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A Review on Fault Diagnosis of Ball Bearing Using Sound and Vibration Signals

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ABSTRACT: This review paper reported the detection of the various defects in ball bearing parts like inner race, outer race and balls using the vibration signal and sound signal. The signal emitted by a bearing contain spectral components that are related to the geometry of the bearing, the number of rolling elements, the speed of rotation, the location of the defect and the type of load applied. For the experimental study, good shape ball bearings and localized defect in the inner and outer race ball bearings were tested under various load and speed conditions. Some modern techniques are used to identify various defects through vibration analysis and compare with each technique.

KEYWORDS: Bearing Defects, Rotary Machine, Fault Detection, Condition Monitoring, Acoustics emission and Polymer bearings Self-lubrication.

1. INTRODUCTION

Rolling element bearing was widely used in machine elements in rotary machines. It is necessary to develop a suitable condition monitoring system to prevent malfunctions and breakages during operation. At present the machine condition monitoring became global due to some potential advantages to be obtained from decreased maintenance costs, improved productivity and increased machine availability. The traditional way to inspect and remove defective bearings is Human method but is instable and time consuming. The production area had enormous challenges involving large mechanical devices like power transmissions reducing the machine downtime, in managing repairs and in improving operating time. To reduce this type of problem the online monitoring systems are introduced. Vibration technique is one of the machine condition monitoring provides useful reliable information, bringing significant cost benefits to industry. The fault detection is done by comparing the signals of a machine running in normal and faulty conditions. The early bearing faults signatures are easily submerged in noise. The difficulties in bearing defect diagnosis when the bearing has multiple defects which developed from single can increase the amplitude of the bearing defect frequencies to an unexpected level. The identification of defect size in bearing elements is a challenging task. To increase the tribological properties the polymer usage in bearing had increased due to self-lubricate and their resistance to corrosion. These encourage manufacturers to use polymer bearings in corrosive and lubricant-free and critical lubrication applications and the bearing weight reduction is desirable. Defects inspection plays a vital role in bearing quality control.

II. MULTIPLE-POINT DEFECT (Yaquib, Gondal et al. 2013)

Multiple-point defects induce vibration signatures, have a defect diagnosis models. This study, characterizes the n-point bearing defects. Multiple-point defects and abrasions will depend on the relative location of the defects and width of the abrasive region. The defect frequency variation had degraded the accuracy of defect detection in the diagnostic model. Existing defect diagnostic model nullify the impact of multiple-point defects. Defect signatures created by general abrasion are investigated by effective length variation and the degree of surface roughness. In case of multiple-point defects and abrasion to improve defect detection accuracy these models to incorporate multiple defect frequency based on defect frequency of single point defect. The proposed model described for inner-race defects, it is applicable for outer-race and rolling-element defects.

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(Mohammadi and Safizadeh 2013)

The high frequency resonance technique (HFRT) is introduced to detect multiple defects on one component of the bearing. The time constant in the envelope detector find the amplitude of defect frequency harmonics (ADFH) in the frequency domain. This method compares the ADFH with a curve from vibration modelling of the bearing. The method is investigated with a simulation and a real experiment by created single and multiple defects on the outer race of the ball bearing at different angles. The ADFH in the multiple faults are calculated by the mathematical modelling to check the accuracy of the model.

This method is based on the HFRT and the envelope detector time constant. The effect of the time constant on the ADFH is needed for the method. In the HFRT, the time constant is estimated by the magnitude of the filter poles. The model is evaluated with single and multiple faults in the outer race at different angles. The two criteria properly revealed the existence of a second defect in the outer race .The mathematical modelling shows the ADFH relative to each other.

(Yaqub, Gondal et al. 2011)

A multiple-points defect model (MPDM) simulate fault signature's for n-points bearing faults. The location of the foremost defect frequency change depending upon the relative location of the fault points which inaccurate detections. Analytical and experimental results characterize the variation in the defect frequency. The envelop detection analysis modifies the existing fault diagnostic models to the multiple defect frequency and consider the impact of multiple points fault.

By using analytical, intuitive and experimental results multiple-points fault variation in the foremost defect frequency is validated. The impact of damping factor on the defect frequency is considered as the future works. This model described only the inner-race faults, but its generality holds true for outer-race as well as rolling-elements faults. MPDM revise the diagnostic and prognostic model based on the variation in dominant defect frequency under multiple-points faults.

(Zhang, Sconyers et al. 2009)

The multi-fault modelling method was related to a rolling element bearing of a helicopter's oil cooler. A simple and cost-effective on-line parameter adaptation solution is used to improve the performance of modelling. The emerging Condition-Based Maintenance and Prognostics and Health Management technologies improved reliability, availability, safety and maintainability for complex engineered systems. The accurate representation of the fault stages in terms of a suitable modelling framework is essential in the development of reliable, robust diagnostic and prognostic algorithms.

