Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Impulse excitation analysis of material defects in ball bearing

J.J. Jayakanth *, M. Chandrasekaran, R. Pugazhenthi

Department of Mechanical Engineering, VISTAS, Chennai, Tamilnadu, India

ARTICLE INFO

Article history:
Received 29 July 2020
Received in revised form 11 September 2020
Accepted 14 September 2020
Available online xxxx

Keywords:
Bearing defect
Grindosonic effect
Impulse excitation
Ball bearing defects
Spectrum analysis

ABSTRACT

Bearing is an important element in the modern manufacturing rotating elements, almost all the rolling parts are supported by the bearing. The good maintainability of the bearing is one of the successful productivity balancing strategies. In this work made an attempt to diagnose the fault detection of bearings under the static condition; an effective bearing fault diagnostic technique is critically needed for the industries for early detection of bearing defects. Preventing breakdown/malfunction of machinery reduces the performance of the machine and productivity. The most used rotating element is the ball bearing in the industry 62xx series, in this work the ball bearing HCH 6201-2RS is considered for evaluation for inner race defect and outer race defects. An indigenous workbench was developed and validated it with the new and good working bearings. The amplitude and power spectrum wave formation was observed and recorded with the help of Lab View; a standard wave format of both good working conditions and brand-new bearings of the HCH 6201-2RS was identified.

1. Introduction

The invention of the wheel changes humans from caveman to modern man, similarly in rolling elements wear and tear can easily damage the rolling components contact area. Bearings are one of the best inventions in modern engineering, which plays a vital role in minimizing the wear of any rotating element. In this virtue, all the industries were working a maintenance schedule to maintain the machines especially the bearings are checked and maintained in the proper schedule in some cases the bearings lubricated in every day. The bearings were majorly classified into bushed bearings, ball bearings, and roller bearings, among them the ball bearings were the most commonly used bearings because of its durability and performances. In the ball bearing 6000 series ball bearings were the most highly used bearing especially in the domestic application electrical and electronics appliances were used this type of bearings [1]. The Fig. 1 shows the various elements of the ball bearing and the Fig. 2. shows the important components of rolling (frictional contact area) elements of the bearings. The ball bearings will accommodate moderate to heavy loads and low to moderate thrust loads in either direction. Fig. 1 shows the Ball-bearing nomenclature. Deep groove radial bearings are manufactured as open type bearings for oil or grease lubrication. They are also available with metal shields and/or seals for use where moderate contamination is present in the operation. Angular contact bearings are single row types used where radial and thrust loads are combined in the same application. Double row bearings are manufactured both as filling slot and as Conrad types, in light and medium series. The filling slot type has higher load capacity but the Conrad type provides quieter operation and should be used when noise is a consideration [2].

The Self-Aligning bearings are manufactured with two rows of balls and one continuous spherical raceway in the outer ring. This allows for the limited misalignment of the shaft and housing. Different types of ball bearing are used in industrial and many household products. This gives a good and well-balanced rotating mechanism. When these bearings are used over a period of time it tends to get damaged due to external factors and internal wear. The excessive wear in bearing leads to damage to the other parts of the unit, hence overall stalling machinery happens. When this kind of defective bearing is considered for analysis some common internal defects within the bearing are identified [4]. The defect we see is material wear at the inner race of the bearing or material wear at the outer race of the bearing or wear in the balls of the bearing are common. One major cause of the defect is due to material wear of Bearing.

* Corresponding author.
E-mail address: jj.jayakanth@gmail.com (J.J. Jayakanth).

https://doi.org/10.1016/j.matpr.2020.09.305
2214-7853/

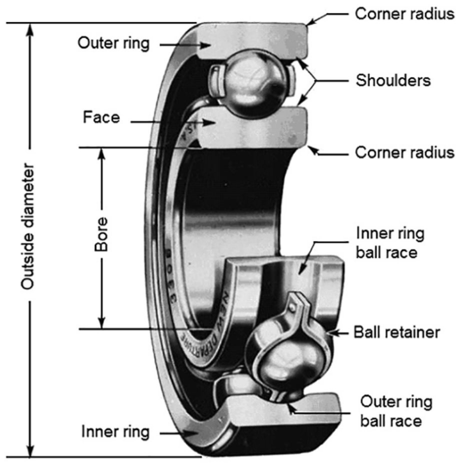


Fig. 1. Rolling element bearing [3]

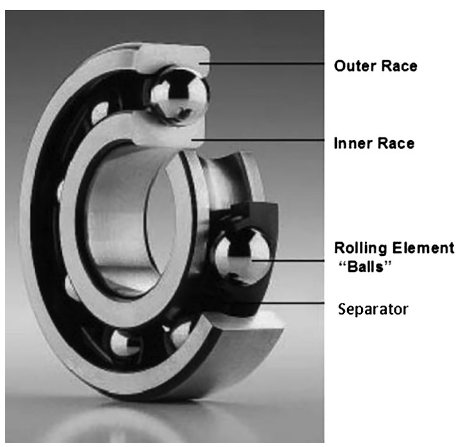


Fig. 2. Internal view shows the parts of ball bearing [7]

The above figure shows the inner race defects of the ball bearing. Fig. 3. (a) shows the mild wear of the inner race defect of the ball bearing. Fig. 3. (b) shows the continuous wear impact after using it for a longer period of time, this loses its surface smoothness and started to affect the components. Fig. 3 (c) shows some pointed impact of the inner race defect when in use, this may be due to any sharp impacts or heavy load acting on the bearing while in operation.

