Bearing Fault Detection Techniques - A Review

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Abstract

Detection of an antifriction bearing faults is one of the most challenging tasks in bearing health condition monitoring, especially when the fault is at its initial stage. The defects in bearing unless detected in time may lead to malfunctioning of the machinery. The defects in the rolling element bearings may come up mainly due to the following reasons; improper design of the bearing or improper manufacturing or mounting, misalignment of bearing races, unequal diameter of rolling elements, improper lubrication, overloading, fatigue and uneven wear. This paper presents a detailed of the different detection techniques used for measuring rolling bearing defects. From in depth study, four different methods for detection and diagnosis of bearing defects; they may be broadly classified as vibration measurements, acoustic measurements, temperature measurements and wear debris analysis have been identified. It is observed that the vibration analysis is most commonly accepted technique due to its ease of application.

Keywords: Bearing Defects**,** Vibration Measurements, Acoustic Measurements, Temperature Measurements, Wear Debris Analysis**.**

1. Introduction

In the recent years, condition monitoring and fault diagnosis of equipment are of great concern in industries. Early fault detection in machineries can save millions of dollars in emergency maintenance costs. In rotating machinery, rolling element bearings are one of the most critical components because they are the most commonly wearing parts and a large majority of system failures arise from faulty bearings. Proper functioning of these machine elements is extremely important in industry in order to prevent long term, costly catastrophic downtimes. A reliable online machinery condition monitoring system is very useful to a wide array of industries to recognize an incipient machinery defect so as to prevent machinery performance degradation, malfunctions, or even catastrophic failures [1]. It was obvious that more attention must be paid to the condition of a rolling element bearing if the human life is in question. Thus, advanced technologies are needed to monitor the health status of bearings efficiently and effectively [2].

Generally, bearings can basically be categorized as two types, sliding bearings and rolling bearings. Sliding bearings includes linear bearings and journal bearings. Ball and roller bearings, together called rolling bearings, are commonly used machine elements. Rolling element bearings are machine elements that permit rotary motion of shafts in in machinery for a wide range of applications such as bicycles, roller skates, electric motors, aircraft gas turbines, rolling mills, dental drills, gyroscopes, and power transmissions [3]. Compared with other types of bearings, rolling bearings have many advantages. They are often referred to as antifriction bearings because they require a small amount of lubrication [1]. Rolling bearings can operate with low friction and they are suitable for high-speed shaft speeds that demand outstanding endurance. Actually, rolling bearings are consists of different parts: an outer race, an inner race, rolling elements that are in contact under heavy dynamic loads and relatively high speeds, and optionally a cage around these rolling elements, as shown in Figure 1. A detailed introduction to rolling element bearings is available in [4-6].

Faults may occur in any of these parts, and often these faults are single point defects such as chips or dents [7]. As these elements move past each other, these defects come into periodic contact with other elements in the bearing, and at each contact they can excite a high frequency resonance in the overall structure. Rolling bearing damage may result in a complete failure of the rolling bearing at least, however, in a reduction in operating efficiency of the bearing arrangement. Only if operating and environmental conditions as well as the details of the bearing arrangement are completely in tune, can the bearing arrangement operate efficiently. Bearing damage does not always originate from the bearing alone. Damage due to bearing defects in material or workmanship is exceptional [8].

In the recent years, manufacturing community has been concentrating on finding out various techniques and methodologies in order to improve the bearing designs. However, the large number of bearings associated with any given process increases the likelihood of system failure. Researches are using various approaches like mathematical models, computer aided engineering (CAE) based simulation models and experimental models. The main purpose of this paper is to present a detailed of the different measurement techniques in the last period on bearing defects. From in depth study, four different methods for detection and diagnosis of bearing defects; they may be broadly classified as vibration measurements, acoustic measurements, temperature measurements and wear debris analysis have been identified.