III. CYCLOSTATIONARITY TECHNIQUE

(Kilundu, Chiementin et al. 2011)

Cyclostationarity was a technique that analysis of vibrations from defective bearings. The Acoustic Emission (AE) technology had emerged for preventive maintenance of rotating machines. This experimental study characterizes the cyclostationary (AE) signals recorded from a defective bearing. The cyclic spectral correlation was a proof to evidence the presence of cyclostationarity and compared with other technique. Cyclic spectral correlation was most efficient to find small defect on outer race it was not mirrored on inner race defects. This cyclostationary technique was better sensitivity to the continuous monitoring compared to temporal indicators (RMS, Kurtosis, Crest Factor).The ICS indicator sensitivity increased over (RMS, Kurtosis, and Crest Factor) was explained. This effectiveness is only on outer race defect but the inner race defect was challenge based on small defects.

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(Dong and Chen 2012)

Wigner–Ville spectrum based on cyclic spectral density was studied, which represent the cyclostationary signals reducing the masking effect of additive stationary noise. Both simulations and experiments clear that CSWVS is a noise resistant time frequency analysis method for extract bearing fault under influences of unsystematic noise and gear vibrations. The CSWVS 3-D feature proved the extracting bearing fault and the signals are affected by gear meshing vibration and noise. This is more sensitive method for bearing performance degradation, compared with the spectral entropy (SE), squared envelope spectrum entropy (SESE) and Renyi information's for WVD, PWVD, when SNR is low.

IV. CONDITION MONITORING TECHNIQUES

(Stack, Habetler et al. 2004)

Most condition monitoring techniques categorizing bearing faults according to fault location (inner race, outer race, ball, or cage fault). The ability to detect the four characteristic fault frequencies is necessary but this approach neglects another important class of faults that arise in many industrial settings. This concept categorizing bearing faults as either single-point defects or generalized roughness. Bearing faults were separated according to the fault signatures by the physical location of the fault. Single-point defects produce the four predictable characteristic. The faults categorized as generalized roughness produce irregular broad band changes in the machine vibration and stator current. Experimental results are produced from bearings failed in situ via a shaft current. This issue successful bearing condition monitoring techniques must be able to reliably detect both classes of faults.

The faults categorized as generalized roughness are not over looked. The most techniques used for bearing condition monitoring focus on detection of single-point defects. But this method is able to detect both generalized roughness and single-point defect bearing faults. This can grouping faults according to fault signature and clearer that how these faults should be detected. Shaft current is only one way, this type of fault can be produced; it is a common source for bearing failures in industry. Microscopic inspection reveals pitting and roughness on all bearing surfaces. This further supports the assertion of a non localized or generalized roughness type of fault.

(Renaudin, Bonnardot et al. 2010)

A new method instantaneous angular speed measurement is introduced for bearing condition monitoring. The faults like pitting in bearing generate small angular speed fluctuations which can be measured with the help of optical or magnetic encoders. The instantaneous angular speed was measured with the pulse timing method through implicit angular sampling which ensures insensitivity to speed fluctuation. The operating conditions have been tested for the two applications with varying speed, load, external excitations and gear ratio. The conventional Fourier transform, angular frequency channels kinematically related to the fault periodicity show magnitude differences related to the damage severity.

The instantaneous angular speed measurement takes advantage of the Pulse Timing Method and the kinematics of the device under monitoring. It requires counter/timer devices and a high frequency clock (80 MHz). The measurements have been carried out on an automotive gearbox equipped with optical and magnetic encoders and with one bearing have spalling on its outer race. In second step, only magnetic encoders have been used on the front wheels of a small industrial vehicle with double row tapered roller bearings. Different kinds of spalling fault damage on the outer or inner races. The measurements with varying speed, load, external excitations and gear ratio. The measurement requires a high resolution spectrum available through angular sampling. The post-processing consists in a classical and simple Fourier transform. Sideband effects are seen when the fault is located on rotating parts of the bearing due to load modulation. Slip effects will be at the origin of widening of spectrum peaks in the case of double row bearings loaded in a pure radial direction.

(Ericsson, Grip et al. 2005)

Wavelets techniques are well suited for bearing condition monitoring. The true condition of the bearing is known from the signal acquiring from visual inspection of several different automatic bearing monitoring methods using 103

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laboratory and industrial environment. The four best performing methods in detail (two wavelet-based, and two based on envelope and periodisation techniques). In the four best methods 9–13% error rate and are good for further fine tuning and optimisation. Wavelet techniques are particularly well suited for bearing monitoring and are too sensitive to inevitable deviations from this model (due to big variety of different machines and industrial environments). The some trial and error with test signals for improvements and then our large systematic test to rule out the four currently best ones.

