theless it may be stated that, in applications with surface speeds of less than about 5 m/s, such a bearing with suitably chosen groove dimensions and lubricant will not leak, even in eccentric operating conditions.

References

1 Bootsma, J., "The Gas-to-Liquid Interface of Spiral Groove Journal Bearings and its Effect on Stability," JOURNAL OF LUBRICATION TECHNOLOGY, TRANS. ASME, Series F, Vol. 96, 1974, pp. 337–345.

2 Bootsma, J., "Liquid-Lubricated Spiral-Groove Bearings," Thesis, University of Technology, Delft, 1975, and Philips Research Reports Supplement, 1975, No. 7.

3 McGrew, J. M., and McHugh, J. D., "Analysis and Test of the Screw Seal in Laminar and Turbulent Operation." *Journal of Basic Engineering, TRANS. ASME,* Series D, Vol. 87, 1965, pp. 153–162.

4 King, A. E., "Screw Type Shaft Seals for Potassium Lubricated Generators," Supplement to *IEEE Trans. on Aerospace,* 1965, pp. 471–479.

5 Stair, W. K., and Hale, R. H., "The Turbulent Viscoseal-Theory and Experiment," *Third International Conference on Fluid Sealing, BHRA,* Paper H2, Cambridge, England, 1967.

6 Zuk, J., Strom, T. N., Ludwig, L. P., and Johnson, R. L., "Convective Inertia and Gas Ingestion Effects on Flow Regimes of The Viscoseals; Theory and Experiment," *ASLE Trans.*, Vol. 10, 1967, pp. 273–293.

7 Fisher, C. F., and Stair, W. K., "On Gas Ingestion and Fluid Inertia Effects in Viscoseals," *Fourth International Conference on Fluid Sealing, ASLE-BHRA-ASME,* Paper 31, Philadelphia, Pa., 1969.

8 Heslenfeld, M. W., and Braat, A. M. M., "Comparison of Viscoseals and Mechanical Seals for Application in Sodium Pumps in a Nuclear Power Plant," *Seventh International Conference on Fluid Sealing, BHRA,* Paper H2, Nottingham, 1975.

9 Crease, A. B., "Windback Seals—a Simple Theory and Design Method and The Main Practical Limitations," *Seventh International Conference on Fluid Sealing, BHRA,* Paper H1, Nottingham, 1975.

10 Muijderman, E. A., "New Possibilities for The Solution of Bearing Problems by Means of The Spiral Groove Principle," *Proceedings Institute of Mechanical Engineers,* Vol. 180, 1965/66, pp. 174–183.

11 Remmers, G., "Grease-Lubricated Spiral-Groove Bearings of Plastic: Full-Time Lubrication for Consumer Products," Convention Tribology 1976, *Institute of Mechanical Engineers,* Paper 3, Durham.

12 Coyne, J. C., and Elrod, H. G., "Conditions of Rupture of a Lubricating Film. Part 1: Theoretical Model," JOURNAL OF LUBRICATION TECHNOLOGY, TRANS. ASME, Series F, Vol. 92, 1970, pp. 451–456.

DISCUSSION

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The problem taken up by the authors is one of importance which has received little attention in the past. A leakage-free journal bearing could be very useful in many applications where a clean environment is desired. The leakage-free bearing eliminates the need for seals and can therefore result in simpler, less expensive, and more reliable systems. However, the present concept, which is based on the surface tension of the lubricant, seems to be limited to low speed and small eccentricity; that is, low load capacity. From Fig. 4 the surface speed at which leakage commences is 2 m/s for $\epsilon = 0.3$ and only 1 m/s for $\epsilon = 0.8$. Further reduction in load capacity will result from poor cooling of the bearing. This is due to the fact that heat is not removed from the bearing by out-flow of hot lubricant.