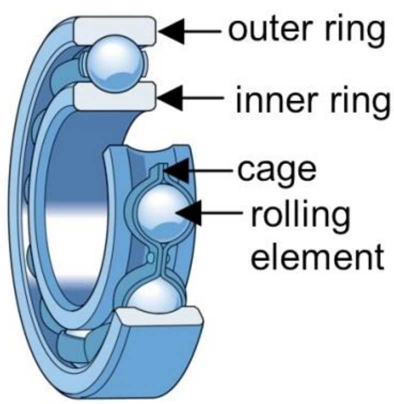

Fig. 1 Main components of the rolling bearing (SKF).

2. Vibration Measurements

Vibration analysis is among the most common method used in the monitoring applications since a defect produces successive impulses at every contact of defect and the rolling element, and the housing structure is forced to vibrate at its natural modes. The vibration pattern of a damaged bearing includes the low-frequency components related to the impacts and the high-frequency components. The structural information of the bearing structure or the machine is stored.

The use of the statistical moments of the rectified data was proposed and compared to the moment of the original data, [19]. Simulation analysis studies the effects of the disturbing signals on different parameters. Simulating the development of a bearing provides a good understanding of the behavior of the statistical parameters which are going to be used for condition monitoring of bearing.

The statistically efficient method is used in frequency estimation of envelope-autocorrelation from the fault rolling element bearing under very low shaft speed and light load. By using the estimated frequency, a simple notch filter removes the frequency component so that further detail in the vibration signal may be analyzed, [20]. In this instance, the fault characteristic frequency and its harmonics are estimated and subsequently removed with this technique. The vibration data captured and used for determination and validation is composed from four different defects states of the rolling element bearing -outer raceway defect, inner raceway defect, ball defect, and combination of the bearing elements defect- and one representing normal state of the bearing for four different running speeds with two load levels, [21].

An alternative framework for analyzing bearing vibration signals, based on cyclostationary analysis, was proposed, [22]. The degree of cyclostationary function can provide a first overall indication of the appearance of several distinct modulating frequencies. The basic concepts of the approach are demonstrated both in illustrative simulation results, as well as in experimental results and industrial measurements for different types of bearing faults.

The synchronous averages are used to examine the calculation of the envelope signal of the high-frequency vibration produced by rolling element bearings with spalling damage, [23]. By synchronizing with the rotation speed of the shaft relative to the cage, an estimate is obtained of the distribution of the damage on the inner race of the bearing, and of the variations between rolling elements. The techniques are demonstrated by experiments on a laboratory test rig with a rolling bearing under radial load and multiple simulated spalls on the inner race.

The effect of local defects on the nodal excitation functions is modeled. Simulated vibration signals are obtained, [24]. The signal analysis is applied to the simulated signals to obtain an indicator value for the defect. RMS values are obtained in the time domain and the high frequency resonance technique is used in the frequency domain. The indicator values are obtained for various rotational speeds, for different loading and housing structure. The indicator value from different signal processing methods which is most sensitive to the defect is found for different cases.

Estimation of the running speed and the bearing key frequencies are required for failure detection and diagnosis. Experimental data were used to verify the validity of the algorithms. Data were collected through an accelerometer measuring the vibration from the drive-end ball bearing of an induction motor. Both inner and outer race defects were artificially introduced to the bearing using electrical discharge machining, [25]. A linear vibration model was also developed for generating simulated vibration data. The simulated data were also used to validate the performance of the algorithms.

A complex filter for Hilbert transform is proposed to apply in the real-time vibration signal demodulation. The filter could provide a complex signal directly, as a function of both frequency and time, and the envelope could be derived from the absolute value of the complex signal. Three parameters, the scaling factor, center frequency and pass band width, are designated to achieve the satisfactory properties of fast waveform convergence, constant pass band gain and little phase distortion. Thus, a finite waveform interval of the proposed filter could be possibly applied in the vibration signal demodulation, [26]. From theoretical analysis and experimental studies, it is shown that the proposed filter could be effectively applied in the real-time vibration signal demodulation for a roller bearing system.