(Baljit Singh 2013)

The misalignment in the bearing lead to decrease in transmission efficiency, jerk and generate noise. The methods based on acoustics to identify bearing defects due to missing ball. The analyses are done on bearing under varying speeds at different conditions. A mike is used to record the acoustic signals generated by the bearing assembly. It has been demonstrated that acoustic condition monitoring can effectively be used for detection in bearing arrangement. In this sensor do not alter the behaviour of machine due to its non contact type. The method works satisfactorily in rpm range 0- 1000rpm. This method developed for the condition monitoring and for predictive maintenance of the many components.

V. ACOUSTIC EMISSION

(Tandon and Choudhury 1999)

They used vibration and acoustic measurement methods for detect the bearing defects like localized and distributed categories. The vibration and noise generation in bearings was explained. Both time and frequency domains in vibration measurement with the high-frequency resonance technique had enclosed. The acoustic measurement techniques like sound pressure, sound intensity and acoustic emission had explained. The recent techniques wavelet transform method and automated data processing used for identifies the defects in bearing have also been included.

In vibration measurement the frequency domain had detect the location of the defect. The vibration signals from a defective bearing cannot indicate the defect. For this high-frequency resonance technique is used but this had a disadvantage that highly developed damage is difficult to detect. To overcome this problem wavelet transform method had used to extract very weak signals. The sound intensity measurements are better than sound pressure measurements in bearing diagnostics. Acoustic emission measurements can detect a defect even before it appears on the surface. The neural networks are used to obtain data from vibration measurements in detection of defects in rolling element bearings.

(Eftekharnjad, Carrasco et al. 2011)

This investigation compares the AE and vibration technologies in monitoring a naturally corrupted roller bearing. The Kurtogram techniques are used on both vibration and AE data from a defective bearing. The Acoustic Emission and Vibration methods were studied to identify the defect of a naturally damaged bearing. AE was more sensitive on fault detection than vibration, reinforcing methods. Furthermore, the application of SK analysis and Kurtogram denoising both AE and vibration signals. The Kurtogram method for AE bearing was more effective.

(Al-Dossary, Hamzah et al. 2009)

The investigation centered the application of the acoustic emissions (AE) technology for characterising the defect sizes on a radially loaded bearing. The defects of varying sizes are seeded on outer and inner races of a test bearing and results were taken out by the experiment. The aim to investigate defect size with specific AE parameters and to discover the relationship between the periods of AE transient bursts related with seeded defects to the actual geometric size of the defect. The geometric defect size of outer race defects can be determined from the AE waveform was concluded.

(Pandya, Upadhyay et al. 2013)

This paper based on acoustic emission analysis with the Hilbert–Huang Transform (HHT) and data mining tool by analyzes the AE signal using intrinsic mode functions (IMFs), which are extracted using Empirical Mode Decomposition (EMD). K-nearest neighbour algorithm is observed to be more efficient classifier with default setting parameters in WEKA. APF-KNN approach, which is based on asymmetric proximity function with optimize feature

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selection shows better classification accuracy is used. Experimental evaluation for time frequency approach is presented for five bearing conditions such as healthy bearing, bearing with outer race, inner race and ball and combined defect.

These intrinsic features are inserted to compare and selected KNN as the most efficient supervised learning method with three different filters. Then to further improvement modified KNN algorithm is proposed based on symmetric proximity function (APF). The value of K plays a significant role in performance of KNN as concluded. Experimental results clearly shows that proposed APF-KNN algorithm with optimize feature has outperform the KNN algorithm with 96.6667% without compromising classification time and computational memory requirement. State of art classification can be achieved by storing 36 examples with 9 feature vectors in one class and that no significant improvement can be expected with optimized 6 feature vectors.

(Amarnath, Sugumaran et al. 2013)

Acoustic signals (sound) acquired from good and faulty bearing conditions for the purpose of fault diagnosis through machine learning approach. The statistical features were extracted from sound signals and were selected using decision tree (dimensionality reduction). This algorithm based interpretation of sound signals for automated evaluation of bearing condition. Decision tree algorithm was used to learn and classify the condition of the bearing. The built model was tested with 10-fold cross-validation method and found its accuracy to be 95.5% and it causes error about 5%. Hence, the results of the decision tree model can be practically used for diagnosing the condition of the bearings successfully. Compared to accelerometer (for vibration signals), microphone is costing less and hence, the result will be more useful and acceptable.

