AN EMPIRICAL FORMULA FOR EFFECTIVE RECESS PRESSURE IN RECTANGULAR GAS BEARINGS

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ABSTRACT

During the last 20 years, a lot of experimental and theoretical investigations concerning externally pressurized bearings were conducted in the fluid mechanics laboratory, Faculty of Engineering, Alexandria University. There was always remarkable deviation between the experimental and theoretical results due to the pressure depression observed at inlet region. This was minimized when the value of recess pressure used in the theoretical work was substituted by the experimental value of maximum pressure obtained after depression instead of the inlet pressure. The task of the present work is to use the great number of available experimental results to deduce an empirical formula relating the supply pressure and the effective recess pressure for an orific restricted externally pressurized rectangular gas bearing to help the designers working in this field to make proper estimation of bearing performance.

INTRODUCTION

The main reason for using gas as a lubricant is its low viscosity which means small internal shear and friction within the film. Further, the range of temperature over which the gas bearing may operate is very wide with slight changes in viscosity and without phase change or decompose. Gas lubrication also solves several contamination problems besides the advantage of good rigidity while it can be made quite stiff so that it adequately resists bearing motion with variations in load [1]. These advantages have resulted in numerous applications ranging from bearings for dental drills and variety of metrological and measuring instruments to bearings for jet engines [2 to 5].

According to this wide scope of applications, a research program concerning externally pressurized gas bearings has been underway in the mechanical engineering department in Alexandria University for about two decades. The results of this program have been published periodically [6 to 17]. The present investigation is a continuation of the same program in a trial to minimize the deviation between experimental and theoretical bearing performance. This deviation results mainly due to the pressure depression at the inlet region. This is very obvious in the measurements of pressure distribution obtained by Kassab [11]. Kassab calculated the pressure distribution along the bearing theoretically using two methods. In the first method, the measured inlet pressure was used as the recess pressure in the theoretical equation, while in the second method he used the maximum pressure obtained after depression. The results obtained using the second method showed more agreement with the experimental results than those obtained from the first method.

Since in practical applications, the supply pressure is the known parameter for the bearing designer, then it will be useful to have a relation between this supply pressure and the maximum pressure after depression as function of bearing dimensions and operating conditions. This relation will help the designer to obtain a value of recess pressure adequate enough to calculate more accurate values for bearing characteristics. To the best knowledge of the present author, no similar theoretical relation has exist yet for externally pressurized rectangular gas bearing using orifice resistrictor. This may be due to the fact that many variables are involved causing the theoretical analysis to be very complicated. This is clear in the analysis made by Mori and Miyamatsu [18] concerning the same problem in circular gas bearings.

The present investigation aims to use the available experimental results to deduce an empirical formula relating the effective recess pressure to the supply pressure for the considered type of bearing.

The experimental apparatus, from which experimental data was obtained, is briefly described in the following section followed by the results and their discussion in the next section, finally the conclusion will be given.

EXPERIMENTAL APPARATUS

The present investigation is based on a number of experimental runs by different investigators using the same set-up shown schematically in Figure 1. It consists of the apparatus (Figure 2), the hydraulic circuit, and the measuring devices. Detail description of the test apparatus is given by Salem and Shawky [9].

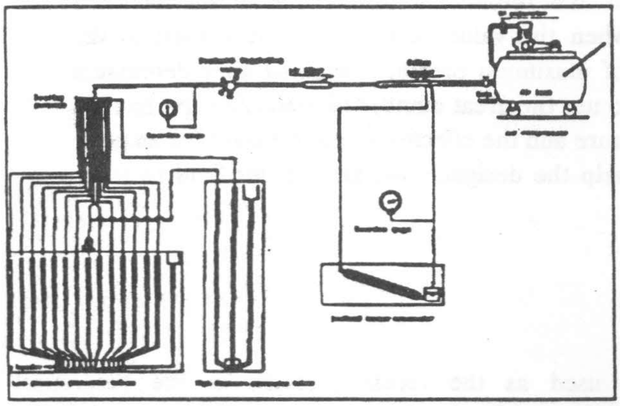

Figure 1. The experimental set-up.