Dynamic loading model is proposed to model the localized rolling element bearing defects. Statistical properties of the vibration signals for healthy and defected structures are compared, [27]. The envelope high frequency resonance technique method is employed in the frequency domain analysis. The effect of the rotational speed on the diagnostics of rolling element bearing defects is investigated. An optimum sensor location on the structure is sought. Effect of the structure geometry on the monitoring techniques is studied.

Time domain analysis, frequency domain analysis and spike energy analysis have been employed to identify different defects in bearings, [28]. Spike energy factor helps to identify the severity of the defect in antifriction bearings. The distinct and different behavior of vibration signals from bearings with inner race defect, outer race defect and roller defect helps in identifying the defects in roller bearings. The results have demonstrated that each one of these techniques is useful to detect problems in antifriction bearings.

The machine is a single stage centrifugal compressor with a rolling element thrust bearing on the motor free end and a sleeve bearing on the motor drive end. The expert system severity score is an excellent way to consistently trend the bearing health because it always applies the same logic and looks at a number of features in the data. The increase of the severity towards the extreme level and a bearing replacement is ordered. The defect was detected using off the shelf portable vibration analysis hardware and software, [29].

The partial correlation integral algorithm is used to analyze machine vibration data obtained throughout a life test of a rolling element bearing. The dimensional exponent computed from the partial correlation integral algorithm tends to increase as time progresses and the useful remaining life of the bearing is decreasing, [30]. The dimensional exponents of a healthy bearing and a bearing close to failure are statistically different. As a result, the condition of the bearing can characterized from the results of the surrogate data test. Furthermore, the dimensional exponent can be used to predict the failure of rolling element bearings in rotating machinery from real-time vibration data.

A dynamic simulation method is proposed to study ball bearing with local defect based on the coupling of the piecewise function and the contact mechanism at the edge of the local defect, [31]. The ball bearing is modeled as a two-degree of freedom system. The impulse force is determined by the ratio of the ball size to the defect size and the contact deformation at the edge of the local defect is included. The proposed method can provide a more close to real impulse for the contact between the ball and the race with different defect sizes compared to the assumed rectangular or half-sine impulse function.

The localized bearing defects in spindles were modeled visually. The vibration responses generated due to the outer ring defect were simulated. The finite element model of the spindle is capable of predicting the acceleration time responses due to the excitation, [32]. The noise decreases the amplitudes at the bearing characteristic frequencies in the envelop spectrum.

The detection of local defects existing on races of deep groove ball bearing was investigated using envelope analysis and Duffing oscillator. Experiments have been carried out using a test rig for capturing the vibration signals of test bearing. The external vibration has been imparted to the housing of the test bearing through electromechanical shaker, [33]. The Duffing oscillator has acquired the weak defective bearing signal. The close phase plane trajectories of Duffing oscillator have confirmed the presence of the defects on the races of the test bearing.

The scalar parameters, peak-to-peak value, RMS, Crest factor and kurtosis, show damage at the ball bearing but they do not give information about the location of defect. Therefore, spectrum analyses are conducted at specified test durations in order to predict defect locations, [34]. Vibration signatures produced are recorded and statistical measures are calculated during the test. Vibration spectra are obtained and examined to determine where the defect is on the running surfaces.

The vibration signals obtained from an accelerometer were measured and analyzed for comparative purposes. The time-domain statistical parameters and frequency-domain modified Peak Ratio were calculated and compared. The study revealed that ultrasound technique is demonstrably superior to vibration acceleration measurements for detecting incipient defects in low speed bearings, [35]. The RMS of ultrasound signals provided the best parameter at almost all speeds. However, at very low speeds, the kurtosis and crest factors performed best. In the frequency domain, a modified Peak Ratio was proposed and was proven to a better indicator than the original Peak Ratio.