VI. HERTZIAN CONTACT DEFORMATION THEORY

(Patil, Mathew et al. 2010)

This paper presents an analytical model for predicting the effect of a localized defect on the ball bearing vibrations. In the analytical formulation, the contacts between the ball and the races are considered as non-linear springs. The contact force is calculated using the Hertzian contact deformation theory. By using time domain and frequency domain defect on the raceways are simulated. This experiment had discussed about the 6305 deep groove ball bearing. The defect itself is modelled as half sinusoidal to simulate the effect of the defect size and its position and predict the spectral components. The frequency spectrum of the bearing vibrations due to the defects comprises mainly BPFO and its harmonics for outer race defect and, BRFI and the combination of BRFI and the shaft frequency for the inner race defect.

The amplitude level of vibrations for the outer race defect is more than that for the inner race defect and the ball defect. The defect on the inner race moves in and out of the load zone during each revolution of the shaft. The strong fault signatures produced while the defect is in the load zone and the weaker signatures acquired while the defect is outside the load zone. The amplitude of vibration increases with the increase in the defect size. Ball slip is a function of lubrication, ball, cage clearance, angular alignment, as well as speed and load. Lubrication traction has dominant effect on the ball skidding. Including the ball raceway interaction and ball skidding phenomenon would make the model more accurate.

(Kankar, Sharma et al. 2012)

This was based on microns level localized defects (like spalls) on the bearing components. The contacts between rolling elements and races are taken as nonlinear springs and its stiffness's are finding by using Hertzian contact deformation theory. The formulation predicts the discrete spectra with the characteristic defect frequencies and their harmonics, which is helpful in prediction of system stability and to avoid severe (chaotic) vibrations in a rotor bearing system. The results are presented in the form of bifurcation diagrams, Fast Fourier Transformation (FFT) and Poincare maps for individual defects of bearing components. The system also shows the three different categories of system behavior under nonlinear dynamic conditions.

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(Tadina and Boltežar 2011)

This model discuss about the vibrations of a ball bearing during run-up. The numerical bearing model assumes that the inner race has only 2 DOF and the outer race is deformable in the radial direction by finite elements method. The centrifugal load effect and the radial clearance are taken into account. Hertzian contact deformation describes the contact force for the ball. The detailed geometry of the local defects is modelled as an impressed ellipsoid on the races and as a flattened sphere for the rolling balls. The outer ring can be coupled with the FE model of the housing. The obtained equations of motion were solved numerically by modified new mark time-integration method for the increasing rotational frequency of the shaft. The continuous wavelet transformation was used for the bearing-fault identification and classification.

The outer ring was deformable and is modelled with finite elements, and can couple with arbitrary housing structure if it is discretised with finite elements. The contact force between the outer race and the ball is moving within the finite element. The contact properties are described with detailed geometrical properties and small changes in the contact stiffness are taken into account. The rotational frequency is increasing with time; the envelope analysis method could identify simulated local bearing defects. The time interval is short because the frequencies will smear out over a few frequency lines of resolution due to the changing rotational speed of the shaft and the characteristic defect frequencies will be harder to identify. The continuous wavelet transformation was able to identify simulated local bearing faults during the run-up. When using the CWT we do not need to give special attention to the analysed time interval.

(Rubio and Jáuregui 2012)

Mechanical vibrations and sound signals from defective and healthy wheel hub bearings were analyzed with signal processing methods in frequency and time-frequency domains. The FFT and STFT are the off-line analysis of accelerometer measurements of bearings. The upper frequency was measured when the measurements were conducted in a raw environment such as a regular highway road. Statistical signal processing of acceleration data can also be used. Noise measurements inside the vehicle cabin are only significant at low frequencies, as higher frequencies are virtually non-existent.

The localized defects (like spalls) of microns level on the bearing components, which is essential to the design for high performance. The contacts between the rolling elements and the races are considered as nonlinear springs its stiffness's are obtained by using Hertzian contact deformation theory. The results are presented in the form of bifurcation diagrams, Fast Fourier Transformation (FFT) and Poincaré maps for individual defects of bearing components. The system also shows the three different categories of system behaviour under nonlinear dynamic conditions.

VII. ANALYTICAL WAVELET TRANSFORM

(Jena, Singh et al. 2012)

The seeded defects are introduced in the form of an axial groove on the inner race of a radial ball bearing. The nature of the acoustic and vibration signal bursts, and their correlation with the inner race defects, are established and estimated. Experimental investigation reveals that the analytical wavelet transform (AWT) is an effective tool for analyzing the acoustic and vibration signals, transmitted from the bearing. AWT followed by the time marginal integration (TMI) have been implemented on acoustic and vibration signals of a defective radial bearing. Size of the defect in the inner race of bearing is corroborated with AWT scalogram. The segregation of the defect is carried out on TMI graph across the highest amplitude spike, which is due to signal burst (due to a contact of ball with bearing inner race defect). The acoustic and vibration signal of defective bearing has higher RMS, SD, kurtosis, and rest factor but has lower skewness and SNR than the healthy bearing which gave indication about the presence and severity of defect. The denoising technique is helpful in spotting the defect but is not suitable for evaluating the size and nature of defect. Size of defect in the bearing can be corroborated well with the AWT scalogram. Error in measurement obtained from signal processing by AWT and physical measurement is less than 5%. Summarizing, the proposed method can be reckoned in precise radial bearing inner race defect measurement from acoustic and vibration signal processing.

