Study of Influence of Grease Contaminants in Vibration Response of Ball Bearings

K.A. Kumawat[1], S.H. Sarje[2]
[1, 2] Department of Mechanical Engineering
[1, 2] JSPM's, ICOER Wagholi, Pune.

Abstract- *Lubricant contamination is one of the major reasons for early bearing failure. The effect of lubricant contamination by solid particles on dynamic behavior of rolling bearings by using Vibration analysis method is discussed in this work. Three different materials, as iron Powder, Aluminum powder, and dust are used to contaminate the lubricant. The tests are conducted at different speed and load and change in the amount of vibration affected by grease contamination are determined. Vibration signatures are analyzed with respect to RMS values of amplitude in terms of acceleration and acceleration values at defect frequencies. A considerable variation in overall RMS acceleration and on acceleration value at all defect frequencies on changing contaminant material, size, concentration and running parameters is observed.*

I. INTRODUCTION

Bearings are in a central position in the monitoring of the condition of rotating machinery. The goal in the development of vibration measurement methods for rolling bearings has usually been to develop techniques for detection of bearing faults in their earliest stage. The vibrations are measured at point where bearing is supported. The vibration amplitude are directly related to the machine condition.

The different methods available for bearing condition monitoring are, vibration analysis method, acoustic emission method, shock pulse method, etc. Out of the above stated methods, Sir Juha mittain[1] applied the AE method for the study of effect of lubricant contamination. The effect of different contaminants on vibration characteristics is studied by Mr. Tandon[2] and also by Mr. Hariharan[7]. According to Juha Mittain[1], the AE method is most suitable method for such study but is costlier hence the next method of vibration analysis is suggested.

For measuring the vibration amount, the accelerometer is used which is highly efficient in measuring acceleration parameter of vibration which is selected for analysis in the current study. The different contaminant materials have generate different effect on amplitude of vibration, hence in the current experimental work three different materials iron powder, aluminium powder and dust are used as contaminant with different particle sizes, and with different concentration levels. Acceleration is considered as the parameter for analysis of vibration amplitude.

II. PROBLEM STATEMENT

Particles are the most harmful form of lubricant contamination. A sample of lubricant may appear to be immaculate but actually contain many microscopic particles. Dirt, dust, sand, metal shards, metal oxide particles, soot, fibers, lint, coal dust, and other miscellaneous debris can contaminate lubricants. There are many types of contaminants. These include hard particles (silica), bauxite, wear debris (surface fatigue, cutting wear, flakes), soft particles (fibers, polymers, cellulose), water and corrosive chemicals, which can be ingested or generated within the machine.

There are many potential sources of these microscopic particles:-During production of the lubricant, raw materials and manufacturing equipment can Introduce particles. New or used machinery and reservoirs may contain dirt, metal fines, casting sand, bits of solder, and fibers from rags, paint chips, chemical residues, sludge, and water.Particles can enter through apertures, leaks, worn seals, and vents in machinery. Fatigue and wear of aged or imperfectly balanced parts can generate wear particles. Contamination can occur when components are replaced or equipment is serviced.

III. LITERATURE REVIEW

Generally bearings do not reach their calculated life time and they fail during service. Fifty percent bearings fail due to the lubrication problem. Mainly the lubrication fails due to contamination. The study of bearing failures is carried out by many authors.

Zhenyu Yang and Uffe C. Merrild[1] stated that, bearing faults could happen with the raceways, ball or rolling-element and the cage as well, such as a scratch on the surface of the raceway(s). The bearing faults can be caused due to improper installations of the bearing onto the shaft or into the housing, misalignment of the bearing, contamination, corrosion, improper lubrication, brinelling or simply due to wear-out. The experimental results show the powerful capability of vibration analysis in the bearing point-defect fault diagnosis under stationary operation. Bearing faults can be classified into two general categories: single-point defects and generalized roughness. A single-point defect is defined as a single, localized defect on a bearing component surface. Generalized roughness corresponds to the situation where the condition of a bearing surface has degraded considerably over a large area, and become rough, irregular, or deformed.

Extensive research work can be found focusing on the FDD (Fault Detection and Diagnosis) of the single-point defect, due to the fact that a single defect will produce one of the four characteristic fault frequencies depending on which bearing component contains the fault. The most popular way to detect these characteristic frequencies is to use the vibration measurement of the motor shaft plus advanced signal processing techniques. The Fast Fourier Transform (FFT) is the natural choice to retrieve frequency features from measured stationary time-domain data. Theoretically, the single-point fault characteristic frequencies can be predicted based on the shaft speed and the bearing geometry. By comparing the spectra generated based on a nominal operation and a fault-suspected operation around these characteristic frequencies, if some obvious difference can be observed, the corresponding fault scenario will be claimed.