Fig. 4. (a) shows the outer race and inner race of the bearing where the outer race has some sharp defects and this causes the bearing to lose its smooth functioning. This kind of defect gives sharp peaks in the identifying mechanism. Fig. 4. (b) shows a steadily worn-out outer race of the bearing when it is subjected to usage for a longer period of time. Fig. 4. (c) shows the outer race of the bearing with multiple smaller impacts which is also defective.

The Fig. 5. (a) shows a closer look at the Inner race defect caused under continuous load. Fig. 5. (b) shows the sharp impact caused in the outer race of the ball bearing. To identify the material wear, defect some methods are implemented to analyze it. When the bearing loses its intactness it starts giving some issues, this causes some vibration in the component [4]. Because of this vibration measuring analysis is one major factor for identifying the defects in the bearing. The vibration analysis is the most commonly accepted technique due to its ease of application. The results of vibration are more reliable and accurate, whereas the other methods have some inaccuracies and complexity in identifying the defect [5].

2. Literature review

The literature review focuses on the material wear impact on the ball bearing. The results of the test consist of the machine vibration due to the radial movement of the bearing, air gap variation due to relative motion between the raceways, variation in rolling resistance due to load torque. The ball bearing radial movement confirms the machine vibration with a faulty frequency. The measurements are taken through vibration transducers. From the results, a model is developed with a time-domain convolution of white noise with that of the mechanical frequency response of the mechanical function [6].

To a large extent, the magnitude of this radial movement depends on the magnitude of the radial load applied to the inner raceway. Bearing illustrated in Fig. 6. Shows, defect impact causes a minimal effect in a rolling element, in the absence of a radial load. This is because of the radial separation between the inner and outer raceways maintained in the neighboring rolling elements and can pass over the defects. However, the rolling element exhibits elastic deformation under the application of a radial load and experiences a compressive force. This force rolling element into the defects and causes impact effect. It also increases the inner race defects due to raceway and rolling element couplings [7]. When the characteristic fault frequency of inner-race is an integer multiple of rolling element characteristic frequency the rolling elements are easy to identify. Hence the identification of the defects

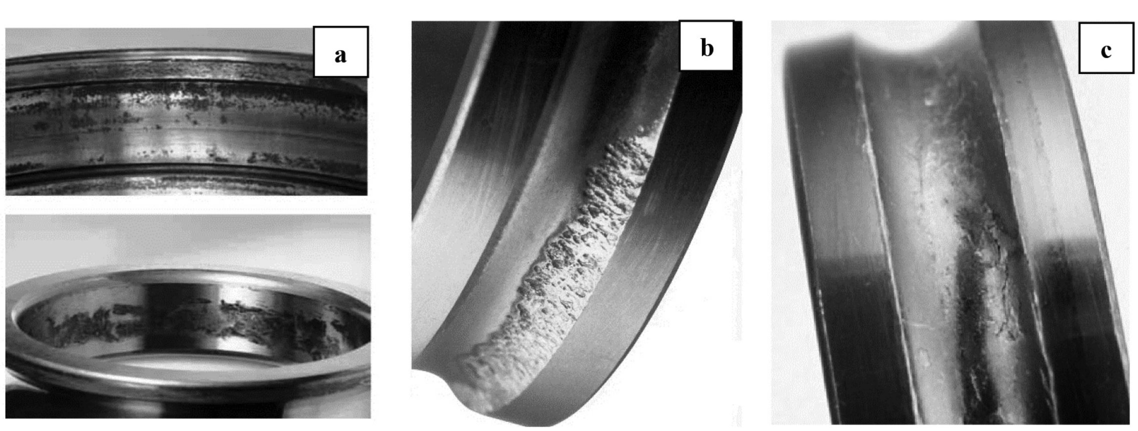


Fig. 3. (a, b, c) Inner race defect of the ball bearing.

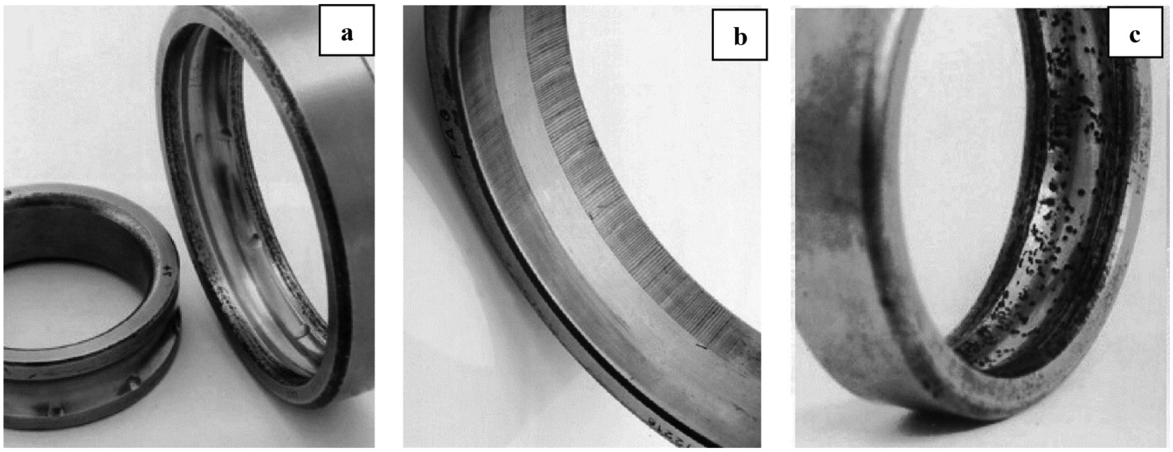


Fig. 4. (a, b ,c) Outer race defect of the ball bearing.