A simple time series method for bearing fault feature extraction using singular spectrum analysis of the vibration signal is proposed, [36]. The algorithms were evaluated using two experimental data sets one from a motor bearing subjected to different fault severity levels at various loads, with and without noise. The effect of sample size, fault size and load on the fault feature is studied. The experimental results demonstrate that the proposed bearing fault diagnosis method is simple, noise tolerant and efficient.

A finite element contact mechanics bearing model is established based on a contact algorithm suited to high-precision elastic, [37]. The computational model includes all the important bearing details besides basic geometry, such as, internal clearance, roller and race crowning, race width and thickness, and dimensions of the raceway shoulders. The computed stiffness matrix captures the coupling between radial, axial, and tilting deflections of rolling element bearings. The proposed stiffness determination method is validated the experiments and compared to existing analytical models. A method is presented for calculating and analyzing the quasi-static load distribution and varying stiffness of a radially loaded double row bearing with a raceway defect of varying depth, length, and surface roughness, [38].

The resonance frequency in the first vibration mode of mechanical system was studied, [39]. Under the assumption of a stepwise function for the envelope signal, the modulated signal could be decomposed into a sinusoidal function basis at the first vibration mode resonance frequency. According to the experimental study, the envelope detection method for the first vibration mode resonance frequency could be effectively applied in the signal processing for the bearing defect diagnosis.

A mathematical model for the ball bearing vibrations due to defect on the bearing race has been developed, [40]. It is found that, the amplitude level of vibrations for the case of outer race defect is more than that for the inner race defect and the ball defect. The defect present on the inner race moves in and out of the load zone during each revolution of the shaft. In this instance, the strong fault signatures produced while the defect is in the load zone are averaged with the weaker signatures acquired while the defect is outside the load zone. The theoretical model was aimed to study the effect of defect size, load and speed on the bearing vibration and predict the spectral components.

Finite element model can be effectively used to differentiate between vibration signatures for defects of different sizes in the bearing, [41]. Assumptions have been made for the variation of forces exerted by the rolling element on the outer ring in the vicinity of the defect. Experiment result has been taken for the analysis of the signal that has been obtained through the use of FFT analyzer. The vibration signal response of the defected bearing is analyzed and compared with the normal bearing. The vibration signal pattern obtained from the simulation was found to have similar characteristics with experimental data.

A dynamic loading model simulates the distribution load in the outer race due to transfer load from the ball. Time domain analysis is performed to evaluate the output result of vibration analysis from the finite element software. RMS and peak to peak value is used as the time signal descriptors and can be used as a parameter for condition monitoring purposes. The vibration response of healthy and defected bearing is compared. The simulated vibration pattern has similar characteristics with results from experimental results, [42]. The effect of shaft rotational speed and radial load is investigated. The finite element model of a bearing and housing structure has been developed. Then the model is analyzed to obtain the vibration signal in the frequency domain, [43].

An analytical model is proposed to study the nonlinear dynamic behavior of rolling element bearing systems including surface defects, [44]. Various surface defects due to local imperfections on raceways and rolling elements are introduced to the proposed model. Mathematical expressions were derived for inner race, outer race and rolling element local defects. The validity of the proposed model verified by comparison of frequency components of the system response with those obtained from experiments.

The vibrations generated by deep groove ball bearings having multiple defects on races was studied, [45]. The vibrations are analyzed in both time and frequency domains. The equations for time delay between two or more successive impulses have been derived and validated with simulated and experimental results. The relationships between amplitudes of frequencies for impulse train, delayed impulse train and combination of two impulse trains have been established. Frequency spectra for single and two defects on either race of deep groove ball bearings are compared.

Wavelet transform provides a variable resolution time-frequency distribution from which periodic structural ringing due to repetitive force impulses, generated upon the passing of each rolling element over the defect, were detected, [46]. A basic wavelet considered optimal for bearing localized defect detection is constructed. Finally, the scheme is described and its effectiveness is evaluated using actual vibration signals measured from bearings with defects at different locations and operating under different conditions.

