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Observing early stage rail axle bearing damage

N. Symonds [a,*], I. Corni [a,b], R.J.K. Wood [a], A. Wasenczuk [b], D. Vincent [b]

[a] National Centre for Advanced Tribology at Southampton, Faculty of Engineering and the Environment, University of Southampton, UK
[b] Perpetuum Ltd, Southampton, UK

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ABSTRACT

Rail axle-bearing failure is a serious issue that can affect passenger safety and generate large costs for operators from penalties, recovery, reduced train availability and repairs. Southeastern have fitted bearing sensors to their Electrostar fleet; these sensors identify rail axle-bearing degradation. In this paper (presented at ICEFA VI) we introduce an on-going study where ex-situ rail axle bearings with recorded vibration histories are being forensically examined. The ultimate aims of this work are (1) to link vibration signatures to levels of physical damage and (2) to identify any common factors that are causing bearing failures. The current work presents results from one removed bearing; this work highlights the methods and techniques being used to measure and quantify the physical damage, which include profilometry, X-ray tomography and metallography. The bearing described herein presented large subsurface white etched layers, rolling contact fatigue crack propagation and evidence of electrical arcing damage.

1. Introduction

1.1. Axle bearing failures

Rail vehicle axle-bearing failure is a serious issue often resulting in service delays and potentially fire and derailment, with obvious risks to life. A 'dead' train on the railway line has implications for customer perception, operator and manufacturer reputation, along with large costs from penalties, recovery, train availability and repairs.

A common 'old age' mechanism for bearings is rolling contact fatigue (RCF), which can propagate from both surface- and subsurface-initiated failures. Surface defects often originate from contaminated lubricants; foreign particles entrained in the moving elements of the bearing produce wear or denting of the bearing surfaces. RCF then progresses from the resultant stress-raiser.

Subsurface microstructural changes due to RCF occur if the maximum Hertzian shear stresses exceed the elastic limit of the bearing steel. These changes may greatly reduce the fatigue life of bearings by initiating cracks, which lead to macro pitting on the bearing surfaces [1]. The cracks start at subsurface flaws within the material of the race and are driven by the repeated load from the passage of the rolling elements. These cracks spread and eventually rise to the race surface, releasing a 'spall' of material and leaving an RCF macro-pit. If allowed to continue, the running surface of the bearing becomes more worn and the passage of the rolling elements more disrupted [2]. Bearing failure due to material defects has been greatly reduced by using clean and properly heat-treated steels [3].

* Corresponding author.

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Bearing manufacturers provide life predictions; this information gives the operator a statistical indication (L_{10} or B_{10}) of when RCF might occur [4–6]. The operator then sets a service life (given in miles) and when a bearing has reached it, it must be replaced. This approach of giving a usage limit to bearings is common in safety critical applications (e.g. large bearings in helicopter gearboxes [2]). However, the life predictions are statistical and only as good as the loading data provided [3]. RCF life is significantly influenced by the material microstructure, which is inherently inhomogeneous, and therefore the RCF lives of a seemingly identical batch of bearings operating under identical load, speed, lubrication, and environmental conditions show a significant degree of scatter [1,5], so infantile failures can and do occur. However, premature failures of train wheel bearings have also been blamed by operators and design authorities on various operational issues including vibration, grease failure, overloading or uneven loading, misalignment, electrical shorts, wheel flats, installation problems and suspension design.

Fig. 1 shows the condition of a bearing following catastrophic failure (one of two reported by Southeastern over the 2012–2013 period). The outer ring has been removed; revealing all that remains of the two inner (cone) rings, the central spacer, the 46 rollers and two molten polymer cages. Examinations revealed that the rollers had been smeared across the raceway and the shoulders of the inner (cone) rings had been worn down.

In addition to the serious catastrophic cases where the bearing has melted and fire is inevitable, many bearings are 'caught' in time either by experienced 'riders' listening for additional bogie noise or by passengers and on-board train crew. Southeastern prematurely (before the service life expired) replaced 80 wheel-set axle bearings (i.e. 160 bearings) due to reported noise over a two year period (2011–2013).

1.2. Condition monitoring of bearings

Various technologies and approaches have been adopted to continuously monitor the state of bearings. For example, military helicopters have gearbox Health and Usage Monitoring Systems (HUMS) with additional wear debris monitoring and oil analysis. The former is a data recording of the temperature and vibration signature of the gearbox, which is downloaded and analysed at intervals. The latter is the chemical and physical analysis of the condition of the lubricants, looking for RCF debris [2]. These methods are not real-time but do give diagnostic warning of any changes in behaviour from 'normal'.

Hot axlebox detection (HABD) has been used in the UK national rail network for decades as a safety requirement. The HABD are sited either on-train for inboard or high-speed bearings, or trackside for outboard axleboxes. Approximately 220 trackside HABD detectors are currently installed in the UK [7]. A bearing that is creating sufficient heat to trigger an HABD will already be in full failure mode. Therefore the train has to be stopped immediately causing disruptions to passengers and railway traffic. HABD detectors are expected to be phased out over the next 10–15 years leaving a requirement for a new diagnostic tool.

For train operators in the UK, two approaches to degradation diagnostics are currently available as 'state-of-the-art', (1) a trackside system e.g. Railway Bearing Acoustic Monitoring (RailBAM) by Siemens or Trackside Acoustic Detection System (TADS) developed by the American Transportation Technology Centre, Inc. (TTCI) both employing microphones to listen to passing wheel-set bearings [7] or (2) an on-board system by Perpetuum Ltd [8]. The latter approach (the subject of this paper) provides each wheel bearing with local real-time vibration monitoring using accelerometers. Neither method of detection (track-side or on-board) will prevent early bearing degradation, but similarly to the helicopter HUMS, each will alert the operators so early intervention (before HABD) is possible, preventing catastrophic outcomes and reducing maintenance costs.

Southeastern operated rail axle bearings used in this study are currently given a service life of 500k miles, which is 10% of the calculated L_{10s}, the rating life at 90% reliability expressed in operating mileage, as calculated using the basic method

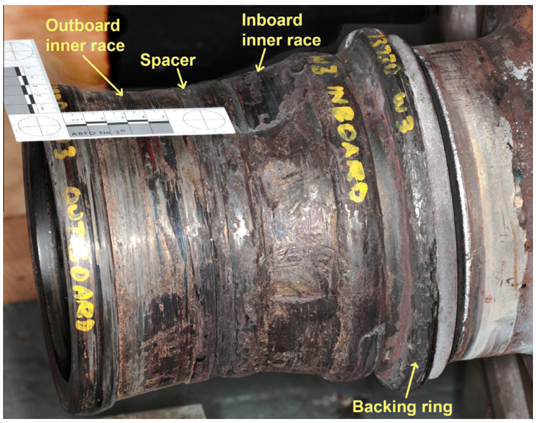

Fig. 1. Catastrophic bearing failure. (a) Condition of the bearing on the axle shaft after the outer ring was removed.