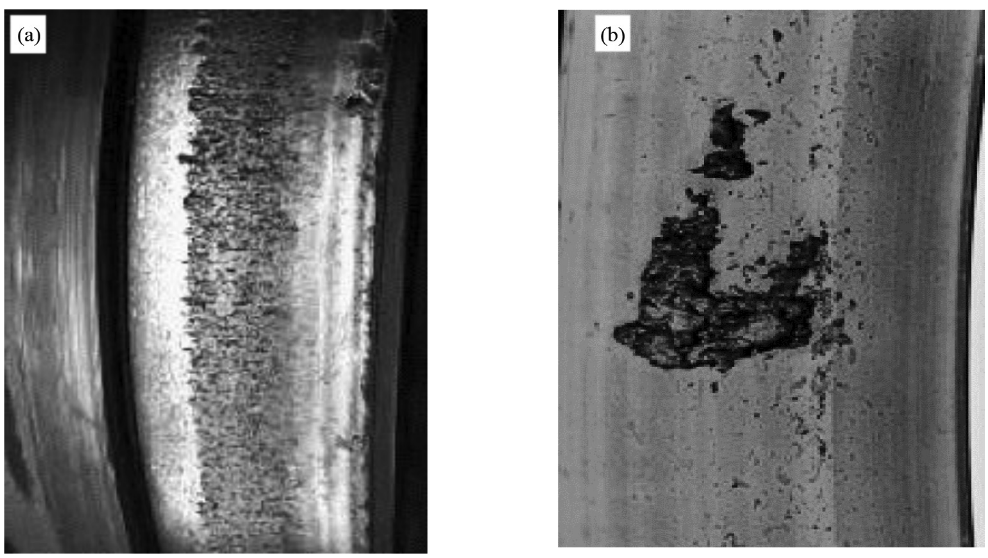


Fig. 5. (a) closer look at the Inner race defect caused under continuous load. (b) sharp impact caused in the outer race of the ball bearing.

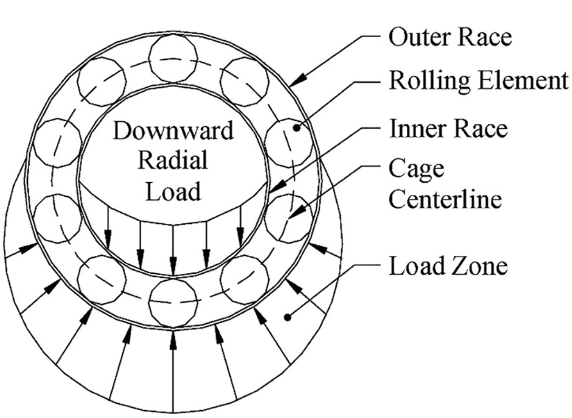


Fig. 6. Shown in the above figure is: downward radial load applied to the inner race of four bearing surfaces as well as the resulting load zone [6]

in a rolling element or cage, this model is can be easily extendable. Vibration analysis is one of the most powerful tools for bearing fault detections. It would be a simple process if noiseless vibration signatures are measured on bearings to identify the fault in it. But practically the acquired vibration signals from the bearing element and its housing, buried in noise due to random vibration caused by friction, misalignments, and imbalances. These random vibrations dominate the fault signature in the measured spectrum and the expected vibration spectrum is lost in the higher harmonics and its spectral noise floor.

Bearing failure occurs due to several mechanisms, including damages caused by mechanical, crack, wear, lubricant deficiency, and corrosion [8]. Nicks and dents are due to the abusive handling of berating elements. When higher stress on the contact impair the smooth surface, i.e., marred and reduces the lifetime of bearing element drastically. 'Brinelling' is another harmful condition caused in the rolling element due to its overload. Cyclic loading and overloading create a crack in bearing, manufacturing defects also leads to crack. In a bearing element gradual deterioration due to wear leads to dimensioning related faults. Normally metal-to-metal friction occurs and increases due to inadequate or poor lubrication also increases the temperature of the bearing element, reduces bearing lifetime. Plastic deformation occurs due to operating forces. Scuffing or scoring is lighter adhesive damage; sizing or galling is highly intense damage. Abrasive wear occurs if any hard particle intervenes with the smooth contact surface. A higher humidity environment due to surface oxidation produce rust and pits and raises the stress and ultimately leads to abrasion and rapid wear. In an example of an outer race of a ball bearing is flawed because of one of the failure mechanisms in which one of the balls rolls over the flaw, an impulsive force is incurred that causes the bearing to vibrate [9]. The bearing responds by "ringing" at its Fig. 7.

The response excitation occurs each time one of the balls rolls over the flaw, hence the fundamental frequency of the response waveforms is the rate at which the elements roll over the flaw, is of interest in the detection of bearing faults, not the resonance frequency. Depending on the nature of bearing fault like outer race, inner race, balls, and cage, different characteristic frequencies are generated [8]. In this work, a synthetic signal was constructed with a square wave approximation and random noise, ringing pulse sequence, and their sum has been carried out and obtained simultaneous spectra and composite waveform. But in this analysis, the higher harmonics in the pulse sequence spectrum higher harmonics in the spectrum disappearing slowly compared to square wave approximation. The peaks in the composite signal spectrum are lost. Finally, they used bandpass filtering in "envelope analysis" rejects the high-amplitude low-frequency signals associated with misalignment and imbalance to eliminate random noise [9]. The analyzers and data loggers used in envelope analysis usually have user-selectable bandpass settings of required frequencies. The final step in the envelope analysis process is the calculation of the spectrum of the rectified bandpass filtered signal with Hilbert transform. In bearing fault frequency and its harmonics are distinctly visible in the spectrum obtained with MATLAB based graphical user interface (GUI) program. This confirms the effectiveness of this spectrum analysis method in bearing fault deduction analysis [10].

