COMPARATIVE ANALYSIS OF PLAIN AND HERRINGBONE GROOVED JOURNAL BEARING UNDER THE HYDRODYNAMIC LUBRICATION CONDITIONS

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ABSTRACT

Journal bearings are important machine elements which are used for supporting the shafts. They are used in various applications like gas, oil engines, aircraft, automobile engines, machine tools, and turbines, etc. One such application is two- wheeler oil pump to which the paper is concerned with. The plain journal bearings are used in the oil pump to support the radial loads. Though the load carrying capacity of the PJB is higher, it has some common problems like low radial stiffness, instability in concentric operations, hydrodynamic pressure losses, etc. To overcome these problems, a beveled-step herringbone grooved journal bearing can be used. This is because it has higher radial stiffness, stability in concentric operations, hydrodynamic pressure recovery in divergent zone, increased pumping capacity, etc. Thus, by replacing the PJB by HGJB, the problems in the oil pump can be rectified and the oil pump works more effectively than before. ‘C’ and ANSYS are the tools used for proving the effectiveness of HGJB over PJB. ‘C’ program is used to determine the maximum hydrodynamic pressure where ANSYS is used to determine the maximum stress developed in the journal bearing due to the hydrodynamic pressure. By observing the results of PJB and HGJB, their working eccentricity ratios are determined. This itself would provide information about compensation of radial stiffness, load carrying capacity, pressure recovery, etc.

1. INTRODUCTION

Bearing is applied to a machine or structure, which refers to contacting surfaces through which a load is transmitted. Bearing are of two types namely Sliding contact bearing and rolling contact bearing. The Journal bearing is a type of sliding bearing. It is an important machine element used for supporting the radial loads in shafts. In the oil pump, the journal bearing is used to support the radial loads in the shaft transmitting power to the oil pump (Gad 2006).

Generally, journal bearing operates under three types of lubrication regimes. The bearing load is supported by lubricant pressure generated by hydrodynamic action. Such a type of lubrication is called hydrodynamic lubrication. To reach this full film lubrication condition, the journal bearing should pass through metal to metal contact and partial contact stages during starting and stopping which are called Boundary lubrication and mixed lubrication respectively (Gad 2009).

2. NOMENCLATURE OF JOURNAL BEARING:

This chapter deals with the nomenclature of plain and herringbone grooved journal bearing. The various terms related to them are explained here.

2.1 PLAIN JOURNAL BEARING

The plain solid cylindrical portion attached to the shaft or a part of it is called the journal or shaft. The hollow cylindrical portion having less thickness is said to be a bearing or bush (Bernard J. Hamrock 2004). The various parameters related to this journal bearing is given below Fig 1

TERMINOLOGY:

➢ Eccentricity - The distance between the centers of the journal and bearing
➢ Clearance - The space/gap between the journal and the bearing
➢ Eccentricity Ratio - The ratio between the eccentricity and clearance

The working eccentricity ratio is to be found using analysis. (G. Bhushan 2007)

3.2 HERRINGBONE GROOVED JOURNAL BEARING:

Here the journal has a double helical groove on it instead of plain cylindrical surfaces as in plain journal bearing, while the bearing has the same shape and there is no change in its geometry show in fig 2

Fig 2: Nomenclature of Herringbone Grooved Journal Bearing

TERMINOLOGY:

➢ Groove angle - The angle at which the helix is inclined to the axis of the journal from its surface
➢ Groove Width ratio - Ratio of width of the groove to that of the groove and ridge combination
➢ Groove depth ratio - Ratio of the total depth of the groove from a reference surface to that of the ridge from the same reference.

