AN INVESTIGATION OF THE SHEAR AND PRESSURE FLOWS INTERACTION IN A HYDROSTATIC JOURNAL BEARING POCKET

M. J. BRAUN, D. PELOSO, C. DANIELS
Department of Mechanical Engineering, The University of Akron, Akron, Ohio 44325, USA; e-mail: mjbraun@uakron.edu

SUMMARY
The present paper studies parametrically the flow patterns and pressure profiles inside of, and on the adjoining seals of a single hydrostatic pocket, characteristic component of hydrostatic journal bearings. The major focus is on the interaction between the effects of the shear flow (Couette) created by the rotation of an eccentric shaft and the pressure induced flow due to hydrostatic jet penetrating at the bottom of the pocket. The pocket is square in nature with a size of 17.8 mm × 17.8 mm footprint. Its bottom surface has a radial sliding capability, such that the depth of the pocket can be changed, without breaking pocket integrity. This construction allows the study and ensuing comparison of the influence of changes in clearance, jet strength and shaft angular velocity on the flow patterns, pressure profiles and the combined hydrostatic and hydrodynamic effects. The flow structure of the jet and its interaction with the flow in the pocket itself is visualised qualitatively using long distance microscopy (up to ×400). The PIV system used herein is equipped with a digital video-camera and a pulsing laser (30 mJ/pulse) with a repetition capability of up to 5000 Hz.

Keywords: hydrostatic pocket, design, flow visualisation, shear flow, jet flow

1 INTRODUCTION
Speen [1] studied flow and pressure characteristics in an externally pressurised gas lubricated bearing. He demonstrated that one could obtain enhanced load support, increased stability, and greater stiffness characteristics utilising an integral journal-thrust bearing rather than using separate journal and thrust bearings. Hunt and Ahmed [2] analysed load capacity, stiffness, and flow characteristics of hydrostatically lubricated six-pocket journal bearing. The authors concluded that as the rotational speed increased, the hydrodynamic effect of the rotating shaft tended to center the shaft, thus nullifying the hydrodynamic effect of the “squeezed” fluid film. Ho and Chen [3] analysed the pressure distribution in a six-pocket hydrostatic journal bearing. The authors found from the pressure measurements that the bearing acted in a hybrid fashion and that the film pressures exhibited at the same time hydrodynamic and hydrostatic effects. Chaomleffel and Nicolas [4] conducted an experimental investigation of pressure distributions in a hybrid journal bearing. Their work focused on the influence of inertia effects on pressure distributions at the recess outlets and concluded that when the bearing was lightly loaded (eccentricities < 0.4) the performance was similar to that of an unloaded bearing, while at higher loads (eccentricities > 0.4) a hydrodynamic pressure “add-on” was building on the sills between the pockets. Braun and Batur [5] analysed flow in a six-pocket hydrostatic journal bearing using computer aided image processing in combination with experimental non-intrusive particle tracking. The method used long distance microscopy and special software created by the investigators to evaluate trajectories, velocities, and accelerations in the flow field. Krga [6] analysed experimentally flow patterns and pressure distributions in a six-pocket hydrostatic journal bearing. The author varied parametrically mass flow rate, bearing clearance, shaft angular velocity, and pocket geometry. Finally Braun et al. [7] presented findings from a study of a variable depth hydrostatic pocket and detailed the flow formations in a pocket of aspect ratios 1 and 0.25 respectively.

2 SCOPE OF WORK
The work published in [7] is continued and extended by the work presented in this study. The table below presents in a centralised manner the parametric study of the effect of angular velocities, sill/shaft clearance and jet strength on the flow patterns and pressure profiles in a pocket of aspect ratio 1 with a foot print of 0.700×0.700 in (17.8×17.8 mm) and depth of 0.700 in (17.8 mm).

<table>
<thead>
<tr>
<th>Angular Velocity [RPM]</th>
<th>Flow [gpm / (cc/m)]</th>
<th>Clearance [in /mm]</th>
<th>Aspect Ratio / Actual Depth [– / in (mm)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1130</td>
<td>0.0594/225</td>
<td>0.013 / 0.330</td>
<td>1 / 0.700 (17.8)</td>
</tr>
<tr>
<td>1000</td>
<td>0.0555 /210</td>
<td>0.013 / 0.330</td>
<td>1 / 0.700 (17.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.004 / 0.102</td>
<td></td>
</tr>
<tr>
<td>0.115 / 435</td>
<td>0.013 / 0.330</td>
<td>0.004 / 0.102</td>
<td></td>
</tr>
</tbody>
</table>