From the literature, it is found that most of the bearing analysis is done in dynamic analysis. In this research, the bearing faults induced in rotating machinery are investigated experimentally using vibration analysis techniques that are based on time, frequency, and time–frequency domains. Also, the literature survey brings out the essential requirement of simple user-friendly design to monitor the rolling bearing functionality to maintain the smooth functioning of bearing towards its lifetime [11]. The essential need in industries and R&D environment is to support the continuous fault-free operation of the machinery. Through the influence of the literature survey, there is a requirement for finding a methodology to identify the ball bearing defects in their housing position. Grindosonic is one of the best methodologies to identify the problems of ball bearing in their in-house positions. The vibration analysis is done by static analysis using the vibration signal. Testing at the static state requires a separate vibration signal source. A trigger signal is required to generate vibration in bearing. The Impulse Excitation Technique is used for triggering impulse in bearing. This kind of NDT testing methodology to test the conditions of the bearings very few researches were focused to find the methodology to solve this issue [12].

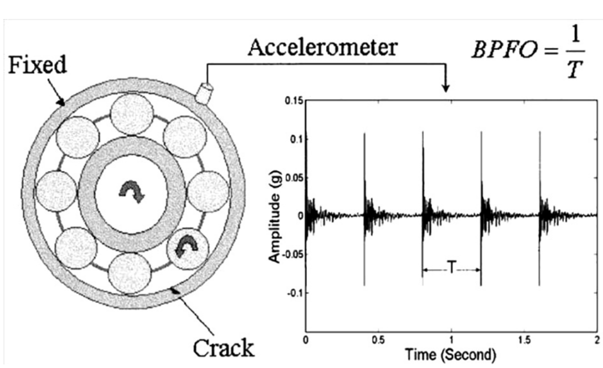


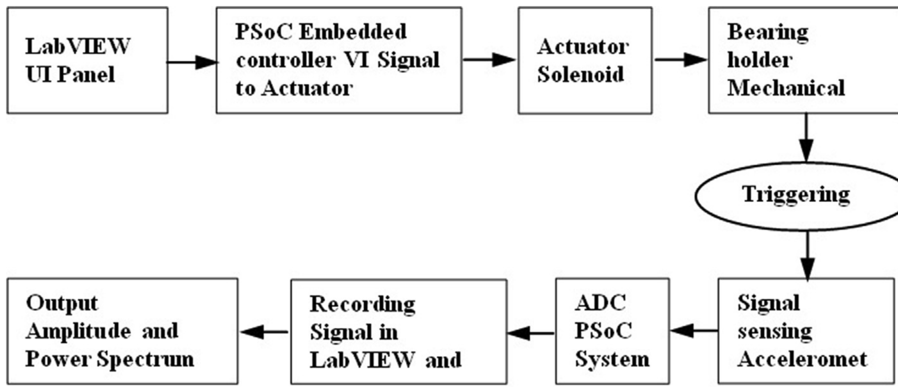
Fig. 7. Vibration signal plot, amplitude as a function of time of a bearing shows ringing excitation due to fault in the outer bearing race [10]

Non-Destructive measurement of material characteristics can be identified by using Impulse Excitation Technique (IET). The object under test is subjected to an initial deformation by means of a light mechanical impulse. The amount of strain (deformation) is linearly proportional to the applied stress (load), hence the material is said to be linearly elastic. Robert Hooke described the proportionality between stress and strain Stress/Strain = Constant. The constant is a factor of proportionality known as the modulus of elasticity of the material. The object will act as a spring-mass system and produce a transient mechanical vibration. The frequency of this vibration depends on the mass of the object and its stiffness, which is determined by its shape, dimension, and modulus of elasticity of the material [13].

3. Methodology

From the literature survey, various ball bearing fault analysis is identified. The factors which influence the defect parameters are cage defect, outer race defect, inner race defect, crease hardening, and the ball defect. These are the causes of the major bearing failure rate [14]. From the study analysis selection of factors considered based on the influencing parameter and the defect identification analysis methods are taken into consideration. Based on this a new Virtual Instrumentation Workbench is designed. In this work MEMS (Micro Electro Mechanical System) accelerometer interfaced with PSoC (Programmable System on Chip) microcontroller with its design creator tool, the vibration signal obtained by impulse excitation (Impulse Excitation Technique) IET, is based on the analysis of the vibration signal from a test sample by gently tapped impulse signal. The resonance frequencies are the main characteristics of the test element, as they are related to its stiffness, mass, and geometry of bearing. The characteristic vibration frequency can be obtained by gently hit the inner race by a tiny hammer automated with a LabVIEW program, controls the hammer, and acquires the MEMS sensor vibration signal through the PSoC interface board. The workbench is designed and fabricated for the test setup. The hardware setup has an interface with the PSoC embedded design platform which will bridge the hardware and the analysis tool of LabVIEW. The embedded PSoC designer controls the hardware and receives the signal from the sensors. The LabVIEW will have the entire Virtual Instrumentation control over the hardware. The trigger signal is given from the LabVIEW and PSoC controller is used to execute the operations over the test bearing. The signals from the accelerometer are given as input to the LabVIEW model [15]. This spectrum signal and the amplitude plot are analyzed using the LabVIEW spectrum plot and amplitude plot. Fig. 8 shows the workflow of the research work.