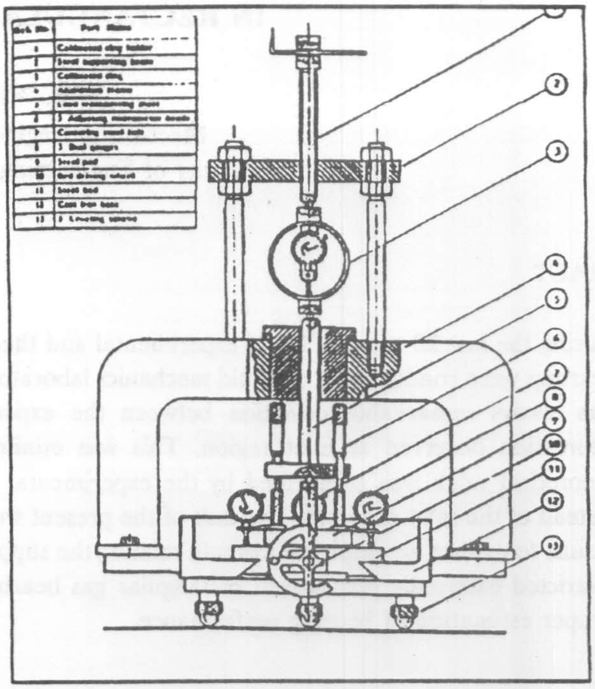

Figure 2. Test apparatus.

The deduced empirical formula is based on the experimental results obtained using air as a lubricant for the three pads of outer dimensions shown in Figure (3). They have outer width, B_o, to outer length, L_o, ratios of 1, 2/3 and 1/2. The outer length L_o for all these pads is the same and equal to 12.6 cm. The present investigation covers variation in bearing film thickness, H, ranging from 10 to 50 μm and supply pressure, P_s, ranging from 1.5 to 2.5 bar absolute.

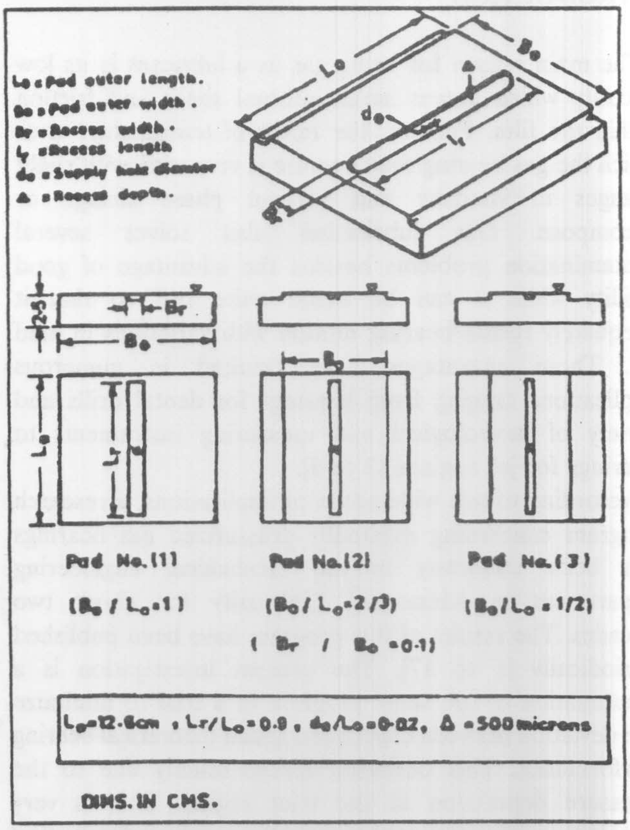

Figure 3. Tested pads.

RESULTS AND DISCUSSION

The pressure distribution along the bearing is one of the main parameters in calculating all other bearing characteristics. The load carrying capacity is a result of integrating the pressure over bearing area while the mass flow rate at certain film thickness, is a result of differential pressure between recess and ambient pressure. Thus accurate determination of pressure distribution is a must to conclude precise bearing performance. The pressure distribution was measured in many experiments [13] and Figure (4) is a sample of these measurements along bearing center line. The Figure shows the pressure

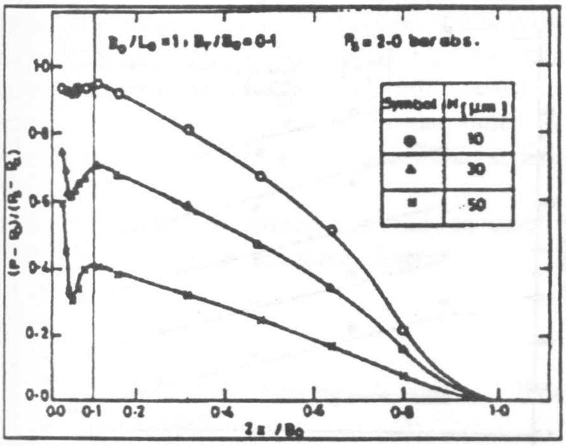

Figure 4. Pressure distribution along the bearing centerline for different film thicknesses.