The discrete wavelet transform can be used as an effective tool for detecting single and multiple faults in the ball bearings, [47]. Furthermore, discrete wavelet transform has been proposed for measuring outer race defect width of taper roller bearing. Experiments were carried out on a customized test setup, [48]. Vibration signals from ball bearings having single and multiple point defects on inner race, outer race, ball fault and combination of these faults have been considered for analysis, [49]. Wavelet transform provides a variable resolution time–frequency distribution from which periodic structural ringing due to repetitive force impulses, generated upon the passing of each rolling element over the defect, are detected. The decomposed signal evidently splits the peak corresponding to the ball entry into and exit from the fault, enabling in an estimation of the defect size present in the bearing, [50]. Experiments conducted for different sizes of the defect present on the outer race of deep groove ball bearing affirm the efficacy of the applied technique for different vibration signals. The output of the proposed technique finds close correlation with the actual defect size measured from optical microscope

Wavelet Packet Analysis is a much better option than discrete wavelet transform. The method is designed in such a way that it can exploit the underlying physical concepts of the modulation mechanism, [51]. In Wavelet Packet Analysis, both the details and the approximation are decomposed into lower level, resulting in a wavelet packet decomposition tree. The experimental results indicate that, the wavelet packet analysis is a very reliable time-frequency domain approach capable of capturing high frequency transients in bearing signals, [52]. Wavelet Packet Analysis is used as a powerful diagnostic method for the detection of initial bearing failures via stator current analysis, [53]. The presented method is evaluated using experimental signals. Sets of data are gathered before and after using defective bearings. Compared to conventional methods, the superiority of the proposed method is shown in the success of fault detection.

Continuous wavelet transform is implemented to generate the scalogram. The generated scalogram is used to identify and measure the seeded defects in bearing and gears, [54]. The designed adaptive wavelet is used to compute the Continuous wavelet transform coefficients. The Continuous wavelet transform coefficients so generated are compared with the standard wavelet based scalogram. The adaptive wavelet transform is shown to be apposite in analyzing the vibration signals and also is corroborated with the acquired experimental data. The scalogram generated from Continuous wavelet transform is used to measure the time duration that the roller takes to roll over the defect. The vertical strips drawn on the ridge spectrum corroborates well with defect width. It found that, the proposed method can be reckoned suitable and reliable in measuring bearing defect width in real-time from vibration signal, [55].

1.1.1 Acoustic Measurements

Acoustic emission is the phenomenon of transient elastic wave generation due to a rapid release of strain energy caused by a structural alteration in a solid material under mechanical or thermal stresses, [56]. Generation and propagation of cracks, growth of twins, etc. associated with plastic deformation are among the primary sources of Acoustic emission. Hence, it is an important tool for condition monitoring through non-destructive testing.

Acoustic emission instrumentation consists of a transducer, mostly of the piezoelectric type, a preamplifier and a signal processing unit. The transducers, which have very high natural frequency, have a resonant type response. The bandwidth of the Acoustic emission signal can also be controlled by using a suitable filter in the preamplifier. The advantage of acoustic emission monitoring over vibration monitoring is that the former can detect the growth of subsurface cracks, whereas the latter can detect defects only when they appear on the surface.

A bearing condition monitoring technique based on processing the acoustic emissions of the monitored bearing was investigated, [57]. A bearing was mounted on a mechanical platform which allowed the adjustment of the following three parameters; the thrust load, the angular misalignment, and the position of the center of the bearing. Based on the experimental data of seeded bearing defects, acoustic emissions is found to be a better signal than vibrations when the transducers have to be remotely placed from the bearing.

Defects were simulated in the roller and inner race of the bearings by the spark erosion method. Acoustic emission of bearings without defect and with defects of different sizes has been measured, [58]. For small defect sizes, ring down counts of acoustic emission signal has been found to be a very good parameter for the detection of defects both in the inner race and roller of the bearings tested. However, the counts stopped increasing after a certain defect size. Distributions of events by ring down counts and peak amplitudes are also found to be good indicators of bearing defect detection. With a defect on a bearing element, the distributions of events tend to be over a wider range of peak amplitudes and counts.