The input to the hardware is given from the LabVIEW virtual instrumentation workbench. The signal from the User Interface front panel of LabVIEW is given to the PSoC Embedded hardware through which the external hardware is interfaced. The system uses the gryndosonic technique for measuring the vibration signal. To implement this triggering method for the bearing, a solenoid acts as a trigger mechanism instead of a hammer. A mechanical set up is designed to hold the bearing with proper support mechanism which holds the bearing intact without any external vibration influence. The solenoid is fixed at a required height so that the solenoid head with a soft rubber bush strikes the inner race of the bearing gently at a constant speed. When this solenoid head strikes the bearing, it starts vibrating and this vibration is measured using the accelerometer. The measured signal is captured using PSoC embedded system platform and then it is computed to LabVIEW Virtual Instrumentation programming platform. The



LabVIEW records the signal from the Accelerometer and then it plots the amplitude plot and power spectrum signal plot using the spectrum pallet. This gives a clear view of the analysis of different signals

4. Development of workbench

This design carries out its measurements on the short transient vibration resulting from the mechanical disturbance in the test object caused by striking the test object with a small hammer. In operation, an accelerometer, a MEMS sensor, is mounted on the outer surface of the test material, viz., ball bearing, to pick up and to measure vibration signals as a function of time, which can provide information on the health condition of bearing under test. Fig. 9 shows that the block diagram and principle of the Impulse excitation technique used for bearing fault detection Fig. 10. shows the amplitude wave pattern of Brand new 6201 bearing and Fig. 11. shows the Power spectrum wave pattern of Brand new 6201 bearing.

An electrically operated solenoid mounted in a test bench, act as a hammer, such a way, to adjust its rubber-mounted tip to strike the inner race of test bearing gently. In this setup ADXL 335, the tri-axial accelerometer is used to acquire the vibration signal from bearing housing, the bearing under test is mounted on the test bench and the accelerometer is mounted on the top of the bearing outer race.

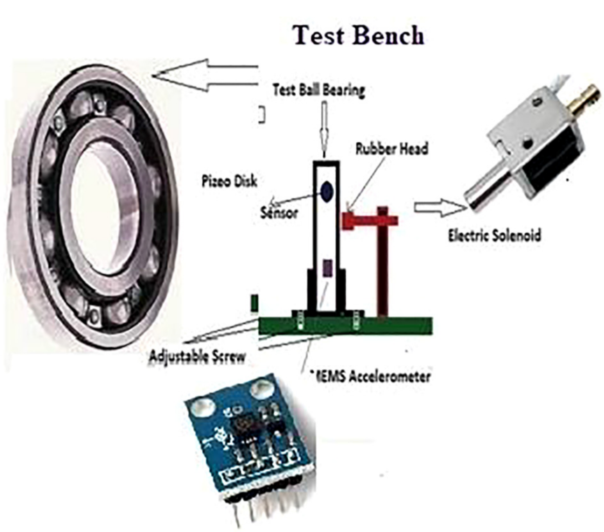


Fig. 9. Block diagram of the Impulse Excitation Technique used in Bearing Fault Detection System.

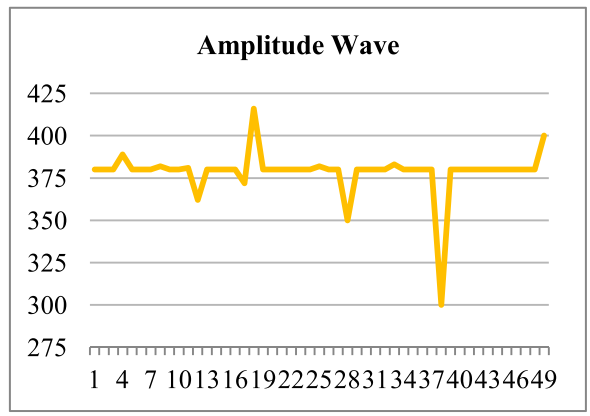


Fig. 10. Amplitude wave pattern of Brand new 6201bearing.

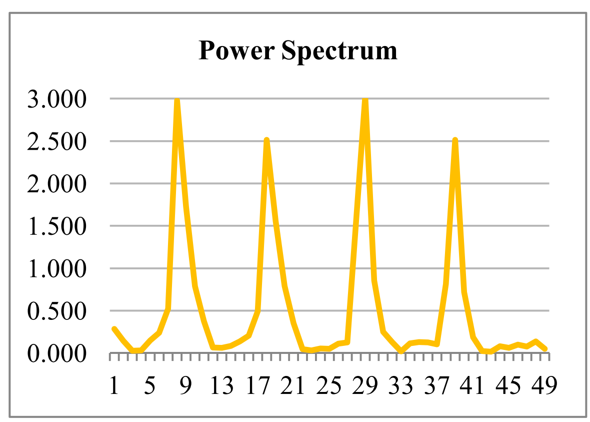


Fig. 11. Power spectrum wave pattern of Brand new 6201bearing.

5. Validation of work bench

The validation is an important function of any new system design, the designer has to validate the system with various experimental investigations which should be comparable with other commercially available benchmarks or to be justified with the theoretical models. In this work, the indigenously designed fabricated test bench for monitoring defects and flaws in the ball bearings with minimal discomfort, a very user-friendly way the tests can be carried out in a very short duration. Some of the results tested with this test bench are shown here, which shows clear validation of the system design. The amplitude wave patterns of the brand new 6201 bearings are shown in the Figs. 12,14 and 16 and the power spectrum wave patterns of the brand new 6201 bearings are shown in Figs. 13,15 and 17.

The brand new 6201 bearing is fitted to the workbench and is triggered by using a solenoid. The triggered signal generates vibration data and is recorded with the accelerometer and the signal is analyzed by using the LabVIEW amplitude plot and frequency spectrum analysis. The validation of workbench is done for the defect-free new bearing, the impact of shockwaves generates a smooth spectrum with a small amplitude without any sideband. The defect-free bearings mechanical contacts are in a perfect manner without any deformation results in a smooth rotation, hence only the excitation frequency appears.

