DISCUSSION

D. R. Garner[2] and F. A. Martin[2]

The author is to be congratulated for presenting extensive dimensionless design data for thrust bearings. These data are orientated toward the use of point pivot tilting pads, and do indeed indicate certain benefits over line pivots. It should perhaps be pointed out that these benefits are not always attainable in practice because of mechanical strength considerations in the pivot. The point pivot, with its smaller contact area, would be higher stressed than a line pivot for a given pad load, and therefore under some circumstances a point pivoted pad must operate at less than its maximum hydrodynamic load capacity.

The final concluding remark in the paper, that the so called "Michell bearing" approximation in unsafe since it overestimates the load carrying capacity of tilted, flat, sector pads, caused some surprise. Computer programmes developed by the discussers' company have not shown such significant differences in the load carrying capacity of essentially similar oil film shapes, and accordingly test cases were run against the author's data to try and identify the cause of this contradiction.

Using the 30° pad case of Table 1 in the paper (chosen since it is a very practical pad size) the load capacity for the tilted, flat, sector was computed. The results are plotted in Fig. 7 as the three solid lines, with the author's results, taken from Table 1, shown as crosses; as can be seen the agreement is excellent. The thumbnail sketches of the pads are included to give a picture of the film shapes—the lines drawn within the pads being arbitrary contour lines.

Accordingly the same computer programme was then used to analyze the radial taper case (the Michell bearing), and this is plotted as the dotted line, with the corresponding results from Table 1 shown as circles. Obviously here is the disagreement—with the information used by the author (his reference [6]) showing the overestimate, and our results indicating a much reduced load capacity. Further investigation into reference [6] suggests that the results are inaccurate due to the relatively coarse mesh size used in the finite difference solution, and due to the method of step integration used.

Could the author, using his computer programme, confirm our results on the radial taper (Michell bearing) case. If so, then his conclusion about the radial taper bearing always predicting a larger load carrying capacity than the tilted flat sector is no longer true.

It is rightly stated in the paper that, for the tilted flat sector pad, the highest load capacity is obtained when the pad is so arranged that its mimimum film thickness occurs along the trailing edge. In non-tilting, or fixed inclined, pads it is quite possible, and indeed usual, to have the minimum film occurring not just over a line, but over a considerable area of the pad. This land area is provided so that a finite surface is available to support any external load when the bearing comes to rest, but additionally it can substantially improve the hydrodynamic action of the pad. As an example, a "parallel taper" with a land has been plotted in Fig. 7. This parallel taper is a very common and conveniently manufactured form, and in its limiting case where there is no land is exactly equivalent to the tilted flat sector with a pitch line at the leading edge (i.e. $\theta p/\beta = 0$). It can be seen from Fig. 7 that using 30 percent land area improves the hydrodynamic load capacity considerably—much more than by moving from $\theta p/\beta = 0$ to 1.

The benefit to be gained from using a land applies to the radial taper case also, and Fig. 8 shows the improvement as a function of the percentage land area.

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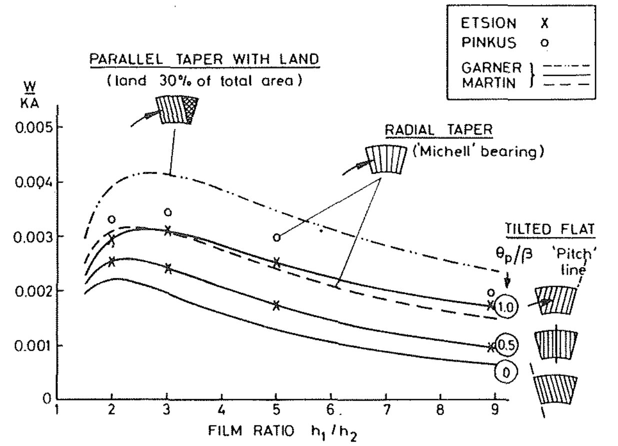

Fig. 7 Comparison of load capacity for various profiles ($r_i/r_o = 2/3$, $\beta = 30°$)

