ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 15, Issue, 03, pp.24054-24056, March, 2023
DOI: https://doi.org/10.24941/ijcr.45020.03.2023

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

BALL BEARING FAULT CLASSIFICATION AND DIAGNOSIS TECHNIQUES: A REVIEW

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ARTICLE INFO

Article History:
Received 14th December, 2022
Received in revised form
17th January, 2023
Accepted 05th February, 2023
Published online 29th March, 2023

Key words:

Bearing defect, vibration, fault classification, AE, ANN.

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ABSTRACT

In the early stages detection of faults in antifriction bearing in health condition monitoring of bearing is a very cumbersome task. The defects in bearing unless detected in time may lead to downtime of setup. The main cause of rolling element defects are following ; inappropriate design of the bearing or inappropriate manufacturing or mounting, bearing races misalignment, uneven diameter of rollers, improper lubrication, wear, fatigue, overloading. The *objective of this* paper is to present a detailed overview of the different detection techniques used for measuring rolling bearing defects. This paper presents an overview on various detection techniques used for measuring ball bearing defects; they may be majorly classified as vibration measurement, acoustic measurement, temperature measurement. Vibration and AE signal analysis techniques like time, frequency, time-frequency domain, fast and accurate techniques like ANN are focused study areas. Effectiveness of three ANN classifier MLP, RBF, PNN are also studied. Latest topic of interest like KNN, CNN, AEN, ML, DL are also reviewed.

Citation: ***Rajat Tomar, Dr. Amit Suhane and Dr. Mandloi, R.K.*** **2023.** "Ball Bearing Fault Classification and Diagnosis Techniques: A Review". *International Journal of Current Research*, 15, (03), 24054-24056.

INTRODUCTION

Fault diagnosis and condition monitoring of equipment are of great concern in industries. Almost every rotating device are composed of most critical components like rolling elements of bearing, machineries have very high functionality upon these bearings. The concept of predictive maintenance, which uses vibration information to reduce operating costs and reduce machine downtime, is pervasive throughout the industry. Since most machines include rolling bearings in their predictive maintenance programs, it is essential to have proper condition monitoring procedures in place to prevent failure or damage during operation. Hertzian contact stress between rolling elements and races is one of the basic mechanisms that produce localized defects. When rolling elements encounter local defects, impulses are generated that excite structural resonances. Therefore, the vibration signature of the defective bearing composed of an exponentially decaying sinusoid possessing the structure resonance frequency. The interval of impulses is quite larger than the span of impulse, it consist of large window of frequency of lower amplitude hence it is very obvious that it would be concealed by noise and low frequency components. Position of defect, bearing geometry, speed of operation, type of bearing load directs the magnitude and periodicity of impulses. Periodicity and magnitude of impulse possess some level of uncertainity because in the load zones of bearing there is occurrence of slip among rollers and races hence same pattern of occurrence do not replicate from one cycle to another cycle. This results in series of amplitude modulated impulses. Magnitude and periodicity of impulses contains randomness upto certain level. Health of bearing is traced by various condition monitoring techniques; these are motor current monitoring, wear debris analysis, noise conditioning, temperature monitoring, vibration analysis etc. But the vibration and AE monitoring techniques are of greater importance because it is reliable and sensitive towards severity of fault. Bearings act as a source of vibration and noise because of either variability of compliance or the presence of defects among bearing elements. Identification of faults needs a reliable, pace, and automated course of diagnostics but sometimes visual go through of frequency domain plot of vibration signal is sufficient to identify the presence of fault. Field of machine condition monitoring has been advanced a step in zone of detection automation. Acquired time domain features from vibration signals are used post preprocessing in various ANNs as inputfor machine health observation. Wavelet transforms are used in t-f domain as preprocessor in collaboration with ANN. Time domain features like mean, kurtosis, rms, skewness are extracted and preprocessed, fed to ANN as input to train the system. Different sensor locations, envelop detection(demodulaton), simple preprocessing like band pass/high pass filtering and complex processing such as wavelet transforms are also studied to some extent. Khalid al F Raeem (1) used laplace wavelet to successfully preprocess the time domain signal for extraction of feature and extracted feature fed into three classifier MLP, RBF, PNN to classify four type of bearing condition.