The brand new 6201 bearing is fitted to the workbench and is triggered by using a solenoid. The triggered signal generates vibration data and is recorded with the accelerometer and the signal is analyzed by using the LabVIEW amplitude plot and frequency spectrum analysis. The validation of workbench is done for the defect-free new bearing, the impact of shockwaves generates a smooth spectrum with a sharp rise in amplitude with small external peaks in the sideband. This shows its good working condition. The defect-free bearings mechanical contacts are in a perfect manner without any deformation results in a smooth rotation, hence only the excitation frequency appears.

The brand new 6201 bearing is fitted to the workbench and is triggered by using a solenoid. The triggered signal generates vibration data and is recorded with the accelerometer and the signal is analyzed by using the LabVIEW amplitude plot and frequency spectrum analysis. The validation of workbench is done for the defect-free new bearing, the impact of shockwaves generates a smooth spectrum with sharp amplitude without much sideband peaks. The defect-free bearings mechanical contacts are in a perfect manner without any deformation results in a smooth rotation, hence only the excitation frequency appears.

The brand new 6201 bearing is fitted to the workbench and is triggered by using a solenoid. The triggered signal generates vibration data and is recorded with the accelerometer and the signal is analyzed by using the LabVIEW amplitude plot and frequency spectrum analysis. The validation of workbench is done for the defect-free new bearing, the impact of shockwaves generates a smooth spectrum with a sharp amplitude without any sideband. The defect-free bearings mechanical contacts are in a perfect manner without any deformation results in a smooth rotation, hence only the excitation frequency appears. From the validation of different bearings, the signal from the workbench is validated and the pattern is identified from the results. The different good bearings show similar power spectrum plots at different amplitudes, with a sharp peak for good working bearing and in some cases very meager variations. This shows that working bearings and new bearing has similar power spectrum plots.

Fig. 18. The Amplitude Plot is shown in the graph through the LabVIEW program for new bearing (Green line), working bearing (Blue line), and Defective bearing (Redline). Fig. 19. The power spectrum in the LabVIEW program identifies the difference between new bearing (Blue line), working bearing (Green line), and defective bearing (Redline). In this plot, the power spectrum provides a clear signature of new, working, and faulty bearing in all cases tested. In power spectrum plots the good bearing has minimal peaks and the working bearing has some medium peaks and the defective bearing has high peaks when compared with the new and working bearing. The peaks are not near perfect it has

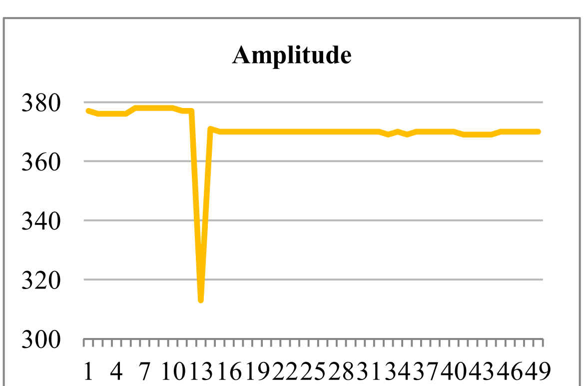


Fig. 12. Amplitude wave pattern of Brand new 6201bearing.

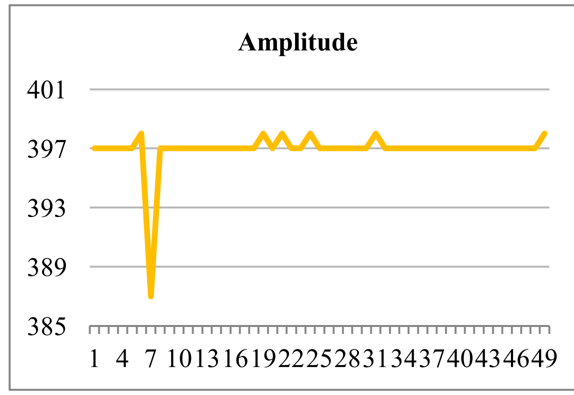


Fig. 14. Amplitude wave pattern of Brand new 6201bearing.

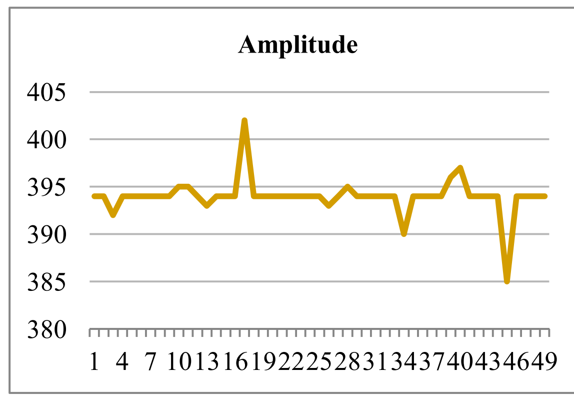


Fig. 16. Amplitude wave pattern of Brand new 6201bearing.

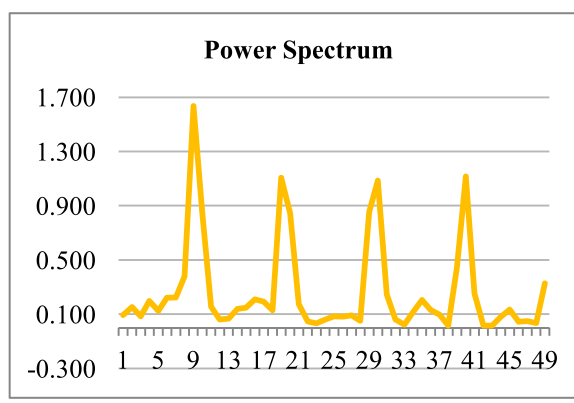


Fig. 13. Power Spectrum wave pattern of Brand new 6201bearing.