Sir Juha Miettinen[2] gives the classification and distribution of the reasons for which rolling element bearings did not reach their calculated lifetime. Fifty per cent consists of lubrication problems: poor lubrication and contamination. The acoustic emission signal measured from a grease lubricated rolling bearing during its running indicates risks in the lubrication of the bearing. By reducing the level of the acoustic emission the risk of premature failure of the bearing can be reduced. The influence of the fundamental grease parameters and the running parameters of the bearing have been verified and an empirical model for predicting the AE pulse count rate for a deep groove ball bearing lubricated with clean grease has been formulated. Though he has used the AE method for his work, he also has given very great explanation of Vibration analysis method, as it is the most commonly used technique for condition monitoring. The idea current study which I have done is taken from same literature. As the author is used AE method and has suggested the Vibration Analysis Method as a second suitable method for condition monitoring, it is decided to follow the same.

N Tandon [3] in his research paper stated different condition monitoring techniques to detect the defect in rolling bearing. The vibration and stator current signal measurements performed on the bearing of an induction motor are successful in detecting simulated defects in the outer race of the bearing. Current harmonics for bearing outer race defect characteristic vibration frequency has shown significant increase in the current spectrum components for maximum size of defect. The AE and SPM measurement performed are very good in detecting the bearing defect. On comparing the results of good and defective bearing, it is observed that AE peak amplitude and shock pulse maximum normalized value level increase much more than other techniques as defect size increases.

N. Tandon and et. al. [4] have been studied the grease used in the ball bearings of electric motors. According to him, the lubricating grease often gets contaminated either from external particles or particles generated within these bearings. The effectiveness of vibration, stator current, acoustic emission and shock pulse measurements in detecting the presence of contaminant particles in bearing grease has been investigated. Silica and ferric oxide particles were used to contaminate grease. The levels of vibration, stator current, acoustic emission and shock pulse appreciably increased as contaminant level and contaminant size increased. Acoustic emission peak amplitude proved to be the best condition monitoring technique for the detection of grease contaminants in motor bearings. It is followed by shock pulse maximum value and carpet value in terms of effectiveness. Vibration velocity, stator current, acoustic emission peak amplitude and SPM, dBM and dBC values of bearings were measured at different loads. The values for different levels of silica contaminants and for ferric oxide contaminants of different particle size are given in. It is observed that there is not much change in the parameters measured with increase in load. So, the plots for 15 kg load only are given in his report.

According to the results obtained by M. Kotb Ali, M. F. H. Youssef [5], the vibration amplitude affected by changing both load and/or speed, therefore, it is important to fix the measuring positions as well as speed and load as much as possible to implement a good maintenance vibration monitoring program.

Pavle Boˇskoski [7] has stated in his study that, precise selection of frequency band where the changes in vibration signatures are the most expressed. Consequently, the problem of improper lubricant detection through vibration analysis requires proper model that describes the elasto-hydrodynamic lubrication (EHL) influence on vibrations and systematic procedure for selecting the correct frequency band in which the demodulation resonance analysis can be performed. The results rise the question of the possibility of using vibration analysis for detecting more subtle lubricant changes, like contamination or aging process. As the lubricant characteristics change as a consequence of aging or external contamination its damping characteristics change. These changes at some point will become significant so their influence can be detected by observing the produced vibration signals. Thus, one may be able to effectively estimate the lubricant quality just by observing the produced vibration signals.

Mr. M.M.Maru [9] explains in his work, the effect of contaminant concentration on vibration is distinct from that of the particle size. The vibration level increased with concentration level, tending to stabilize in a limit. On the other hand, as the particle size increased, the vibration level first increased and then decreased. Particle settling effect was the probable factor for vibration level decrease. Vibration levels increased along the test in contaminated oil even with only 16 min of test. Such an increase in vibration is related to an effect produced by the wear of bearing elements. The bearing parts were severely damaged by a peeling-like mechanism, distributed along all the surfaces. Abrasion was also identified through ferrography. This was indicative of severe wear regime, although measurements of internal radial clearance of the bearings have indicated absence of dimensional wear. The vibration amount due to the bearing wear was dependent on the contamination feature. An apparent correlation between the trends of the worn bearing vibration and those of its overall surface damage was observed. The vibration due to the presence of particles was proportional to the vibration of the worn bearing as particle concentration increases. On the other hand, when the contaminant particle size increased, the dynamical action of the particles passing through the contact interface

V Hariharan and P S S Srinivasan [12] worked on ball bearings and he tested the bearings in order to study the effect of solid contamination. The method of vibration analysis was effective in characterizing the trends in vibration due to solid contaminant in lubrication. The tests were conducted for defective and good bearings. Silica particles were considered as grease contaminants. Experimental tests have been performed on the ball bearings lubricated with grease, and the trends in the amount of vibration affected by the contamination of the grease were determined. The contaminant concentration as well as the particle size is varied. Vibration signatures were analyzed in terms of root mean square (RMS) values. From the results, some fruitful conclusions are made about the bearing performance. The effects of contaminant and the bearing vibration are studied for both good and defective bearings. The results show significant variation in the RMS velocity values on varying the contaminant concentration and particle size.

