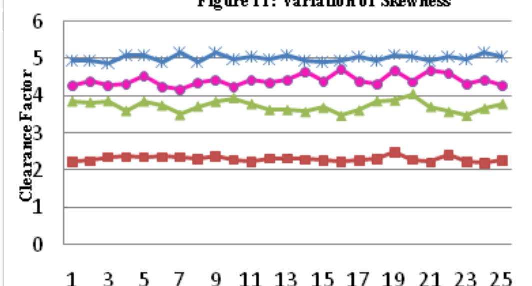

Figure 12: Variation of Clearance Factor

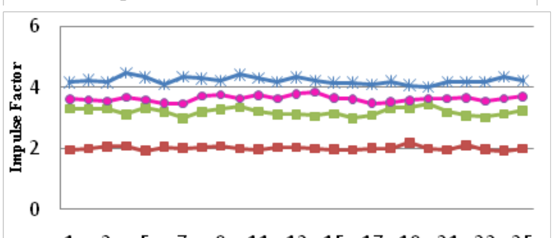

Figure 13: Variation of Impulse Factor

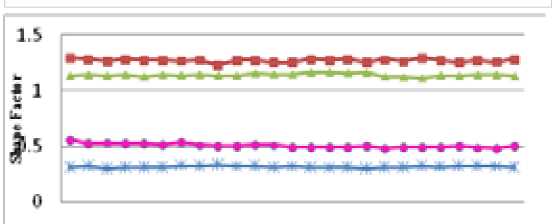

Figure 14: Variation of Shape Factor

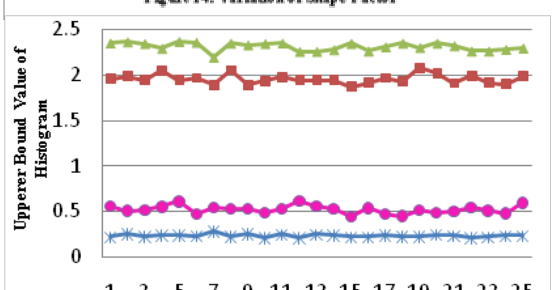

Figure 15: Variation of Upper Bound Value of Histogram

Following observations are made from these plots:

1) Figure 6 is standard deviation curve which is a measure of variation from mean position. For healthy condition, standard deviation of vibration data is very closed to zero i.e. 0.0036. The value of standard deviation increases with introduction of fault. Standard deviation for DB, DIR, and DOR is 0.1773, 0.1745 and 0.9010 respectively. It can be seen that standard deviation for DIR and DOR is much higher as compared to that of DB. This indicates that raceway fault introduces greater asymmetry in vibration data.

2) Figure 7 represents the RMS level of the vibration for four bearing state considered in this study i.e. for healthy bearing (HB), bearing with defective ball (DB), bearing with defective inner race (DIR) and bearing with defective outer race (DOR). It can be observed that there is no overlapping in values of RMS level for healthy and faulty bearings. Therefore RMS parameter can be a good indicator of fault classification.

3) The variation in the peak value for healthy to faulty bearing condition is shown in figure 8 It increases with severity of fault however peak level for defective outer race is more than that for defective inner race.

4) It can be seen that crest factor for healthy bearing, DOR bearing, and DB bearing is overlapping therefore these three conditions cannot be differentiated using crest factor. However crest factor is good indication to identify DIR fault. Peak level value is high for DB as compared to that of DIR and DOR as shown in figure 9.

5) Kurtosis technique detects the presence of impulsiveness in the vibration signal. The value of kurtosis for different bearing condition is shown in figure 10. It can be easily noticed that it increases for ball defect, indicating vibration data with distinct peaks with rapid declination in data. However, for other defective cases, increase in number of peaks make data distribution is flat and therefore gives low value for kurtosis.

6) Variation of skewness of vibration data for different cases is shown in figure 11. It can be observed that for healthy condition, skewness of vibration data is very close to zero which increases with introduction of fault. As, skewness is a measure of symmetry of probability density function giving zero value for symmetric distribution. From figure 11 it can be concluded that skewness is good indication to identify DIR fault.