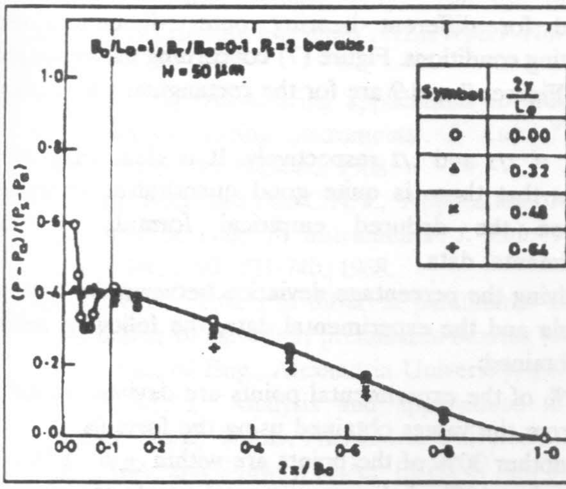

Figure 5. Pressure distribution along different lines parallel to the bearing centerline.

depression usually observed in the inlet region of gas bearings. In this region, the first point on the curve represents the pressure adjacent to supply hole which is considered as the inlet pressure to the bearing recess. This point is followed by sudden depression in pressure, which is more clear at large film thickness, to reach a minimum value followed by quick regain in pressure up to a maximum value less than the inlet pressure. The pressure distribution after this maximum value obtained after depression, starts to drop gradually along the bearing till it reaches the ambient pressure. To demonstrate the pressure distribution away from center line, Figure (5) is presented [11]. The Figure shows the pressure distribution at operating film thickness of 50 μm along different lines parallel to the bearing center line. This Figure shows that the pressure inside the recess far from the inlet region is nearly constant and equal to the maximum pressure reached after depression and completely deviated from the inlet pressure. This means that the assumption of constant pressure inside the recess is still valid, but the value of this pressure equals to the maximum pressure after depression and not to the inlet pressure.

Most of the investigators working is this filed [7,9,15] concluded theoretical relations for pressure distribution in the externally pressurized rectangular bearing assuming constant recess pressure. When they compared their results with experimental values, they found good qualitative agreement but not quantitative. This was a result of using constant recess pressure equal to the inlet pressure. Kassab [11] proved that the assumption of constant pressure in the recess leads to good quantitative agreement when the maximum pressure after depression is used as the effective recess pressure.

In order to obtain an empirical relation between this effective recess pressure (P_r) and supply pressure, Figure (6) is plotted. This Figure represents the relation between recess pressure, supply pressure, film thickness and bearing outer dimensions, each in a dimensionless form. It includes 57 experimental points. Each point represents the maximum pressure after depression and is extracted from a complete survey of the pressure distribution in the bearing area, i.e. extracted from about 40 experimental readings represented in a figure similiar to Figure (5). Figure (6) shows that the relation between the recess pressure and the film thickness, in their dimensionless form, at different bearing outer dimensions and supply pressures is linear and having constant gradient. As long as any line can be completely determined by the knowledge of its gradient and one of its points, so, it is required to have a relation that determines the coordinate of a point as a function of the different previously mentioned parameters.

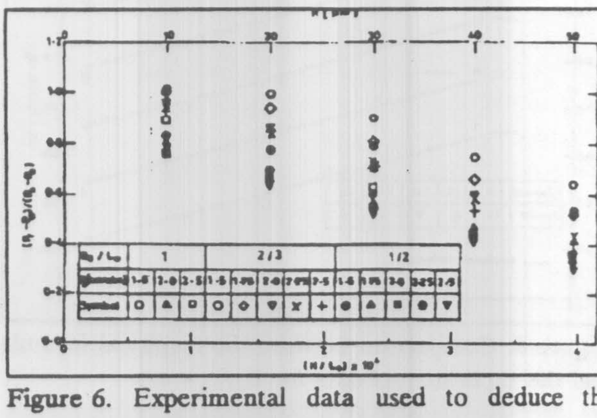

Figure 6. Experimental data used to deduce the empirical formula.

A preliminary study concerning the relation between effective recess pressure and bearing outer dimensions, for different film thicknesses and supply pressures, clarified that this relation is parabolic having its apix at $B_o/L_o \simeq 0.8$. This is in agreement with the results obtained by Shawky and Kassab [12]. Considering the previously mentioned geometrical relations between different parameters, the following empirical formula is obtained.

