International Journal of Engineering Sciences &Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

[Kaur, *et al.*, 8(10): October, 2019]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

SPECTRUM ANALYSIS OF WIND TURBINE BALL BEARING FOR FAULT DETECTION

Surinder Kaur[*1], Gora Ram Sharma[2] & Amit Gupta[3]
[*1]Research Scholar, BhaiMaha Singh College of Engineering, Muktsar
[2&3]Assistant Professor, BhaiMaha Singh College of Engineering, Muktsar

DOI: 10.5281/zenodo.3490446

ABSTRACT

By the passage of the time all the power sources will vanish as their related failure are not only losses of production time, it also have harmful consequences. There are many general purpose and specifically applicable software available nowadays which are user friendly in programming and operation as well as capable of simulating such renewable and green energy harvesting by generating mathematical model of the whole system. This work represents the diagnosis of faults of wind turbine bearing to estimate the life of wind turbine as bearing is moving part of turbine which supports both axial and radial loads. The wind turbine was modelled in MATLAB/SIMULINK using asynchronous generator and synchronous condenser(480v) to get input values for the simulation of results by setting the initial conditions of model. The results were simulated under four types of analysis (PSD ,Kurtosis, envelop and time frequency) methods at variable rpm, to demonstrate performance of wind turbine bearing under the presence of faults in inner and outer race of bearing.

KEYWORDS: PSD, Kurtosis, Spectrum Analysis.

1. INTRODUCTION

All power generation systems will degrade over time. This may lead to an unwanted and uncontrolled situation..Thus, in order to maintain critical industrial systems before the failure takes place, maintenance strategies should be planned. Prognostics and Health Management (PHM) is a system that is able to work on real collected monitoring data and helps in estimating and alerting health of a system [1]. PHM is considered as the fusion of 7 purposes adapted from Open System Architecture for condition-based maintenance (CBM) strategy, that all together enable involving failure mechanisms with life management (Fig. 1).

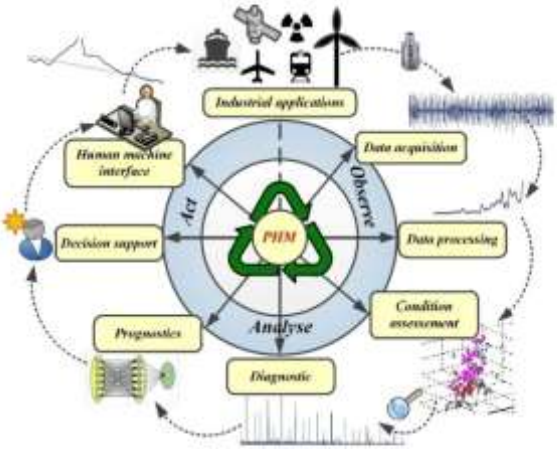

Figure 1:Prognostics and Health Management (PHM) Cycle

The results provided by them are really effective in early alert and warning system[1][2]. Diagnostics describes the status of damage through detection, isolation and identification process using collected data from different installed sensors. India has started to recognize the importance of developing this sector and to acknowledge its potentialities for cutting down greenhouse gas emissions, as a viable and efficient solution to taxes on carbon – a

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Impact Factor: 5.164
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method implemented through a $4 tax per metric to non coal [3]. Up to date the share of renewable in the energy mix amounts to less than9%, but India committed to a cut of 25% of emissions by 2020, and this share is planned to increase over time. To this purpose, hydro, solar and nuclear energy capacity must increase up to 90GW production, meaning a 20% in the total energy mix, which will further increase over time according to the ambitious Indian plan for the investments in renewable: indeed, the renewable market in India is estimated to account for a $10.51 billion opportunity, and generate business prospects worth $160billion in the next five years[4][5].

