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Onboard detection of railway axle bearing defects using envelope analysis of high frequency acoustic emission signals

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ABSTRACT

Railway wheelsets consist of three main components; the wheel, axle and axle bearing. Faults can develop on any of the aforementioned components, but the most common are related to wheel and axle bearing damages. The continuous increase in train operating speeds means that failure of an axle bearing can lead to very serious derailments, potentially causing human casualties, severe disruption in the operation of the network, damage to the tracks, unnecessary costs, and loss of confidence in rail transport by the general public. The rail industry has focused on the improvement of maintenance and online condition monitoring of rolling stock to reduce the probability of failure as much as possible. This paper discusses the results of onboard acoustic emission measurements carried out on freight wagons with artificially damaged axle bearings in Long Marston, UK. Acoustic emission signal envelope analysis has been applied as a means of effective tool to detect and evaluate the damage in the bearings considered in this study. From the results obtained it is safe to conclude that acoustic emission signal envelope analysis has the capability of detecting and evaluating faulty axle bearings along with their characteristic defect frequencies in the real-world conditions.

1. Introduction

Due to the increasing demand for safer and quicker rail transportation, rolling stock wheelsets operating under high axle loads, speed and heavy usage require more rigorous and reliable maintenance and inspection. While in service, wheelsets are constantly operating under harsh conditions including rolling contact fatigue, thermal variations and impact [1]. Gradual deterioration of the structural integrity of wheels and axle bearings can increase the risk of failure and hence the possibility of delays, unnecessary costs and derailments, increased levels of vibration, noise and temperature produced by the axle bearing is a sign of a developing defect [2].

Acoustic emission (AE) in structural health condition monitoring is defined as the generation of elastic waves made by a sudden redistribution of molecules inside or on the surface of a material. When an external stimulus such as temperature or load is applied to a material, the released energy will be in the form of stress waves. These stress waves can be detected using piezoelectric sensors. In recent years, there has been much progress in on-line predictive maintenance of rotating machinery within the oil and gas and maritime industry. These advances have led to a very reliable technique based mainly on trending of vibration signals and occasionally AE waveforms [3].

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The bearing in a railway wheelset sustains part of the weight of the vehicle as the wheel rotates. If the bearing seizes, then the affected wheel will block. This will cause only the other wheel of the wheelset to continue rotating. As a result of the abnormal wheelset motion caused from the blocked wheel, the axle will eventually rupture causing the train to derail.

Therefore, in the railway industry axle bearings are considered as a critical rolling stock component. Any axle bearing defect unless detected in time, will almost certainly become worse gradually before final catastrophic failure occurs. The presence of a defect in axle bearings will give rise to significant changes in vibration and AE patterns and amplitude. Therefore, vibration analysis and AE are possible techniques for the continuous and efficient condition monitoring of axle bearings.

Faults in axle bearings can be categorised as distributed or local [4]. Distributed defects such as surface roughness, waviness, etc., and the variation of contact force between rolling elements can increase the level of vibration and noise produced by the axe bearing. Localised defects, such as cracks, pits, spalls, etc., can generate impulses which can give rise to short duration vibration or AE signals [5].

Relevant research on diagnosis of faulty railway axle bearings using vibration analysis technique was reported by C. Yi et al. Vibration data were acquired using a sampling frequency of 10 kS/s. Vibration data analysis was carried out using Ensemble Empirical Mode Decomposition (EEMD) and Hilbert marginal spectrum [6].

2. Theoretical background

Certain bearing defects, such as roller and race defects, give rise to a fundamental frequency. Knowing the fundamental frequency of the defects is paramount in diagnosing the exact nature of the problem rather than only identifying a faulty axle bearing from a healthy one. When an axle bearing rotates, any irregularity in the race surfaces or in the roundness of rolling elements will excite periodic frequencies or otherwise fundamental defect frequencies. The amplitude of these frequencies or tones is an indication of the severity of the defect detected. Ball bearings illustrate four distinct tones (frequencies). These frequencies depend on the bearing geometry and rotational speed [7]. Once the type of the bearing and the shaft speed are identified, the defect frequencies can be calculated. The information regarding the characteristic frequencies of an axle bearing are generally provided by the manufacturer of the bearing. The formulas for calculating these specific frequencies are [8]:

$$BPFI = \frac{N}{2} \times F \times \left(1 + \frac{B}{P} \times \cos\theta\right)$$

$$BPFO = \frac{N}{2} \times F \times \left(1 - \frac{B}{P} \times \cos\theta\right)$$

$$FTF = \frac{F}{2} \times \left(1 - \frac{B}{P} \times \cos\theta\right)$$

$$BSF = \frac{P}{2B} \times F \times \left[1 - \left(\frac{B}{P} \times \cos\theta\right)^2\right]$$

Where
BPFI = Ball pass frequency inner race (Hz)
BPFO = Ball pass frequency outer race (Hz)
FTF = Fundamental train frequency – Frequency of the cage (Hz)
BSF = Ball spin frequency circular frequency of each rolling element as it spins (Hz)
N = Number of balls
F = Shaft frequency (Hz)
B = Ball diameter (mm)
P = Pitch diameter (mm)
θ = Contact angle.

3. Acoustic emission signal envelope analysis technique

Typically, when an impact occurs in a defective rolling element as it rotates an impulse will occur. This impact will give rise to excitation of the characteristic frequencies of the structure [9]. The main idea of the AE signal envelope analysis technique is to eliminate the disturbance influence and highlight the fault feature using the envelope spectrum. In practical applications the characteristic frequency may vary due to different types of bearings being used. At early stages of evolution of an axle bearing defect, the chance of detecting it reliably using conventional power spectral analysis (FFT) is low. Signal envelope analysis provides an effective extraction method from low Signal to Noise Ratio (SNR) when vibration or AE signals are considered [10].