The vibration level increased with the concentration level, tending to stabilize at a certain limit. With an increase in the particles size, the vibration level initially increases and then decreases. This decrease in vibration amplitude is due to more internal resistance of the bearing, due to not only the large particles but also the concentrations.

From the literature it is clear that, for the condition monitoring of bearing lubricated with contaminated grease the velocity parameter of vibration is applied hence here the acceleration parameter of vibration can be utilized. Also the different materials are used with different particle sizes and different concentration levels.

IV. METHODOLOGY

A. Test Bearing Preparation:

Bearing selected for test is a deep groove ball bearing with specification number 6206-2RS. 2RS indicates rubber seal on both sides. The test bearings are prepared by removing the existing grease from standard bearings and adding the grease which contains the contaminants with varying size and concentration. Total 27 test bearings are which contain the contaminant and one bearing with clean grease are tested for under current experimental work. The contaminants added are in three different sizes as 53μm, 75μm and 106μm and with different concentration levels as 5%, 15% and 25%. The bearings are numbered as B1 to B28 as below.

Table.1 Bearing sample numbers with specifications

Sr. No.	Material	Size	Concentration	Bearing Sample No.
1	Nil	Nil	Nil	B1
2	Iron-	53μm	5%	B2
3	Iron-	53μm	15%	B3
4	Iron-	53μm	25%	B4
5	Iron-	75μm	5%	B5
6	Iron-	75μm	15%	B6
7	Iron-	75μm	25%	B7
8	Iron-	106μ	5%	B8
9	Iron-	106μ	15%	B9
10	Iron-	106μ	25%	B10

B. Defect Frequencies :

The data obtained during experiment is analyzed at the defect frequencies of bearing. The frequency equations required for calculation of same are given below along with calculated defect frequencies for given bearing with given speeds.

Table.2 Frequency equations required

Ball-pass frequency for inner race (Fi)	$\frac{n}{2}Fr[1+(BD/PD)\cos\beta]$
Ball-rotational Frequency (Fb)	$\frac{PD}{BD}Fr\left[1-\left(\frac{BD}{PD}\right)^2(\cos^2\beta)\right]$
Ball-pass frequency for outer race (Fo)	$\frac{n}{2}Fr[1-(BD/PD)\cos\beta]$
Fundamental train frequency (Ft)	$\frac{1}{2}Fr[1-(BD/PD)\cos\beta]$

Where,

n:-No. of balls, Fr:-Shaft Rotation Frequency, BD:-Ball Diameter, β -Contact angle, PD:-Pitch Diameter

Table.3 Fault frequencies at various speeds

Sr. No.	(N) RPM	(Fr) Hz	(Fi) Hz	(Fo) Hz	(Fb) Hz
1	1080	18	97.90	64.09	82.49
2	1820	30.33	164.96	108	139
3	2960	4.66	270	176.83	227.59

C. Experimental Work

A. Test Rig:

The experiment is carried out on the test rig as shown in figure4.3. The setup is designed in order to get the nine speed variations, to have ease of applying the loading arrangement and to have the negligible setup vibrations.

Figure : Actual experimental setup

For getting the vibration signatures the 4-channel FFT Analyzer is used. The accelerometer is used to sense the vibrations generated at the bearing surface. The accelerometer is a transducer used to sense the vibrations.

B. Selection of Running Parameters:

Every sample bearing prepared is tested under different running parameters. The two main parameters are varied and combined to have different running conditions. The two parameters are Speed and Load. Three different speeds are selected for carrying out the test combined with three different loads. The three different speeds selected are 1080RPM, 1820RPM and 2960RPM, and three different loads selected are 10Kg, 20Kg, and 30Kg. Total nine combinations are obtained by varying speed and load, for carrying out the test on every single sample bearing.