In case of wind turbines, main mechanical moveable part is ball bearing.[6] In general, rolling element bearings are designed to carry axial and/or radial load while minimizing the rotational friction by placing rolling elements such as cylinders or balls between inner and outer races. There are different types of rolling element bearings, among all of them, ball bearings are the cheapest since balls are used instead of cylinders in their construction[7]. They are widely used in industry today, in variety of applications in production line, in electric motors, pumps and gearboxes. There are also different types of ball bearings such as thrust, axial, angular contact and deep groove ball bearings.[8]

2. LITERATURE REVIEW

Jianfeng Wang et al. studied that a new type of deep-water offshore foundation, the bucket foundation has been gradually used in the design and construction of offshore wind turbines and ocean engineering. Offshore wind turbine foundation is not only subjected to huge vertical loading, but also always sustains horizontal loading and moments caused by hurricane or storm. LotfiSaidi et al. investigated that an integrated prognostics method dedicated to the wind turbine high-speed shaft bearing prognosis, which integrates physical degradation model and data driven approaches. Sharafet al investigated Common mechanical failures in wind turbine generators (WTGs) result in unplanned downtime, loose of production and increase the maintenance cost. Statistical studies have shown that failures due to high-speed shaft bearing (HSSB) account for 64% of all drive train failures. Consequently, prognostic and health management (PHM) of WTGs aims to estimate the future state of health and predict the reaming useful life (RUL) of HSSB.

LotfiSaidi and Jaouher Ben Ali examined that Track degradation of wind turbine high-speed shaft bearing can reduce unscheduled maintenance events, and safe power generation system. They proposes a particle filter-based prognostic approach for high-speed shaft bearing track degradation; this approach is validated by inspecting a real data from a wind turbine drive train. The particle filter-based prognostic results are compared with the standard support vector regression and Kalman smoother results. The particle filter method shows better results. For longer prediction times, the error of the proposed method is equal to or smaller than that of the regression method. Jun Wang et. al. studied that Sparse representation of massive condition monitoring signals is an effective approach to save the cost for data storage and transmission in fault diagnosis of wind turbines.Qian Huanget. al. discussed about The state-of-the-art advancement in wind turbine condition monitoring and fault diagnosis. Since the existing surveys on wind turbine condition monitoring cover the literatures up to 2006, this review aims to report the most recent advances in the past three years, with primary focus on gearbox and bearing, rotor and blades, generator and power electronics, as well as system-wise turbine diagnosis. There are several major trends observed through the survey. Due to the variable-speed nature of wind turbine operation and the unsteady load involved, time-frequency analysis tools such as wavelets have been accepted as a key signal processing tool for such application.

MeikSchlechtingen and Ferreira Santos explained the research results of a comparison of three different model based approaches for wind turbine fault detection in online SCADA data, by applying developed models to five real measured faults and anomalies. The regression based model as the simplest approach to build a normal behavior model is compared to two artificial neural network based approaches, which are a full signal reconstruction and an autoregressive normal behaviour model.

3. METHODOLOGY

The ball bearings themselves act as a source of vibration, even if there are no defectspresent and they are perfectly aligned and adjusted . A defect on one of theelements of a ball bearing can cause the vibration level to increase. There are severaltype of defects that can occur on a ball bearing, such as cracks or pits on rotating

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

surface or rolling elements, distributed defects such as roughness or misaligned races. Those distributed or localized defects form the vibration pattern that can be detected by a transducer and then analyzed and processed with the algorithm, which can enable the condition monitoring system to detect even the occurrence of a failure before it damages the machine or interrupt the production. When a rolling element strikes to a defect on one of the races, this strike creates animpulse. Since the rolling element bearing rotates, those impulses will be periodic with a certain frequency . A model to describe the vibration pattern produced by a single point defect on the inner race is described by McFadden and Smith .In case the defect occurs on the inner or outer race, how frequent each rolling element strikes to the defect is called “Ball-pass frequency” and determined by the bearing geometry and rotation speed.

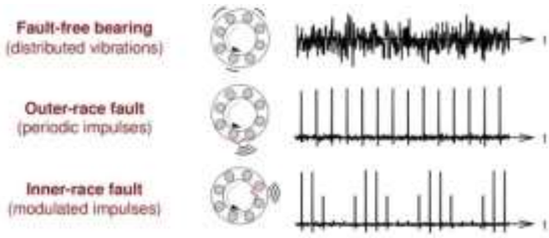

Figure2: Ball Bearing Faults and their vibration pattern

Ball pass frequency can also be calculated theoretically, where the formulations are given in, and compared to the detected one after the signals are processed, which can also be an indicator of the performance of the algorithm.

