EFFECT OF THE PRESENCE OF SOLID CONTAMINATION AND THE RESULTING WEAR ON THE MECHANICAL SIGNATURE OF BALL BEARINGS

Marcia Marie Maru
Departamento de Engenharia Mecânica da Escola Politécnica da Universidade de São Paulo, Av. Prof. Mello Moraes 2231 CEP 05508-900 - SP
mmmaru@usp.br

Ricardo Serrato Castillo
Departamento de Engenharia Mecânica da Escola Politécnica da Universidade de São Paulo, Av. Prof. Mello Moraes 2231 CEP 05508-900 - SP
ricardo.castillo@poli.usp.br

Linilson Rodrigues Padovese
Departamento de Engenharia Mecânica da Escola Politécnica da Universidade de São Paulo, Av. Prof. Mello Moraes 2231 CEP 05508-900 - SP
lrpadove@usp.br

Abstract. *The work aims to present results from experimental studies on the detection of contamination by solid particulate in the lubricant oil of rolling bearings, through vibration signature analyses. Comparisons between data from clean and contaminated oil tests are presented. The experimental tests were performed with pure mineral, ISO 32 viscosity oil. The oils were contaminated with quartz particulate in several concentration levels, ranging from 0.04 to 0.7 g/l. All the vibration data were acquired from an accelerometer and the signal processing was performed through power spectrum density and RMS value calculations. The results show possibility of identifying the presence of contamination from some specific frequency bands of the vibration signal. Re-testing the rolling bearings with clean oil revealed that some frequency bands are excited due to wear in the contacting elements.*

Keywords*: contamination, vibration, ball bearing, wear*

1. Introduction

Investigation on the performance of rolling bearings is very important because these elements often represent the most critical components of rotating machinery. Vibration measurement is one of the most widespread ways to monitor the performance of rotating machinery. When a radial load is applied to a bearing, the number of rolling elements carrying the load varies during operation; this generates a displacement in the direction of the load and, then, vibration occurs (SKF, 2005). When operating in contaminated conditions, particles of dirt may enter the bearing; the generated vibration level being dependent on the amount, the size and the composition of the entering contaminant particles. Some manufacturers state that in this case, no typical frequency pattern is generated, although an audible and disturbing noise may be created (SKF, 2005). Solid contamination is an important question related to the monitoring of rolling bearing performance because of its action on fatigue failure acceleration resulting from surface denting (Snyder *et al*., 1995, Ai and Nixon, 2000, Kuhnell, 2005).

Despite several works in the literature on vibration monitoring of bearings, there is no common sense concerning which information in vibration data is related to contamination. For instance, one states that lubrication related phenomena excite frequencies higher than 50 kHz (Miettinen and Andersson, 2000), others indicate the possibility of detecting lubricant contamination in lower bands, up to 10 kHz (Komiya, 1992, Johnson, 2005, Lian-Chun, Jia-ju and Zhi-ren, 2003). Another one mentions an intermediate range for vibration due to inadequate lubrication, from 900 to 1600 Hz (Berry, 1991).

The present work aims to identify how the vibration response of ball bearings is affected when operating under contaminated oil. For vibration analysis, basic procedures were applied based on previous work (Maru, Castillo and Padovese, 2005). The vibration from tests with clean oil, contaminated oil and worn bearings were compared concerning the respective frequency spectra.

2. Experimental procedure

A laboratory rig was set up for the vibration tests; the testing bearing was positioned in the rig as seen schematically in Fig.1. The bearing was oil bath lubricated. An oil mixing system (not shown in Fig.1) was applied for dispersing the particles within the oil. The procedure for electronic instrumentation and assembling is described elsewhere (Maru, Castillo and Padovese, 2005).

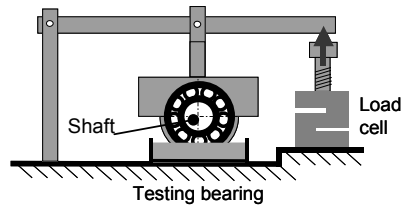

Figure 1. Laboratory rig used for the tests.

In the tests, the sampling rate of the vibration signal was set to 20 kHz; 100,000 data were collected at each acquisition. The data were stored in a PC and analyzed through the Matlab software, in both time and frequency domain, with respect to the values of rms (root mean square) related to specific frequency bands. These were calculated as $((1/100{,}000)*\Sigma(x_i^2))^{1/2}$, where x_i are the vibration data in the respective frequency band. The power density spectrum (PSD) of the acceleration signal, estimated through the Welch method (Proakis and Manolakis, 1996), was also studied.

The testing ball bearings were 6205 type (9 balls, 8 mm diameter). The contaminant was quartz of two average sizes, 59 μm (T2) and 111 μm (T3), obtained through screening method. Several contamination concentrations were used, from 0.04 to 0.7 g/l. The oil was mineral without additives, of 100 viscosity index and 32 cSt viscosity at 40 ºC.