C. Actual Test and Data Collection

Every test followed a sequence of three steps. In the first step, the bearing is running in healthy grease in order to stabilize the grease temperature. In the second step, the test is continued in healthy grease to collect the vibration data at different speeds and at different loads. In the third step, the contaminated grease is applied to the bearing. A separate bearing is used for each concentration level of the test. Vibration signals with contaminated grease are acquired from the bearing housing at different speeds. The above procedure is repeated for all concentration levels. Data is recorded and analyzed with respect to peak values and the root mean square (RMS) values, related to specific defect frequencies

V. RESULT AND DISCUSSION

By using the data obtained graphs are plotted and the detailed discussion is made as below

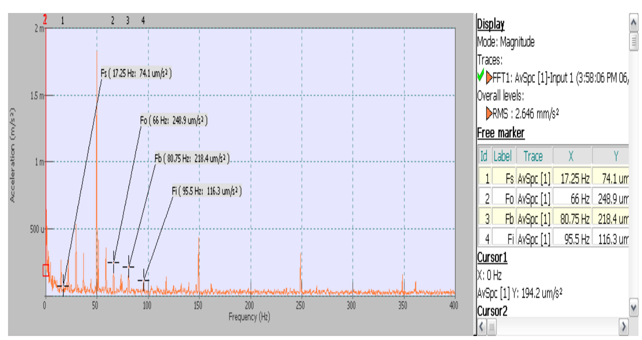

Fig. Acceleration-Frequency plot for bearing sample B1 running at 1080RPM

The Fig. 5.1 is obtained from the bearing lubricated with clean grease running at a speed of 1080RPM under the load of 10Kg.

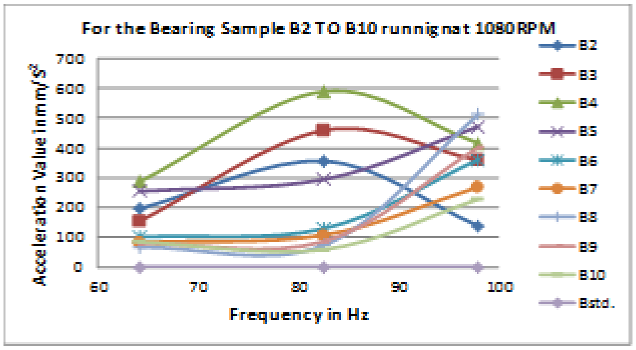

Fig. Acceleration Vs. Frequency, at speed 1080RPM, for bearing sample B2 to B10.

The Fig indicates the effect of Iron-Powder as a contaminant with different sizes and different concentration levels with 1080RPM running speed and 10Kg load. The Fig. clearly indicates that at these running parameters contaminants affect more on the balls followed by inner-race. For the particle size 53µm, as the concentration level increased, the acceleration value goes on increasing for all the defect frequencies. Also it indicates that the effect of contaminant at lower particle size is more on Ball. Followed by inner-race and then on outer-race. It also describes that for higher particle size, at lower speed the effect is more on inner-race and least on outer-race. This is happening because at lower speed particles remain at inner-race portion because of their weight and cannot move towards the outer-race. Because of same they are affecting more on inner-race and very less on outer-race.

The Fig. is also about the effect of Iron-Powder as a contaminant with different sizes and with different concentration levels at 1820 RPM and 10Kg load. The graph indicates that as the speed is increased the contaminant has a considerable effect on outer-race as compare to inner-race. The effect of contaminant on inner-race and ball is quite similar. The same effect and same pattern of graph is observed at all particle sizes and at all concentration levels at these running conditions.

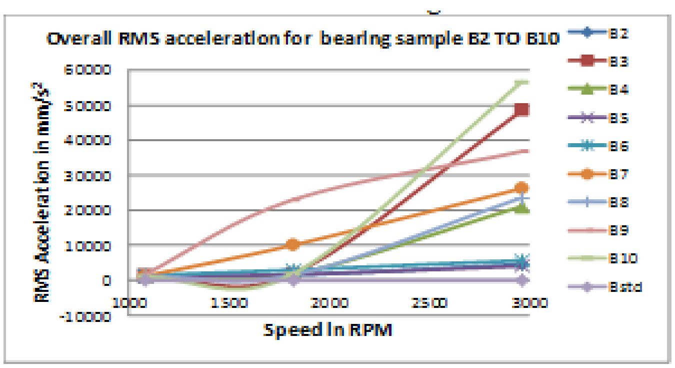

Fig. Running Speed Vs. Overall RMS Acceleration, for bearing sample B2 to B10

This Fig is more indicative of the effect of contaminant on the bearing and its rolling elements. The fig. clearly indicates that, for any sample bearing as the running speed increased the RMS acceleration value also goes on increasing. It means that, every contaminant affect more at higher speeds and the effect is less as the speed is lowered. Also the conclusion can be drawn as, for same particle size as the contaminant concentration is increased, at higher speeds the RMS acceleration value goes on increasing whereas at lower speed as the concentration is increased the RMS value first increases and then decreases. This may be happening because at lower speed the particles may escape from the rolling elements.

