HEALTH MONITORING OF ROLLER ELEMENY BEARING BY USING VIBRATION AND ACOUSTIC EMISSION

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Abstract*: Bearing elements are very critical components of rotating machines and the presence of defects in the bearings may leads to failure of machines. Early detection of such defects along with severity of damage under operating condition of the bearing may avoid malfunctioning and breakdown of machines. The defects in bearings may arise due to improper manufacturing, improper lubrication, overloading, fatigue and uneven wear. The defects in bearings includes inner race defects, outer race defects and ball defects. From the review, four different methods are used for fault detection such as vibration measurements, acoustic measurements, wear debris analysis and temperature measurements. Acoustic emission (AE) signal generated by defects in roller element bearings are investigated using simulated defects and compared with vibration signals captured from the bearing. To analyse the characteristic of vibration frequency of the bearing, AE signal, short-time rms, kurtosis, skew are evaluated. The parameters such as load, speed and defects are considered for the present study. The relationship of sensitivity of various AE parameters to the running conditions of the machine are evaluated.*

Key Words: Bearing elements, Acoustic emission, Vibration signals, Data acquisition unit, MATLAB

1. INTRODUCTION:

Defect detection and its diagnosis has been an important area in the field of condition monitoring and its related researches due to importance in modern industries for their safety and manufacturing quality. Roller bearings are one of the important parts of rotating machineries for their purpose of controlling relative motion between the rotating and stationary parts. The accuracy of the manufacturing process can be greatly affected even if there is small disturbances in the bearing parts and if there any defects in the bearing it will lead to severe catastrophic failure of the machine parts. So early detection of defects and the type of defect and severity of the defect can help us to deal with diagnosing its effects.

1.1 Roller Element Bearings

For minimzing friction ball or rollers are used in roller element bearings. A rolling-element bearing carries load placing rolling elements (like either balls or rollers) in the races. The relative motion of the races causes the rolling elements to roll with little or no rolling resistance and with little sliding. A rolling element rotary bearing uses a shaft during a much larger hole, and cylinders called "rollers" tightly fits the space between the shaft and hole. As the shaft turns, each roller acts because the logs within the above example. Since the bearings are round, the rollers will not fall out under the influence of the load. Rolling-element bearings have the advantage of an honest tradeoff between cost, size, weight, carrying capacity, durability, accuracy, friction, and so on. Coefficient of friction for roller steel balls are usually ~0.005 (adding resistance due to seals, packaged grease, preloading and misalignment can increase friction to the maximum to 0.125). The stiffness of the bearing is good, but some slack is always there or usually present. Moderate to high (often requires cooling) speed machines are usually preferred. Life of the bearing is also Moderate to high (depends on lubrication, often requires maintenance).

Fig -1: Ball bearing

Roller element bearings are generally used for higher moment loads than plain bearings with lower friction. Due to this wide range of applications the roller element bearings are generally preferred. The rolling element bearings defects can develop due to the following actions which includes designing faults of the bearing or improper manufacturing or mounting, uneven wear, bearing races may get misaligned, uneven distribution of metal mass diameter of rolling elements, improper lubrication, overloading of the bearing, fatigue etc. The rolling element bearing defects is divided into; distributed defects and localized defects.

1.2 Loads in Bearing

Thrust bearings are wont to support axial loads, like vertical shafts. Usual designs includes tapered roller thrust bearings or cylindrical roller thrust bearings Thrust ball bearings, spherical roller thrust bearings, Also non-rolling-element bearings like hydrostatic or magnetic bearings see some use where particularly heavy loads or low friction is required . Radial loadings Rolling-element bearings are often used for axles thanks to their low rolling friction. For light loads, such as bicycles, ball bearings are often used. For heavy loads and where the hundreds can greatly change during cornering, like cars and trucks, tapered rolling bearings are used. The change in contact force between roiling elements and raceways due to distributed defects.

1.3 Defects in the Bearings

The roller element bearing defects must be caused due to the following reasons which may include; design faults of the bearing due to the designers lack of knowledge or due to manufacturing faults or mounting, misplacing of bearing balls, undistributed metals of rolling elements, improper lubrication, overloading, fatigue, wear etc. Distributed defects are developed due to manufacturing errors, improper installation or inadequate mounting, abrasive wear, etc. Distributed defects include uneven surface roughness, increased waviness, misaligned races and unequal diameter of balls in rolling element bearings. The change in contact force between roiling elements and raceways due to distributed defects. These defects include cracks, pits and spalls on rolling surfaces caused by fatigue. The common failure modes in roller element bearing is the crack formation in the races or rolling elements, mainly arises when a crack due to fatigue develops under the metal bearing and propagated over the surface and then the metal pieces may detach from bearing which causes severe wear and tear in the roller elements and races. This defect accelerate when the bearing is overloaded or subjected to shock (impact) loads during their functioning and also increase with the rotational speed. Spalling may form on the inner ring races, outer ring races, or rolling elements.

