## Conclusions

This paper has shown how the simplified analysis of bearing distortion to a spherical cap can be extended to a more general profile and how the mode of heat removal from the bearing is included. The use of the simplified program permits easy generalization. A wide variety of conditions is contained in relatively few curves. Use of the comprehensive method would have required many diagrams to account for the different heat transfer modes.

In the worked example a spiral-grooved thrust bearing was considered. The design was for inward pumping and maximum load capacity. There is no reason, however, why the methods presented should not be valid for a design for absolute stability.

During thrust bearing operation, self-heating causes thermal distortion. With the information provided the consequent effects on performance can be determined.

## Acknowledgments

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## References

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2 Malanoski, S. B., and Pan, C. H. T., "The Static and Dynamic Characteristics of the Spiral-Grooved Thrust Bearing," JOURNAL OF BASIC ENGINEERING, TRANS. ASME, Series D, Vol. 87, No. 3, Sept. 1965, pp. 547–558.

3 Ralston, Anthony, and Wilf, Herbert S., *Mathematical Methods for Digital Computers*, Wiley, New York, 1960.

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# DISCUSSION

## R. B. Gildersleeve[2]

The methods outlined in the "comprehensive" section of this paper treat the design of a thrust bearing realistically instead of considering the design to be an exercise in fluid mechanics. The authors are to be congratulated for a fine paper. Previous work by Pan and Sternlicht[3] assumed a systen that was so simplified mechanically that it no longer had any relevance to real hardware problems. However, there are still some rather arbitrary assumptions made regarding boundary conditions. In particular, one can and should do more than assume the fraction of heat absorbed by the distorting member. Since gas bearings have inherently low load capacity, much care must be exercised in integrating them into usable machines. A thermal analyses of the complete machine application will specify boundary conditions. The exact performance of the candidate thrust bearing will therefore be determined by how successfully the machine integration has been accomplished.

## C. H. T. Pan[4]

This paper is a sequel of an earlier work [1], of which this discusser shares the coauthorship. As before, the main concern is the degradation of load capacity due to self-heating. Two worthwhile contributions are contained in the present work. The first one is a more accurate calculation of the power loss. It is gratifying to note from Figs. 5, 6, and 7 that the "power loss factor" is fairly insensitive to the "curvature index" so that, in most instances, one can use the flat disc "power loss factor" if an inaccuracy of about 2.5% in the "curvature index" is acceptable. The second worthwhile contribution is the consideration of radial heat flux. The possibility of using a single "heat transfer mode coefficient" to account for this effect is most convenient. A remark was made indicating that the axial thermal expansion led to a reduction in the load degradation. It appears that if the radial heat flux is outwardly directed, the axial thermal expansion would cause the gap to increase in the same direction, then the load degradation would worsen. Perhaps the authors' remark only applies to the case that the radial heat flux is inwardly directed? To consider the thermal distortion of the thrust bearing in a machine, the "heat transfer mode coefficient" would have to be established by an appropriate thermal map. Once this becomes available, then the results of the present paper can be applied directly. The value of the present paper is the compilation of distortion and load-degradation calculations once for all. The inclusion of rather complete design analysis oriented information should be most welcome to practically inclined readers.

[2] Airesearch Manufacturing Co., Phoenix Ariz.

[3] Pan, C. H. T., and Sternlicht, B., "Thermal Distortion of Spiral-Grooved Gas-Lubricated Thrust Bearings Due to Self-Heating," JOURNAL OF LUBRICATION TECHNOLOGY, TRANS. A.S.M.E., Series F, Vol. No. 2, Apr. 1967, pp. 197–202.

[4] Mechanical Technology Inc., Latham, N. Y.

## Authors' Closure

The authors are greatly indebted to the discussers for their pertinent comments.

In general a comprehensive thermal analysis which yields a thermal map of the machine in question is necessary, but this becomes too complicated and expensive if it is used to carry out detailed bearing calculations. Given the thermal boundary conditions from such analysis in broad terms the present analysis, as an extension of the Pan and Sternlicht analysis, can be used effectively for the rapid determination of the anticipated bearing performance.

The remark concerning the beneficial effect of axial thermal expansion was made with reference to the condition of purely axial heat flow; if axial thermal expansion is included, then, in the absence of axial cooling, radial heat flow inwards would act to improve the load degradation, whereas radial heat flow outwards would act to worsen it.