For diagnosis, such as determining the size of the defector decision making, ball pass frequencies and noise-free vibration pattern can be useful. The vibration signals from a fault-free bearing, bearings with inner and outer race faults are given in Figure. As illustrated, the characteristics of the impulses that occur from a defect on an inner race or outer race are different. Impulses from a defect in outer race have approximately equal amplitudes, since the race is stationary with respect to the load zone; that is, each time a rolling element passes by (or strikes) to the stationary defect on the outer race, equal amplitude impulses will be created. Impulses created from a defect on the inner race have different amplitudes and still periodic.

The behaviour can be concluded as the impulses are amplitude modulated. Since the impulses occur due to the resonance from bearing elements, the amplitude is directly related to the applied force on the ball bearing. As the rotating inner race, with a defect, passes through the load zone; that is, as a rolling element strikes to the defect which moves into and out of the load zone, modulated impulses will occur periodically with each shaft rotation.

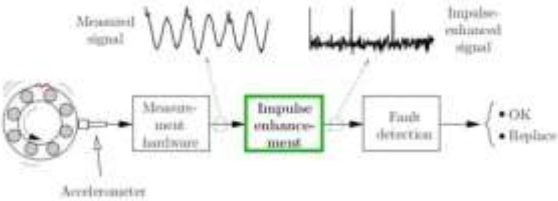

Figure3: Fault detection Process

Therefore, the envelope of the impulses can be described as a function of load distribution. The characteristic signals from a faulty bearing are masked after the measurement system, noise, distortions and disturbances. The purpose of the algorithm is to recover and enhance those signals by removing the undesired effects, as illustrated in Figure 2.4. Achieving this with minimum computational power, effort and complexity, without additional pre-processing applications such as filtering or envelope detection, and as a low cost system is surely the desired goal.

With the most general point of view, adaptation can be described as a process for an organism or a human-made system to adjust itself according to the conditions of the environment that it is placed, in order to maximize its performance and/or life-spandue to a prescribed criterion. Adaptive systems – the ones that are human-made- are well-known research area in signal processing, and there are many different literature published for the subject. "Adaptive Signal Processing" by Widrow and Stearns is the one that is mostly referenced in this chapter. Detailed information about the derivations, characteristics and different approaches can also be found in that reference.

4. Results

A generic model of the High-Penetration, No Storage, Wind-Diesel (HPNSWD) system is used in the work. This technology was developed by Hydro-Quebec to reduce the cost of supplying electricity in remote northern communities. The optimal wind penetration (installed wind capacity/peak electrical demand) for this system depends on the site delivery cost of fuel and available wind resource. The first commercial application of HPNSWD technology was commissioned in 1999 by Northern Power Systems (Vermont, USA) on St. Paul Island, Alaska. The HPNSWD system presented in this example uses a 480 V, 300 kVA synchronous machine, a wind turbine driving a 480 V, 275 kVA induction generator, a 50 kW customer load and a variable secondary load (0 to 446.25 kW).

For simulation and results, the Matlab model of a wind turbine is executed on the platform and the initial states are embedded in the model properties. This makes the model to run in ideal state without any faults. The Model is simulated for a period of 20 seconds at a wind ideal speed of 10 mph. This allows to record the spectral properties of the signal generated at the turbine during the operation.

The Graphical User Interface is user friendly and there are four methods with which the conditions of defect are analyzed. These are programmed as per the objectives and are summarized as:

- Spectrum (Power Spectrum Density)
- Kurtosis
- Envelop Detection
- Time-Frequency Spectrum

These methods are implemented on both Inner ring and Outer ring of ball bearing. It is likely that the defects may arise at inner side of outer ring and outer side of inner ring of ball bearing. the possibility of these faults may interrupt the operating as well as breaking / damping system of a wind turbine.