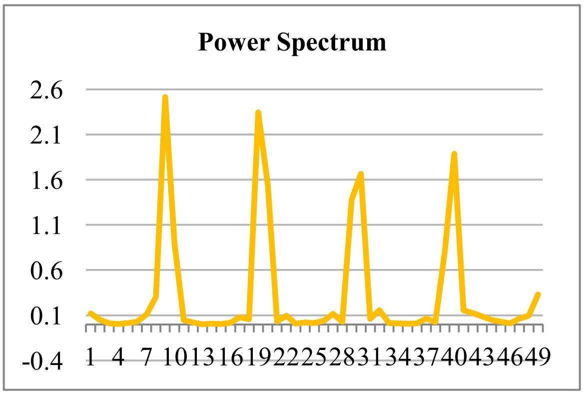


Fig. 15. Power spectrum wave pattern of Brand new 6201bearing.

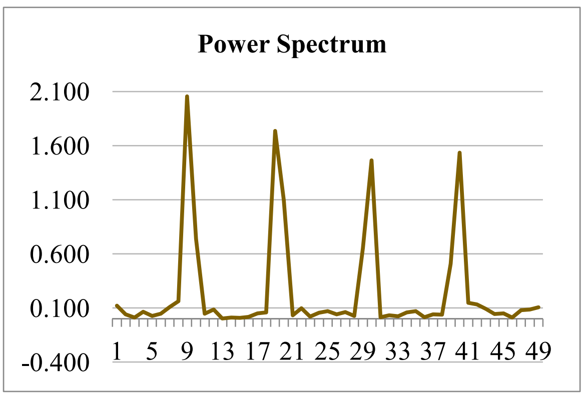


Fig. 17. Power spectrum wave pattern of Brand new 6201bearing.

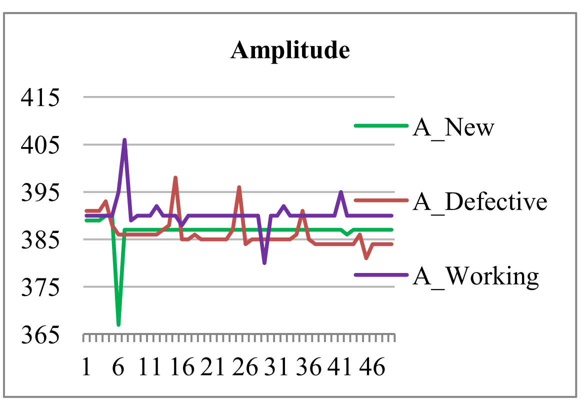


Fig. 18. The Amplitude signal of bearing 6201-2RS new, working, and defective bearing are plotted in the graph.

variations in peak value. Peak rising alone indicated Outer Race defect. The impact shockwaves pass through the ball element while reaching the outer race. In the case of Outer Race defect, mechanical deformation in outer race causes only amplitude rise. Hence peaking without sideband is a clear identification of Outer Race defect.

Fig. 20. The Amplitude Plot is shown in the graph through the LabVIEW program for new bearing (Green line), working bearing (Blue line), and Defective bearing (Redline). Fig. 21. The power spectrum in the LabVIEW program identifies the difference between new bearing (Blue line), working bearing (Green line), and defective bearing (Redline). In this plot, the power spectrum

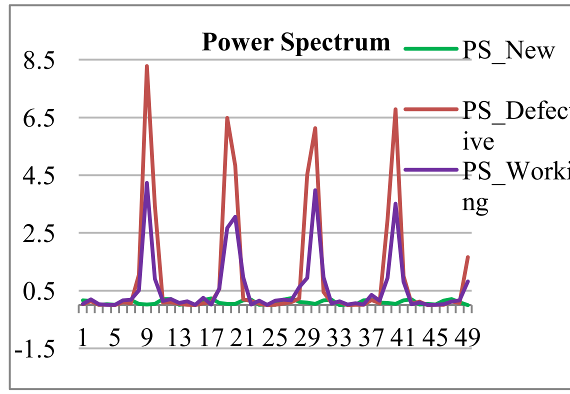


Fig. 19. the power spectrum of the new bearing, working bearing and defective bearing is plotted in the graph.

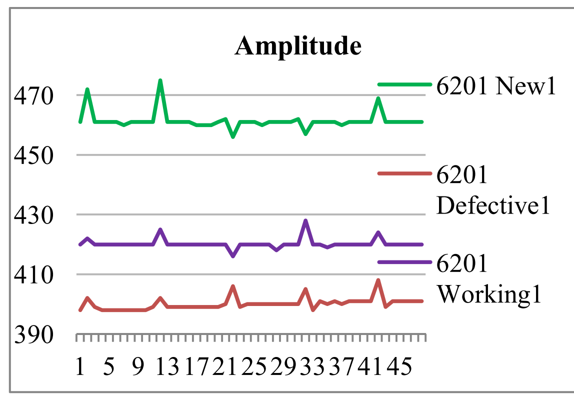


Fig. 20. The Amplitude signal of the new bearing, working bearing and defective bearing are plotted in the graph.