3 TEST FACILITY
3.1 Experimental Set-up
A schematic of the overall test loop has been presented in detail by Braun et al. in [7]. The test section, Figure 1, containing the single hydrostatic pocket is mounted in a closed fluid circuit that is fed by a gear pump. The pump provides a constant flow of 30 gpm (1900 cc/s) at pressures as high as 120 psi (830 kPa). The pump is motored by a variable speed motor connected to a 100-gallon (380 liter) reservoir. The working fluid is an oil
whose index of refraction is matched to that of the Lucite manufactured test section. The rotating shaft, shown in Figure 1, is driven by means of a 25 HP variable-speed motor. Finally a positive displacement flowmeter allows precise measurement of the mass flow to the hydrostatic pocket. The installation, Figure 1, contains a Lucite casing (1) with an inner diameter of 8.000 in. (203.2 mm). The Lucite rotor (2) diameter is 7.974 in. (202.5 mm) and is rotated by the shaft (4). The hydrostatic pocket insert (HPI) (3) incorporates a sliding bottom, thus making possible the variation of the pocket depth. The HPI is formed out of an outer cylindrical enclosure that houses the inner piston. The outer enclosure provides the sidewalls of the pocket while the piston forms its moving bottom. The piston moves along the radius of the test section under manual micrometer operation allowing precise changing of the pocket depth. The piston and its cylindrical enclosure contain the pressure taps used to measure the pressures in the pocket and on the upstream and downstream sills. Details regarding the position of these taps and of the pressure transducers used are also given in [7].

3.2 The Laser and Vision System
Various embodiments of the visualisation system used in these experiments have been described previously in great detail (Braun and Batur [5], Braun and Canacci [8]). The system, Figure 2, contains a high-power multi-kilohertz (15 to 5000 Hz) intra-cavity doubled Nd:YLF laser, a combination of cylindrical lenses that transform the cylindrical beam of light into a light sheet that is approximately 0.020 in. (0.5 mm) thick, and an image recording system. The fluid was seeded with 5 to 20 micron magnesium oxide particles. A modified digital Pulnix camera allows either interlaced or non-interlaced viewing of the illuminated fluid plane, at a frequency of 30 Hz. The camera-lens system has been configured as a long distance microscope, thus simultaneously allowing both a large working distance (10 to 25 in / 254 to 635 mm) and high magnification (up to ×400). The images were recorded in analog interlaced format on a video recorder and in digital non-interlaced format on a real-time card-based RAM memory. The laser, while not synchronised with the camera, was externally pulsed at frequencies that were even multiples (120 Hz, 240 Hz) of those of the camera.

4 EXPERIMENTAL RESULTS
4.1 Change in Flow Effects with Angular Speed
Figure 3 presents a sequence of photographs that detail the development of the flow patterns characteristics in a hydrostatic pocket with a rotating shaft. Figure 3.1 presents the flow formations when there is NO shaft rotation. One can distinguish two large recirculation zones (1a) and (1b) with recirculation cores (2a) and (2b). They are arranged symmetrically and fill their entire portion of the pocket on the either side of the hydrostatic jet (4), which impinges on the shaft in region (5). The total lack of rotation allows the fluid to flow out symmetrically through both the upstream (3a) and downstream (3b) exits. Figures 3.2 and 3.3 present flow modifications in the pocket when the shaft rotates at 250 and 400 rpm respectively. One observes the formation of a turn-around zone (TAZ) (6), that grows with rotation (see also Fig3.4) and increasingly prevents the fluid from exiting through the upstream exit (3a). Thus, as the velocity of the shaft increases one witnesses the increasing Couette effect, which, for the given jet flow conditions, 0.0594 gpm (225 cc/min), dominates the flow geometry in the pocket. As the shaft velocity increases (from 250 to 400 and 1130 rpm), it gradually destroys the flow symmetry, with the effect being most pronounced in Figures 3.3 and 3.4. The latter figure shows a powerful bent of the jet with a large TAZ and diminished (2a) zone, while the core (2b) has increased and almost suppressed (1b).

4.2 Change in Flow and Clearance Effects
Figures 4 and 5 present the pocket pressure profiles when both clearance and hydrostatic jet flow are varied, while rotation is kept at 1000 rpm. In Figures 4.1 and 5.1 the clearance is kept constant at 0.004 in (0.102 mm) while the flow is increased by a factor of two. The
examination of the photographs show the suppression of the Couette effect in Fig. 5.1, while the pocket pressure profiles show an increase of approximately 30% across the pocket in the direction of rotation. The rotation and change in flow conditions are similar in Figs. 4.2 and 5.2, respectively. However, the clearance has now been increased to 0.013 in (0.330 mm). An inspection of the photographs and pressure profiles shows that qualitatively and quantitatively the flow patterns and pressure magnitudes have only changed minutely. This indicates that for a pocket with aspect ratio of 1 for the flow and angular velocities studied here the clearance change has not a pronounced effect.

5 REFERENCES

Figure 3. Photographs of flow streams as a function of shaft rotation (with pocket aspect ratio = 1, flow rate = 0.0594 gal/min (225 cc/min), pocket depth = 0.7 inches (1.778 cm) and clearance = 0.013 inches (0.03302 cm))
Figure 4. Photographs of flow streams in the pocket and graphs of pressure distributions as a function of clearance (with 1000 rpm shaft rotation, pocket aspect ratio = 1, and pocket depth = 0.7 inches)

Figure 5. Photographs of flow streams in the pocket and graphs of pressure distributions as a function of clearance (with 1000 rpm shaft rotation, pocket aspect ratio = 1 and pocket depth = 0.7 inches)