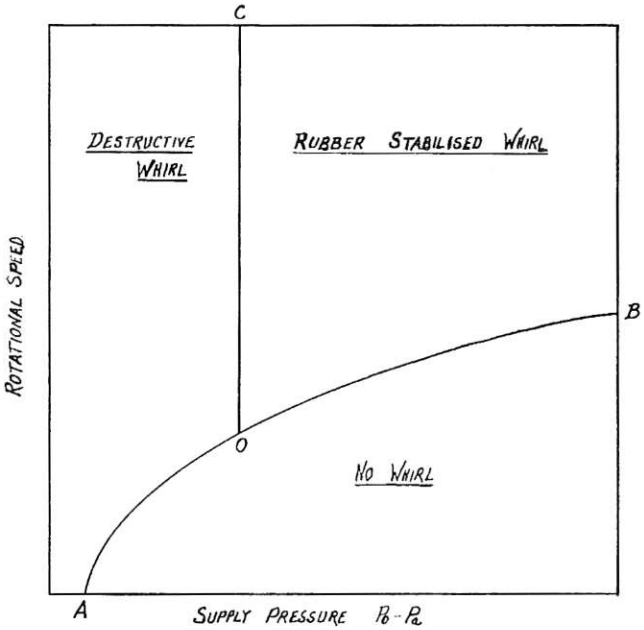

Fig. 10 Stability diagram for rubber mounted bearing systems

motor. However the capacitance probes confirmed that the rotor whirl was in the conical mode.

At ambient temperatures (20 deg C ± 5 deg) it was found that butyl "O" rings were the most effective in suppressing whirl. With 75 deg hardness "O" rings no whirl was observed at speeds up to 65,000 rpm at bearing supply pressures above 14 psig. This performance was superior to that with 60 deg nitrile "O" rings but both 50 deg nitrile and 50 deg butyl provided stable operation up to 65,000 rpm at pressures above 10 psig. These results again emphasized the effectiveness of soft "O" rings.

Testing at elevated temperatures immediately revealed the limitations of nitrile and butyl rubbers. Butyl "O" rings were found to loose their ability to suppress whirl at about 80 deg C and this result appeared to be largely independent of hardness number or air supply pressure. The whirl onset was observed to be sudden and failure would undoubtedly result from such a temperature rise occurring in service.

Two types of rubbers have been developed for use at high temperatures. These are fluorinated hydrocarbon rubber (viton) and silicone rubber. Unfortunately neither of these rubbers are available in the softer grades. The grades tested were 60 and 70 deg in silicone rubber and 70 and 90 deg in viton rubber.

Both types of rubber showed a deteriorating performance with rising temperature but both were remarkable in being able to provide stable operation at temperatures up to 160 deg C which was the highest "O" ring temperature that could be maintained. The viton "O" rings showed a small but significant superiority over the silicone rings. 60° silicone "O" rings were better than 70° silicone and roughly comparable to 70° viton. 90° viton "O" rings performed much better than expected. They were inferior to 70° viton at ambient temperature but maintained almost constant performance at temperatures up to 160 deg C, so that at the higher temperatures the performances were almost identical. Thus 90° viton "O" rings could provide a whirl stabilized bearing system which was effectively independent of temperature over the range 20 C to 160 deg C.

Comparing the experience with the two test machines it is apparent that, on the larger machine with bearings of greater stiffness, rubbers of higher hardness number could be effectively employed. It is an impressive demonstration of the effectiveness of this method of whirl suppression to observe a machine running at well over twice its whirl onset speed for rigid bearings on rubber "O" rings as hard as the heel of ones shoe and continuing to operate without any observable manifestation of whirl even at a temperature of 160 deg C.

Conclusions

The following conclusions can be drawn concerning the use of rubber "O" rings for the whirl stabilization of high speed machines.

1 At ambient temperature all the rubbers tested could be used in their softer grades (less than 60°).

2 At elevated temperatures (80 C to 160 deg C) of the rubbers tested only viton and silicone "O" rings can be used.

3 The effectiveness of all rubbers tested decreased with hardness number.

4 The effectiveness of all rubbers tested tended to decrease with temperature but only slightly in the case of 90° viton.

5 A high loss angle is desirable and of the rubbers tested butyl was outstanding in this respect and performed very well at ambient temperatures.

6 Increasing the bearing supply pressure by increasing the gas film stiffness increases the energy absorption in the rubber and provides a powerful whirl offsetting effect.

7 Harder rubbers can be used on larger machines with stiffer bearings. On small machines only very soft "O" rings appear to be effective.

8 It is important to minimize the mass and inertia of the bearing sleeves. A high mass or inertia can give rise to a destructive bearing whirl.

9 In a machine which must operate at a fixed supply pressure a reduction in bearing clearance can increase the gas film stiffness to permit the effective operation of the rubber.

10 Within the limits investigated (2–12 percent) the amount of precompression of the "O" rings was found to have no significant effect upon the whirl stabilization.

It may be concluded that rubber "O" rings can provide a simple and very effective method of whirl stabilization of air bearings for high speed machines. A wide variety of rubber compounds are available, and, while there is a lack of precise design data in terms of dynamic properties of "O" rings, two or three suitable rubbers can usually be chosen for a particular application. The final selection can be quickly determined from tests on a prototype machine. In the future, high speed machines with rubber stabilized air bearings could find widescale application for scientific and industrial purposes.

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DISCUSSION

H. J. Wood[2]

I have used rubber mountings of hydrodynamic bearings similar to those described in the subject paper since 1947. All were oil-lubricated systems. The most prominent application was on the first small gas turbine (AiResearch model GTC-43/44) to see profitable series production. Our approach was highly empirical, and I am delighted to see some quantitative information become available for bearing mountings of this sort.

[2] H. J. Wood and Associates, Mechanical Engineering Consultants, Sherman Oaks, Calif.

In the applications with which I have been associated, the oil film trapped between the "O" rings had a radial clearance which was a small multiple of the inner journal clearance. The subject paper does not indicate what clearance ratio was involved in their testing, but one gets the impression that it was a high multiple of the journal clearance. From experience with floating bushings with and without "O" rings, I am quite sure that the outer films has a major damping effect on half order whirl when the clearance ratio is of the order of three. I would expect similar results with gas-lubricated bearings. It would be interesting to have the author's comments on this point. The theoretical base for a clearance ratio of three is given in my reference paper.[3]

[3] Wood, H. J., "Nonlinear Vibration Damping Functions for Fluid Film Bearings." SAE Paper No. 670061, presented at the Automatic Engineering Conference, Detroit, Mich., Jan. 1967.

Authors' Closure

We were interested to learn of Mr. Woods parallel experience with rubber mounted air bearings. We can understand the effectiveness of an outer oil film formed in the space between the 'O' rings between the outer surface of the bearing bush and the housing bore. We suspected such an effect with air and initially maintained a ratio of clearances of the order two to three. Any advantage, however, proved too small to measure and under some conditions the bearing bush could contact the housing bore, for example when an airborne machine was subjected to gyroscopic forces. Eventually the clearance between the bush and the housing became established at about ten times the bearing clearance. However, where flexibly mounted bearings are used in combination with a rigid thrust bearing assembly it is often desirable to limit the maximum permissable radial deflection to avoid contact of the thrust bearing surfaces.