OIL FLOWS IN SUBMERGED MULTI-PAD JOURNAL BEARINGS

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SUMMARY
The effect of pad spacing, pad shape and eccentricity on oil flows in a submerged multi-pad journal bearings, especially the behaviour of Taylor vortices, was investigated by means of tracer method experimentally. Critical Taylor number in the bearing clearance of multi-pad journal bearing under the concentric condition, decreased with an increase in pad spacing. The effect of pad shape on those phenomena was not found clearly.

Critical Taylor number in the bearing clearance of four pads bearing under eccentric condition decreased once slightly, and then increased with an increase of eccentricity as in the case of full cylinder. But the increasing rate is smaller than in the case of full cylinder. Two-dimensional cavity flow field between pads were measured by PIV.

Keywords: Multi-Pad Journal Bearings, Vortex, Taylor Vortices, Cavity Flows, Particle Image Velocimetry

1 INTRODUCTION
In this study, the Taylor vortices of the film flow in the bearing clearance and the cavity flow between the pads in a submerged multi-pad journal bearing were visualized by means of tracer method.

The effects of pad spacing, pad layout and pad shape on the Taylor number of the film flow and cavity flow were discussed under concentric condition.

The effect of eccentricity on the Taylor vortices of the film flow was discussed in the case of four pads of different arc extent.

In the present study, the bearing clearance was set much larger than an actual bearing carrying high load, in order to realize visualization of Taylor vortices at very low rotational speed. The clearance ratio was from 0.0363 to 0.0421. Similarity may be held for high speed bearings with somewhat large bearing clearance.

Notation
R : Journal radius
C : Radial clearance
k : Clearance ratio = C / R
ω : Journal rotating speed
e : Eccentricity
ε : Eccentricity ratio = e / C
ν : Kinematic viscosity of fluid
Re : Reynolds number = ωRC / ν
Ta : Taylor number = k^{1/2}Re
Ta_c : Critical Taylor number
Ta_c* : Critical Taylor number for full cylinder
θ_p : Pad arc extent
θ_s : Pad spacing

2 EXPERIMENTAL APPARATUS
Schematic diagram of the experimental apparatus is shown in Fig.1, and two types of bearing pads are shown in Fig.2. Transparent acrylic circular arc pads were fixed around the aluminium rotary shaft in the transparent acrylic cylindrical housing. Radius of curvature of the bearing surface of each pad is set just equal to the sum of shaft radius and bearing clearance. Observation of the Taylor vortices under concentric condition is carried out for five kinds of pad layout as shown in Fig.3. In the figure, from (a) to (e), the pad spacing, in other words the arc extent of cavity region is widened to consider the effect of cavity flow. The eccentricity of the shaft center to the bearing center is directed to the center of the subject pad. The shaft isrevolved by an electric motor of variable speed. Water is used as the lubricant and aluminium powder is used as the tracer. The top of the housing is covered with a transparent acrylic plate to protect the lubricant flow from the effect of its free surface. Variation of temperature of the lubricant water was kept within ±0.1 K during one test run.

Fig. 1: Schematic Diagram of Experimental Apparatus
Fig. 2: Schematics of Two Kinds of Bearing Pads

(a) Standard type
(b) Streamlined type

Fig. 3: Schematics of Pad Layout

The observation areas are also shown in Fig. 1. Visualized sections are a central horizontal plane perpendicular to the shaft and a cylindrical plane along the shaft surface. Visualization of the flow in those sections is realized by two kinds of halogen light sheet, flat and curved. Visualized images in the horizontal plane are recorded in a digital VTR and transferred to an image processing board on PC. Velocity vectors and path lines are calculated by means of PIV, and the difference in flow patterns for the cornered pads, standard pads, and streamlined pads are compared with each other.

Experimental conditions are shown in Table 1.

