Wind Turbine Bearing Diagnostics Based on Vibration Monitoring

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Abstract. Reliability maintenance can be considered as an accurate condition monitoring system which increasing beneficial and decreasing the cost production of wind energy. Supporting low friction of wind turbine rotating shaft is the main task of rolling element bearing and it is the main part that suffers from failure. The rolling failures elements have an economic impact and may lead to malfunctions and catastrophic failures. This paper concentrates on the vibration monitoring as a Non-Destructive Technique for assessing and demonstrates the feasibility of vibration monitoring for small wind turbine bearing defects based on LabVIEW software. Many bearings defects were created, such as inner race defect, outer race defect, and ball spin defect. The spectra data were recorded and compared with the theoretical results. The accelerometer with 4331 NI USB DAQ was utilized to acquiring, analyzed, and recorded. The experimental results were showed the vibration technique is suitable for diagnostic the defects that will be occurred in the small wind turbine bearings and developing a fault in the bearing which leads to increasing the vibration amplitude or peaks in the spectrum.

1. Introduction

In the last few years, there has been a growing interest in the vibration monitoring has been gaining importance in recent years [1]. The current paper focused on the wind turbine (WT) bearing diagnostics based on the vibration monitoring. Vibration is one of the most established procedures utilized as a part of the field of wind turbine condition monitoring (WTCM) and it is typically used to recognize wind turbine faults like bearings faults, mechanical imbalance etc.as mentioned in [2,3]. This technique applicable on the wind turbine bearings, moving parts to decide mechanical and electrical issues as for damages, bearing issues, mechanical detachment, unbalanced, twisted shafts, tower vibrations, blades vibrations, electrical issues, reverberation issues. Bearing condition has been famously and dependably measured by means of machine vibration [4], also, it is problem is broadly gotten as the main issue for wind turbine prepare condition checking among all subsystems as studied in [5,6]. This is true as stressed Brian McNiff in his study [7], bearing failure is the main problem of turbine gearbox. Specifically, it was called attention to that it has been a tendency to destroy in various rates. It can be pointed that among the moving parts in a planetary gearbox, both the middle and high-speed shaft-supporting bearings have a tendency to fail at the quickest rate [8]. Also, the vibration measurement and spectrum analysis can be considered as a typical choice for bearing monitoring and diagnostics and rolling element bearing fault diagnosis [9, 10] targets at identifying the underlying anomalies based on the corresponding condition monitoring information. for summed up faults of
bearing, the bearing deficiency attributes have been seen observed in the WT vibration; for summed up faults of bearing, a critical broadband changes caused by the faults have been seen in the WT vibration spectrum [11]. It is possible to measure the vibration by utilizing vibration sensors, such as accelerometer what’s more, vibration speed transducers [12]. Estimations ought to be gone up against the bearing, bearing reinforcement housing, or other structural parts that altogether react to the dynamic force and describe the general vibration of the machine. It has been perceived that WT vibration is a dependable warning to identify bearing issues. In this way, vibration observing is attractive proceeding, and well-acknowledged specification is accessible, for example, ISO 10816 [13]. Accelerometers are utilized as vibration sensors and it can be situated on rotor bearing [14]. Vibration signals from accelerometers have the upside of giving a wide unique range and wide frequency range. ‘Figure 1’ shows a bearing made out of the external race, inward race, moving component, fixing [15].

![Figure 1. The rolling bearing component.](image1.jpg)

Faults in bearing may be occurred due to crack in outer race, hole in the outer race, corrosion, deformation of the protective shield, etc. ‘Figure 2’ shows the types of bearing faults that can be detected by monitoring the increased vibration in high-frequency spectra.

![Figure 2. The bearing faults. (a) Crack in the outer race (b) Deformation of the protective shield (c) Corrosion (d) Hole in the outer race.](image2.jpg)

The causes of bearing vibration are the outside time changing qualities between the portions and the transmission instrument of the WT amid the bearing operation however different signal processing procedures have been created to examine and interpret waveform and multidimensional information to extricate valuable data for promoting analytic and prognostic reason [14]. It can be outlined four kinds of deficiencies are recognized on the moving bearing relying upon where the fault happens. The
alleged bearing defect frequency ascertained on the premise of bearing parameters and rotational frequency relates to each of these faults and the following formulas are used to determine bearing defect frequencies:

- **Ball Pass Frequency Inner (BPFI)**
  \[
  \text{BPFI} \ (\text{Hz}) = \frac{N_b}{2} \left(1 + \frac{b_d}{p_d} \cos \theta \right) \times \text{RPM} 
  \] (1)