1.4 Causes of Defects in the Bearings

IMPROPER LUBRICATION

Improper lubrication is the main reason for bearing failure. Issues include: too much lubricant; too little lubricant; using the wrong lubricant; mixing incompatible lubricants; incorrect lubrication intervals; using old, deteriorated grease or oil; and water contamination.

OVERLOAD

Bearings are supposed to be operated under rated limits of design for load, temperature and speed. If they are operated above the limit it can leads to catastrophic failure of the bearings and its machine components. The damages may vary in their effects according to their loads.

POOR MAINTENANCE

Maintenance personnel should be trained in the proper methods and tools to use when handling, removing and installing bearings. Even the most miniscule contaminant or the smallest dent or nick will reduce their performance and reliability.

1.5 Condition Monitoring

Condition-monitoring techniques are required to accumulate the operation condition data of a rotating machine. The Condition-monitoring data can be dealt with number processing tools and analyzed using required signal analysis techniques to get the most absolute relevant characteristic parameters before a diagnosis or prognosis algorithm to evaluate/predict the health condition of the machine. The data employed during a condition-monitoring program are often vibration, noise, current, oil and grease, temperature or a mixture of those data. The Condition-monitoring data can be analyzed using either time-domain techniques, frequency domain techniques, or time-frequency techniques according to the data properties such as linearity or nonlinearity, stationary or non-stationary, to extract the most available, useful and effective features for diagnosis of the bearing. This section summarizes a number of the foremost commonly employed techniques in condition-monitoring applications of rolling element bearings. Vibration technique is that the most often employed technique for machine condition monitoring. A change of the vibration signal during a machine without changing the operation condition can imply a change of health state of the machine. Vibration signals are typically generated by defects within the moving components of the machine like defects during a bearing, gearboxes, reciprocating components, and so on. For instance, when a bearing runs under a defective condition, an impulse signal are to be developed as other bearing components passing into the faulty position. This will lead to an increase in overall vibration amplitude of the machine. The defect component of the bearing and its severity are often determined by the characteristic defect frequency component contained within the condition monitoring signal. The frequency range of vibration measurement can be as low as in the infrasonic region (below 20 Hz) and span across to the upper limit of the audible frequency (20 kHz). Though the vibration technique are often problematic in acquiring useful signals when it's deployed for condition monitoring of huge low-speed rotating machine where the energy of an incipient defective signal is usually have less strength in their data and usually overlapped under the background noise. High-frequency techniques like acoustic emission technique are often employed to beat this limitation. Acoustic emission may be a transient elastic wave generated by the sudden release or redistribution of stress during a material. For example, in bearing condition-monitoring applications, Acoustic emission is generated by the sudden release of energy caused by the fabric deformation as other bearing components passing through a defect part. The signal after propagating to the bearing house is then detected by a monitoring Acoustic emission sensor. Compared to vibration signals, the Acoustic emission signal is a smaller amount likely to be suffering from the dominating noise and vibration generated by the moving mechanical components is usually above 100 kHz. Care should be taken in choosing the mounting locations of Acoustic emission sensors to minimize the energy loss along the Acoustic emission propagation path for better signal clarity. Furthermore, Acoustic emission also comes with inherited problems like calibration, nonlinearity, data storage and transfer, processing and interpretation. Recently, Scientists developed a number of signal-processing algorithms to overcome the problems of nonlinearity and large Acoustic emission data. Nowadays, an outsized industry deployment of Acoustic emission technique in bearing condition monitoring remains restricted by the expensive highly specialized Acoustic emission data acquisition devices

2. METHODOLOGY

The methodology is based on the objective of this project which is to improve bearing monitoring using vibration indicators and by acoustic signal indicators separately and evaluating the acquired signals using MATLAB. The methodology of the present work is shown in Fig. Initially, the bearing defects, causes and its effects are analyzed rigorously by performing literature review. Then, the bearings are selected as various categories of defected samples for the experimental study. The experimental setup is developed by using sewing motor. Then the experiments are conducted and collected the data such as noise signals and vibration signals using sensors. The measured data are interpolated for various defected samples.