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(Prabhakar, Mohanty et al. 2002)

Bearing race faults have been detected. Vibration signals from ball bearings having single and multiple point defects on inner race, outer race and the combination faults have been considered for analysis by using discrete wavelet transform (DWT). It is found that the impulses appear periodically with a time period corresponding to characteristic defect frequencies. It has been shown that DWT can be used as an effective tool for detecting single and multiple faults in the ball bearings.

In case of single defects and two defects on outer race at 180 apart, the impulses appear periodically with a time period corresponding to characteristic defect frequencies. But, in the case of two defects, one on the inner race and the other on the outer race, one set of impulses is running at a time period corresponding to the inner race defect frequency while the other set of impulses is running at a time period corresponding to the outer race defect frequency.

(Tomović 2012)

In this paper, a mathematical model for calculating the necessary boundary bearing-deflection level for supporting the inner bearing ring on q rolling elements has been derived. The model considers two boundary positions of the inner ring supported on an even or an odd number of rolling elements. The boundary position for support on an odd number of rolling elements emerges the centre of the rolling elements overlaps with the vertical axis of the bearing. In the case of support on an even number of rolling elements, the boundary position is determined when the rolling elements are symmetrically placed in relation to the vertical axis of the bearing. This is a new approach in the mathematical modelling of rolling bearings. The necessary boundary bearing deflection for bringing the q -th rolling element in contact with both bearing rings.

In a physical sense, the coefficients of the boundary displacement and the boundary deflection indicate how many times larger the mutual displacement of the bearing rings should be in relation to half of the internal radial clearance so that the q -th rolling element comes in contact with both bearing rings. The values of the boundary coefficients depend on the number of rolling elements that come into contact with both bearing rings (q) and the total number of rolling elements in the bearing (z). As the total number of rolling elements in bearing increases, the values of these coefficients asymptotically tend to zero. The number of rolling elements participating in the external load transfer in a bearing with internal radial clearance is determined from the relation of the bearing deflection and half of the internal radial clearance. The developed model for calculating the boundary displacement and the boundary deflection is related to an ideal radial bearing, either a ball bearing or a roller bearing. Such a model can serve well as the foundation for developing a model for real bearings, which have errors in their micro- and macro-geometry, and for developing models for other types of bearings, such as bearings with angular contact.

(Park, Choi et al. 2013)

Minimum variance cepstrum (MVC) has been introduced for the observation of periodic impulse signal under noisy environments. In this particularly focusing on the definition of MVC that goes back to the original definition by Bogert et al. in comparison with the recently prevalent definition of cepstral analysis. In this work, the MVC is, therefore, obtained by liftering a logarithmic power spectrum, and the lifter bank is designed by the minimum variance algorithm. We were able to detect incipient faults in 4 out of 12 normal bearings which passed acceptance test as well as in bearings that were recalled due to noise and vibration.

Automotive ball bearings play an important role in enabling a vehicle to run. Small faults often grow very quickly due to stress concentration even under normal operation. The faults in the bearings finally cause vibration and noise, and as a result, vehicle reliability is lowered. Based on the observation of the different characteristics between early fault signal and operating noise, the MVC can clearly show fault period that may be buried by operating noise. In addition, cepstral analysis can separate system response from fault period that has important information for identifying bearing faults. This means that the MVC can provide fault information consistently in the form of fault period without considering frequency spectrum variation due to system and measurement conditions, such as the kind of vehicles, the changing of other parts near a bearing, fault location, measurement position, and so on. MVC follows the original lifter definition by Bogert et al., because it is inherently more convenient to take the minimum variance algorithm into account. In addition, our experiment using ball bearings provided results that indicate that the MVC could be an efficient way to detect periodic fault signals; using the proposed method, we found that four out of twelve newly-made

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bearings that passed conventional acceptance test had small early faults in them. Moreover, comparison between these results and those obtained using other fault detection methods indicate that the MVC is much more capable of detecting early faults under the given conditions.

(de Moura, Souto et al. 2011)

Signal processing and pattern recognition techniques are combined to detect bearing faults. The signals were pre-processed by detrended- fluctuation analysis (DFA) and rescaled-range analysis (RSA) techniques and investigated by neural networks and principal components analysis. Three different levels of bearing fault together with a standard no-fault class were studied and compared. Signals from the bearings are taken under different frequency and load conditions. An evaluation of fault recognition efficiency was performed for each combination of signal processing and pattern recognition techniques. All four schemes of classification yielded reasonably good results.