Comparisons between acoustic emission and vibration analysis over a range of speed and load conditions were presented, [59]. An experimental test rig was designed such that defects of varying sizes could be seeded onto the outer race of a test bearing. The primary source of acoustic emission activity from seeded defects is investigated, in addition to determining the relationship between defect sizes. The second test program aimed to establish a correlation between acoustic emission activities with increasing defect size. It is concluded that, the acoustic emission offers earlier fault detection and improved identification capabilities than vibration analysis. Furthermore, the acoustic emission technique also provided an indication of the defect size, allowing the user to monitor the rate of degradation on the bearing.

The acoustic emission acquisition system consisted of a piezoelectric type sensor fitted onto the top half of the bearing housing. An increase in defect size resulted in an increase in levels of acoustic emission energy for outer and inner race seeded defects. A correlation between the geometric size of outer race defects and the acoustic emission bursts associated with such defects has been shown, [60]. It is concluded that, the geometric defect size of outer race defects can be determined from the acoustic emission waveform.

The effectiveness of acoustic emission technology in detecting and monitoring the initiation and propagation of cracks was investigated, [61]. To undertake this task a special purpose test rig was built that allowed for accelerated natural degradation of a bearing race. The results of classical Fast Fourier Transformer of measured acoustic emission data are compared with three non-linear power spectral estimation methods. It is concluded that sub-surface initiation and subsequent crack propagation can be detected using a range of data analysis techniques on acoustic emission’s generated from natural degrading bearings.

Cyclostationarity is a relatively new technique that offers diagnostic advantages for analysis of vibrations from defective bearings. Similarly the Acoustic Emission technology has emerged as a viable tool for preventive maintenance of rotating machines. The cyclic spectral correlation, a tool dedicated to evidence the presence of Cyclostationarity, was compared with a traditional technique, the envelope spectrum. The comparison showed that, the cyclic spectral correlation was most efficient for small defect identification on outer race defects though the success was not mirrored on inner race defects. It is concluded that, its offers better sensitivity to the continuous monitoring of defects compared to the use of traditional temporal indicators, [62].

A new method is able to identify localized defects in an incipient stage, in which the signal-to-noise ratio (SNR) is extremely low. This method combines Wavelet packet, for acoustic emission signal, the Hilbert Transform (HT) for envelope extraction and autocorrelation function, to find patterns in the acoustic emission signal. An extensive experimental investigation was carried out in order to evaluate the performance of the proposed method under extremely low SNR, adding high level of noise to the signals. The results indicate that the proposed enhanced envelope method is able to detect incipient defects with 9 dB lower SNR than traditional envelope analysis, [63].

3. Acoustic Measurements

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4. Temperature Measurements

The operating temperature plays a key role in the overall performance of a bearing system. Affected by the bearing temperature are many critical parameters, such as the lubricant viscosity, load-carrying capacity, load distribution and power loss. In contrast to the thermal analysis of journal bearings were investigated. The influence of groove location and supply pressure on the performance of a steadily loaded journal bearing with a single axial groove was studied, [51]. Hydrodynamic pressure and temperature distributions on the bush surface, shaft temperature, flow rate, and bush torque were measured at variable supply pressure, using bushes with a single groove located at three different positions.