The implementation operational properties includes the simulation of the rings on different rpm. This allows to analyze the faults with maximum possibilities such as selection of position of faults on the rings, different processes to detect and analyze them and at variable rpm. The results of all the combinations of the processes are keenly observed during implementation stepwise selecting the ring and method of observation at a selected rpm.

The main window of GUI (Graphical User Interface) allows the system to clear any previous assigned value or state to any variable that is used in the program.

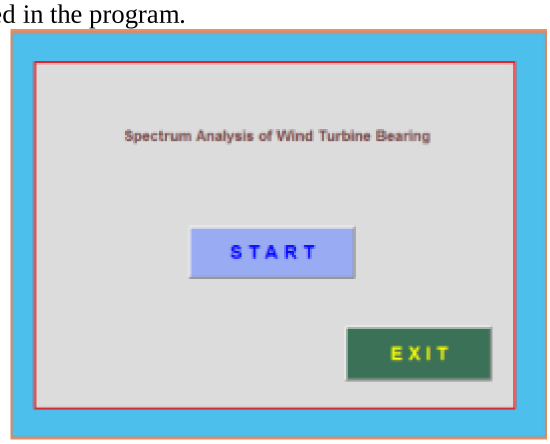

Figure4 Main Window of GUI

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Figure5: Window platform to analyze and observe the signal waveforms.

The process of detection and analysis is done by keeping the rpm value static and the observations are made on inner ring and outer ring one at a time using a selected method. For easy understanding and organizing, the process is divided into four steps.

Step-I

In step-I the analysis method chosen is Power Spectral Density (PSD). The rpm is chosen anonymously and is kept as 610. The simulation results for Inner ring at these parameters are shown in figure 6.

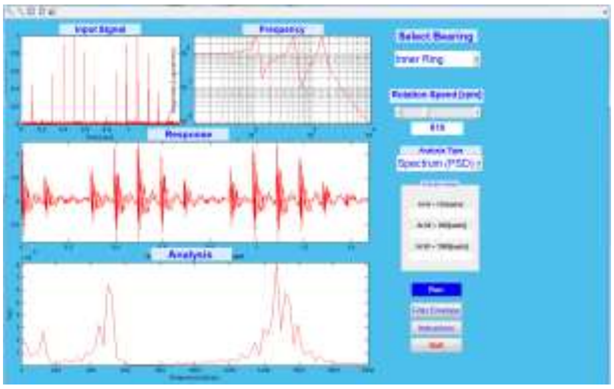

Figure 6 Simulation results of Inner ring using PSD at 610rpm.

The analysis shows the detection of fault in the ring at each rotation. The process is repeated after selecting outer ring and the results are shown in figure 7.

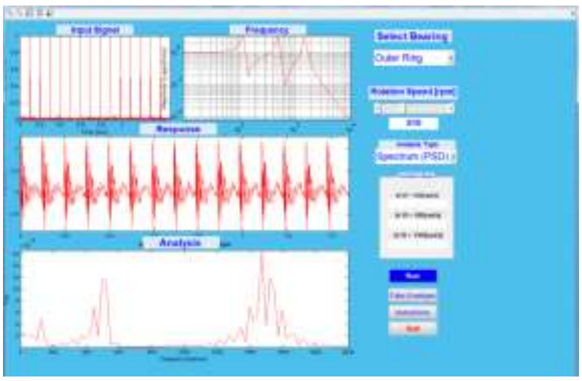

Figure 7 Simulation results of Outer ring using PSD at 610rpm.

Step-II

The analysis method chosen in step-II is Kurtosis. The rpm is chosen anonymously and is kept as 1210. The simulation results for Inner ring at these parameters are shown in figure 8.

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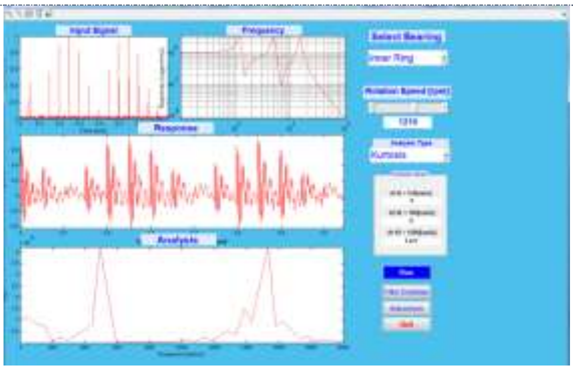

Figure 8: Simulation results of Inner ring using Kurtosis at 1210rpm.