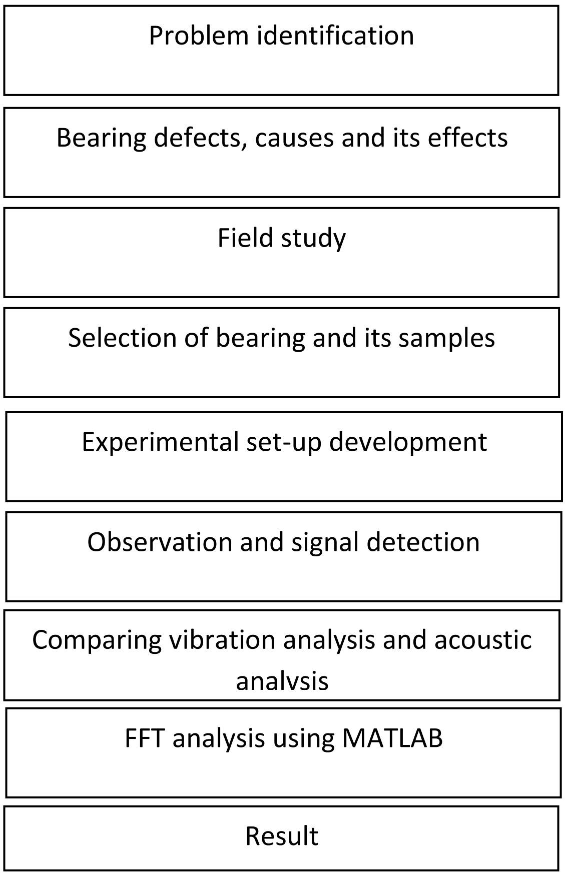

Fig -2: Methodology for Experimental Investigation

2. EXPERIMENTAL INVESTIGATION

An experimental test bench is built to simulate the different defects of roller element bearings. This bench is a two bearing assembly, coupled to an electric motor and its rotation is controlled by a speed variator. Here one of the bearing is fresh healthy bearing and another one is defected bearings from which signals are acquired. Defected bearings are used to run at various rotating speeds and loads to get different vibration and acoustic measurements. The vibration and acoustic measurements are performed with the ardiuno, using an accelerometer and a microphone. The main objective of our study is to improve bearing monitoring using acoustic indicators.

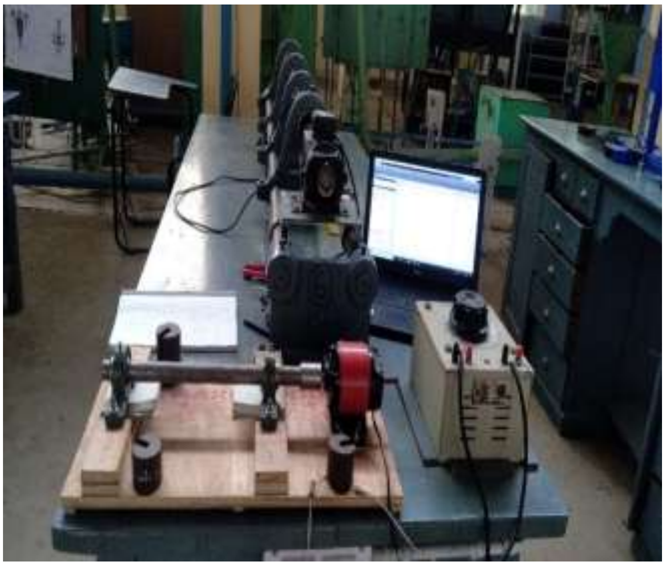

Fig -3: Experimental Test Rig

Thus, the experiment is done by simulating three types of defect: outer race defect, inner race defect and ball defect on an UC205-16, UC 200 wide inner ring ball bearings type roller element bearing. They are combined with a bearing defect created on one of the bearings. The UC205-16, UC 200 wide inner ring ball bearing has been selected and has cylindrical bore type and the bearing is ball type bearing. The bearing has inner diameter of 25mm and outer diameter of 52mm and the weight of the bearing is 0.50lb or 0.2Kg and has set screw type locking. The bearing has static load rating of 7850N and has dynamic load rating of 14000N.

Fig -4: ADXL335 Accelerometer

The accelerometer utilized Experimental in the experiment is GY-61 DXL335 3-Axis Accelerometer Module which may be a three axis accelerometer sensor module supported ADXL335 microcircuit**.** The ADXL335 may be a triple axis accelerometer with extremely low noise and power consumption. The sensor features a full sensing range of 3g. It can measure the static acceleration of gravity in tilt-sensing applications, also as dynamic acceleration resulting from motion, shock, or vibration. There is an on-board 3.3V transformer to power the ADXL335 so power provided should be between 3.3V and 6V DC. The motor used in the experiment is VICCO Sewing Machine Motor with full copper winding Motor Model 1/12 Fits, and has the specification of 0.32 Amps 6000 RPM,220/230 Volt,50 Watt. The microphone has frequency range 20 Hz to 20 KHz.