$$\frac{[P_r - P_a]}{[P_s - P_a]} = 3.95\left(\frac{B_o}{L_o}\right) - 2.5\left(\frac{B_o}{L_o}\right)^2 - 1386\left(\frac{H}{L_o}\right) - 0.16\,\frac{[P_s - P_a]}{P_a} - 0$$

where P_a = ambient pressure

To check the validity of this relation Figures (7 to 9) are

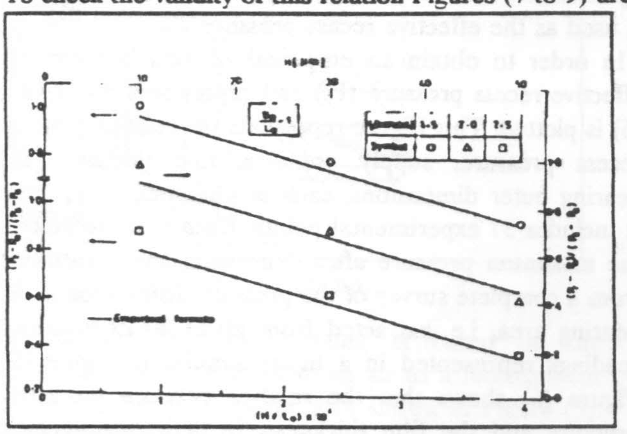

Figure 7. Comparison between the empirical formula and the experimental data for $B_o/L_o = 1$.

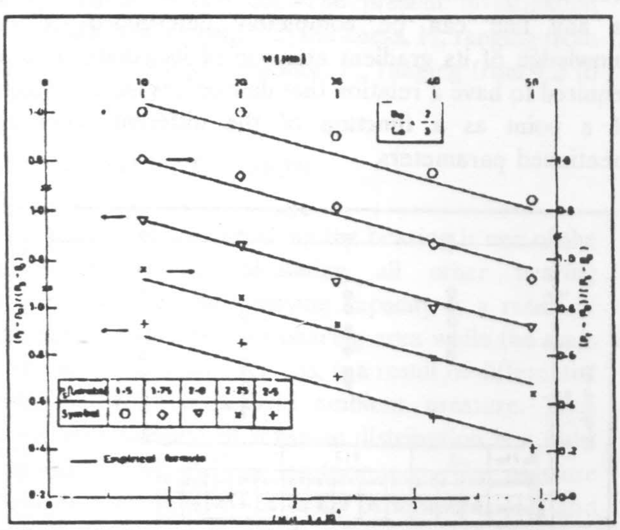

Figure 8. Comparison between the empirical formula and the experimental data for $B_o/L_o = 2/3$.

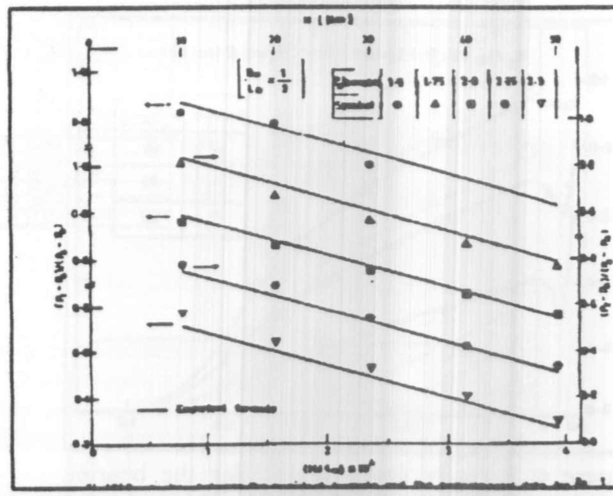

Figure 9.Comparison between the empirical formula and the experimental data for $B_o/L_o = 1/2$.

plotted for different bearing outer dimensions and operating conditions. Figure (7) concerning the square pad while Figures 8 and 9 are for the rectangular pads having

$B_o/L_o = 2/3$ and $1/2$ respectively. It is clear from these figures that there is quite good quantitative agreement between the deduced empirical formula and the experimental data.

Studying the percentage deviation between the deduced formula and the experimental data, the following results are obtained:

a) 60% of the experimental points are deviated within $\pm$ 5% from the values obtained using the formula.

b) Another 30% of the points are within $\pm$ 6 - 8 %.

c) The last 10% of the experimental points are within $\pm$ 9 - 10% .

It is important to note that in case of large film thickness the deviation is in the range of $\pm$ 10% due to the small value of the effective recess pressure which causes the percentage error to increase although the absolute values are close to each other.

CONCLUSION

The assumption of constant pressure inside the recess can be fairly used to calculate pressure distribution along the bearing region and consequently other bearing characteristics using the maximum value of pressure regained after depression as the effective recess pressure. For an externally pressurized rectangular gas bearing restricted with certain orifice an empirical formula can be obtained to relate this pressure to the outer supply pressure for different bearing outer dimensions at different operating conditions.

It is recommended to extend this study to cover wide range of restrictor types and dimensions.

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