7) Clearance factor is dependent on peak value. As shown in figure 12 the value of clearance factor is maximum for healthy condition and it goes on decreasing for DB, DOR, and DIR respectively. The clearance factor has highest separation ability for DIR.

8) Figure 13 shows that the trend of impulse factor for all the four bearing state and is similar to the clearance factor but with a much lower value.

9) The variation in values of shape factor from healthy to faulty bearing condition is shown in figure 14. There is no overlapping in the values and it increases with increase in level of fault value.

10) The vibration of upper and lower bound values of histogram is shown in figure 15 and 16 respectively. Value of upper bound histogram is maximum for outer race fault. Whereas for lower bound histogram value is highly negative for inner race fault.

Vibration in range of these parameters is shown in table 1.

Mean and standard deviation for different features were obtained under no load condition in all the four bearing conditions. Results are summarized in table 2.

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Conclusion

Separation between healthy bearing and outer race fault are maximum in the plots of peak value, skewness and upper bound value of histogram and can successfully classify these two conditions. The plots of standard deviation, RMS, and shape factor, lower ground value of histogram, clearance factor and impulse factor clearly show the difference between healthy bearing and inner race fault. Similarly, the difference between healthy bearing and rolling element fault is shown in plots of kurtosis and skewness.

In this research work, time-domain domain analysis technique has been employed for study of vibration signals on healthy bearing as well as different bearing fault conditions and it is observed that developed faults diagnosis system gives good classification for different fault conditions of induction motor ball bearing.

Table 1: Statistical Parameters of Time Domain Analysis

S.No.	Features	Healthy		Inner race fault		Outer race fault		Faulty ball	
		Min	Max	Min	Max	min	Max	min	max
1	Standard Deviation	0.0635	0.0795	1.0945	1.2174	0.8509	0.9376	0.1597	0.2518
2	Peak Value	0.2069	0.2826	1.8619	2.0738	2.1881	2.361	0.4451	0.6152
3	RMS Value	0.0634	0.0795	1.0942	1.2171	0.8507	0.9373	0.1597	0.1974
4	Creast Factor	2.9421	3.7679	1.6073	1.8117	2.4093	2.7526	2.6128	3.4873
5	Kurtosis	2.6901	3.1509	2.4431	2.7794	2.6526	2.9552	2.728	3.4172
6	Skewness	-0.176	0.0847	-0.621	-0.406	-0.078	0.1896	-0.326	-0.087
7	Clearance Factor	4.8668	5.17509	2.1879	2.5038	3.4797	4.0523	4.1693	4.7182
8	Impulse Factor	4.0091	4.4472	1.9092	2.1839	2.9744	3.4411	3.4551	3.8407
9	Shape Factor	0.307	0.3412	1.2293	1.2972	1.1191	1.1702	0.4838	0.5592
10	Upper Bound value of histogram	0.207	0.2828	1.8633	2.0753	2.1893	2.3624	0.4454	0.6155
11	Lower Bound value of histogram	-0.328	-0.2125	-3.845	-3.497	-3.488	-2.741	-0.884	-0.498

Table 2 Time Domain Features

Stastical Parameter		Healthy Bearing	Inner race faulty	Outer race faulty	Ball faulty
Standard Deviation	mean	0.0712	1.1745	0.9010	0.1773
Peak Value	Std	0.0164	0.0523	0.0446	0.0457
	mean	0.2318	1.9554	2.3050	0.5236
RMS Value	Std	0.0036	0.0293	0.0216	0.0104
	mean	0.0709	1.1740	22.5191	4.3667
Crest Factor	Std	0.2126	0.0503	0.0918	0.2577
	mean	3.2664	1.6715	2.5608	2.9929
Kurtosis	Std	0.0946	0.0983	0.0798	0.1256
	mean	2.9037	2.5958	2.7990	3.5453
Skewness	Std	0.0241	0.0522	0.0459	0.0502
	mean	-0.0309	-0.5276	-0.0579	-0.2171
Clearance Factor	Std	0.0908	0.0715	0.1505	0.1503
	mean	5.0189	2.3058	3.7308	4.4113
Impulse Factor	Std	0.1070	0.0615	0.1226	0.0997
	mean	4.2086	2.0024	3.1784	3.6229
Shape Factor	Std	0.0078	0.0160	0.0131	0.0182
	mean	0.3232	1.2712	1.1454	0.5086
Upper Bound Value of Histogram	Std	0.0172	0.0537	0.0446	0.0457
	mean	0.2310	1.9511	2.3064	0.5239
Lower Bound Value of Histogram	Std	0.0294	0.0857	0.2105	0.0910
	mean	-0.2426	-3.7155	-3.1012	-0.6830

