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TRIBOLOGYS CONTRIBUTION TO ROLLING BEARINGS MAINTENANCE

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Abstract

Rolling bearings are one of the most frequently used machine elements. In many applications they are considered as critical components, and failure of such cause mailfunction and failure of machinery. Failure in this context can mean not only that which relates to deterioration in terms of rolling bearings functionality but also in terms of reduction in machinery operational quality to a level that is unacceptable to the customer. The issues limiting the life expectations of rolling bearings are primarily material fatigue and wear of the raceway and rolling element surfaces that experiance relative motion. Because of that rolling bearings tribological behavior is essential in relation to the needs of detecting and diagnosis faults before catastrophic failure occurs. In this paper, a guiding principles governing the friction, lubrication and wear of rolling bearings are examined in the context of the need to try and ensure their intended function, and continue to do so during their expected service life.

Keywords: *rolling bearings, tribological failure, maintenance methods, cost benefits*

1. INTRODUCTION

The reliability of many machine systems depends on the functionality and reliability of moving parts and elements, the rolling bearings being among them the most important.

The major factors that, singly or in combination, may lead to premature failure of rolling element bearings in service include: incorrect fitting, excesive preloading during installation, insufficient or unsuitable lubrication, overloading, impact loading, excessive vibration, excessive operating or enviromental temperature, contamination by abrasive matter, entry of harmful liquids, and stray electric currents [**1**]. The deleterious effects resulting from the above factors are described generally in terms of, respectively, fatigue, wear, and corrosion.

Hence, there is a requirement to acknowledge the possibility that rolling bearings will experience tribological distress and failure.

2. TRIBOLOGICAL FAILURE IN ROLLING BEARINGS

The normal service life of a rolling bearing under load is determined by material fatigue and wear of the raceway and rolling element surfaces that experiance relative motion.

Depending on the bearing design, the loads acting on the bearing may be radial, angular or axial. When a bearing is rotated under load, the raceways and rolling elements are subjected to cyclic Hertzian stresses as they pass through the load zone. For description of such stresses, among numerous other references, see the textbook by Harris [**2**].

Under repeated loading, fatigue cracks ultimately initiate at the point of maximum stress, within the subsurface material of highly stressed rolling element and raceway contacts. The subsurface cracks propagate causing removal of a portion of the contacting surface, resulting in the formation of pits. Under continued operation, the pits formed by rolling contact fatigue may progress to form a more severe form of damage known as fatigue spalling, shown in Fig. 1 from reference [**3**].

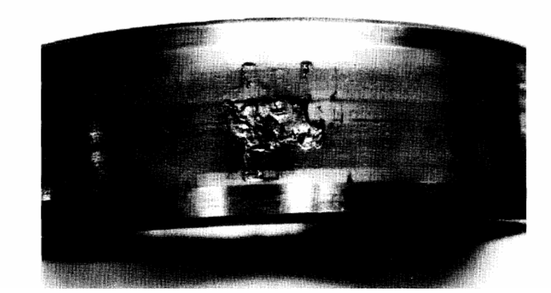

Fig. 1: *Severe spalling on the inner ring of the thrust bearing [**3**]*

According to reference [**4**], when a bearing generates a fatigue spall, the contact stresses, vibratory loads, and heat generation rates are increased. This in turn causes more fatigue cracks to form within the unfailed subsurface material of the contacts. The propagation of existing subsurface cracks and the creation of new subsurface cracks causes continued deterioration of the contact surface. Repeated operation of the bearing progresses the fatigue spall until the entire contact area has been roughened. The increased heat generation rates and vibratory loads within a spalled bearing can lead to catastrophic failure of the mechanism. If the heat dissipation is such to cause the internal clearances within the bearing to disappear, the bearing could seize. Alternatively, the internal clearances could increase. This would lead to larger ball loads and possibly component fracture. Finally, the increased vibratory loads may be too high for the mechanism or system surrounding the bearing. Again, this could lead to catastrophic failure.