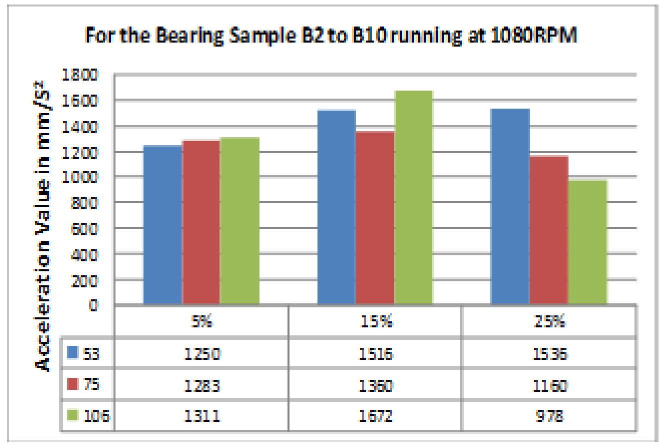

Fig. Overall RMS Acceleration Vs. Contaminant Concentration for bearing sample B2 to B10, at 1080RPM

The effect on RMS acceleration can also be indicated by above figure. The Fig. 5.15 shows the effect of concentration variation along with particle size on RMS acceleration value at speed, 1080

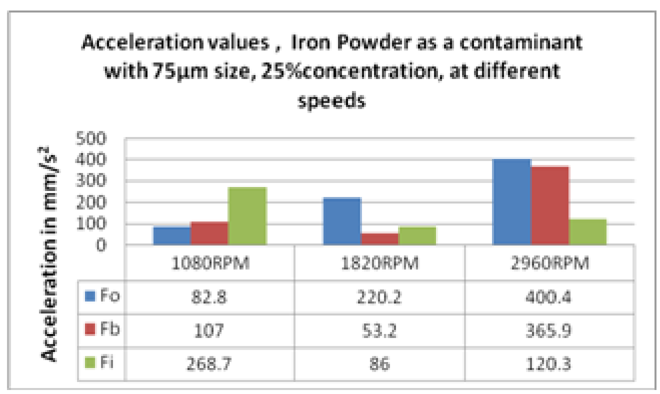

Fig. Acceleration Vs. Running Speed for Sample bearing

B5 the inner-race is more affected by contaminant at lower speed than the outer-race whereas at higher speeds the effect is more on outer-race as compare to inner-race

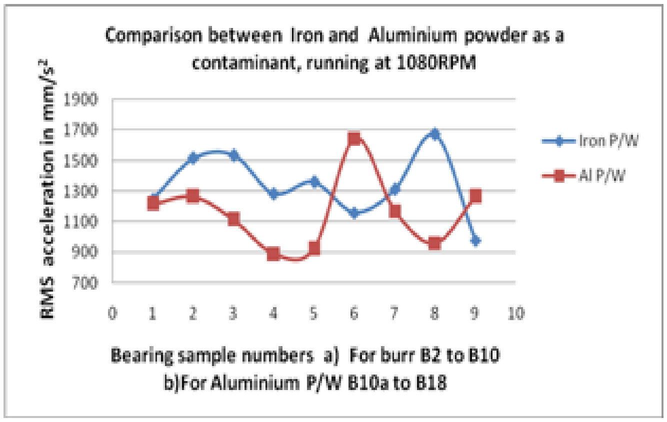

Fig. Comparison of Iron-Powder and Aluminium as a contaminant at speed 1080RPM

VI. CONCLUSION

The effect of contaminant concentration on vibration is different from that of particle size. The vibration level increased with the concentration level, starts stabilizing at a certain limit. With an increase in the particles size, the vibration level initially increases and then decreases. This decrease in vibration amplitude is due to more internal resistance of the bearing, due to not only the large particles but also the concentrations. It is observed that, as the material of contaminant is varied, there is variation in the vibration level. For the material Iron-Powder, the maximum effect is observed followed by Aluminium-Powder and dust. This effect is because of material properties like hardness, brittleness and malleability. But the pattern observed by changing the particle size and concentration is same for all materials.

For every material with all sizes and all concentration levels, the greater effect is observed on RMS acceleration value at 2960RPM followed by 1820RPM and 1080RPM. At lower speed the more effect is on inner-race where as, at the higher speeds the effect is dominant on outer-race. There is no much difference in vibration signatures because of variation in load on bearing.

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