REFERENCE

1. Thomas Vinod V., Vasudevan Krishna and Kumar Jagadeesh V., "Online Cage Rotor Fault Detection Using Air-Gap torque spectra", IEEE Trans. on Energy Conversion, Vol. 18, No. 2, June 2003, pp.265-270. | 2. Sinha B.K., "Condition Monitoring and Machine Fault Diagnosis", Indo-US Symposium on Emerging Trends in Vibration and Noise Engineering Delhi, March 1996, pp. 18-20. | 3. Albrecht P.F., Appiarius J.C., McCoy R.M., Owen E.L. and Sharma D.K. "Assesment of the Reliability of Motors in Utility Applications – Updated", IEEE Trans. On Energy Conversion, vol. EC-1, No. 1, March 1986, pp. 39-46. | 4. Natrajan R., "Failure Identification of Induction Motors by Sensing Unbalanced Stator Current", IEEE Trans. on Energy Conversion, Vol. 4, No. 4, December 1989, pp. 585-590. | 5 Caryn M. Riley, Brian K. Lin, Thomos G. Habetler and Randy R. Schoen, "A Method for Sensorless On-line Vibration Monitoring of Induction Machines", IEEE Trans. on Industry Applications, Vol. 34, No. 6, November/ December 1998, pp. 1240-1245. | 6. Changting Wang and Robert X. Gao, "Wavelet Transform with Spectral Post-Processing for Enhanced Feature Extraction", IEEE Transaction on Instrumentation and Measurement, Vol. 52, No. 4, August 2003, pp. 325-1332. | 7. Thomson W. T., "Current Signature Analysis to Detect Induction Motor Faults", IEEE Industry Applications Magazine, July/Aug. 2001, pp. 26-34. | 8. Sottile J. and Kohler J.L., "An On-Line Method to Detect Incipient Failure of Turn Insulation In Random –Wound Motors," IEEE Transactions on Energy Conservation ,vol.8, no.4,pp. 762-768 , Dec ,1993. | 9. Ram Badri & Vishwakarma D.N., Power System Protection & Switchgear second Edition, Tata Mc Graw Hill Education Pvt. Ltd., New Delhi, pp 510-512. | 10. IAS Motor Reliability Group, "Report of Larg Motor Relibility Survey of Industrial and Commercial Installation, Part I", IEEE Transaction on Industry Applications, Vol. IA-21, July/Aug. 1985, pp.853-864. | 11. Thomas W.T., "On-line Current Monitoring to Detect Rotor winding and Electro-mechanical Problem in Induction Motor Drive", IEEE Colloquium Condition Monitoring of Electrical Machine,January 30, 1995. | 12. Wardle F.P. "Vibration forces produced by waviness of the rolling surfaces of thrust loaded ball bearings", part 1: Theory. Proc. Inst. Mech.Eng., 1988, 202 (C5): 305-312. | 13. Finley W. R., Hodowanec M. M., and Holter W. G., "An Analytical Approach to Solving Motor Vibration Problems", IEEE Transactions on Industry Applications, Vol. 36, No.5, September/October, pp. 1467-1480, 2000. | 14. Choy F.K., Mugler D.H., and J. Zhou(2003), "Damage Identification of a gear transmission using vibration signatures", Journal of Mechanical Design, vol. 125, pp 394-402. | 15. Li Lingxin and Mechefske Chris K. "Induction Motor Fault Detection and Diagnosis Using Artificial Neural Networks", International Journal of COMADEM, Vol. 9 No.3, July 2006, pp.15-23. | 16. Yadav Manish and Wadhwani Sulochana, "Automatic Fault Classification of Rolling Element Bearing using Wavelet Packet Decomposition and Artificial Neural Network", International Journal of Engineering and Technology, Vol. 3, No. 4, (2011), pp. 270-276.