The analysis shows the detection of fault in the ring at each rotation. The process is repeated after selecting outer ring and the results are shown in figure 9.

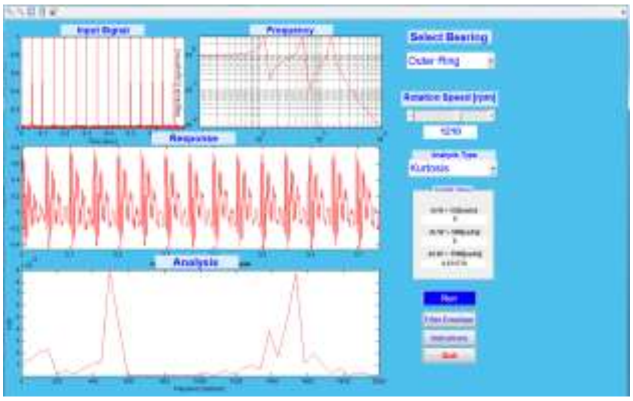

Figure 9 Simulation results of Outer ring using Kurtosis at 1210rpm.

Step-III

The analysis method chosen in step-III is Envelop Detection. The rpm is chosen anonymously and is kept as 1410. The simulation results for Inner ring at these parameters are shown in figure 10.

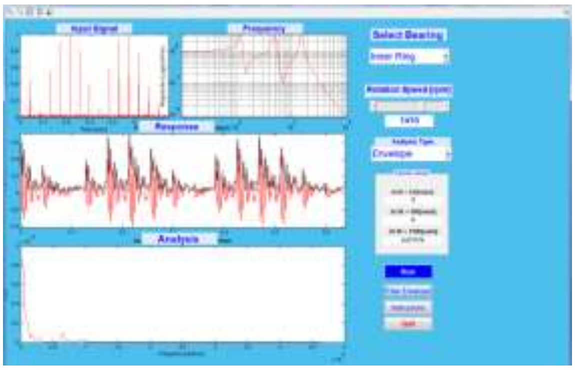

Figure10 Simulation results of Inner ring using Envelop Method at 1410rpm.

The analysis shows the detection of fault in the ring at each rotation. The Response portion of the graph shows the detection of the envelop as black line at the upper portion of waveform. The process is repeated after selecting outer ring and the results are shown in figure 11.

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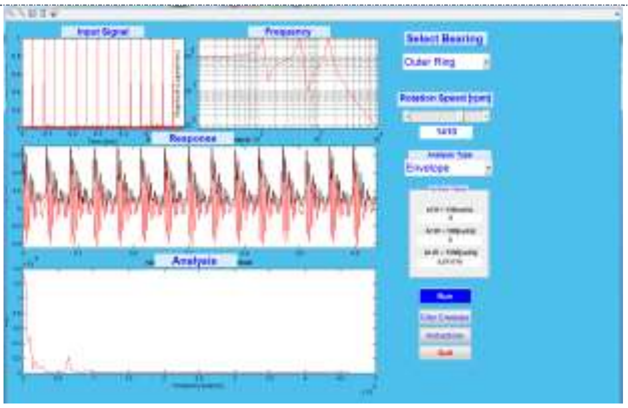

Figure 11 Simulation results of Outer ring using Envelop Method at 1410rpm.

Step-IV

The analysis method chosen in step-IV is Time-Frequency Detection. This method analyze the waveform in time as well as frequency spectrum. The spectrum is visible at Analysis portion of the GUI. The rpm is chosen anonymously and is kept as 410. The simulation results for Inner ring at these parameters are shown in figure 12.

