Experimental Studies on the Effect of Viscosity grade on Mechanical Vibration Behavior of deep groove ball bearing

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ABSTRACT

The purpose of this work is to investigate the vibration suppression characteristics of ball bearing supplied with lubricants without additives. Experimental tests were performed in SKF6305 ball bearings, lubricated with mineral oil of three different viscosity grades (ISO 32, 68 and 100). The mechanical vibration was determined through the processing and analysis of bearing radial vibration data, obtained from each of the lubrication conditions, during 2 h of test run for temperature stabilization and under several bearing shaft speeds. The test rig setup consists of a ball bearing and loading arrangement operated by a DC motor the applied radial load was 20% of the bearing nominal load. And take a reading by digital accelerometer through root mean square (RMS) analysis of the vibration signals.

KEYWORDS: Lubrication, ball bearing, Viscosity, Vibration, Lubricant

1. INTRODUCTION: The word Tribology was first reported in a landmark report by scientist Sir Jost in 1966. The word is derived from the Greek word teimos meaning rubbing, so the literal translation would be "the science of rubbing." Its popular English language equivalent is friction and wear or lubrication science, alternatively used. The latter term is hardly all-inclusive. Dictionaries define tribology as the science and technology of interacting surfaces in relative motion and of related subjects and practices.

Notations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Notations</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Bearing outside diameter (mm)</td>
</tr>
<tr>
<td>W</td>
<td>Weight (kg)</td>
</tr>
<tr>
<td>D</td>
<td>Bearing bore diameter (mm)</td>
</tr>
<tr>
<td>ISO</td>
<td>Indian standard organization</td>
</tr>
<tr>
<td>B</td>
<td>Bearing width (mm)</td>
</tr>
<tr>
<td>VG</td>
<td>Viscosity grade</td>
</tr>
<tr>
<td>N</td>
<td>Number of balls</td>
</tr>
<tr>
<td>EHL</td>
<td>Elastohydrodynamic lubrication</td>
</tr>
<tr>
<td>BD</td>
<td>Ball diameter (mm)</td>
</tr>
<tr>
<td>HD</td>
<td>Hydrodynamic lubrication</td>
</tr>
</tbody>
</table>

Depending on some aspects, lubrication in mechanical systems can occur in different regimes: full film, mixed or boundary lubrication. Full film lubrication can be further divided into elastic-hydrodynamic lubrication (EHL), which occurs in non-conformal contacts under high pressure, and hydrodynamic lubrication (HD), occurring under low pressure and usually in conformal contacts [1–3]. Among the group of mechanical components operating under EHL condition, there are the rolling bearings. This machine element type is one of those more sensitive to development of faults related to lubrication deficiency. According to technical publications of rolling bearing manufacturers [3–4], from the total of faults found in this type of component, 50–80% are related to deficient lubrication, resulting from inadequate lubricant use, lack or excess of lubricant, lubricant aging, and presence of solid or liquid contaminant. In the face of high percentage of rolling bearing failures, the development of techniques for detection and diagnosis of faults in rolling bearings, due to lubrication deficiency, is a fundamental contribution to the preservation of machine precision. According to Serridge [5], other techniques such as oil analyses and temperature monitoring can also provide advance warning of faults; however, vibration monitoring is more versatile since it can reveal a wider range of faults. Defects in bearings can excite vibration frequencies in both low- and high-frequency bands. The influence of the particular bearing faults on the observed vibrations was further more developed by Tandon and Choudhury [6]. Experimental studies analyze the variations of the bearing dynamics for different values of the load, speed and lubricant's viscosity. For example, Dietl [7] measures the damping capabilities of two rolling element bearings supporting a rigid shaft. Also, Mitsuya [8] investigates the damping characteristics of a single deep groove ball bearing. The difficulty of performing sufficiently accurate measurements and the multitude of parameters influencing the results (type of bearings, radial and axial preload, speed, loose/interference fits of the bearing seats, lubricant Properties , temperature,…) is emphasized in most of these publications.

In the same context, another study [9] concludes that vibration energy of a bearing depends on surface irregularities, external loadings, running speed and lubricant viscosity. For instance, it was observed in experimental tests that the influences of lubricant viscosity on vibration response depended on speed for a bearing under large load and low running speeds; increase in lubricant viscosity causes reduction in vibration energy. In contrast, at high running speeds, vibration energy is high when lubricant viscosity is high.

All the mentioned works reinforce the already known complexity concerning the analysis of vibration phenomena occurring in mechanical contacts. The present work intends to contribute for improving knowledge on the relationship between vibration phenomena and lubrication in bearings. This is done by studying how a change in lubricant viscosity can affect the mechanical vibration of a rolling bearing by means of basic procedures of vibration analysis [10].

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2. Experimental Setup Details:
Selection of Lubricants:

The lubricants were mineral oils of viscosity ISO 32 (V1), 68 (V2) and 100(V3) without additives with the purpose of obtaining the vibration response related to different lubrication regimes in the bearing element contacts. Oil heating occurred and a mixer system was used to keep temperature homogeneous within the oil bath. A Mercury thermometer immersed in the oil bath was used to monitor the oil temperature during the test.