A new simple model was established for analyzing the thermally induced seizure of fully lubricated eccentric circumferential groove journal bearings, [52]. The model was consisted of eccentric operation, introduction of hydrodynamic lubricant flow rate component, and evaluation of friction power losses. The decrease of viscosity, as a consequence of temperature increase, does not always limit clearance loss, and the seizure process ends with a concentric journal bushing merged system. As a result, bearing designers and users should check whether if several safe operation criteria were met. A three-dimensional computational thermal contact model was developed. The frictional heat generated at the contact interface is instantaneously partitioned between the bushing and the shaft. Two methods to couple the heat and temperature at the contact interface were presented, [53]. Application of the model to the heat transfer analysis of journal bearing systems experiencing oscillatory motion was presented. Non-uniformly distributed frictional heat along the axial direction was considered. The model was capable of predicting the transient temperature field for journal bearings. It can also be used to determine the maximum contact temperature, which is difficult to be measured experimentally. Applying the basic laws of heat transfer to rolling bearing assembly and using the lumped-mass assumption, the steady- state temperature of the bearing components was estimated. The model improved by solving a set of governing equations for the heat transfer in a complete assembly of a tapered roller bearing including the housing, [54]. The model was able to estimate the temperature of the bearing elements during the transient as well as the steady-state condition.

The thermal contact resistance between the ball and the inner and the outer rings of a space use deep groove ball bearing was investigated assuming that heat transfer between smooth contacting elements occurs through the elastic contact areas, [55]. The stationary bearing sustains axial, radial, or combined loads under a steady state temperature condition was assumed. The shapes and sizes of the contact areas were calculated using the Hertzian theory. In particular, the contact force for the axial load was determined with careful consideration of the change in the contact angle induced by elastic deformation at the contact area. The correlation between the experimental data and the calculated values confirms the validity of the prediction method for the thermal contact resistance between the elements of a dry bearing with a surface roughness under the mean temperature.

A new vacuum test rig designed to measure bearing conductance under simulated operational conditions, [56]. Experimental variables include control of the bearing rotational speed, applied axial load, and average bearing temperature and temperature gradient via an applied heat source/heat sink mechanism. The experimental variables data was allowed parametric studies to be conducted under controlled thermal and mechanical conditions, permitting the exploration of the influences of the operational variables on bearing thermal conductance.

An analytical method to calculate the heat generation rate of supporting bearing in a kind of ball screw system was studied, [57]. The operating conditions, rotation speed and external loads, were taken into account for calculating heat generated by the bearings. The determination of bearing element torques was mainly focused on both of the friction torque due to applied load and the sliding torque at the contact area. Compared to the experiment results, the introduced method shows its validity with accuracy calculation. The evolution of temperature with time in a deep groove ball bearing in an oil bath lubrication system was studied. The model was proposed and simulations were carried out to investigate the thermal behavior of ball bearings, [58]. The proposed model was used to predict the evolution of the transient temperatures in the bearing components. Experiments were performed for different speeds and loads to validate the model. The predicted temperatures under different loads and speeds were found to be in close agreement with those measured experimentally.

5. Wear Debris Analysis

In the wear debris analysis, the presence of metallic particles in the lubricant is detecting using sensitive sensors. Moreover, the spectrographic analysis of the different metallic elements in the lubricant can facilitate the location of the fault [59]. The wear process of a given machine is usually the result of several different, simultaneous wear mechanisms, each of which has its own way of affecting to the machine’s operating environment and the changes that occur in it. If unfavorable operating conditions persist, the wear and the dynamic forces might either cause parts of the machine to break or disturb the machine’s operation. To allow detection at a sufficiently early stage and control of the wear process, the amount, size, and appearance of wear debris particles in the machine’s lubricating oil must be monitored [60].

6. Conclusions

In this paper, an attempt to summarize the recent research and developments in the detection techniques for diagnosis and monitor the health of rolling element bearing faults has been made. Study of such attribute defects gained importance due to increased awareness of cost of quality. From the previous study, four different methods for detection and diagnosis of bearing defects namely: vibration measurements, acoustic measurements, temperature measurements and wear debris analysis have been identified. This study found that the vibration monitoring is the most useful technique because it is reliable and very sensitive to fault severity. Also, it gives clear indications regarding the condition of the bearing in question; in addition the level of vibrations and the frequency at which these vibrations occur can serve in determining the exact location of the defect and possibly severity of such defect. It can be concluded that the vibration analysis is most commonly accepted technique due to its ease of application.

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