Vibration analysis of commercial machinery has been around for several decades, but gained prominence with the introduction and widespread use of the private computer. Vibration Analysis refers to the method of measuring the vibration levels and frequencies of commercial machinery, and using that information to work out the "health" of the machine, and its components. When an industrial machine (such as a lover or pump) is operated, it generates vibration. This vibration are often measured, employing a device called an accelerometer. An accelerometer generates a voltage signal, proportional to the quantity of vibration, also because the frequency of vibration, or what percentage time per second or minutes the vibration takes place. This voltage signal from the accelerometer is fed into a knowledge collector, which records this signal as either a time waveform (amplitude vs. time), as a Fast Fourier Transform (amplitude vs. frequency), or as both. This signal can then be analysed by a trained vibration analyst, or by the utilization of a "smart" computer virus algorithm. The analysed data is then wont to determine the "health" of the machine, and identify any impending problems within the machine, like misalignment, unbalance, and an impact or lubrication problem.

Statistical time-domain features such as mean, root mean square (RMS), standard deviation and variance were usually used in past studies to identify the differences between one vibration signal and another. More advanced statistical-based features such as skewness and kurtosis can be applied to the signal which is not purely stationary. These features examine the probability density function (PDF) of the signal. It is a well-known fact that if the condition of the bearing changes, the PDF also changes, thus the skewness and kurtosis might also be affected. In particular, skewness is used to measure whether the signal is negatively or positively skewed, while kurtosis measures the peak value of the PDF and indicates if the signal is impulse in nature. For a signal with a normal distribution i.e., normal bearing signal has a skewness value of zero. In addition, kurtosis is obtained from the height of the PDF of the vibration signal, while skewness is obtained from the mean of the PDF of the vibration signal. It is documented that the kurtosis value of vibration signal from normal bearing is approximately three and therefore the skewness value of roughly zero. Then, when the PDF of vibration signal changes thanks to faults, the kurtosis value will increase to greater than three and therefore the skewness value will shift to either negative or positive. Other features which may be calculated from PDF of the vibration signal includes: entropy, which calculates the histogram of the PDF and measures the degree of randomness of the vibration signal; lower bound and upper bound histogram, which measure the lower and upper values of the PDF respectively. Aside from the statistical time-domain features mentioned above, there are other non-dimensional features like shape factor (defines as RMS divided by mean) and crest factor (defines as standard deviation divided by RMS). Both features will change because the mean, RMS and variance change. So, every aspect has to be analysed in order to get the most required data in such a parameter which gives optimum result. From the processed parameters we can decide the condition of the bearings.

3. RESULT AND DISCUSSION

An initiation and development of localized defect in the bearing is investigated under applied condition, the test is conducted for new healthy ball bearings and defect simulated bearings under bearing simulator test rig. The vibration signals and acoustic signals are captured for 6 sec duration during the test. The test is done for both healthy bearing and defected bearings. During the test, the temporary results are calculated periodically to monitor and analyses data for judgment of incipient fault in bearing. Vibration data and acoustic data are investigated to detect localized defects and its characteristic frequencies. Scalar measures such as peak-to-peak value, root mean square and are calculated while conducting the test. The formation of defect and its location and severity of the defects in ball bearings which are detected during the testing condition and also the features of the defects are plotted in required parameters. The vibration spectra are procured where the scalar measures indicate an anomaly in signal. Using MATLAB the audio and vibration signals using accelerometer are detected and analyzed.