The testing conditions for the vibration acquisition were: applied load of 1300 N (corresponding to approximately 10% of bearing dynamic capacity and 2.3 GPa hertzian pressure) and shaft speed of 42 Hz. After setting the load and the speed, the powder contaminant was poured into the oil bath, taking 2 min to disperse the particles in the oil. Vibration was then measured. Two methods of oil contamination were used in the study: in one set of tests, known quantities of contaminant material were sequentially increased in the oil, another set was run with fixed particle content. In the last method, a running step of 2 h was performed with clean oil before pouring the contaminant, so as to stabilize the oil bath temperature; which was typically at 40 ºC after 2 h. In this period, the changes in vibration were minimal and the oil preserved transparency. After 2 h running, the test was stopped and the powder contaminant poured into the oil bath, taking 2 min to disperse the particles in the oil.

3. Results

Figure 2 shows the frequency spectra (PSD) related to the vibration signals acquired in a test under clean and contaminated oil. Both spectra are very similar: visible magnitudes are in the lower frequency band range (0-600 Hz).

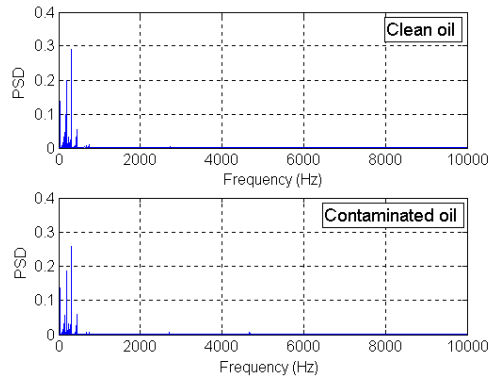

Figure 2. PSD from a test run with clean oil (up) and 0.04 g/l contaminated oil (down).

For better analysis, the spectra were separated in two bands, low (LF, 0-600 Hz) and high (HF, 600-10000 Hz). Figure 3 shows the results obtained from a test where the contaminant content was sequentially increased from 0.04 to 0.71 g/l. Comparing both set of spectra, it can be noticed that the vibration frequencies affected by oil contamination are mainly in HF. In this band, there are specific vibration frequency bands, whose magnitudes increase with the contaminant content. It is likely that they are natural frequencies excited from the contacts among the bearing elements (Massouros, 1983, Berry, 1991).

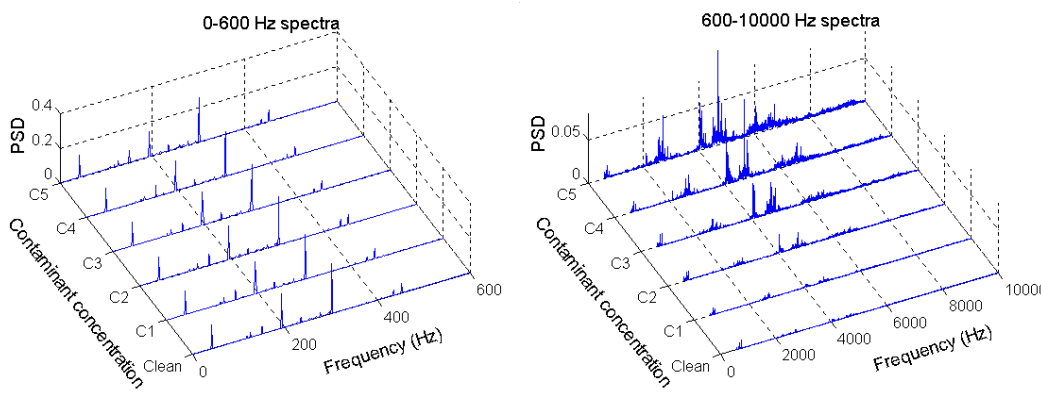

Figure 3. PSD plots from a test with increasing contamination, T3 size (C1=0.04, C2=0.13, C3=0.27, C4=0.44, C5=0.71 g/l). Left: 1 to 600 Hz band; right: 600 to 10000 Hz band.

The influence of oil contamination on vibration can be better seen in Fig.4, which shows the rms values of the vibration data acquired in the tests, related to the overall vibration and the vibration in low (LF) and high (HF) frequency bands. It can be noticed that the detection of contamination was more accurate through the HF rms values than through the overall rms. The vibration data analyzed through HF rms indicates a continuous increasing vibration as contamination increases.