Fire point is the minimum temperature under a certain pressure at which a uniformly heated fluid gives off sufficient vapor to burn continuously for at least five second. Flash point is the minimum temperature to which, under specified test conditions, oil must be heated for sufficient vapors to be given off to form an inflammable mixture with air. The flash point is one of the characteristics of oils; it is not a criterion for their quality. The physical properties of base lubricant ISO VG 32, 68 and100 Mineral oil are shown below in table-1 as

<table>
<thead>
<tr>
<th>S.NO.</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density kg/m³ at 29.5°C</td>
<td>0.71 0.85 0.88</td>
</tr>
<tr>
<td>2</td>
<td>Viscosity index</td>
<td>100 115 98</td>
</tr>
<tr>
<td>3</td>
<td>KV at 40°C mm²/s</td>
<td>32 68 95</td>
</tr>
<tr>
<td>4</td>
<td>KV at 100°C mm²/s</td>
<td>5.4 9.3 10.5</td>
</tr>
<tr>
<td>5</td>
<td>Flash Point °C</td>
<td>70 210 250</td>
</tr>
<tr>
<td>6</td>
<td>Pour Point °C</td>
<td>-10 -36 -18</td>
</tr>
</tbody>
</table>

2.1 Experimental Apparatus and procedure

The Ball bearing in this study was SKF 6305 with an outer diameter of 62 mm, bore diameter 25mm, width of bearing 17mm and ball diameter 7.5 mm. The technical specification of roller bearing is given below in table-2 as

<table>
<thead>
<tr>
<th>Components</th>
<th>Dimensions (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing outside D</td>
<td>62mm</td>
</tr>
<tr>
<td>Bearing bore d</td>
<td>25mm</td>
</tr>
<tr>
<td>Bearing width B</td>
<td>17mm</td>
</tr>
<tr>
<td>Ball diameter BD</td>
<td>7.5mm</td>
</tr>
<tr>
<td>Contact angle β</td>
<td>0</td>
</tr>
<tr>
<td>Number of balls, n</td>
<td>8</td>
</tr>
</tbody>
</table>

The tested ball bearing is vertically loaded and oil bath lubricated. The lubricants were mineral oils of viscosity without additives with the purpose of obtaining the vibration response related to different lubrication regimes in the bearing element contacts. The radial vibration of the studied ball bearing is measured by a piezoelectric accelerometer attached to the bearing housing known values of radial load can be applied in the tested bearing through a lever and a load cell with a screw system during the test run as shown in figure -1. Experiments with every lubricant condition were repeated 3 times to check. Repeatability

Figure-01 Experimental line Diagram for bearing vibration measurement

A system with pulleys transmits the power from an electric motor to the bearing shaft. Two ball bearings are used to support the shaft. A frequency inverter controls the shaft speed. Actually, machines have an inherent vibration that characterizes the baseline of their dynamical behavior. The baseline dynamics certainly affects the vibration of any monitored component. In fact, in the performed tests, the vibration measured by the accelerometer was affected by the overall dynamical response of the equipment, including all the component parts (shaft, structure, etc.).
Then, the results presented in the paper are related to the changes in the vibration, on of the equipment with respect to its baseline vibration, as a function of the different viscosity grade mineral oil of the tested ball bearing. After mounting the bearing, 2 h running time with clean oil was performed so as to stabilize the oil bath temperature; typically to 45 °C in 2 h. The applied load was static and the shaft speed to 40 Hz. The vibration signal was acquired at every 15 min, up to 2 h, in order to verify the existence of some abnormality in the system. The test continued to record the vibration data corresponding to the clean oil condition, varying the shaft speed (keeping the load constant).

Table 3: The brief description of various measuring instruments

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Instruments</th>
<th>Capacity</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Accelerometer</td>
<td>0-10KHz</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Digital temperature</td>
<td>100 c</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Load cell</td>
<td>100Kg</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Electric Motor</td>
<td>1h .p.</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Frequency Controller</td>
<td>0-1KHz</td>
<td>1</td>
</tr>
</tbody>
</table>

In order to verify the effect on the bearing vibration of oil viscosity change caused by the increase in oil bath temperature, vibration signals were acquired at every 15 min, during 2 h of testing (time for oil bath temperature stabilization). The applied load was set to (400N) (corresponding to approximately 20% of the bearing dynamic capacity) and the shaft speed to 40 Hz. This procedure was applied in the tests with the three oil viscosities. After temperature stabilization, vibration signals were acquired for three shaft speeds (1000rpm, 2000rpm,3000rpm and 4000rpm), in order to verify if the trends in vibration behavior with the tested viscosity grades would be kept constant when the speed changed. Experiments with every lubrication condition were repeated several times to check repeatability.

3. Result and Discussion

3.1 Oil Temperature

Fig.3 shows oil bath temperature as a function of test time, for three tested viscosities. A gradual increase in temperature can be observed during first hour of test and trends to stabilization in the second hour. This behavior is repetitive for the three tested viscosity grades.