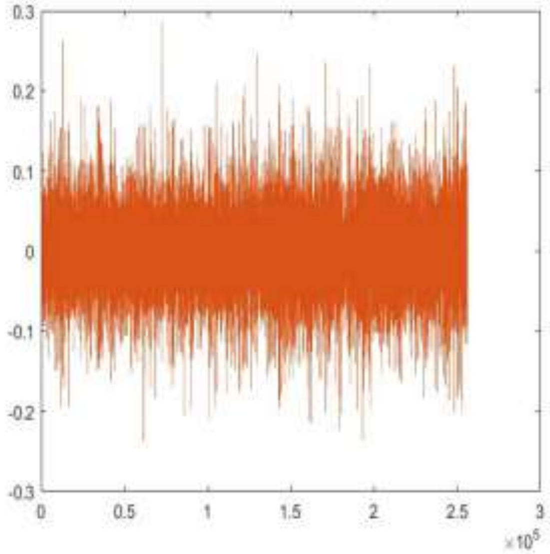

Fig-5: Inner race defect at 100 RPM

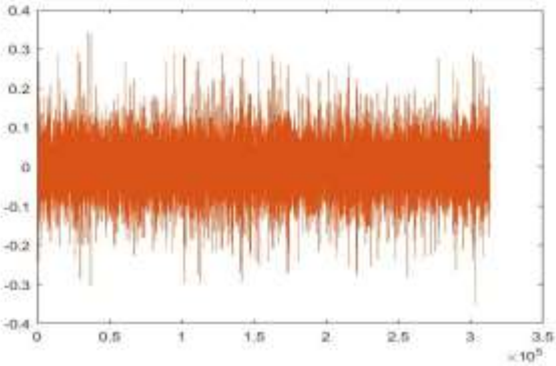

Fig-6: Inner race defect at 200 RPM

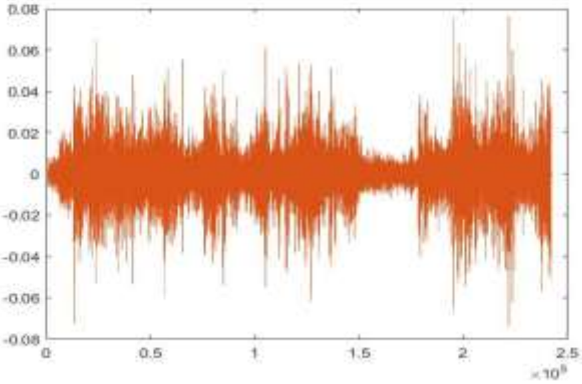

Fig-7: Outer race defect at 100 RPM

For the inner race defect the following rms, kurtosis, Skewness, peak to peak values are measured for loads of no load, 1.86N, 3.72N.

Table -1: Peak values for the inner race defect

RPM	SKEWNESS	RMS	PEAK2PEAK	KURTOSIS
100	-0.0267	0.011	0.1495	13.0192
200	-0.03	0.07	0.5237	6.8205
300	-0.0255	0.118	1.5164	5.2244

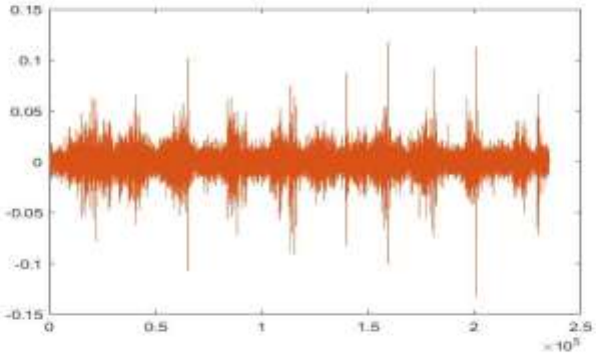

Fig-8: Outer race defect at 200 RPM

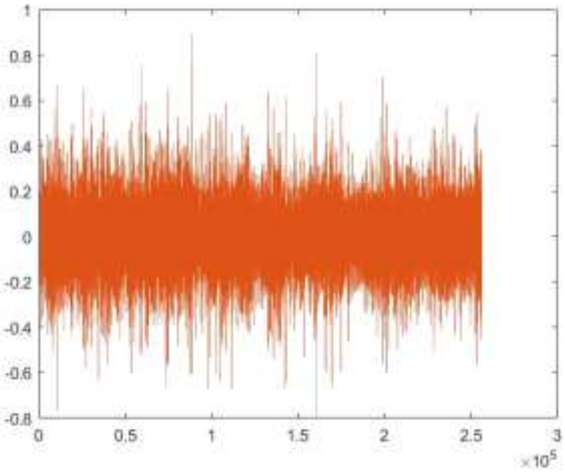

Fig-9: Outer race defect at 300 RPM

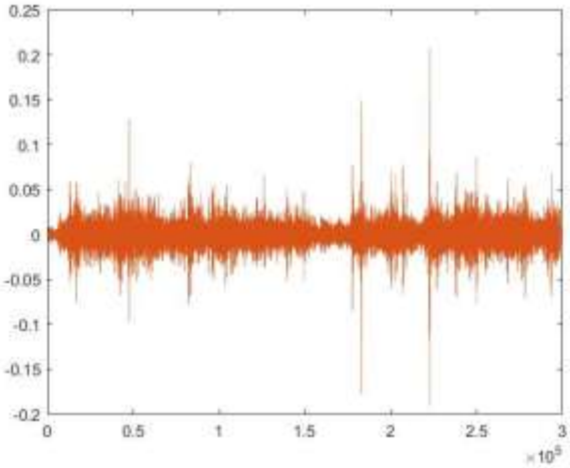

Fig-10: Ball defect at 100 RPM

For the outer race defect the following rms, kurtosis, Skewness, peak to peak values are measured for loads of no load, 1.86N, 3.72N.

