

Overload and failure of wind turbine gearbox bearings

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Abstract Premature failure of gearbox bearings in wind turbines is a significant issue, with transient wind loads believed to be responsible for bearing overload events, leading to White Etching Cracks and fatigue failure initiation. The aim of this research is to explore the link between bearing overload and fatigue failure via Finite Element and experimental methods. To this end, overloads determined through numerical modeling work have been applied to a cylindrical roller bearing, and fatigue tests subsequently performed. Initial results highlighted the link between overload and premature fatigue failure, with fatigue failure propagating from overload damaged regions in the bearing raceway sub-surface.

Introduction The wind turbine industry has seen significant recent growth, as concerns over fossil fuels and their impact on climate change grows. However, wind turbine technology from the outset has suffered from a range of reliability issues. Additionally due to the relatively low power density of wind energy, and in order to keep pace with increased demand for clean energy, a market shift has occurred with turbine sizes increasing and locations sought with higher wind speeds. As a result, system loads have increased, and turbines are often located in harsher environments, with such factors making failures more likely, maintenance more challenging, and advanced condition monitoring essential.

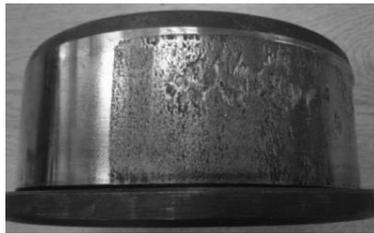


Fig.1: Failed planetary support bearing from a 600kW turbine

Wind turbine gearboxes have been the source of a significant proportion of failures. Indeed, in the UK alone, 35.1% of insurance claims made from turbine operators related to gearbox damage [1]. Whilst alternatives exist, for cost reasons geared systems remain the market leader. These systems have high gear ratios, capable of converting rotor input speeds in the range of 15 – 20 rpm, to shaft speeds in the region of 1500 rpm to facilitate power generation at grid compatible frequencies. In order to keep gearboxes within acceptable size and weight limits, epicyclic stages are frequently employed, with bearing supports experiencing high loads and low rotational speeds. Whilst this type of operating regime is not ideal for a bearing, application of the L_{10} life rating at the design stage has been found to significantly over predict actual life achieved. Failure analysis [2] of such bearings has indicated that the failure mode is not a result of rolling contact fatigue, and is significantly more complex, with the operating regime resulting in the formation of sub-surface White Etching Cracks, which are then rapidly propagated to failure through normal operation of the turbine (Figure 1).

Recent research has highlighted that the transient nature of wind loads on turbines, combined with the inertia of the system drivetrain, may lead to torque spikes through the gearbox [3]. This results in bearing overload events, with gearbox bearings particularly susceptible to White Etching Cracks as a consequence of such an overload, due to the presence of manganese sulphide inclusions in the bearing steel. However, this work is at a relatively early stage, and the role of overload in initiating damage in bearing steels has seen limited research. The aim of this study, is therefore to investigate the link between initial overload and subsequent bearing raceway failure, through Finite Element simulation of the overload event, combined with experimental overload and fatigue of a bearing raceway. The results from this study will provide insight into the initial damage mechanism in wind turbine bearing raceways, and will be particularly relevant to condition monitoring approaches aiming to detect the onset of such failures and estimate remaining useful life.

Methodology An 80mm cylindrical roller bearing (SKF, NU010 ECP) was identified, upon which a scaled version of the contact conditions experienced in a wind turbine gearbox bearing could be achieved. Contact conditions were scaled through maintenance of average contact pressure in the contact. As shown in Figure 2, overload conditions for the bearing were then investigated using an elastic-plastic Finite Element model in

ABAQUS, with isotropic hardening assumed as the elastic-plastic constitutive model. Overloads were simulated for the outer bearing raceway, and were representative of the bearing supporting a rotating shaft. As shown in the Figure, using this approach a range of overloads for the bearing raceway were identified, and the associated size of the sub-surface plastic zone estimated in each case.

