Design Optimization of High Speed Axially Loaded Ball Bearings of a Turbo-pump

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Introduction

In the turbo-pump design, the bearings are required to operate at high speed under large misalignment. The misalignment imposed on the bearings is generated by a combination of: 1) Rotor flexibility; 2) Changes in bearing support stiffness due to changes in temperature and vacuum; 3) Geometric tolerance build-up; 4) Unbalance magnetic pull.

This Turbo-pump has a design similar to a multi-stage axial flow compressor and is used to create ultra-high vacuum environment. It consists of a single flexible rotor supported on two precision grease lubricated angular contact ball bearings, and rotates at 52,000 RPM using a three phase induction motor. The bearings are axially preloaded to prevent gross sliding motion, i.e., skidding, between the balls and the raceways. The bearings are supported by rings made of elastomer (inserted between the bearing outer race and the main housing) in order to protect the bearings against lateral vibrations caused by unbalance (during both normal running condition and final stage of balancing).

Frequent failure of one of the bearings was encountered during the development phase of this pump. In all cases, detailed surface analysis revealed that the bearings suffered from excessive friction and heat generation which consequently resulted in a cage failure.

Measurements

Vibration measurements carried out on this pump are presented in figure 1 and 2. Figure 1 shows a typical vibration measurement up to 2.0 KHz frequency range. The existence of spectral peaks at cage frequency, shaft operating speed and its first harmonic are quite apparent. In all our measurements, the amplitude of vibration at cage frequency for one of the bearing was excessive which suggested that the bearing cage was under severe stress. This information was also supported when further measurements were carried out at a higher frequency range (Figure 2).

Attempts undertaken to reduce the cage stresses by re-designing the support flexibility and reducing the geometric tolerances were unsuccessful and a decision was made to look for an alternative bearing design.

Alternative Bearing Design

The bearing selected as a replacement was physically very similar, however, the number of balls, the ball diameter and the raceway curvatures differed substantially. The aim , essentially, was to make the bearing more tolerant to misalignment, without too much sacrifice on life expectancy.

The aim of optimization was to achieve high stiffness, low friction and temperature generation and low vibration levels and still have adequate life. At high speed, the friction was the most important parameter. Bearing life was considered secondary importance and was only checked to ensure it was adequate.

Numerical Results

Detailed computer analysis was carried out for this design to assess the performance of these bearings. To keep data to a minimum whilst still giving a good insight to the effects of the difference of the two bearings, a total of nineteen runs per bearings were carried out. These covered the general operating environment of the bearing when used in the pumpset.

The runs were devised to include the effect of axial and radial loads, speed and angular misalignment on the cage forces and the life expectancy of the bearing.

General Findings

Figure (3) represents the life expectancy of the bearings against the imposed axial loads for no misalignment (T=0) and an angular misalignment of T=0.005 Rad. It is evident that the original bearing life is substantially higher than the replaced one at low axial loads, however, the advantage decreases as load increases and the life expectancy of the two bearing become very similar. With high misalignment, the original bearing shows no such advantage, and, the replaced one is not substantially affected by tilt.

Figure (4) shows that the contact angle variation is substantially less for the replaced bearing than the original one when operating under high misalignment. The contact angle variation between the outer and inner races is an indication of the amount of spin that the ball experiences during operation. Spin drastically reduces the traction forces in the rolling direction with increased risk of skidding, loss of cage stability and increased temperature generation. Performance improves when the difference between the contacts is a minimum.

Figure (5) shows that the original bearing has a much higher tilt stiffness than the replaced one, specially at high tilts. In this application, this is considered to be a disadvantage. The aim is to allow tilt without increasing resistance to that tilt.

Additional analysis showed that the magnitude of the cage force is reduced by a factor of 4 when the replaced bearing was used under the same degree of misalignment.

Conclusion

Vibration measurements performed on the modified pump (Figure 6) showed that the replaced bearing was much superior to that of the original one with regards to the general parameters used to measure suitability under the adverse conditions. The cage forces were shown to be dramatically reduced in the modified bearing which greatly improved cage performance and reduced wear and excessive torque. In this design optimization, the dynamics of the system was unaffected inspite of the fact that the stiffnesses of the two bearings were different. This was largely due to the fact that the pedestal stiffnesses were very much less stiff and the change in bearing stiffnesses were small in comparison.