The classifier based on principal component analysis presents performance slightly inferior to the one implemented by neural network with an inferior computational cost. The principal component analysis is an unsupervised method but the classifier implemented by neural network was trained by supervised learning.

(Stack, Habetler et al. 2006)

This signal model presented the production and propagation of an inner-race fault signature. This examines machine-vibration peaks with phase-coupled sidebands occurring at a spacing predicted by the model. The fault-detection on inner-race of the bearing is then experimentally verified by 12 bearings with varying degrees of fault severity. The location of a single-point defect due to the load zone can affect fault-signature saliency. Inner-race faults periodically rotate in and out of the load zone this model was developed to investigate this problem. This model showed the power spectrum of machine vibration of inner-race defect to be comprised of peaks separated by FIRF and peaks within the groups separated by FS. This detector was then applied to machine-vibration data, and the peaks it exhibited that were spaced by FIRF were counted and used as the fault index. Inner-race defects fault-index counts are one to two orders of magnitude greater than healthy bearings for most values of m . Single-point defects fault-index counts are low (between 0–5) for all values of m . Rolling-element defects when FIRF is an integer multiple of FRE. This fault-signature model and detection scheme to handle rolling-element or cage defects.

(Purushotham, Narayanan et al. 2005)

Discrete wavelet transform (DWT) techniques are used to find the bearing race faults. Vibration signals from single and multiple point defects on inner race, outer race, ball fault and combination of these faults are analysis. Wavelet transform provides a variable resolution time frequency distribution from periodic structural ringing. Results are compared with feature extraction data and results from spectrum analysis. DWT is an effective tool for detecting single and multiple faults in ball bearings. A new method of pattern recognition for bearing fault monitoring using hidden Markov Models (HMMs).

Experimental results improve the bearing fault detection rates as high as 99% among other methods. The bearing defects can be extracted from the time signals of the faulty bearings using discrete wavelet transform at Mel-frequency scales. The spacing of the impulses by wavelet decompositions of time signals to detect bearing race faults. The vibration data from the bearings were used to obtain the complex cepstral coefficients for wavelet transformed time windows at Mel-frequency scales. Training the models on processed data to ensure the validity of the models no assumptions are made for measuring signals.

(Kumar and Singh 2013)

Symlet wavelet was handled for measuring outer race defect width of taper roller bearing. Seeded defects of different size were form on the outer race of taper roller bearings using laser engraving technique. The confusion gets reduced to detect the initial grove position by using Symlet5 wavelet by its linear phase maintains sharpness in the signal even a sudden change in signal occur.

Sharp and high amplitude impulses are obtained at the defect entry and exit point when roller crosses it. The roller contact with the groove base between entry and exit, the impulses due to roughness of the groove surface are observed. The difficulty in detecting the entry point of the defect in the signal is reduced by using Symlet5 sharpness of the

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signal. By using this method defect width can be measured over a range of 0.5776–1.9614 mm and it can be verified by using image analysis. Maximum deviation 4.06% for the defect width of 1.1820 mm at no load then it can be reduced to 1.02% with increase in load.

(Kiral and Karagülle 2003)

Dynamic loading of a rolling element bearing structure is modelled by Visual Basic programming language. The vibration response of the structure to the dynamic loading is obtained by finite element analysis. The vibration signals of healthy and defected structures are compared. The envelope high frequency resonance technique (HFRT) method is introduced in the frequency domain analysis. The effect of the rotational speed of rolling element bearing defects is investigated.

A computer program was developed to model the dynamic loading of the bearing structure and considering the bearing kinematics and load distribution. A force model simulates the impulse force at ball defect impact. The variation in vibration signal between the healthy and defected bearings is examined. Time domain parameters RMS, crest factor and kurtosis are analyzed with regard to their effectiveness in defect detection. The effect of the rotational speed, geometry of the bearing structure and type of loading are analysis between two different bearing structures at two different loading conditions with different rotational speeds. In this the time and frequency domain techniques are sensitive to changes with respect to rotational speeds, structure geometry and loading type. This method is used to determine the ideal sensor position and signal processing technique based on rotational speeds, structural effects and loading conditions at the beginning of an industrial condition monitoring application.

(Zahari Taha 2010)

Finite element analysis method was used for identifying the defect in rolling element bearing which having single point defect on its outer raceway by using vibration analysis with frequency domain. A load mechanism helps to simulate the nodes excitation force as external loading. The housing and outer raceway of the bearings FEA models are created and vibration response analyzed by using finite element software ABAQUS.