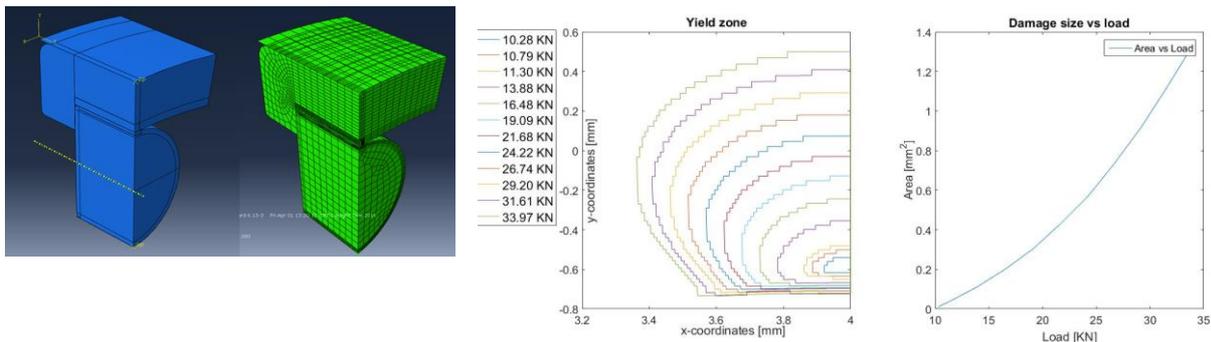


Fig 2: Finite Element Modelling

(b) Estimated Plastic Zone Size and Overload.

(a) Raceway

Overloads were applied to the bearing using a purpose built grip arrangement on a tensometer as shown in Figure 3a. In order to apply the overload, the bearing was disassembled, and the outer race and a single roller mounted within the grips. Overloads in the range of 13 – 34kN were then applied, simulating the initiation of sub-surface plasticity, through to plasticity at the surface. Fatigue tests were then performed on the outer race specimens for a given overload condition, using the same test arrangement. These initial fatigue tests, whilst not representative of rolling contact fatigue were performed in order to assess the impact of overload on the fatigue behaviour of the bearing steel in a simplified test arrangement. All tests were performed at the same conditions, with a maximum applied load of 10kN and a load ratio of 0.001. Figure 3b shows a typical result from these tests, where fracture of the bearing raceway occurred, originating from an apparent failure in the sub-surface, co-incident with the overload applied.

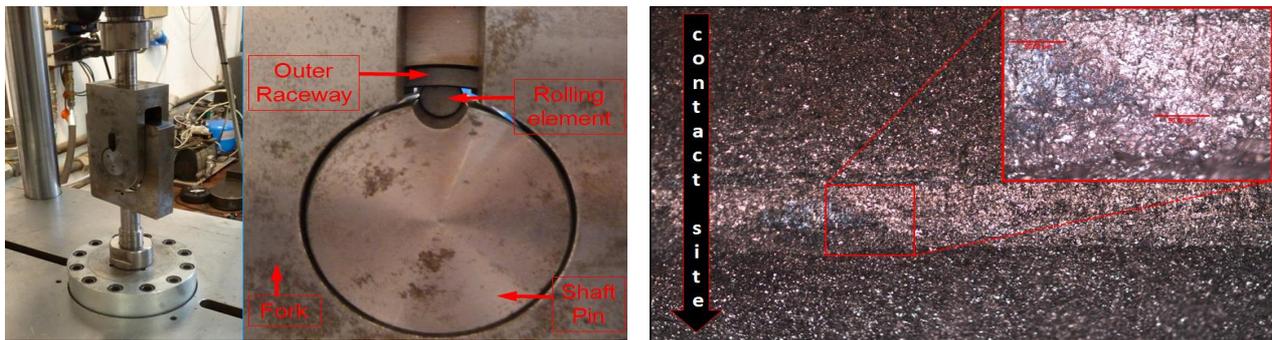


Fig 3: Experimental Testing (a) Test Bearing and Mounts,

(b) Failed Raceway

Following on from the initial trails, a new set of overloaded outer raceways were created using the detailed approach, and the bearings re-assembled with a full compliment of rolling elements and inner race. These bearings were then tested on a driven bearing test rig to failure. A load of 10kN was once again applied to bearing, in this case via a screw thread, with the overloaded portion of the raceway in line with the applied load. Whilst the bearing was under load, the inner race was rotated via a driven shaft at a speed to match the lubricant entrainment velocity in a typical wind turbine gearbox bearing. Through the rolling contact fatigue arrangement created, the pre-overloaded bearings were then tested to failure, and the fracture surfaces of the raceway once again investigated.

Conclusion Initial results highlighted the link between bearing overload and fatigue failure, with a significant and increasing reduction in bearing life, compared to the expected value, as a consequence of increasing initial overload. Further tests will now be performed, and the fracture surfaces further investigated for evidence of White Etching Cracks, and the link between overload and premature fatigue failure further explored.

References

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