Investigation of wind turbine gearbox bearing subsurface damage considering transient loading and the separation of MnS inclusion

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1. Introduction

Premature bearing failures have been frequently observed in wind turbine gearboxes. The failures may initiate either on the surface or near the surface of contact in the bearing raceways. The surface initiation hypothesis suggests that cracks could be caused by surface flaws and worsen by loading conditions. On the other hand, manufacturing factors such as the non-metallic inclusions could serve as initiation points, according to the sub-surface hypothesis. The various explanations given by bearing manufactures include the effect of hydrogen, plastic deformation, brittle fracture due to high traction on the surface, and unconsidered loadings, such as impact load, causing lubricant film failure. However, a clear explanation with sufficient evidence based on both the effecting factors such as the high loading during the transient events and the observed premature damages such as the White Etching Cracks (WEC) is not established.

A failed bearing in planetary gear stage of a wind turbine gearbox is destructively investigated where different stages and features of the premature damages have been observed. Alongside this work, the load, lubricant film thickness, maximum contact pressure and subsurface stress are calculated for planetary bearing during shutdown event. The extreme subsurface stress due to transient loading and the stress concentration around the MnS inclusion in the case of non-perfectly bonded to the steel matrix are correlated to the yielding of the material and thus concluding the observations from the destructive investigation of the failed bearing.

2. Approach

The failed planetary bearing has been sectioned and investigated in the circumferential and axial directions. Different techniques have been utilised to gather the sufficient information required to explain the subsurface damage. More than 200 MnS inclusions in etched and un-etched samples are examined using the optical microscopy. More detailed images have been acquired using Scanning Electron Microscopy (SEM) which reveals the size and the topography of the WEA as well as the size and the directions of the micro cracks inside the inclusion and the matrix. Further characterizing of the separation of the inclusions from the matrix and the chemical elements of the inclusions is curried out with the Energy Dispersive X-ray analysis (EDX). Also, the Atomic Force Microscopy (AFM) is utilized to show clearly the gaps or separation attached to the MnS inclusion, as well as the micro cracks. In order to identify the WEA in more details, the nano indentation is employed to determine the hardness of the inclusion, the matrix and the WEA.

In this study, a simplified method is used to calculate the load on the planetary bearings which is validated against a more complicated model. This load is utilised in the calculation of the contact pressure and the resulting subsurface stress distribution using the Hertzian contact theory. Also, the minimum lubricant film thickness is calculated using the Elasto Hydrodynamic Lubrication (EHL) theory. Once the stress under certain depth from the surface is calculated, it is increased due to the stress concentration around the stress riser, inclusion or gap.

3. Main body of abstract

The observed damages varies between surface and subsurface as in Figure 1 (a). This study focuses on the subsurface initiated damages marked in Figure 1 (b) and (c). The character specifications of the inclusions include the length, width, inclination angle with the rolling direction and depth from the surface. The observations are classified into five types which are undamaged inclusions, inclusions separate from the matrix by gap(s), internal cracks of the inclusions, external cracks into the matrix, White Etching Area (WEA) around the inclusion (Butterflies). Statistical study for the characters specified for the inclusions associated with each specified damage type is curried out. This study results in the range and the dominated depth for each damage feature as well as the possible combination of damages. The focus on the MnS inclusion in the literature is less reported than the harder inclusions such as Al_2O_3 because it is assumed that the MnS always deformed without causing gaps attached to it. However, in this study, the results of the EDX and the AFM evidence show that this is not always the case. Moreover, the internal cracking of this type of inclusions is not highlighted before which is investigated here and it is observed to be associated with other kinds of subsurface damages.