Wear is another common cause of bearing failure. The most often cause of wear is the inadequate lubrication, either in terms of quantity or quality. In such cases, the formation of a lubricant film between contacting surfaces with sufficient carrying capacity is impossible. At the highly stressed region of Hertzian contacts, when there is insufficient lubrication, the contacting surfaces will weld together, only to be torn apart as the rolling element moves on. The three critical points of bearing lubrication occur at cage-roller interface, the roller-raceway interface and the cage-raceway interface. Lubricant starvation or improper lubricant selection can have severe consequences as high temperatures can anneal the bearing elements and reduce hardness and fatigue life. The process is more intensive in the cases of heavy loads and smaller speeds.

Contamination by abrasive matter is another common cause of rolling bearings wear. It is caused mainly by dirt and foreign particles entering the bearing through inadequate sealing or due to contaminated lubricant. The film of lubricant between the rolling elements and raceways is typically less than a micron in thickness. Much of the particles found in the lubricant will be larger than this and thus, some form of surface damage occures. The extent of the damage depends on the size, shape and materials of the particles. Large, hard or tough particles cause severe surface damage, which subsequently acts as a stress raiser and initiates material fatigue.

Without regard to the cause of wear, during this process the bearing internal geometry and load distribution between rolling elements are changed. Friction and consequential wear will increase, with corresponding rise in temperature and removal of surface material, leading to either seizure or unacceptable wear, culminating in rolling bearings failure.

3. TRIBOLOGY AND MAINTENANCE OF ROLLING BEARINGS

Rolling bearings maintenance includes all actions necessary for retaining a bearing in a desired operational state. Currently there are two basic methods for rolling bearings maintenance: time based preventive maintenance and condition monitoring.

Preventive maintenance includes regular inspections conducted typically on shutdown basis, in wich rolling bearings are inspected and worn or otherwise faulty, are replaced. This activities are generally based on statistical method of bearing service life estimation. When, for example, a rolling bearing is correctly specified, designed to perform the task intended, manufactured and installed as per specification, there is a probability that it will function satisfactorily for its intended service life.

Owing to the fact that fatigue failure progession process is stochactic [**5**], the statistical method, widely applied by industry, is not necessarily the best practice. This approach has two obvious deficiencies. First, the procedure results in costly machine shutdown and perfectly good bearing replacement. This approach can damage machine components during reassembly, and perhaps, exchange a bearing with the potential for long life by a new one yieldin a shorter life. Second, abrupt mailfunction can occur outside scheduled maintenance hours.

Alternatively, rolling bearings condition monitoring has been the focus of a wide range of studies over the past years. It can be of great value in cases involvinng critical machinery, where an unexpected shutdown can have disastrous economic and enviromental consequences.

An enormous variety of techniques has been developed and more are appearing all the time. The most comonly utilized monitoring techniques deployed throughout general industry are: vibration analysis, wear particle analysis and temperature measurement.

Vibration analysis is one of the most commonly used monitoring techniques in general industry. As inffered in reference [**6**], in tribologically compromised condition, it has proved to be very effective in sensing changes in rolling bearings kinematics as a precursor to surface damage and subsequent detection of piting fatigue. This serves to provide a reliable indication of impending failure, notably in situations where the remaining time to a critical condition that requires maintenance action is of order of days or even weeks.

By its very nature wear particle analysis react directly to wear occurring in the contact, usualy us a consequence of failure of the lubricant film with consequential damage as the opposing surfaces come into contact with one another. Wear particle analysis involves monitoring collected particles to determine normal conditions and the diagnosis of abnormal conditions as indicated by changes in the particle types, sizes, and quantities. Rolling contact fatigue associated primarily with rolling bearings may produce three distinct particle types [**7**]: fatigue spall particles, spherical particles and laminar particles. Rolling spall particles are the most critical, because they indicate damage to a bearing elements has already occurred.

Themperature is a well established and powerful characteristic for the assessement of rolling bearings condition, where its magnitude is indicator of variance from normal or acceptable operational performance. It is influenced by kinematics, heat generation and heat dissipation, lubrication and surface interactions. Therefore it is important to predict the heat generation and temperature rise of rolling bearings under different operating conditions.

