DISCUSSION

L. J. Nypan[2]

The authors are to be commended for providing such novel and ingenious concept. In addition to the concept and analytical predictions of potential performance, experimental work is reported to verify that speed reductions of 33 percent may be realized.

A possibile difficulty in the application of the concept to larger diameter bearings than the 75-mm-bore ball bearing tested may lie in the difficulty of matching the torque characteristics of the fluid film bearings with that of larger ball bearings. From equation (13) of the authors' paper, the thrust bearing fluid film friction is proportional to the fourth power of the radius. Ball bearing friction might be expected to be nearly proportional to the first power of the radius. While the experimental results indicate a promising performance for the 75-mm-bore ball bearing, a larger assembly might have a considerably larger fluid film friction torque than ball bearing friction torque so that the larger fluid film bearing might behave more like a static fluid film damper than an active speed sharing device.

It would seem that a conical hydrostatic bearing designed for minimum friction could provide a better friction torque match than the experimental fluid film journal and thrust bearing assembly. Careful attention to fluid film bearing design to match the ball bearing friction torque-speed characteristic may be necessary to produce useful series hybrid bearings of larger size.

J. H. Rumbarger[3] and E. G. Filetti[3]

The authors' work is a significant contribution to the design of higher speed bearings for jet engine main shaft applications. Four million DN bearings will be needed in the near future. Research is currently pointing towards this speed regime. The use of an oil film inner bearing to provide a speed differential, thereby reducing the speed of the rolling element bearing and especially the cage and rolling element complement, is of great interest. The subject program was a good blend of theory and experiment to show feasibility.

With additional emphasis placed upon the design of the oil film bearings, it is felt that a better speed-sharing ratio could be obtained. This will come as a result of optimization of oil film bearing designs to minimize frictional torque. Current work at The Franklin Institute for design of a high speed main shaft roller bearing includes consideration of a series hybrid concept. In this roller bearing application, the oil film bearing between the shaft and inner race carrying radial load becomes most important. Thrust surfaces for location of the inner race are of secondary importance because of low thrust values. The authors' program for a thrust ball bearing demanded close attention to the oil film thrust bearing as the major load member, and the oil film journal bearings were used for location purposes only. Hence, the stability of the oil film journal bearings must be studied in much more detail for future applications. Perhaps, journal bearing instability could be an explanation of the slight scuffing of the journal bearing surface observed after test. In any event, the journal bearing area presents a challenging problem of boundary lubrication at initial start-up or lift-off until a full speed differential is realized. Materials combinations will be all important.

The present application was not affected by the load capacity of the journal bearing. However, it should be noted that for two rotating bodies operating at speeds in the same rotational direction the sum of the two angular velocities should be used in computing the hydrodynamic load effect.[4] Equation (12) of the paper suggests the use of the difference of the relative speeds. This is correct only for a description of the frictional shear of the fluids.

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[4] Shapiro, W., Colsher, R., and Decker, O., "Analysis and Selection of Fluid Film Bearings for Spool Shaft Gas Turbines," Journal of Lubrication Technology, Trans. ASME, Series F, Vol. 92, No. 4, Oct. 1970, pp. 597–606.

L. W. Winn[5] and D. F. Wilcock[5]

The concept of sharing load between a fluid-film bearing and a rolling element bearing,[6] has made possible order of magnitude extensions of bearing life at normal speeds. The authors have astutely pointed out that for very high speed bearings, where centrifugal forces severely limit life, sharing the speed between these two types of bearing is a most effective means of increasing life. In doing so, they have assumed that the rolling element bearing is the outer, lower speed, element and that the fluid film bearing is operating at a differential speed, the full magnitude of which depends upon the torque balance between the rolling element and fluid-film bearing. The authors have furthermore considered as a prime example, an application which is loaded in thrust. This indeed is a fortunate choice, inasmuch as a large number of bearing problems associated with jet engine applications can be attributed to the main thrust bearing. In a jet engine the main radial loads (which are usually low compared to the thrust loads), are normally carried by roller bearings, and the thrust carrying capacity can be, and normally is, decoupled from the radial capacity through a radially "floating" thrust bearing outer race.

Let us consider, however, applying the concept to radial load bearings and the implications of the location of the rolling element bearing. If for some reason the fluid film bearing fails, and it is located on the shaft or inner position, a failure of this bearing may result in an eccentric position of the rotor. The rolling element bearing will continue to operate, but there will be a rotating load

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[6] Wilcock, D. F., and Winn, L. W., "The Hybrid Boost Bearing—A Method of Obtaining Long Life in Rolling Contact Bearing Applications," Journal of Lubrication Technology, Trans. ASME, Vol. 92, Series F, No. 3, July 1970, pp. 406–412.