The dynamic loading distribution is introduced to simulate the load distribution on the outer raceway due to load transfer from the shaft through the balls. The impulse force by the impact between the defect and the bearing components is obtained by amplifying the excitation force on the defected area with a factor of 6. The vibration signal of defected bearing is compared with healthy bearing for defect detection. This method is possible to predict the condition of a bearing.

(PIYUSH and PRAJAPATI 2011)

Artificial Intelligence (AI) is an emerging technology focused on computational approaches to intelligent behaviour. The artificial intelligence method development for the condition monitoring procedure for various types of bearings, which involves an AI methods and techniques to effectively address various hard-to-solve design tasks and Issues relating different types of bearing fault. This guide for researchers who are interested in AI and wish to explore the opportunities offered by fuzzy logic, artificial neural networks and genetic algorithms for further improvement of conditioning monitoring for different types of bearing under different operating conditioning.

(Zoubek, Villwock et al. 2008)

This frequency response analysis for non-rigid multi-mass systems with mechanical resonance frequencies and is calculated during the commissioning of the plant for reasons of safety and controlling. Two-channel analysis method for bearing damage diagnosis without additional sensors is developed. The measurement of two signals can be carried out during normal operation of the plant, online BF diagnosis is achieved.

This examine single-point bearing defects on the inner and outer raceways of rolling bearings and generalized roughness faults. The effectiveness of the frequency response analysis by this method had different bearing failures with significant damage pattern. The calculation can be carried out during normal operation of the plant, online condition monitoring without the need of additional sensors can be achieved.

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(Sreenilayam-Raveendran, Azarian et al. 2013)

The performance of polymer and metal in rolling contact bearing is compared by monitoring the acoustic emission, vibration and operating speed during their operation. For this analysis both 8 mm radial bearings comprising polymeric inner race, outer race, and cage as well as 52 mm thrust bearings comprising polymeric top race, bottom race and retainer. The polymers used in these bearing components are polyetheretherketone (PEEK) and polytetrafluoroethylene (PTFE) and the rolling elements used in these bearings were made of alumina. The performance of these materials in both radial and thrust bearings was evaluated and these polymers performance was compared with the stainless steel in similar bearings. 8 mm polymer ball bearings and 8 mm metal bearings under dry lubrication conditions were used in these tests. Performance is compared using vibration, acoustic emission as well as changes in the rotational speed. A lower level of vibration is observed with the usage of PEEK in the bearing elements when compared to that of PTFE and metal. The transfer film formation in PEEK bearings resulted in unstable operating speed of the bearing. Stable operating speeds after an initial running-in period is observed due to transfer film formed in carbon-filled PTFE bearings; by this a higher level of vibration is observed.

The most common failure mechanisms in these kinds of bearings are lubricant degradation, which represents 36% of premature bearing failures. Polymer self-lubricated materials are considered as candidate materials for critical lubrication. Vibration, operating speed and acoustic emissions signals taken to compare the wear behaviour of polymer bearings with metal bearings. Even though PEEK is normally preferred over PTFE due to its better mechanical properties at high temperatures, PEEK will be better over PTFE if the friction between the contacting surfaces is reduced. Hybrid bearings formed by PEEK inner and outer races and a carbon-filled PTFE retainer will be constructed and evaluated in the future. The high wear resistance properties of PEEK is combined with the low coefficient of friction of the PTFE material can able to increase life time and more stable operation levels.

(Tóth and Tóth 2013)

The formation of defect like pitting, spalling formulation on the inner race of deep groove ball bearings. The inner race fault was created artificially. A new signal model for a point-wise fault on the inner race of a deep groove ball bearing is introduced. Filtering method was used, which is suitable for eliminating the effect of amplitude modulation and noise that usually arise in the case of bearing vibration measurements. We showed that a three parameter model is adequate to describe the transient pulses. This model does not take magnitude of the load into account.

(Shen, Li et al. 2012)

The system designs a novel image acquisition system to enhance various types of defects on bearing covers, such as deformations, rusts, scratches and so on appearances and get controlled image acquisition environment. The proposed system is evaluated and compared with skilled human by the recall, precision and F-measure. This study develops a machine vision system for the inspection of bearing surfaces. This system, a novel inspection algorithm is proposed for inspect the deformation defects on seals. The machine vision system is applied to the automatic production line to replace the human workers.

(Rybczyński 2011)

The computer simulation of bearing misalignment defects in a power turbo generator. The calculations were carried out by the computer code system MESWIR, developed and used at the IFFM in Gdansk for calculating dynamics of rotors supported on oil bearings. This analysis focuses on the vibration effects of displacing the two most in danger machine bearings in horizontal and vertical directions by the maximum acceptable range calculated with bearing vibration criterion. We show the relations between the attributes of bearing trajectories and bearing displacements in their base design position. The trajectories can be a source of information about the position and direction of bearing misalignments. The mechanism changes in journal trajectory shape and dimensions due to bearing misalignment can be based on the hydrodynamic theory of lubrication. The bearing trajectory patterns depend on the direction and range of the bearing displacement and the relation between direction of the bearing displacement and direction of the shaft revolution. This is the best method of presenting the dynamic state of a rotating machine. It makes clear detail about bearing absolute and relative vibrations in two perpendicular directions.