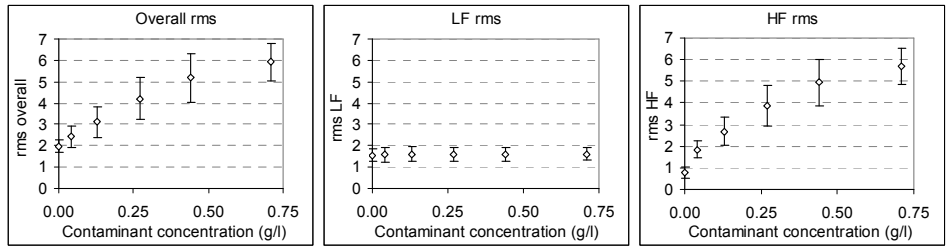

Figure 4: Rms values from the tests with increasing contamination (T3 size). Left: overall rms; middle: LF rms; right: HF rms. Error bars refer to standard deviation of two tests.

In the tests of Fig.4, the occurrence of wear was noticed, since the oil became highly darkened in the end of the test. Thus, the vibration levels might possibly be affected by a vibration factor due to increasing wear. In order to identify the amount of vibration caused by specific contaminant contents in the oil and by bearing wear, a set of tests with fixed contaminant content was performed. Figure 5 shows the previous results again, adjacent to the HF rms vibration values resulting from the tests run under fixed contaminant content of 0.25 g/l. Comparing the column heights of similar contamination levels and test time (T2 with 0.27 g/l, to T3 with 0.25 g/l), it can be seen that the last one is lower.

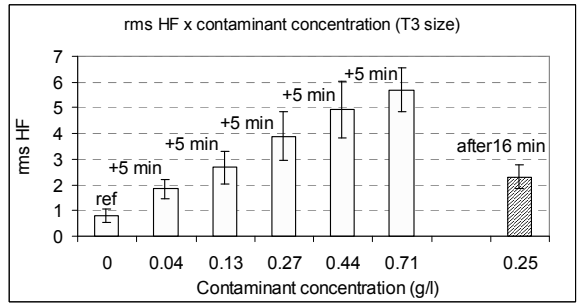

Figure 5. HF rms values of vibration, obtained from the tests with increasing (white columns, data of two tests) and fixed (hatched column, data of three tests) contaminant content.

Before discussing the results in Fig. 5, it is necessary to draw attention to prior analyses of some tests performed with different sizes and concentrations of contaminant material and different oil viscosities (Maru, Castillo and Padovese, 2005, Castillo, Maru and Padovese, 2005). The results of these tests have indicated that, depending on the

studied factors, the contaminant content that is actually circulating in the oil may decrease along the test time, because of decantation phenomenon. It is likely to occur even with the use of a system for particles dispersion. With T3 size, which is fairly large, the decantation effect is even higher.

To minimize the decantation phenomenon and follow studying the wear effect on vibration, tests with lower size particles (T2) and fixed concentration were performed. Additionally, the tested ball bearings were cleaned and re-tested with clean oil for determining the amount of vibration caused by wear in the contaminated tests. Figure 6 presents the comparative results of vibration from the tests with T2 and T3 particle sizes under fixed concentration of 0.25 g/l. The first two columns in the graphs are respectively the HF rms values obtained in 2 min and 16 min of test time after pouring the contaminant in the oil. The third column corresponds to the HF rms values of the tests run in clean oil with worn bearings. The error bars represent the standard deviation of three tests. Comparing both graphs in this Fig. 6, it is possible to notice higher vibration with T2 size, even though the test had only run for 2 min after oil contamination, becoming the difference more pronounced when run 16 min after contamination. Furthermore, with worn bearings, the vibration was also higher in the tests with T2 contamination. All these comments denote that, in the tests with T2 particles, the concentration of the particles circulating in the oil remained more constant along the test time. Also, the vibration measurement could indicate that the bearing surfaces have experienced more damage when tested with T2 size particles.

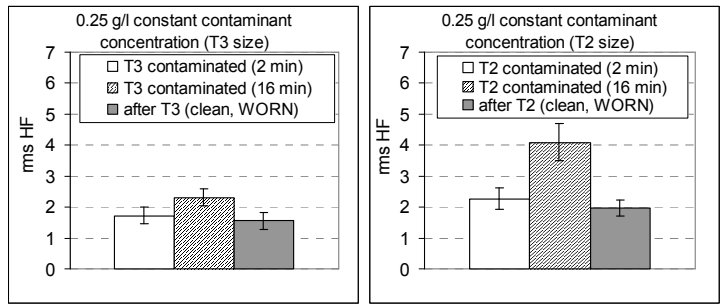

Figure 6. HF rms values of the tests with contaminated oil (left), relative to vibration measured at 2 min and 16 min, and vibration measured with worn bearings in clean oil (right). Data of three tests.