References

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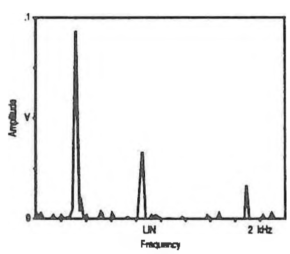

Fig. 1

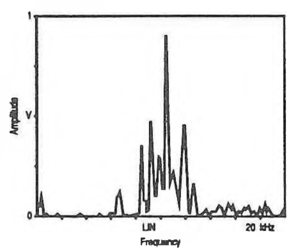

Fig. 2

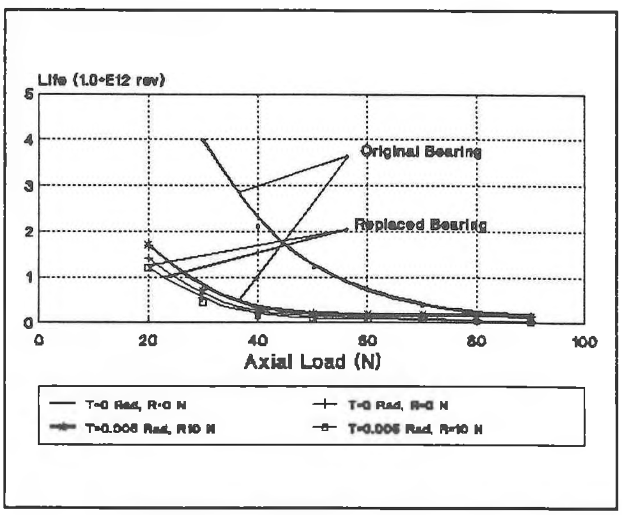

Fig. 3

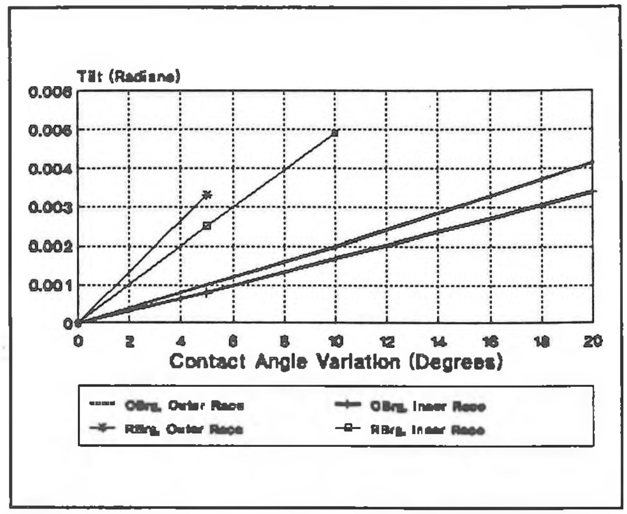

Fig. 4

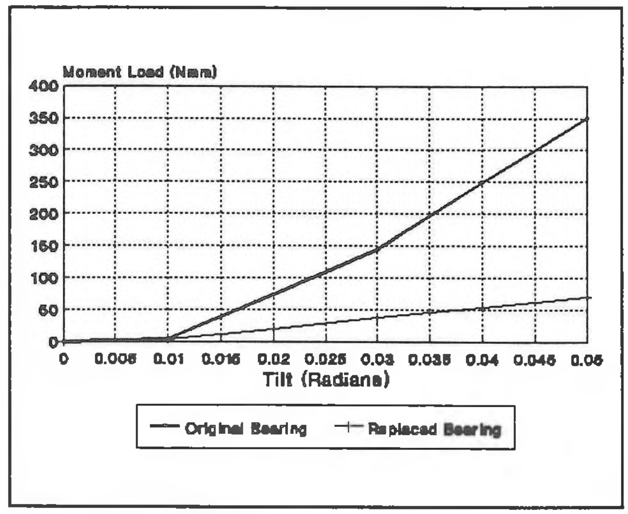

Fig. 5

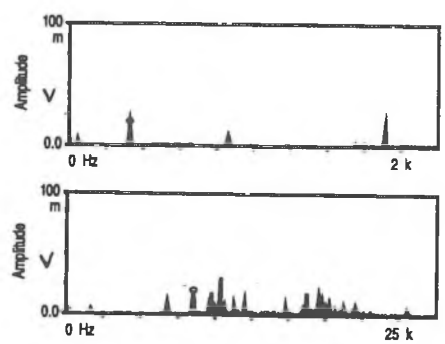

Fig. 6