Table -2: Peak values for the outer race defect

RPM	SKEWNESS	RMS	PEAK2PEAK	KURTOSIS
100	-0.0267	0.018	0.3966	13.0192
200	-0.0228	0.052	0.8649	3.9943
300	-0.06	0.139	1.6504	4.0109

Table -3: Peak values for the defect

RPM	SKEWNESS	RMS	PEAK2PEAK	KURTOSIS
100	-0.0384	0.011	0.2488	6.8205
200	-0.079	0.057	0.6953	3.9803
300	-0.023	0.134	1.6868	4.119

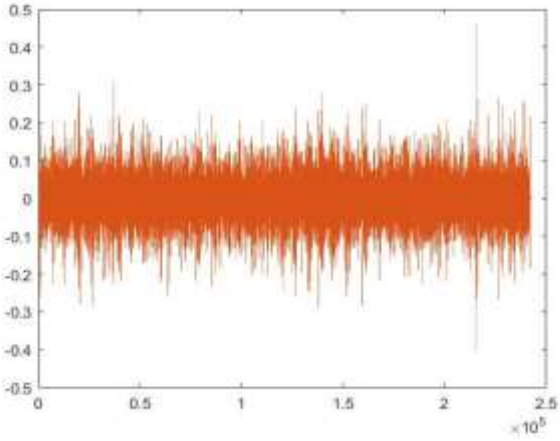

Fig-11 : Ball defect at 200 RPM

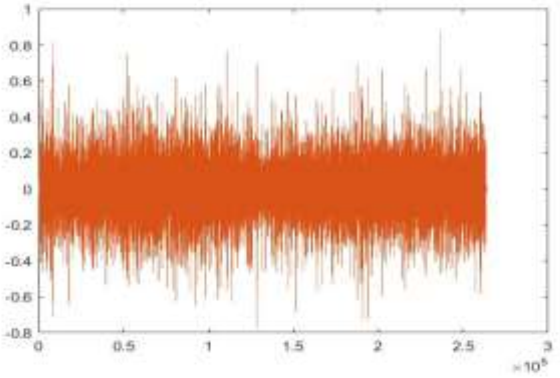

Fig-12 : Ball defect at 300 RPM

For the outer race defect the following rms, kurtosis, Skewness, peak to peak values are measured for loads of no load, 1.86N, 3.72N.

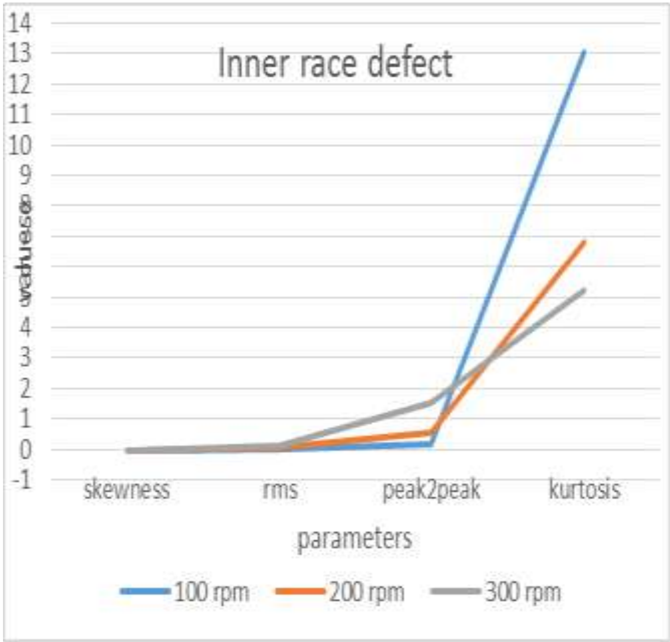

Chart -1: Inner race defect peak values

In this graph it is clear that the defected when the inner race defect comes in contact with the shaft the characteristic vibration frequency for that defect is detected at various speeds such as at 100 rpm rms value is 0.0110, peak to peak value is 0.1495, kurtosis value is 5.2244 which is different from other base values and the characteristic frequencies are compared with vibration frequencies which is rms value is 0.0015, peak to peak value is 0.1254, kurtosis value is 5.1200. So, it is clear that using acoustic data gives more accurate data and the values for speed are given above in the graph.