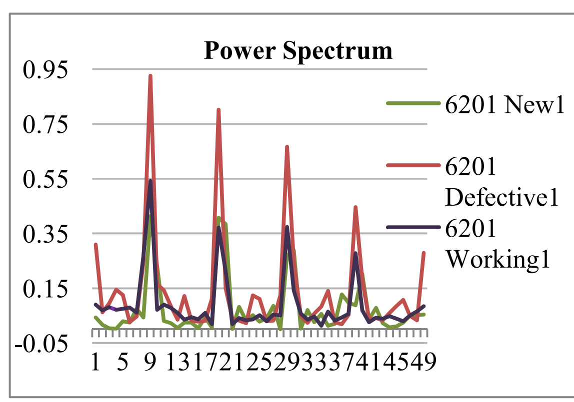


Fig. 21. The power spectrum of the new bearing, working bearing and defective bearing is plotted in the graph.

provides a clear signature of new, working, and faulty bearing in all cases tested. In power spectrum plots the good, working bearing has minimal peaks, and the distortion at the base peak is minimal, whereas in the defective bearing has high peaks and more distortions even before and after the trigger sequences. Shockwave through impact causes Inner Race to vibrate. In the case of a defect in the Inner Race generates sideband peaks with amplitude rise. The sideband peaks occur due to deformation in Inner Race.

Around three hundred ball bearings are tested and it was found that most of the new and working bearings are working well, the most used bearing has the worn-out effect or damaged one. HCH

6201- 2RS is the most widely used bearing and that bearing is considered for result evaluation pattern. This particular bearing is tested for fifty different environmental conditions with new bearing, working bearing, artificially created defect, and completely worn out defects are taken into consideration from the test sequence. From this inference, it is observed that some specific patterns are obtained for the defect-free bearing, working bearing, outer race defect bearing, inner race defect bearing, and ball defect of bearing. The observed information is given in detail below.

5.1. Defect-free

The impact of shockwaves generates a smooth spectrum with a small amplitude without any sideband, since in a defect-free bearing mechanical contacts are perfect without any deformation results in a smooth rotation. Hence only the excitation frequency appears.

5.2. Working bearing

When a working bearing is tested, the impact of shocks generates a smooth spectrum with a small rise in amplitude (when compared with a new bearing) without external peaks in the sideband. This shows its good working condition.

5.3. Outer race defect

Peak rising alone indicated Outer Race defect. The impact shockwaves pass through the ball element while reaching the outer race. In the case of Outer Race defect, mechanical deformation in outer race causes only amplitude rise. Hence peaking without sideband is a clear identification of Outer Race defect.

5.4. Inner race defect

Shockwave through impact causes Inner Race to vibrate. In the case of a defect in the Inner Race generates sideband peaks with amplitude rise. The sideband peaks occur due to deformation in Inner Race. Due to improper mechanical contact between bearing and raceways, it causes additional vibration leads to a central peak and multiple peaks in wings.

6. Conclusion

The bearing plays a vital role in the transmission of power and motion in any rolling element. In this work, a new workbench is designed and developed to test the bearing defects in static conditions by using the gryndosonics technique. In a gryndosonic technique vibration signals were generated by a trigger sequence with the help of an electrically operated solenoid. The major advantage of this novel test bench is: it identifies good and faulty bearing within a short while. The test workbench has the facility to hold the bearings with different sizes. The plunger of the solenoid is fixed with a soft rubber head to strike gently on the inner race of bearing. The triggering impulse on the bearing generates vibration signals and it is measured with an accelerometer. The measured data are computed to LabVIEW for the signal analysis pallet. This system records the set of data from its resonance frequency and plots the amplitude and power spectrum signals of the good and faulty bearing. The outcomes of the result are as follows:

- The amplitude wave of the new bearing has sharp peaks with fewer distortions in the base of the peak signals, it has single peaks for each trigger by the solenoid.
- The good working bearing without any faults, it has similar characteristic graph plots near to new bearing with a slight change in peaks or added distortions in the base of the peak when the solenoid triggered.
- In the case of Outer Race defect, shockwaves pass through the ball element while reaching the outer race the mechanical deformation in the outer race shows the amplitude rise. Hence peaking without sideband is a clear identification of Outer Race defect.
- The shockwave impact causes the Inner Race defects the vibrate generates the sideband peaks with amplitude rise, which occur due to deformation in Inner Race.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] S. Nandi, H.A. Toliyat, X. Li, IEEE Trans. Energy Convers. 20 (4) (2005) 719–729.
[2] A. Amini et al., Case Studies in Nondestructive Testing and, Evaluation 6 (2016) 8–16.
[3] https://elearnstation.com/scenari/BEARINGS/co/module_BEARINGS_3.html
[4] R. Golafshan, K. YuceSanliturk, Mech. Syst SignalProcess (2015).
[5] M. Amar, I. Gondal, C. Wilson, IEEETrans. Ind. Electron 62 (2015) 494–502.
[6] Sunita Mohanta, MS Thesis, Department of Electronics & Communication Engineering National Institute of Technology, Rourkela, Odisha, India. p.2-3. (2011-2013)
[7] Jason R. Stack, I.E.E.E. Senior Member, Thomas G. Habetler, I.E.E.E. Fellow, Ronald G. Harley, I.E.E.E. Fellow, IEEE Transactions on Industry Applications 42 (2006) 1.
[8] S. Mitra, C. Koley, IEEE Calcutta Conference (CALCON) (2017).
[9] X. Ding, Q. He, Mech. Syst. Signal Process. (2016).
[10] S. Braun, Mech. Syst. Signal Process. 25 (4) (2011) 1087–1102.
[11] S.A. McInerny, Y. Dai, IEEE Transaction on education 46 (2003) 1.
[12] Lianhuan Hong, Xiaobo Liu1 and Hongyan Zuo. IOP Publishing Ltd. Measurement Science and Technology, 29,11 (2018).
[13] A. Nabhan et al., EGTRIB Journal of The Egyptian Society of Tribology. 12 (2) (2015) 15–29.
[14] J.J. Jayakanth, M. Chandrasekaran, Int. J. Eng. Technol. 7 (3.27) (2018) 170–173.
[15] J.J. Jayakanth, M. Chandrasekaran, Int. J. Mach. Eng. Technol. 9 (13) (2018) 134–146.