Vibration Measurement: Vibration analysis is one of the most famous method used in the fault detection applications. At every rotation when the defect makes contact with rolling element it produces a impulse which on continuous rotation generates a series of impulses which forces the structure to vibrate. Healthy and defective bearings possess different type of waveform in different domain. Analyzing in appropriate domain may predict the incipient fault and its location. Pattern of vibration of defective bearing accompanies low frequency component which corresponds to impacts and those of high frequency belongs to other activities. Defects are produced in bearing elements and hence these processed signals are compared with normal one. Applicability of vibration monitoring is effective in low frequency applications.

Acoustic Measurement: Thermal and mechanical stresses causes variation in structure of solid material that propagates as rapid release of strain energyresults as transient elastic wave generation and this phenomenon is known as acoustic emission.Occurrence of events like crack propagation and generation, twin growth etc. are due to plastic deformation and so produces an acoustic emission. AE is ansuccessful tool for condition monitoring among the other techniques in realm of non destructive techniques. acoustic emission instrumentationis a collection of a transducer, especiallyof the piezoelectric type, a preamplifier and a signal processing unit. Transducers are of resonant response have high frequency service range . These sensors are of high natural frequency. Preamplification of acoustic signals is done using suitable filter to get control over the bandwidth of signal. Monitoring of acoustic emissions is advantageous over vibration monitoring as the former is capable to catch the subsurface growth of crack whereas vibration monitoring can detect only when they appear on surface. The merit of acoustic emission monitoring over vibration monitoring is that the former can detect the growth of incipient subsurface cracks, whereas the latter can detect defects only when they occur on the surface.Minor events can also appear well in waveform in any domain.

Signal Analysis Techniques: Various available signal analysis techniques are equally applicable in vibration as well as AEdata.

Time domain: Time domain is simple and easy technique for analysis of vibration or acoustic signal waveform.Spike energy factor. Raw signals are generally filtered and preprocessed before feature extraction. Time domain analysis includes study of t-d features like mean, rms, kurtosis, skewness, variance etc whose plot definitely indicates the deviation from normal condition hence ensures presence of fault but lacks in providing identity to a particular defect locality. One of the feature RMS represents overall level of discrete signal. Variation. In actual RMS level from the recommended indicates deviation in bearing health. Time domain features as stated above lacks sensitivity to detect early stage faults(2) . Impulse factor, kurtosis value, crest factor are non dimensional parameters of statistics. Kurtosis is sensitive to surface finish but insensitive to speed and load (3). Does not provide information about defect location.

Frequency domain: *Spike energy* analysis have been employed to acknowledge various defects in bearings by Joshi et al. Defect criticality in antifriction bearings can be identified with the help of factor called Spike energy factor. Raw signals are generally filtered and preprocessed before feature extraction. Therefore James et al.(4) conducted *Spectrum/frequency domain* analysis at specified test duration in order to predict defect location.

To determine the defect over running surfaces obtained vibration spectra are examined. For ball bearing possessing defects in race are studies with the help of mathematical model developed by Steve(5).Bearing defect frequencies or bearing characteristics frequencies are results of shocks generated from defect present in beairng. Each element of bearing has a specific bearing characteristic frequency. The spectrum is integration of numerous peaks in which few peaks corresponds to the bearing characteristic frequency due the higher vibrational energy.

Time-Frequency domain: It facilitates the representation of frequency component alongwith features varying with time. The area of roller bearing fault diagnostics utilizes the potential of time frequency analysis methods like Wavelet Transform(WT), Wigner-Ville Distribution (WVD), and Short-Time Fourier Transform (STFT) . STFT method is used for diagnosis of rolling element bearing faults .STFT involves division of initial signals into small finite segments that constitute a short time window followed by application of Fourier Transform to that segment (6). Wang and Gao(7) concludedWavelet Transform (WT) is superior than STFT as this provides high frequency resolutions with fine time resolutions.An enhanced Kurtogram method has remarkable application in fault diagnosis of ball bearing.