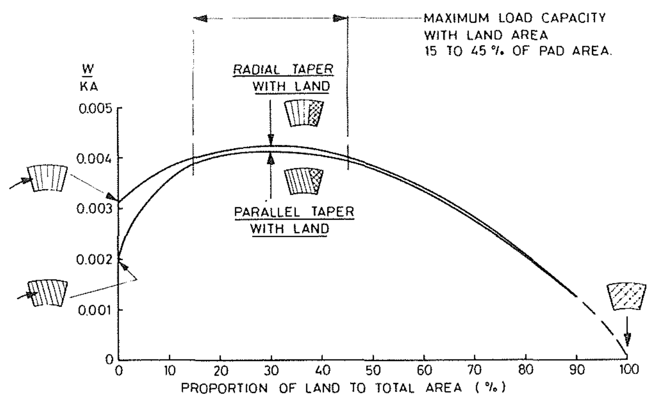

Fig. 8 Effect of land area on load capacity ($r_i/r_o = 2/3$, $\beta = 30°$, $h_1/h_2 = 3$)

The conclusion which we would draw from this study is that the author's results will underestimate the load capacity of fixed inclined pad bearings which have, as is common practice, an integral land area.

E. B. Arwas[3]

Dr. Etsion's paper is a worthwhile addition to the literature on liquid-lubricated, pad-type thrust bearings. The author's observation that any combination of pitch and roll of a flat bearing pad about its pivot point can be represented by a pure pitch about a certain radial line is a useful one that simplifies some of the subsequent analysis and data presentation.

The charts provided in the paper for calculation of pivot-point film thickness, minimum film thickness and shear loss in flat, sector-shaped pads should prove to be useful for such design calculations. However, potential users of the data should be cautioned that, par-

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ticularly with pivoted pad thrust bearings operating under conditions of high load and/or high power loss, there will be substantial crowning of the pads that will have a corresponding major effect on film thickness distribution and shear losses. For critical, high load and/or high speed applications, thrust bearing performance should still be calculated from analyses that treat simultaneously the Reynolds, Energy, and Elasticity equations.

The references cited by the author list some of the prior work on thrust bearing analysis and design charts. One omission here (at least in the early copy of the paper that was furnished to this reviewer) is the work of Messrs. A. A. Raimondi and J. Boyd. In particular, references [16, 17, and 18][4] may be of interest to people conducting thrust bearing design calculations.

Additional References

16 Raimondi, A. A. and Boyd, J., "Applying Bearing Theory to the Analysis and Design of Pad Type Bearings," ASME Paper 53-A-84.

17 Raimondi, A. A., "The Influence of Longitudinal and Transverse Profile on the Load Capacity of Pivoted Pad Bearings," TRANS. ASME, Vol 7, 1955, pp. 321–328.

18 Raimondi, A. A., "An Adibatic Solution for the Finite Slider Bearing (L/B = 1)," *Trans., ASLE,* Vol. 9, 1966, pp. 283–298.

[4] Numbers 16–18 in brackets designate Additional References at end of discussion.

Author's Closure

The author would like to thank the discussers for their comments and interest in the paper.

As to the remark on a higher stress in point pivots, it should be noted that a tilting pad bearing can be designed with a line pivot which is not radial but rather parallel to the pitch line and goes through the center of pressure. Such a design has all the benefits that point pivots have over radial line pivots without the disadvantage of high stresses at the pivot which may limit the maximum permissible load capacity.

The disagreement between Pinkus results [6] and the discussers results is indeed surprising. In [6] several solutions from other sources are compared and the agreement between all these solutions is quite good. In using the Michell bearing approximation the actual tilt of the pad is not accounted for. That is, the Michell bearing approximation treats any θ_p/β indifferently. It is obvious from Fig 7 that the overestimation due to this approximation is greatly increased as θ_p/β decreases, whether Pinkus results or Garner and Martin results are considered.

The author agrees that a "parallel taper" pad provides more load than a flat sector one. Other pad profiles like the stepped or shrouded stepped pad would give an even higher load. Finding an optimum profile that maximizes the load capacity of fixed pads is indeed an important task but altogether different from the objective of this paper.

Dr. Arwas remarks on pad crowning are correct and the additional information is appreciated.