OPTIMUM GROOVE PARAMETERS

The optimum groove parameters are:

➢ Groove Angle, \( \alpha = 29^\circ \)
➢ Groove Width Ratio, \( \beta = 0.5 \)
➢ Groove Depth Ratio, \( \gamma = 2.0 \)
3. SIGNIFICANCE OF HYDRODYNAMIC LUBRICATION CONDITION: The load direction in journal bearing is designed to take up radial loads and constrain certain degrees of freedom of rotating members in machines. Generally, the journal bearings are operated under three lubrication regimes as mentioned in the previous chapters. During rest condition, the journal due to its self weight squeezes the oil in the clearance space and comes into direct contact with the bearings. Thus, there is a direct metal to metal contact between them. At this condition, the lubrication is called boundary lubrication.

Then as it starts rotating, a thin film of oil separates the journal and bearing. However due to the presence of asperities, there is partial metal to metal contact and partial hydrodynamic action. This condition of lubrication is called as mixed lubrication. At this condition, a slight pressure is built up due to the start of the relative motion between the journal and bearing.

Relative motion between journal and bearing.
➢ Wedging action for the pressure build up.
➢ Presence of a suitable fluid.

Three conditions are to be achieved for maintaining the hydrodynamic conditions and figure 3 explains the basic parameters on the type of lubrication are as follows. They are:
➢ Viscosity of oil (µ).
➢ Rotating speed of journal (n).
➢ Bearing unit load (P).

A function including these three parameters is called as SOMMERFIELD or BEARING CHARACTERISTICS NUMBER, given by $S_0$ as

$$S_0 = \frac{\mu n}{P}$$

4. SIGNIFICANCE OF HERRINGBONE GROOVED JOURNAL BEARING: Recently, the herringbone grooved journal bearings have been extensively used in high speed and light weight rotating machineries, due to their improved stability characteristics when compared with plain journal bearing. They can pump the fluid inward, which generates supporting stiffness and improves the dynamic stability, especially for concentric operation. The introduced grooved profile has the capability to increase the pressure recovery from the divergent zone of the flow thereby reduce the pressure loss.

Moreover, herringbone grooved journal bearings can support both radial and axial loads simultaneously. The spiral grooving in it can be used to control the bearing attitude angle and thus improves the bearing stability. The direct stiffness co-efficient increases as the eccentricity ratio lesser than that of plain journal bearing. Hence the stiffness is higher in the case of herringbone grooved journal bearings than plain journal bearing (Rakesh sehgal 2010).

5. DERIVATION AND CALCULATION OF HYDRODYNAMIC PRESSURE DISTRIBUTION

In this chapter, the derivation of the pressure distribution under hydrodynamic condition for both plain journal bearing and herringbone grooved journal bearing.

5.1 HYDRODYNAMIC PRESSURE DISTRIBUTION FOR PJ B: This pressure distribution depends upon certain parameters like film thickness $[h(Ø)]$, surface velocity ($u$), angle of rotation of journal ($Ø$), viscosity of the oil ($µ$) and radius of journal ($r$). Considering all these parameters Christensen and Reynolds have developed a differential equation for pressure distribution which can be applied to infinitely long journal bearings. From this equation, hydrodynamic pressure computations are carried by solving it. Reynolds equation for a one dimensional steady state flow reduces to (Robert C. Juvinall 2002)

$$\frac{dp}{d\theta} = 6 \mu u r j \frac{h(\theta) - h'}{[h(\theta)]^3}$$

Christensen used a mathematical operator, E and included the effect of fluid film thickness in it. Hence the equation is now given by

$$\frac{dp}{d\theta} = 6 \mu u r j \frac{E(H) - E(H')}{E(H^3)}$$

Where

$E(H) = h(\theta) = c (1 + E \cos \theta)$

$E(H^3) = [h(\theta)]^3 + 3 h(\theta) S_1 S_2 S_3$

The method used to determine the expectation operator in the hydrodynamic region is given in detail in the literature by Wu and meyler. Thus, the pressure
at any point $\Theta$, can be found by integrating the above differential equation and it is given below:

$$P = \int_0^{2\pi} \frac{dp}{d\Theta} d\Theta$$

$$6\mu r \int_0^{2\pi} \frac{E(H)}{E(H')^2} d\Theta - E(H') \int_0^{2\pi} \frac{1}{E(H')} d\Theta$$

This pressure equation is used in the “c” program and the pressure distribution for angle of rotation $\Theta=0^\circ$ to $\Theta=360^\circ$ is found. The maximum pressure is observed which is used for analysis.