Extra tests under other concentration levels were performed in order to give support to the considerations on the effect of wear on vibration. The resulting wear was studied through oil spectrometric analyses (adapted for detecting large particles from 5 to 50 μm). Figure 7 shows, in the left side graph, the results of vibration from the tests with contaminated oil and worn bearings in clean oil; the right side graph presents the iron amount detected in the oil.

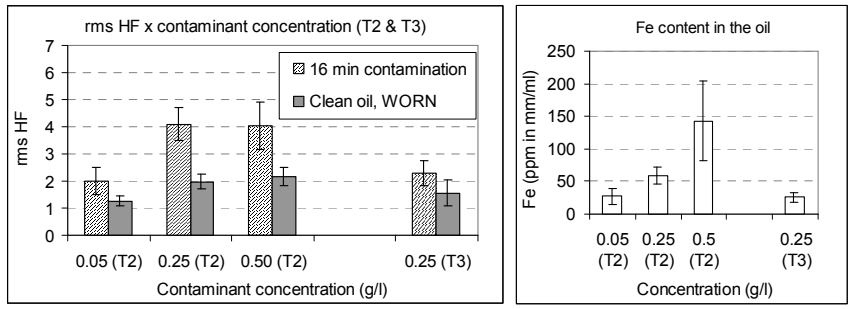

Figure 7. Left: HF rms values of the tests with contaminated oil with T2 and T3 particles, in 16 min and with worn bearings in clean oil (data of three tests); right: iron content from oil spectrometric analyses (data of two tests).

From the graphs in Fig.7, some main observations may be pointed out; the first is that, comparing the columns of both graphs for T2 and T3 tests for 0.25 g/l concentration, both vibration and wear are higher for T2 tests. It could indicate that vibration can be directly correlated with wear originated from oil contamination. However, this fact is not verified when comparing the results among the tests run under only one particle size. In this case, paying attention to the vibration and the iron content as the contamination concentration level changes, one can see that the bearing vibration does not change in such a direct proportion with the iron content in the oil. However, care has to be taken about correlation between vibration excitation and wear, since changes in vibration excitation depends essentially on the changes in the structural dynamics of the system; although high bearing wear experienced, the damage in the surfaces may not necessarily alter the dynamic behavior of the rolling elements proportionally.

To sum up, Fig. 8 presents the frequency spectra resulting from the tests with T2 particles, fixed concentration, and from the tests with the respective worn bearings run in clean oil. Comparing both set of spectra, it is possible to see that the bearing vibration in contaminated oil is distinct from that measured with worn bearings, in this case occurring in a more specific range from 2000 to 3000 Hz. Analyses in low frequency band did not reveal any change either in the spectra or in the rms values.

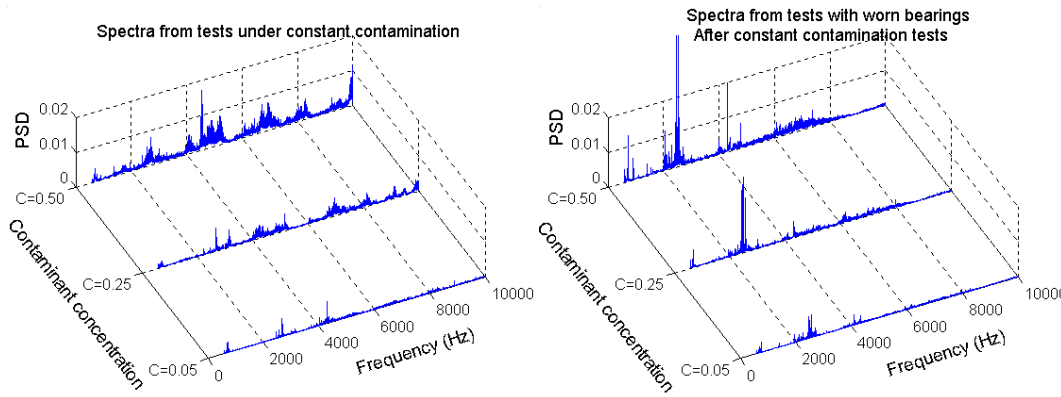

Figure 8. PSD plots (HF band) from the tests with fixed contaminant concentration method (left) and with worn bearings in clean oil.

4. Summary and Conclusions

Ball bearings were tested in order to study vibration caused by the presence of contaminant particles in the oil and by the respective wear. The vibration was analyzed in terms of its rms value and power spectrum density. The results showed that vibration analysis in the high frequency band (600-10000 Hz) is able to distinguish the contamination level in the oil. Even with very low time of test (less than 30 min), significant wear was observed since the oil became darkened. It also affected bearing vibration in the high frequency band. When the bearings were re-tested in clean oil, the change in the vibration was proportional to the contamination level. The bearing vibration is less affected when contamination occurs with large size particles (111 μm) than when it occurs with smaller size particles (59 μm).

5. Acknowledgements

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