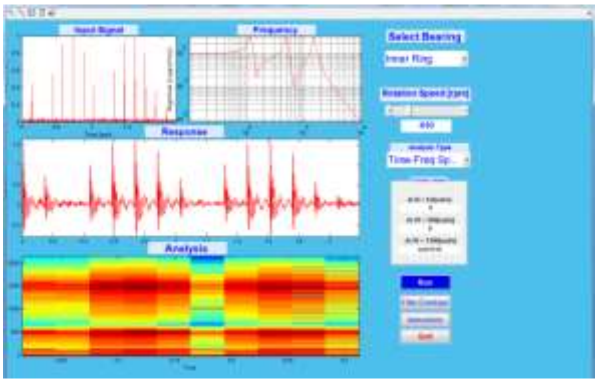

Figure 12 Simulation results of Inner ring using Time-Frequency Spectrum method at 410rpm.

The analysis shows the detection of fault in the ring at each rotation. The process is repeated after selecting outer ring and the results are shown in figure 13.

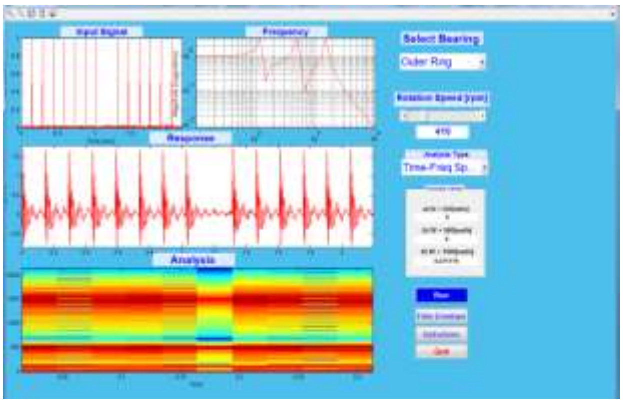

Figure 13: Simulation results of Outer ring using Time-Frequency Spectrum method at 410rpm.

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Table1: Comparison of Different Techniques

Parameters	Ring	Rpm Anonymously chosen	Fault Detection Result
STEP-I (PSD)	Inner Ring	610	Detected Successfully
	Outer Ring	610	Detected Successfully
STEP-II (Kurtosis)	Inner Ring	1210	Detected Successfully
	Outer Ring	1210	Detected Successfully
STEP-III (Envelop Detection)	Inner Ring	1410	Detected Successfully
	Outer Ring	1410	Detected Successfully
STEP-IV (Time Frequency)	Inner Ring	410	Detected Successfully
	Outer Ring	410	Detected Successfully

The results obtained by all four methods has successfully and efficiently detected the fault signal that is present in a regular signal from the turbine. This filtration helps in overcoming any critical situation that may arise due to malfunctioning or defect in the bearing. Although the signal attributes for inner and outer ring differs parametrically but the system can be applied to both the rings of a bearing. Early stage detection of faults might not be visible through visual inspection that may lead to a heavy loss but the irregularity of the signal can be detected using waveform analyzers and software platforms. For example in Figure 6.7 and Figure 6.8, the envelop traced black in color, can be analyzed and any irregularity in the continuity can be detected.

These observations are keenly noted and compared with the available literature. The comparison is as follows:

- In available literature, the process was implemented at a fixed rpm i.e. 2000rmp but this dissertation extends to the possibility of variable rpm of the shaft of wind turbine where bearing under observation is installed.
- The literature has been implemented only by using Envelop Method whereas this dissertation has observed and analyzed using Four different methods or domains.
- Only one part of race was analyzed in the available literature whereas this dissertation analysis the both inner and outer race of the bearing.
- The literature was implemented within fixed frequency ranges i.e. 7.75Hz to11.59Hz. Whereas this dissertation performed under varying frequency ranges.

5. CONCLUSION

The faults has been detected using four analytical methods i.e. PSD, Kurtosis, Envelop, Time frequency which are used to detect stage faults .Out of these envelop method is easy and user friendly as itself detect the faults that are visible in wave form. This system will help in avoiding extreme situation such as system breakdown because presence of any fault in bearing can lead to further loss. The faults are successfully detected via all above mentioned method at early stage for preventive maintenance.

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