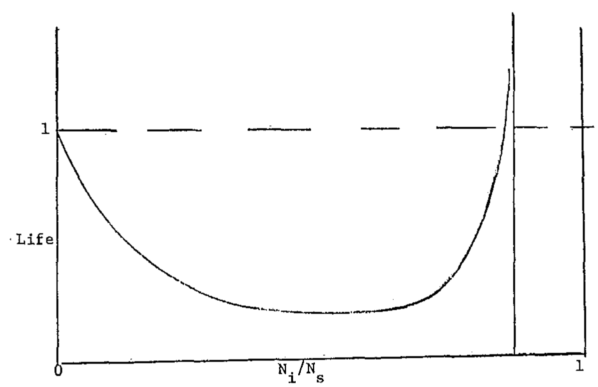

Fig. 11 Relative life of ball bearing with race rotating at speed N_i (fluid film outer)

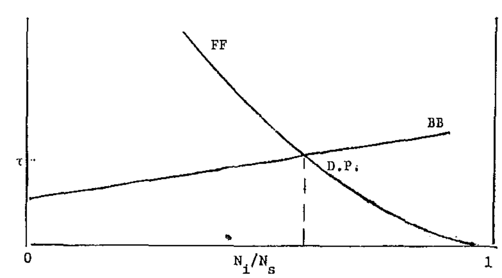

Fig. 12 Torque match in a series of hybrid bearing (fluid film inner)

due to the shaft eccentricity. This situation may be avoided by moving the fluid film bearing to the outer position. However, in this case, the life improvement due to speed sharing is extremely difficult to attain since with both races rotating the rolling elements are orbiting at a higher speed. The life versus relative speed relation is as shown schematically in Fig. 11. For this type of bearing to be truly effective, the outer race speed must approach that of the inner race within 90 percent or better.

This reasoning leads us to conclude that the authors were correct in the configuration they chose. However, additional design thinking will be helpful in order to avoid eccentric rotating loading in the event of fluid film failure.

Power consumption is an important consideration in evaluating hybrid bearings for aircraft application. Fig. 12 shows the nature of the torque balance in a series hybrid bearing of the authors' type. The operating torque at D.P. is lower than for either bearing alone, and therefore the total power loss may also be lower. However, the power consumed in pumping the fluid-film flow through the shaft must also be added, since it too results in heat rejection in the aircraft. There is not sufficient data to calculate this additional loss. This additional loss can easily be calculated from the pressure and flow relationships.

It is indeed refreshing to note novel, perhaps unconventional approaches to the solutions of high-speed bearing problems. The authors should be complemented for this unique mating of the fluid-film and rolling element bearing to achieve the stated purpose: i.e., extension of bearing life.

Authors' Closure

The authors wish to thank the discussers for their pertinent comments. Professor Nypan's discussion of size effect is quite relevant because large aircraft turbine engine rotor bearings are generally larger than the test bearing used in this program. The fluid film bearing design used was, however, far from optimum. It is hoped, therefore, that any losses in speed sharing capability due to size increases can be made up in the design optimization.

Mr. Rumbarger's point on journal bearing instability is well taken. A conical fluid film bearing capable of supporting both axial and radial loads has been studied at the authors' laboratory for that very reason.[7] In this case the authors attribute journal bearing scuffing to oil starvation rather than to instability. The addition of feed holes to the journal bearing in the modified design corrected this trouble.

Mr. Rumbarger's point on the load capacity is quite correct. Equation (12) should contain the sum of ω_1 and ω_2 rather than the difference. This reveals, however, that it is not necessary to achieve the full speed differential to develop load capacity, as implied in Mr. Rumbarger's discussion of materials.

The problem of introducing a rotating load as a consequence of fluid film bearing failure is a real one. Here again, however, a conical fluid film may attenuate or eliminate that problem. Such a bearing should tend to be self-centering if a thrust load is present. Experiments are needed to define the behavior of the hybrid bearing when the fluid film bearing fails.

Moving the fluid film bearing to the outer position would not, as Messrs. Winn and Wilcock state, result in any life improvement unless speed reductions of 90 percent or better are achieved. This is only possible with fluids having extremely low viscosities, such as liquid hydrogen or gases.

[7] Nypan, L. J., Hamrock, B. J., Scibbe, H. W., and Anderson, W. J., "Optimization of Conical Hydrostatic Bearing for Minimum Friction," JOURNAL OF LUBRICATION TECHNOLOGY, TRANS. ASME, Series F, Vol. 99, No. 2, Apr. 1972, p. 136.