<table>
<thead>
<tr>
<th>Pad</th>
<th>Shape</th>
<th>Arc Extent [degree]</th>
<th>Axial Length [mm]</th>
<th>Radius of Curvature [mm]</th>
<th>Inner Diameter of Housing [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta</td>
<td>Standard, Streamlined</td>
<td>70, 80</td>
<td>110.0</td>
<td>100.0</td>
<td>244.0</td>
</tr>
</tbody>
</table>

Table 1: Experimental Conditions

3 RESULTS AND DISCUSSIONS

Some examples of visualized image of the flow along the shaft surface under concentric condition are shown in Fig. 4, and those under eccentric condition of $\varepsilon = 0.56$ are shown in Fig. 5. The results are for equally spaced four pads of standard type. The area between two vertical lines in each figure corresponds to the cavity between the pads. When the Taylor number based on the bearing clearance increases up to 40, clear Taylor vortices appear first in the bearing clearance flow, and the vortices hold their appearance in the cavity between the pads as if the bearing clearance continues. The critical Taylor number for the bearing clearance flow seems, however, to be lowered than that of a fully cylindrical clearance flow due to existence of the cavity. When the Taylor number increases up to 55, the vortices are distorted wavy in the cavity region first, and this proceeds downstream to the bearing clearance. Such phenomena are hardly changed by the eccentricity.

The effect of the cavity on the critical Taylor number of the bearing clearance flow is examined by changing the arc extent of the cavity region, in other words pad spacing. As the results under both conditions, concentric and eccentric, are quite similar, only the results under concentric condition are shown in Fig. 6. Pad spacing was changed by changing the layout of the pads as shown in the same figure. $T_{ac}$ in the ordinate is the...
critical Taylor number at which the Taylor vortices appeared in the bearing clearance in this experiment, and $Ta_c$ is the theoretical critical Taylor number for full cylinders. When the pad spacing is smaller than about 120 deg., $Ta_c / Ta_c^*$ decreases with an increase in pad spacing. In this range, the Taylor vortices appeared first in the bearing clearance, and they were held in the cavity region between the pads as if the Taylor vortices had a kind of inertia effect. This is interesting phenomenon [1]. When the pad spacing becomes larger than 120 deg., $Ta_c / Ta_c^*$ approaches almost constant. In this range, the Taylor vortices of large pitch were observed first in the cavity region between the pads and then in the bearing clearance. The effect of pad shape on those phenomena was not found clearly.

To extract the effect of eccentricity on the critical Taylor number, the data in the cases of four pads are rearranged in the form of critical Taylor number vs. eccentricity ratio. This is shown in Fig. 7, being compared with the Barwell’s [2] for a full circular case of almost the same clearance ratio. The critical Taylor number decreases once slightly, and then increases with an increase in the eccentricity ratio similarly to the full circular case.

Some examples of visualized image of the flow in a horizontal section perpendicular to the shaft under both conditions, concentric and eccentric, are shown in Fig.8, Fig.9 and Fig.10. The results are for the four pads of standard and streamlined type. Until the Taylor number exceeds the critical one greatly, for both cases, the film flow in the upstream bearing clearance is almost carried in the downstream bearing clearance over the cavity region as if the pads are continuous. As the Taylor number increases, the film flow enters the cavity deeply, so that the cavity flow becomes complex and unstable. These correspond to the results of Taylor vortices shown in Figs.4 and 5.

Such a general feature is almost the same for the streamlined pads. In the case of streamlined pads, however, the flow through the back of each pad is induced notably as shown in Fig.10, whereas, in the
case of standard pads, the flow circulates within the cavity as if the back of each pad is closed. The cavity flow itself is strongly influenced by the pad shape.

![Fig. 10: Visualized Cavity Flow (streamlined four pads, $\varepsilon = 0$)](image)

4 CONCLUSIONS

(1) In multi-pad bearings of small pad spacing, Taylor vortices appear first in the bearing clearance, and they are carried over the cavity region between the pads as if the pads are continued.

(2) As the cavity region between the pads increases, the critical Taylor number is lowered due to the cavity flow induced there. The critical Taylor number becomes almost constant, however, if the cavity region exceeds a certain value.

(3) The shape of the pad does not influence the critical Taylor number notably, whereas it influences the cavity flow itself notably.

(4) In a multi-pad bearing, the critical Taylor number decreases once and then increases with the eccentricity. The effect of eccentricity seems to be somewhat smaller than the effect in a full circular bearing.

5 REFERENCES