5.2 HYDRODYNAMIC PRESSURE DISTRIBUTION FOR HGJB: The pressure distribution for herringbone grooved journal bearing depends on the same parameters as that for plain journal bearing. Other than those parameters, there are four other factors on which also the pressure distribution depends. They are groove angle ($\alpha$), groove width ratio ($\beta$), groove depth ratio ($\gamma$) and number of grooves (N) (Weyler, 1982).

The hydrodynamic pressure equation for herringbone grooved journal bearing is not available directly as that for plain journal bearing. But some experimental data are available for herringbone grooved journal bearing in the literature by Nemat Alla. So, by using trial and error method, the hydrodynamic pressure equation is determined.

By substituting the experimental input data, in the pressure equation obtained in each trial, the equation is verified for its output. If the output is more or less closely approximated to the experimental output data, then the equation is appropriate such a hydrodynamic pressure equation is,

$$P=6\mu r \cos \alpha \int_0^{2\pi} \frac{E(H)}{E(H')^2} d\Theta - E(H') \int_0^{2\pi} \frac{1}{E(H')} d\Theta$$

6. GRAPHS, TABLES AND ANALYTICAL RESULTS: This is repeated for a set of two speeds, $n=1500$ rpm and $n=4000$ rpm and a set of five eccentricity ratios. The maximum pressure for each case is applied to the inner ring of the bearing and journal and the maximum stress developed is observed. From these results, the optimum eccentricity ratio that should be maintained under the hydrodynamic working condition can be determined for both plain journal bearing and herringbone grooved journal bearing (Fredrick T. schuller 2010) show in Table 1

6.1 PLAIN JOURNAL BEARING:

<table>
<thead>
<tr>
<th>S.NO</th>
<th>ECCENTRICITY RATIO</th>
<th>MAXIMUM PRESSURE (N/mm²)</th>
<th>MAXIMUM STRESS (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.84</td>
<td>89.3879</td>
<td>184.988</td>
</tr>
<tr>
<td>2</td>
<td>0.85</td>
<td>97.3064</td>
<td>194.982</td>
</tr>
<tr>
<td>3</td>
<td>0.86</td>
<td>106.5502</td>
<td>224.454</td>
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<tr>
<td>4</td>
<td>0.87</td>
<td>118.2527</td>
<td>249.105</td>
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<tr>
<td>5</td>
<td>0.88</td>
<td>132.0039</td>
<td>278.073</td>
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</table>

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<tr>
<th>S.NO</th>
<th>ECCENTRICITY RATIO</th>
<th>MAXIMUM PRESSURE (N/mm²)</th>
<th>MAXIMUM STRESS (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.74</td>
<td>61.7542</td>
<td>136.661</td>
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<tr>
<td>2</td>
<td>0.75</td>
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<td>143.878</td>
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<tr>
<td>3</td>
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<td>68.5200</td>
<td>151.633</td>
</tr>
<tr>
<td>4</td>
<td>0.77</td>
<td>72.3259</td>
<td>160.056</td>
</tr>
<tr>
<td>5</td>
<td>0.78</td>
<td>76.8309</td>
<td>170.025</td>
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</table>

<table>
<thead>
<tr>
<th>S.NO</th>
<th>ECCENTRICITY RATIO</th>
<th>MAXIMUM PRESSURE (N/mm²)</th>
<th>MAXIMUM STRESS (N/mm²)</th>
</tr>
</thead>
<tbody>
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<td>0.76</td>
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<td>523.422</td>
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<tr>
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<td>0.77</td>
<td>192.8070</td>
<td>552.393</td>
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<tr>
<td>5</td>
<td>0.78</td>
<td>204.8825</td>
<td>586.801</td>
</tr>
</tbody>
</table>