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(Moosavian, Ahmadi et al. 2012)

A new method of engine journal bearing fault diagnosis based on Power Spectral Density (PSD) of vibration signals combined with Support Vector Machine (SVM). The vibration signals of an internal combustion engine (IC engine) with three main conditions were gained, (i) normal, (ii) corrosion and (iii) excessive wear. The PSD values of vibration signals were extracted using statistical and vibration parameters and are used as inputs to the SVM for three-class identification. The accuracy rate of fault diagnosis of the IC engine main journal-bearing was 100%. The results show that the method has the potential for fault diagnosis of main journal-bearing of IC engine.

The vibration signals PSD values were calculated from obtained spectrums for the corresponding journal-bearing conditions. Secondly 30 features were extracted from PSD values as inputs to classifier. The structure of SVM classifier with one-against-all (OAA) multiclass method is built by feeding the training dataset and its performance was estimated by test dataset. The classification accuracy of three conditions of journal-bearing was 100% on both training and test dataset. The ability and reliability of given PSDSVM model in condition monitoring of engine journal-bearing is effective.

(Kulkarni and Sahasrabudhe 2013)

The methodology for fault diagnosis of rolling element bearings based on discrete wavelet transform (DWT) and wavelet packet transform (WPT). To obtain the useful information from raw data, db 02 and db08 wavelets were adopted to decompose the vibration signal acquired from the bearing. This de-noised signal was decomposed up to 7th level by wavelet packet transform (WPT) and 128 wavelet packet node energy coefficients were obtained and analyzed using db04 wavelet.

The wavelet transform decomposes the non-stationary bearing vibration signal into components simple frequency content. The wavelet packet node energy coefficients are sensitive to the faults in the bearing. The feasibility of using the wavelet packet node energy coefficients for fault identification as an index representing the health condition of a bearing is established by the process.

(Branch, Arakere et al. 2013)

Short spall propagation times of failing main shaft ball bearings of aircraft engines are a serious safety concern for single engine aircraft. Bearing designers would like to understand the impact of four variables namely (i) ball material density, (ii) subsurface residual stress, (iii) gradient in yield strength with depth (case hardening), and (iv) raceway surface hardness/yield strength that are thought to affect spall propagation. Extensive spall propagation experiments have been conducted at AFRL, Ohio in the past few years to address this issue. However, a detailed mechanistic analysis of these experiments has not been performed. This work presents an elastic-plastic finite element (FE) model that simulates a ball impacting a spall edge to determine the relative contributions of the four material variables on spall propagation. The magnitude and extent of damage of the spall edge material is determined based on critical stresses and plastic strains induced by the ball impact. The results indicate that the influence of ball density is greatest on inducing damage at the impacted spall edge when compared to the other three properties, which also agrees with the hybrid bearing spall propagation tests conducted at AFRL.

Short spall propagation times in failing bearings are a concern for single engine aircraft in terms of engine reliability, pilot safety, and mission success. Different bearing properties such as ball density, residual stress, gradient in race yield strength, and race surface yield strength affect spall propagation as seen by the experiments carried out. This work presented an FEA model that simulated a ball impacting a spall edge from the experiments to determine the relative contributions of these four bearing properties on spall propagation. This model does not simulate bearing material removal rate from the spall edge due to ball impacts, but the magnitude and extent of damage of the spall edge material based on critical stresses and plastic strains induced by the ball impact.

(Shabeer Hameed 2010)

The visual dot pattern technique was used to find out the fault diagnosis in ball bearings. The author considered ball bearing defects such as outer race defect, inner race defect, ball and cage defect. The VDP technique was more efficient explained the bearing faults.

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(Ahmadi and Mollazade 2009)

The objective was to investigate the correlation between vibration analysis and fault diagnosis. This was done by vibration analysis of two bearings of stone crusher in Pirbakran mineral mine company. The vibration analysis was run under regular interval during stone crusher. The vibration and numerical data were compared with vibration spectra in a standard condition of healthy machine, in order to evaluate the effectiveness of the vibration condition monitoring technique. We calculate the frequencies of components which vibrating, as the exterior ring, the internal ring or their balls. With the Fourier transformation and the calculation of spectrum of frequencies we can distinguish the frequencies of ball bearing's elements and visualize if there is any damage in the particular component. In this vibration monitoring technique is a practical technique for bearing defect detection of stone crushers.

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