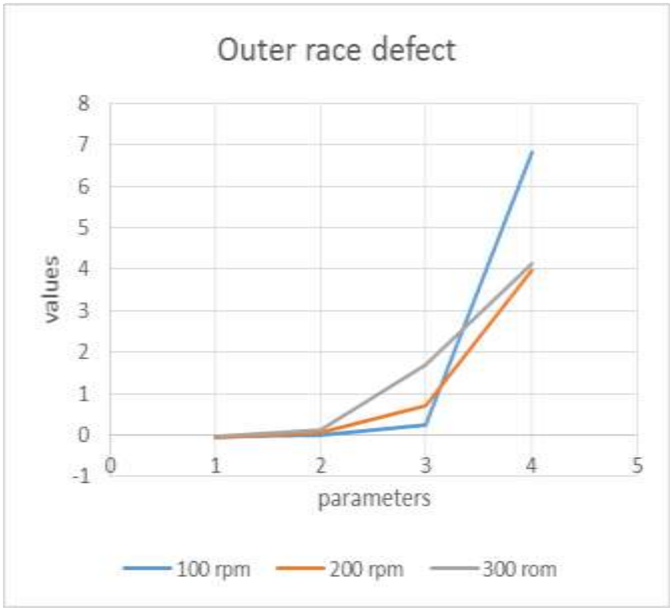

Chart -2: Outer race defect peak values

In this graph it is clear that the defected when the outer race defect comes in contact with the shaft the characteristic vibration frequency for that defect is detected at various speeds such as at 100 rpm rms value is 0.0116, peak to peak value is 0.2488, kurtosis value is 6.8205 which is different from other base values and the characteristic frequencies are compared with vibration frequencies which is rms value is 0.00145, peak to peak value is 0.2298, kurtosis value is 6.91200. So, values for other speeds are given above.

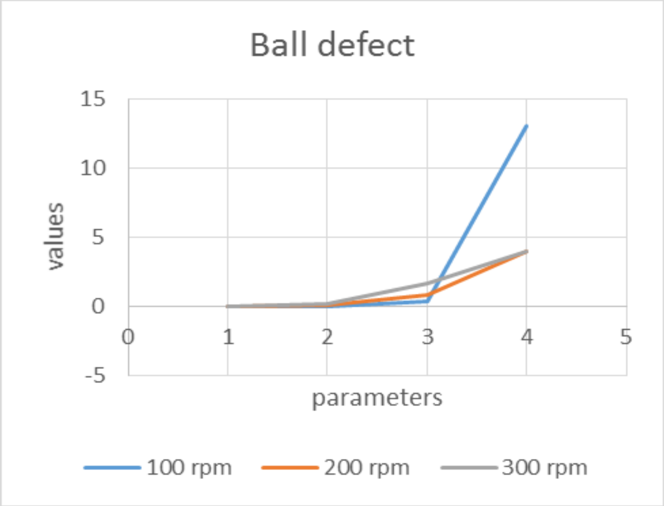

Chart -3: Ball race defect peak values

The above graph shows it is clearly that the defected when the ball race defect comes in contact with the shaft the characteristic vibration frequency for that defect is detected at various speeds such as at 100 rpm rms value is 0.128, peak to peak value is 0.3966, kurtosis value is 13.0192 which is different from other base values and the characteristic frequencies are compared with vibration frequencies which is rms value is 0.118, peak to peak value is 0.3498, kurtosis value is 6.41300. So, values for other speeds are given above chart-3.

Conventional indicators reflecting the simulated defects and illustrated by chart 1, 2, 3, show the overall RMS level generally assumed with the evolution of the severity of a defect, but with several irregularities due to the inclusion of other defects. This indicator is also quite sensitive to different types of defects such as poor lubrication, loosening, resonance problems, etc. The presence of another defect makes it possible to reproduce a behaviour quite close to that of real machines without the presence of a bearing defect that can be assimilated with significant background noise. The kurtosis and crest factor that are not related to the signal energy increase with the appearance of the defect and decrease when it worsens.

In a diagnosis approach, use of slightly more complex treatments such as envelope analysis to identify the nature of the defect. Chart 1, 2, 3 shows that this technique can detect bearing defects even in the case of a nascent defect, knowing that the rotation frequency of the defective bearing is 0.12 KHz and the frequency of the simulated defect on the outer ring bearing is 0.8 Hz. The use of this type of analysis for a machine park is quite complicated and difficult to implement. The optimization of scalar indicators by searching for a linear combination capable of describing the state of the defect from its birth to its aggravation would be very effective and simple to implement.