Could the authors provide more information about temperature range in their experiments? What would be the reduction in load capacity of a leakage free bearing compared with a leaking bearing operating at the same eccentricity and having the same bearing width. In a recent paper[3] another concept of a leakage free journal bearing, based on lubricant supply adjustment, is described. This concept is not limited by speed or eccentricity and provides the bearing with a better cooling capacity. The load reduction with respect to a leaking bearing having an L/D ratio of 1 (where L is the width of the bearing) is about 37 percent at $\epsilon = 0.9$ and 24 percent at $\epsilon = 0.2$.

One remark should be made regarding the calculation of the theoretical speed and Weber number related to interface breakdown. In equation (3) the radial pressure change, due to centrifugal effects, is preserved on the liquid side of the interface but neglected on the air side. The pressure change in the liquid inside the bearing as can be found in [2] (see equations 8.17 and 8.22 in [2]) is

$$p_s = p_b - \frac{1}{3}\rho U^2 \left(\frac{\Delta R}{R}\right) \tag{19}$$

where p_s and p_b are the pressures on the shaft and the bearing, respectively, and U is the shaft surface speed $U = \omega R$. Outside the bearing the air pressure on the shaft is

$$p_s = p_a - \frac{1}{2}\rho_a U^2 \tag{20}$$

where ρ_a is the air density. Hence, for a given speed U, the pressure drop on the air side of the interface is affected by ρ_a while on the oil side this pressure drop is affected by $(\Delta R/R)\rho$. For typical values of ρ_a, ρ, and $\Delta R/R$, the pressure drop in the air, due to centrifugal effects, is therefore about 3 to 10 percent of the pressure drop in the oil and should not be neglected.

Authors' Closure

The authors would like to thank Dr. Etsion for his interest in this work and to comment on the discussion put forward by him.

As any bearing, a leakage-free herringbone grooved journal bearing has its advantages and drawbacks. The advantages of this type of bearing are utilized in small consumer articles, but also in very advanced applications like momentum wheels for space vehicles [10]. Owing to the pumping action of the grooves, it is possible without mechanical means such as sump, circulation pump and seals, to obtain a self-acting fluid film bearing with good stability properties having a long life without relubrication. For applications with imbalance loads where the deviations from the central position of the shaft in the bearing must be small, excellent results can be obtained by using a herringbone grooved journal bearing.

In respect of big heavily loaded systems where the mechanical means are small relative to the bearing a leakage free herringbone bearing is inferior to a smooth journal bearing because in journal bearings with an eccentricity above 0.3 grooves decrease the load capacity [2].

We may say that a small bearing, unlike a large heavily loaded bearing system develops relatively little frictional heat, which can usually be removed by conduction, without substantially lowering the load capacity.

As compared to the widely applied porous bearing, the life, stiffness and hence the stability of a leakage-free herringbone grooved journal bearing is considerably higher, whereas its noise level is lower. The production cost is higher for metal herringbone grooved journal bearings than for porous bearings. By making the herringbone grooved journal bearing from plastic instead of metal a qualitatively good and inexpensive bearing for many small bearing systems can be obtained [11].

As regards Dr. Etsion's note concerning the pressure drop on the air side of the interface, it should be noted that, on integrating

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equation (2), in which $u(r)$ is given by equation (1), with respect to r we get

$$p_s = p_b \exp\left(-\frac{1}{3} C U^2 \frac{\Delta R}{R}\right)$$

where Dr. Etsion's notation according to equation (19) has been used and the constant C is equal to $(\rho/p)_{\mathrm{air}}$. This is the relation of p_s and p_b for air being considered as compressible on the air side of the interface in the bearing gap. If the air is considered to be incompressible, then the calculated pressure drop becomes higher. In this case the pressure is given by equation (19). With ρ (= ρ lubricant) replaced by ρ air and cannot be expressed by equation (20). Since ρ air/ρ lubricant ≈ 0.0015, the pressure drop on the air side is very small as compared to the pressure drop in the lubricant film and hence is neglected.