Table 4: Oil Temperature as Function of Test Time

<table>
<thead>
<tr>
<th>Varying Parameters</th>
<th>Performing Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lubricant Viscosity Grades V1:ISO32</td>
<td>Time (min.)</td>
</tr>
<tr>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>20</td>
<td>33</td>
</tr>
<tr>
<td>40</td>
<td>37</td>
</tr>
<tr>
<td>60</td>
<td>41</td>
</tr>
<tr>
<td>80</td>
<td>42</td>
</tr>
<tr>
<td>100</td>
<td>43</td>
</tr>
<tr>
<td>120</td>
<td>43</td>
</tr>
<tr>
<td>Lubricant Viscosity Grades V2:ISO68</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>33</td>
</tr>
<tr>
<td>40</td>
<td>41</td>
</tr>
<tr>
<td>60</td>
<td>44</td>
</tr>
<tr>
<td>80</td>
<td>46</td>
</tr>
<tr>
<td>100</td>
<td>47</td>
</tr>
<tr>
<td>120</td>
<td>47</td>
</tr>
<tr>
<td>Lubricant Viscosity Grades V3:ISO100</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>34</td>
</tr>
<tr>
<td>40</td>
<td>43</td>
</tr>
<tr>
<td>60</td>
<td>47</td>
</tr>
<tr>
<td>80</td>
<td>48</td>
</tr>
<tr>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>120</td>
<td>50</td>
</tr>
</tbody>
</table>
3.2 Bearing Vibration

Fig. 3 show the RMS vibration values of ball bearing as function of test time. Comparing the result In this figure with those in Fig. 2, two main observations can be done. First, it is observed that both temperature and RMS values tends to increase and stabilize with test time. Secondly, vibration level is smaller as oil viscosity decreases. In this phenomenon is correlated with frictional force that originated from viscous action among the layers in the lubricant film that separates the surfaces in contact. High frictional force (high viscosity) is related to high loss of energy in the contact, resulting in high heat generation.

Table-5 RMS vibration as a Function of Shaft Speed

<table>
<thead>
<tr>
<th>Varying Parameters</th>
<th>Performing parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lubricant Viscosity Grades</td>
<td>Shaft speed (rpm.)</td>
</tr>
<tr>
<td>V1:ISO 32</td>
<td>1000</td>
</tr>
<tr>
<td>V2:ISO 68</td>
<td>2000</td>
</tr>
<tr>
<td>V3:ISO 100</td>
<td>4000</td>
</tr>
</tbody>
</table>

The RMS values of vibration in low frequency band present minimum variation along with time and no appreciable difference in the vibration value among the tested viscosities. On other hand, the RMS values in HF band present a behavior in this band, it is possible to notice more appreciable difference in vibration with smaller oil viscosity grade (V1). According to the performed analyses.

3.2.1 Effect of Shaft Speed

Vibration signal were acquired by subsequence runs in the tests with all the three viscosity grades, in three shaft speed (1000rpm, 2000rpm, 3000rpm and 4000rpm). RMS values of overall vibration. Including HF and low-frequency vibration band are shown in Fig. 6. As can be seen, vibration decrease when increase shaft speed. From the point of view of tribological behavior, an increase in speed leads to an enlargement of the oil film thickness, which implies in better separation between the rolling elements and races of bearing and then decrease the level of vibration. However, as mentioned before, from the point of view of dynamic behavior, vibration measured by the accelerometer, placed on the housing of the tested bearing, was composed by the vibration from contact area of tested bearing itself.

Table-5 RMS vibration as a Function of Shaft Speed

<table>
<thead>
<tr>
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<th>Performing parameter</th>
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<tr>
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<td>Shaft speed (rpm.)</td>
</tr>
<tr>
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</tr>
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<td>V2:ISO 68</td>
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</tr>
<tr>
<td>V3:ISO 100</td>
<td>4000</td>
</tr>
</tbody>
</table>

A change in the shaft speed alone causes a strong change in the excitation of hydrodynamics of all parts of the system. Identification of the vibration coming only from the bearing contact requires a special methodology; which was not the case of the present work.
is certain that the overall vibration of the equipment has affected the measured vibration level of the contact bearing.

CONCLUSION

Ball bearings were tested in order to verify differences in vibration response when lubricated with different viscosity oils. The main conclusions are:

- It can be concluded that changes in oil viscosity, caused by either the use of different ISO viscosity grades or temperature variation, only affect the vibration of the rolling bearing in HF band.
- It can be concluded that if increase lubricant viscosity grade decreasing RMS vibration level.
- It is observed that both temperature and RMS values tend to increase and stabilize with test time. Secondly, vibration level is smaller as oil viscosity degree becomes higher, in contrast to the effect of temperature on oil viscosity.
- It is observed that RMS values tend to increase and stabilize with shaft speed. Secondly, vibration level is smaller as oil viscosity degree becomes higher.

REFERENCES: