The patent literature shows a wide variety of bearing cross-sectional geometries. Undercut or grooved rings have been proposed to increase resilience, to accommodate sudden increase in load, to permit better control of preload, to provide for better cooling, etc. Some of these are listed in reference [4].

Summary

The following is a summary of the results presented:

1 It was found that a modification of a standard ball bearing's cross-sectional geometry by undercutting the raceways to reduce the bearing's spring rate improves the bearing's spalling fatigue durability under a heavy radial load. Bearings of two different cross-sectional geometries were tested which were chosen to bracket a possible and practical range. Two independent tests were made of bearings with a shallow circular arc undercut (0.015 in. deep, Fig. 2) giving a stiffness reduction of 20 percent which showed a significantly increased fatigue life over the standard bearings. The confidence that an improvement exists was determined to be 93 percent at the B-10 life level. One test was made with a deep undercut (0.070 in.) as an upper practical limit. These bearings failed early by bending fatigue indicating 0.070 in. to be an excessive undercut. An optimum value of undercut giving greater improvements would probably lie somewhere between the levels tested.

2 Static deflection tests were made showing the reduction of radial stiffness with the amount of circular arc undercut. A reduction of something less than 50 percent in stiffness is the maximum that could be used with this type geometry change in view of the durability test results.

3 Static deflection tests were also made showing how radial stiffness varies with ball position and how this is modified by an undercut. Stiffness variations between saddle position of the ball and load line midway between balls is reduced by the undercut. This indicates that the load is distributed more uniformly among balls in the more compliant bearing. This also suggests that force oscillations and, hence, bearing-induced vibrations would be less for the undercut bearing. In addition, reducing the bearings radial spring rate makes the bearings less sensitive to contacting surface irregularities and lubricant slugs.

4 When designing a ball bearing cross-sectional geometry to take advantage of elasticity, obviously one must take into account the tensile stresses in the rings and the prospect of bending fatigue mode of failure.

5 The bearing fatigue life can be substantially improved if the flexibility and fit can be designed for a load of known type and magnitude. Improvement in life for one given bearing undercut and general loading conditions was tested.

References

1 Johnson, L. G., *The Statistical Treatment of Fatigue Experiments*, Elsevier Publishing Company, Amsterdam, 1964.

2 Robinson, J. F., Shackelford, L. A., and Joffs, R. E., "The Compliant Ball Bearing," American Ordnance Association Ball Bearing Conference, Dartmouth College, Hanover, N. H., Sept. 4–6, 1968.

3 Kepple, R. K., and Mattson, R. L., "Rolling Element Fatigue and Macro-Residual Stress," Journal of Lubrication Technology, Trans. ASME, Series F, Vol. 92, No. 1, Jan. 1970, pp. 76–82.

4 British Patent Number 206,530; U. S. Patents Numbers 1,305,-131; 2,217,801; 2,283,839; 3,404,925, and 3,504,955.

DISCUSSION

K. M. Gordon[2]

The experimental results contained in this paper are qualitatively similar to results of tests that we have run on much smaller bearings to evaluate the effect of undercuts behind the ball groove on bearing life. It has been our experience that the biggest percentage gain is obtained with a minimum undercut, and increasing the undercut beyond this point results in diminishing percentage returns until one reaches the point where the race gets so weak that bending fatigue sets in and early catastrophic failures ensue. I feel that the reason for this is the fact that the initial undercut changes the fundamental loading of the race system from that of a beam on a continuous foundation with central load to a simple beam supported on both ends and loaded in the middle. There is a dramatic change in stress and deflection between these loading conditions.

The authors' results with regard to the affect of undercutting the raceways on the noise and vibration characteristic of the bearing, opens up a new and intriguing area of investigation which may well prove to have profitable consequences and should be pursued further.

Authors' Closure

The authors wish to thank K. M. Gordon for his remarks. We agree that there is a dramatic difference in the beam with continuous support conditions, as in the case with no-undercut, and the beam support for small undercut conditions. We disagree, however, on his implication that the maximum improvement is obtained with minimum undercut. In our view, there should be an optimum transverse cross section. The beam stiffness distribution should be such that the ball-to-race Hertzian stress distribution covers the largest practical area with the lowest peak value for the given design load. Hence, the optimum undercut shape would depend upon the initial conformity of the ball to the race, the stiffness characteristics of the nonundercut races, and the design load. In some special cases a small undercut may well be close to the best as was observed by Mr. Gordon, but we would hesitate to support the view that this would generally be true.

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