Artificial Neural Network: There are few other vibration/AE signal analysis techniques has been used for diagnosis of rolling element bearing fault i.e. ANN. Bailei and mark (8) applied ANN to diagnose the defect in ball bearing. ANN is rapid and accurate with a certain % as compared to previous techniques. ANN basically learns in initial stage with fed input and tries to recognize the type of defect present when employed in similar application. Probabilistic Neural Network(PNN), Multilayer Perceptron (MLP), Radial Basis Function(RBF) are types of ANN which are found suitable with varied area of application. Radial Basis Funtion(RBF) networks are used by Jack et al.(9) for diagnosis of rollingbearing elements faults but this network failed to classify among outer race and cage defects. Samanta and Al-Balushi (10) succeed to separate bearings with and without fault by utilizing feed-forward ANN with two hidden layers. Combination of wavelet analysis with Neural Network is performed by Khalid F Al (1) where Wavelet Analysis is used for preprocessing. Success rate of classification of ANN depends upon number, type of input feature, hiddenlayers, training algorithm. Samanta and Al-Balushi (10) considered five input features and obtained max 93.75% success fault classification for various mix of inputs. Jack & Nandi (9)found The Genetic Algorithm (GA) as significant feature provider which automatically suggest the features which has significant impact to NN classifier so that the requirement of input features is reduced.Samir Meradi (11) used intelligent technique based on MLP-ANN used statistical indicators of vibration signals and achieved good accuracy in detecting and locating defects, value of mean square error (MSE) obtained lowest as $7.11e^{-11}$.

Maan Rathore (12) developed A-SBiLSTM (Stacked bi-directional long short term memory) with attention mechanism to establish relationship between health status and remaining useful life of bearing, PRONOSTIA platform was employed. Chouaib et al. (13) developed an architecture for diagnosis of bearing fault based on independent feature selection, vector analysis, extreme machine learning classifier. The basis is binary grey wolf feature selection used optimal input vector contained five feature for each sample and error of minimum 0.76% this can be considered as best classification. Aditya sharma et al. (14) made an attempt to diagnose severity of faults in ball bearing used SVM and ANN calculated uncertainity measure as Shannon entropy, log energy entropy, sure entropy etc. they made an attempt for extraction of most appropriate feature and severity of fault. Jing and Carlos (15) done feature extraction through spectral kurtosis and k-nearest neighbor distance analysis decided health index of bearing using principal component analysis(PCA) and semisupervised KNN. This method doesn't rely upon reference data hence can detect incipient faults. Hakim (16) made an attempt to comprehensively overview Deep Learning methods based on ANN and studied applicability of algorithms Convolutional Neural Network(CNN), Autoencoder(AE), Deep belief network (DBN), Recurrent neural network(RNN) in bearing condition monitoring in three categories of machine learning, deep learning, transfer learning.

CONCLUSION

This paper represents an attempt to summarize recent researches and upgradation in field of vibration/AE analysis techniques to diagnose the fault in rolling element ball bearing.

Time domain analysis limits its capability to fault detection and it is unable to depict the location of fault. In any of the domain AE signals are found advantageous in early stage fault detection. On the other hand frequency domain techniques have capability to apparently indicate the location of fault in bearings. Peak corresponding to every frequency represents some specific events hence awareness of defect frequency range serves the purpose. Envelop analysis is applicable to incipient fault detection. Time frequency method possess high resolution hence can effectively detect bearing faults with proper information of time as well as frequency. Many of the researches proved wavelet as an effective feature extraction tool. Since a decade ANN has gained popularity in field of fault detection, location, classification. ANN is the basic foundation of KNN, CNN, ML, deep learning. Different type of ANN and its architecture shows different % of success. Assessing bearing useful life is also a latest area of interest now a days having better accuracy and fast rate.

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