Analyzing the aforementioned it is easy to note, without a need for proving, that a rolling bearings maintenance methods depends crucially on exploiting and applying the results of tribological investigations.

The tribologists contribution to rolling bearings maintenance methods lies primarily in knowledge of the interactions that cause the break down of the lubrication film in the contacts of interacting surfaces, and the practical consequences in relation to the ensuing wear behavior. Knowing why a bearings fail provide us enough time to plan and perform activities to prevent sudden failure, and by that to increase safe, efficient and reliable operation throughout a rolling bearings service life.

This is followed by the consultation of reference books and carrying out of laboratory studies to test preliminary conclusions. It is hoped that a comprehensive explanation of what went wrong emerges, and suggest test which will critically evaluate the explanation, and suggest ways of avoiding future failure.

4. EVALUATING THE COST BENEFITS

Nowdays, manufacturing companies are making great efforts to decrease costs and increase production, and therefore maintenance becomes critical and downtime less tolerable.

Rolling bearings are high precision, low cost machine elements, used in almost all kinds of industrial machinery. Although bearings are relatively inexpensive, they can cause costly shutdowns of important systems and hence significant production loss.

Maintenance costs are generated as a result of corrective and preventive maintenance actions, and are based on the consuption of resources utilized in the performance of these actions and consequential costs incurred through lost production time.

There is no simple formula for determining the potential cost benefits arising from applying the results of tribological investigations in rolling bearings maintenance practice. From a tribological standpoint, rolling bearings functioning in critical applications is area that would seem to benefit substantially from deployment of monitoring techniques. Success of all monitoring techniques, depends on the correct action being taken, at the correct time, based on the correct interpretation of the results. Setting up the programme to achive this will initially require time and effort but this expenditure will soon be repaid by reduced downtime, lower maintenance costs and more efficient rolling bearing operation. The tribological aspects directly attributable to cost avoidance policies will then be identified in relation to the techniques employed for monitoring the condition of rolling bearings.

5. CONCLUSION

In the foregoing discussion rolling bearing failure modes are identified in order to permit examination of the key tribological factors involved.

An overwiev of rolling bearings maintenance methods is given, and in more details various ways in wich tribology contributes to the maintenance activities.

The savings possible with well organised condition based maintenance have been discussed. However, the cost beneficial aspects of exploiting the results of tribological investigation in each of condition monitoring techniques is not easily quantifiable.

According to the foregoing analysis the tribologists contribution to effective maintenance of highly stressed, critically operating rolling bearings lies primarily in combined resources, knowledge and experience, particularly in regard to establishing the most likely cause of failure, its consequential effects

and what needs to be done in relation to the essential needs of detecting and diagnosing faults before catastrophic failure occurs. It gives particular significance to tribologys contribution to rolling bearings maintenance.

REFERENCES

[1] Widner, R.L., "Failures of Rolling Element Bearings", ASM handbook, Vol. 11, pp. 490-513, (1995).

[2] Harris, T.A., "Rolling Bearings Analysis" , John Wiley & Sons, Inc., (1984).

[3] Fernandes, P.J.L., "Contact Fatigue in Rolling Element Bearing", Engineering Failure Analysis, Vol. 4, pp.155-160, (1997).

[4] Kotzalas, M.N., Harris, T.A., "Fatigue Failure Progression in Ball Bearings", ASME Transactions, Journal of Tribology, Vol. 123, pp. 238-242, (2001).

[5] Hoeprich, M.R., "Rolling Element Bearing Fatigue Damage Propagation", ASME Transactions, Journal of Tribology, Vol. 144, pp. 328-333, (1992).

[6] Roylance, B.J., "Machine failure and its avoidance-what is tribologys contribution to effective maintenance of critical machinery", Proc. Instn. Mech. Engrs., Journal of Engineering Tribology, Vol. 217, pp. 349-364, (2003).

[7] Dunn, R.L., "Predictive Maintenance Technologies", Plant Engineering, Vol. 56, pp. 63-71, (2002).