6.2 PRESSURE GRAPHS: PLAIN JOURNAL BEARING:

FOR SPEED, $N=1500$ RPM:

Graph 1 ECC RATIO=0.84

Graph 2 ECC RATIO=0.85

Graph 3 ECC RATIO=0.86
6.3 ANSYS RESULTS:

The stress distribution diagrams, with the maximum stress obtained from ANSYS are displayed below:

**PLAIN JOURNAL BEARING:**

**ANALYSIS OF BEARING:**

**FOR SPEED, N=1500 RPM:**

**Graph 4 ECC RATIO=0.87**

**Graph 5 ECC RATIO=0.88**

**Graph 6 ECC RATIO=0.84**

**Graph 7 ECC RATIO=0.85**

**Graph 8 ECC RATIO=0.86**

**Graph 9 ECC RATIO=0.87**

**Graph 10 ECC RATIO=0.88**

**HERRINGBONE GROOVED JOURNAL BEARING:**

**FOR SPEED, N=1500 RPM:**

**Graph 11 ECC RATIO=0.74**

**Graph 12 ECC RATIO=0.75**

**Fig 4 ECC RATIO=0.84**

**Fig 5 ECC RATIO=0.85**

**Fig 6 ECC RATIO=0.86**

**Fig 7 ECC RATIO=0.84**

**Fig 8 ECC RATIO=0.85**

**Fig 9 ECC RATIO=0.86**

**Fig 10 ECC RATIO=0.87**

**Fig 11 ECC RATIO=0.74**

**Fig 12 ECC RATIO=0.75**
ANALYSIS OF JOURNAL:

FOR SPEED, \(N=1500\) RPM:

- **Fig 10 ECC RATIO=0.84**
- **Fig 11 ECC RATIO=0.85**
- **Fig 12 ECC RATIO=0.86**

FOR SPEED, \(N=4000\) RPM:

- **Fig 13 ECC RATIO=0.84**
- **Fig 14 ECC RATIO=0.85**
- **Fig 15 ECC RATIO=0.86**

HERRINGBONE GROOVED JOURNAL BEARING: ANALYSIS OF BEARING:

FOR SPEED, \(N=1500\) RPM:

- **Fig 16 ECC RATIO=0.74**
- **Fig 17 ECC RATIO=0.75**
- **Fig 18 ECC RATIO=0.76**

FOR SPEED, \(N=4000\) RPM:

- **Fig 19 ECC RATIO=0.74**
- **Fig 20 ECC RATIO=0.75**
9. CONCLUSION

The results of ‘c’ program and ANSYS were tabulated in the last chapter. It is very clear from the results that optimum or working eccentricity ratio is 0.85 for plain journal bearing and 0.76 for herringbone grooved journal bearing. The material currently used for plain journal bearing in two-wheeler oil pump is stainless steel 304. The yield strength is 550MPa and the tensile strength is 600MPa. Now, the Von-misses stress obtained from ANSYS results for various cases is lesser than the yield strength of the material, and then the design is safe.

Thus, for the plain journal bearing at ε=0.85, the design is safe and can be worked in that condition. Whereas for the herringbone grooved journal bearing, at ε = 0.76, the design is safe and can be worked in that condition. The maximum eccentricity ratio within safe design should be chosen as the working eccentricity ratio because, at higher eccentricity ratio, the load carrying capacity of the journal bearing increases.

It is very clear from the results that the working eccentricity ratio of HGJB is lower than PJB. Usually the load carrying capacity is higher at higher eccentricity ratio, but the stiffness is lower for the same ratio and vice versa. So, to suit the application and compromise the problems, it is better to use HGJB instead of PJB.

10. REFERENCES