4. CONCLUSION

The work presented here is focused on finding the defects of the bearings using acoustic signals and comparing the results with the acquired vibration signal acquired using accelerometer and the vibration analysis of rotating machines with the defected bearings is carried out using MATLAB. The results from the experiment reveals that the acquired sound signal having bearing characteristic frequency gives more accurate results when comparing the rms, kurtosis, Skewness, and peak to peak values. It allowed us to develop combinations of vibration indicators, more sensitive and effective than vibration indicators for monitoring bearings.

Classical indicators were unable to do this individually as a function of the degradation of defects. The comparison resulting from using vibration and acoustic signals showed that listening to acoustic signals provides better sensitivity from the calculated combination. This perceptive optimization method was tested on a rotating machine different from the test bench used to implement the combinations of vibration indicators. The results obtained were satisfactory for monitoring bearing degradation. In future work, it would be interesting to apply this method on the industrial scale and extend it to other types of defect.

REFERENCES

[1] Raza, Ahmed, and Vladimir Ulansky. "Optimal Preventive Maintenance of Wind Turbine Components with Imperfect Continuous Condition Monitoring." Energies 12.19 (2019): 3801.

[2] Laissaoui, A., et al. "Perceptive analysis of bearing defects (Contribution to vibration monitoring)." Applied Acoustics 140 (2018): 248-255.

[3] Liu, Yuwei, et al. "A novel method to model effects of natural defect on roller bearing." Tribology International 122 (2018): 169-178.

[4] Mishra, C., A. K. Samantaray, and G. Chakraborty. "Ball bearing defect models: A study of simulated and experimental fault signatures." Journal of Sound and Vibration 400 (2017): 86-112.

[5] Sharma, Ram Bihari, and Anand Parey. "Modelling of acoustic emission generated in rolling element bearing." Applied Acoustics 144 (2019): 96-112.

[6] Gupta, Pankaj, and M. K. Pradhan. "Fault detection analysis in rolling element bearing: A review." Materials Today: Proceedings 4.2 (2017): 2085-2094.

[7] Delgado-Arredondo, Paulo Antonio, et al. "Methodology for fault detection in induction motors via sound and vibration signals." Mechanical Systems and Signal Processing 83 (2017): 568-589.

[8] Amini, Arash, Mani Entezami, and Mayorkinos Papaelias. "Onboard detection of railway axle bearing defects using envelope analysis of high frequency acoustic emission signals." Case Studies in Nondestructive Testing and Evaluation 6 (2016): 8-16.

[9] Kim, Byeong Su, et al. "Rolling element bearing fault detection using acoustic emission signal analyzed by envelope analysis with discrete wavelet transform." Engineering Asset Lifecycle Management. Springer, London, 2010. 596-602.

[10] Xu, Yuanping, et al. "Active magnetic bearings used as exciters for rolling element bearing outer race defect diagnosis." ISA transactions 61 (2016): 221-228.

[11] Saruhan, H., et al. "Vibration analysis of rolling element bearings defects." Journal of applied research and technology 12.3 (2014): 384-395.

[12] Zarei, Jafar, Mohammad Amin Tajeddini, and Hamid Reza Karimi. "Vibration analysis for bearing Sfault detection and classification using an intelligent filter." Mechatronics 24.2 (2014): 151-157.

[13] Muruganatham, Bubathi, et al. "Roller element bearing fault diagnosis using singular spectrum analysis." Mechanical systems and signal processing 35.1-2 (2013): 150-166.

[14] William, Peter E., and Michael W. Hoffman. "Identification of bearing faults using time domain zero-crossings." Mechanical systems and signal processing 25.8 (2011): 3078-3088.

[15] Kilundu, B., et al. "Cyclostationarity of Acoustic Emissions (AE) for monitoring bearing defects." Mechanical systems and signal Processing 25.6 (2011): 2061-2072.

[16] Boumahdi, Mouloud, et al. "On the extraction of rules in the identification of bearing defects in rotating machinery using decision tree." Expert

Systems with Applications 37.8 (2010): 5887-5894.
[17] Tandon, Naresh, and Achintya Choudhury. "A review of vibration and acoustic measurement methods for the detection of defects in rolling element bearings." Tribology international 32.8 (1999): 469-480.
[18] Heng, R. B. W., and Mohd Jailani Mohd Nor. "Statistical analysis of sound and vibration signals for monitoring rolling element bearing condition." Applied Acoustics 53.1-3 (1998): 211-226.