- **Ball Pass Frequency Outer (BPFO)**
  \[
  \text{BPFO} \ (\text{Hz}) = \frac{N_b}{2} \left(1 - \frac{b_d}{p_d} \cos \theta \right) \times \text{RPM} 
  \] (2)

- **Fundamental Train Frequency (FTF) (Cage)**
  \[
  \text{FTF} \ (\text{Hz}) = \frac{1}{2} \left(1 - \frac{b_d}{p_d} \cos \theta \right) \times \text{RPM} 
  \] (3)

- **Ball Spin Frequency (rolling element)**
  \[
  \text{BSF} \ (\text{Hz}) = \frac{p_d}{2b_d} \left(1 - \left(\frac{b_d}{p_d}\right)^2 (\cos \theta)^2 \right) \times \text{RPM} 
  \] (4)

Where: 
- \(N_b\): No. of balls or rollers, 
- \(b_d\): Ball diameter (mm), 
- \(p_d\): Bearing pitch diameter (mm), 
- \(\theta\): contact of angle, 
- \(\text{RPM}\): Rotational speed (Hz).

### 2. Test Procedure

For diagnostic the most popular defects in wind turbine bearing many experiments were carried out in the Renewable Energy LAB at Ministry of Science and Technology. In order to verify the validity of the diagnostic method as shown in Figure 3, an experimental rig was designed and fabricated.

The bearing type of SWG wind turbine 300 watts was used in this study which is 6205RZ deep groove ball bearing. The structure of the bearing is given in ‘figure 4’ and its main geometric parameters can be found in (table 1).
Table 1. Summarizes the geometric parameters of wind turbine bearing.

| Pitch diameter (Pd) | Roller no. | Roller diameter (Bd) | Contact angle (β) |
|---------------------|------------|----------------------|-------------------|
| 52 mm               | 9          | 10 mm                | 0                 |

Figure 4. Deep groove bearing.

To provide the WT with regular speed, a speed control was used through a mechanical coupling which is connected to the DC motor and WT. The bearing vibration signals were acquired by using the piezoelectric accelerometer. According to the fact that accelerometers are climb on the bearing by the magnetic method. So, signal translated to NI USB DAQ-4431 device which is used for vibration readings. Input and output channels are integrated for stimulus-response tests. The sample rate is set to be 25000 Sample/second. As can be seen from ‘figure 5’, the signal was processed by Zoom Fast Fourier Transform (ZFFT) to relatively small bandwidth within the spectrum.

Figure 5. Flowchart of the vibration signal processing

According to the (table 1) geometric parameters must be determined to calculate the characteristic frequencies or orders of rolling-element bearings. The vibration which produced by the bearing changes causes a fault starts to build up when a rolling part experiences a discontinuity of line tracking, a signal is watched and RMS indicator in the front panel of the program will be glow when the vibration value exceeds the threshold value which is determined by the observer as shown in ‘figure 6’.
The subsequent signals of vibration repeated continuously at a specific rate according to the position of the discontinuity and also the bearing structural. From (table 1), the bearing is after nine tests, are called BPFI, BPFO, and BSF individually. These measured the vibration signals of bearing at different shaft speed (2.5, 5, and 7.5 Hz) as shown in (table 2).

**Table 2. Fault frequencies and adjacent harmonic frequencies for 2.5, and 7.5 Hz shaft speed**

| Notation | Fault frequency multiplier | Fault frequency (Hz) | Harmonic frequency |
|----------|---------------------------|----------------------|-------------------|
| **BPFI** | 5.1                       | 38.5                 | 39                |
| **BPFO** | 3.6                       | 27.3                 | 28                |
| **BSF**  | 2.5                       | 19                   | 19                |

Half load condition =5 Hz

| BPFI | 5.1 | 26.7 | 28   |
| BPFO | 3.6 | 18.2 | 18   |
| BSF  | 2.5 | 12.6 | 13   |

Full load condition =2.5 Hz

| BPFI | 5.1 | 13.3 | 13   |
| BPFO | 3.6 | 9.1  | 9    |
| BSF  | 2.5 | 6.3  | 6    |

3. Test results
Depending on the tabulated results, some analysis spectra are clearly discussed. ‘Figure 7’, ‘figure 8’ and ‘figure 9’, showing BPFI, BPFO, and BSF fault frequencies respectively. The velocity waveforms as will reveal bearing damage, looseness, rubs, unbalance, misalignment and other conditions that have a high frequency and occur frequently.
Figure 7. BPFI at shaft speed = 7.5 Hz

Figure 8. BPFO at shaft speed = 7.5 Hz

Figure 9. BSF at shaft speed = 7.5 Hz

‘Figure 10’ illustrates the BPFI, BPFO, and BSF spectrum at 7.5 Hz shaft speed. The method for determining displacement from velocity is the same as determining velocity from acceleration—therefore to go from acceleration to displacement needs two stages of processing, as shown in Figure 11. ‘Figure 11’ show criterion displacement movement for BSF fault of a wind turbine at 7.5 Hz shaft speeds. This type of waveforms can provide indications to wind turbine status that is not always evident in the frequency spectrum.