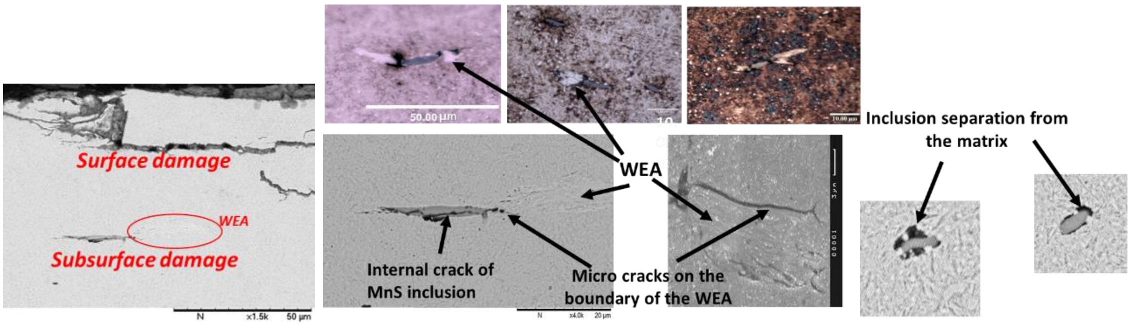

Figure1: Surface and subsurface damages in the failed wind turbine bearing

The results of the loading and contact pressure on the inner raceway of the planetary bearing during different operational conditions can be seen in Figure 2. These results show that the maximum contact pressure exceeds the maximum contact pressure recommended according to [1] and [2]. However, this contact pressure will not cause a subsurface yielding of the through hardened bearing steel if the effect of the inclusion and gaps is neglected. It is generally assumed that bearings working under lubricated condition are exposed to low traction force. Nevertheless, during the transient events it has been found that the condition of a very low lubricant film thickness, relative to the bearing roughness, could occur that elevates the traction force. This high traction results in additional subsurface stress and brings the location of the maximum shear stress closer to the surface. It has been found that the maximum shear stress, from the calculations of the subsurface stresses, is located deeper than the dominated depth of the micro cracks, from the failed bearing examination. This shows the important effect of the surface traction.

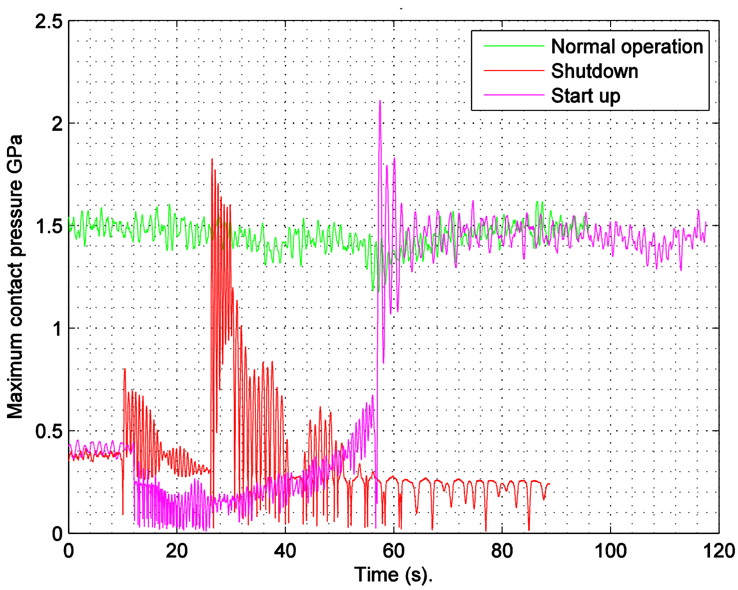

Figure 2: The maximum contact pressure on the planetary bearings

4. Conclusion

Because the MnS inclusion separation from the matrix has been observed at different levels of depth to the contact surface, sometimes far from the load zone, it could be considered that the material defect is caused by the different coefficient of thermal expansion [3]. However, other kind of separation could be caused by impact loading [4]. The non-perfect bonding, separation, of the MnS inclusion results in high stress concentration around the inclusion [5]. Accordingly, local yielding occurs in the form of WEA. This explains the association of high percentage of the observed WEA, butterflies, with the separated inclusions. The experimental results from the examined failed bearing from the field emphasize the effect of tangential traction on the subsurface damage of the wind turbine gearbox bearings.

5. Learning objectives

Identify a significant type of premature bearing failure of WECs and determine the factors causing it.

Distinguish the difference between the effect of perfectly bonded MnS inclusions and the separated MnS inclusions on the yielding and the crack initiation.

Relate the material cleanness and loading during transient event, normal and tangential, in wind turbine gearbox to the bearing premature failure.

References

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