Figure 10: illustrate BPFO, BPFI, and BSF at 7.5 Hz shaft speed

Figure 11. The criterion displacement movement at 7.5 Hz shaft speed
4. Conclusions
The results showed that developing a fault in bearing lead to appearing vibration amplitude or peaks in the spectrum. Spectrum monitoring and analysis are very useful because it is recording exactly what happened in the wind turbine from one moment to the next because the spectrum will have a "spike" when some fault or defect occurred and will record or capture the event. In addition, the spectrum may have harmonics, sidebands will reveal what happened. The fast Fourier transforms (FFT) have a high scope in vibration analysis. An FFT have harmonics, sidebands will reveal what happened. The fast Fourier transforms (FFT) can be considered as especially benefit method. When a problem wind turbine occurs, FFT can tell us the position of the fault, the cause of the fault. BY knowing a certain wind turbine problem that occurs at definite pulsation it can determine the FFT spectrum. From study conditions, it can be concluded that the vibration technique suitable for diagnostic the defects occurred in the small wind turbine bearing.

References
[1] Abbasion S Rafsanjani A Farshidianfar A and Irani N 2007 Rolling element bearings multi-fault classification based on the wavelet denoising and support vector machine Mech. Syst. Signal Process. 21 pp 2933–45
[2] Choudhury A and Paliwal D 2016 Application of Frequency B-Spline Wavelets for Detection of Defects in Rolling Bearings Procedia Eng. 144 pp 289–96
[3] Jardine A Lin D and Banajevic D 2006 A review on machinery diagnostics and prognostics implementing condition-based maintenance Mech. Syst. Signal Process. 20 pp 1483–510
[4] Jayaswal P Wadhwani A and Mulchandani K 2008 Machine fault signature analysis Int. J. Rotating Mach.
[5] Korkua S Lee W and Kwan C 2011 Design and Implementation of ZigBee based Vibration Monitoring and Analysis for Electrical Machines Int. Conf. Wirel. Networks - ICWN.
[6] Lan Y et al. 2016 A two-step fault diagnosis framework for rolling element bearings with imbalanced data 2016 13th Int. Conf. Ubiquitous Robot Ambient Intell. 620–25
[7] Mcgowan J G et al. 2006 Condition monitoring and prognosis of utility-scale wind turbines Condition monitoring and prognosis of utility-scale wind turbines
[8] B. Mcniff and M L Industry The Gearbox Reliability Collaborative
[9] Önel J Y and Benbouzid M E 2008 Induction motor bearing failure detection and diagnosis: Park and Concordia transform approaches comparative study IEEE/ASME Trans. Mechatronics 13 pp 257–62
[10] Randall R B and Antoni J 2011 Rolling element bearing diagnostics-A tutorial Mech. Syst. Signal Process. 25 pp 485–520
[11] Bellini A Filippetti F Franceschini G Tassoni C and Kliman G B 2001 Quantitative Evaluation of Induction Motor Broken Bars by Means of Electrical Signature Analysis IEEE Transactions on Industry Applications 37 5
[12] Safizadeh M S and Latifi S K 2014 Using multi-sensor data fusion for vibration fault diagnosis of rolling element bearings by accelerometer and load cell Inf. Fusion 18 pp 1–8
[13] Si L Wang Z Liu X Tan C, Xu J and Zheng K 2015 Multi-sensor data fusion identification for shearer cutting conditions based on parallel quasi-newton neural networks and the Dempster-Shafer theory Sensors (Switzerland) 15 28772–95
[14] Wang W Q Ismail F and Farid M 2001 Assessment of Gear Damage Monitoring Techniques Using Vibration Measurements Mech. Syst. Signal Process 15 905–22
[15] Wilkinson M Spianto F and Knowles M 2006 Towards the zero maintenance wind turbine 41st Int. Univ. Power Eng. Conf. UPEC Conf. Proceedings 1 74–8