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"Advanced remote condition monitoring of railway infrastructure and rolling stock"

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Advanced remote condition monitoring of railway infrastructure and rolling stock

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The rail network is an integral part of the modern transport system. Railway transportation accommodates the mobility of both passengers and goods cost-effectively and in an environmentally friendly way at large scale. Thus, the contribution of railway transportation to the global economy, sustainable growth and mitigation of climate change effects is profound. Rail operations have become more intense, with traffic density continuously increasing. At the same time rolling stock speed and axle loads have also increased. This has led to strong interest in re-evaluating the fundamentals of the way rail infrastructure and rolling stock are currently inspected and maintained. Recent attention has focused on the development of advanced remote condition monitoring techniques for the assessment of the structural integrity of critical rail infrastructure and rolling stock components. The widespread implementation of effective and proven remote condition monitoring technologies can result in the meaningful reduction of the demand for conventional time-consuming and costly inspection methodologies, helping increase the availability and hence capacity factor of the rail network. This paper presents the most recent developments and results obtained from the experimental work carried out by the authors on remote condition monitoring of rail infrastructure and rolling stock components using acoustic emission and vibration analysis techniques under laboratory and field conditions.

Keywords: Railway, infrastructure, rolling stock, inspection, remote condition monitoring, acoustic emission, vibration analysis

Introduction

Modern railway networks form complex systems involving large-scale infrastructure with a vast number of rolling stock of various types including passenger and freight [1]. Railway networks around the world are increasingly becoming popular for commuting and transport of goods not only within as well as across borders [2]. In Europe in particular the increasing trend in rail passenger and freight numbers is predicted to continue to increase until at least 2030 [3]. The continuous growth of railway transport has led to the construction of new high speed lines (e.g. High Speed 2 in the UK connecting the southeast parts of the country with the Northwest) and significant upgrades of existing infrastructure. At the same time, rolling stock technology has been evolving rapidly with more comfortable, faster and more efficient trains being constructed. Also older types of trains have been undergoing extensive refurbishment to enable them to meet the efficiency and reliability targets set for modern railway network operations.

As with every complex system, the potential of catastrophic failure can have considerable consequences to the reputation of the industry, leading to extensive disruption, economic costs and potentially human casualties [4]. It is therefore of paramount importance that inspection and condition monitoring technologies are employed at a sufficient level to ensure the continuous and uninterrupted operation of railway networks at all times. Due to the increasing traffic density, even relatively minor faults can result in significant disruption and delays in a busy network, subsequently giving rise to higher operational costs. Hence, it is essential that any incipient faults or defects in railway infrastructure or rolling stock are detected in time and well before they become severe enough to result in disruption to normal operations [5].

Nonetheless, replacement of critical railway infrastructure and rolling stock components needs to take place at the optimum time so as maintenance and operational costs can be minimised. Thus, the question that needs to be addressed by railway infrastructure managers and rolling stock operators is the optimisation of predictive maintenance through the effective use of inspection and structural health monitoring techniques. For these reasons, railway infrastructure managers have invested considerably in the use of remote condition monitoring systems for the detection of wheel faults, overloading axles and defective axle bearings [6]. However, the efficiency and reliability of such systems has yet to achieve the level considered to be optimum both from the point of cost per instrumented site as well as sensitivity and resolution capability.

Although condition monitoring technologies have evolved gradually in recent years, this has not been the case for conventional inspection techniques used to evaluate non-destructively rails, crossings and other critical railway infrastructure components [7]. The rail industry has to a large extent adhered to traditional approaches with little evolution having taken place over recent decades. However, as traffic density is continuously increasing, the opportunities to carry out inspection using traditional means are becoming less obvious. These factors combined with the fact that rail networks are used more intensively increases the risk of faults or defects going undetected or being underestimated. Undetected faults can eventually result in delays and disruption or even potential derailments which can profoundly harm the reputation of the rail industry. Worse detected defects which are underestimated due to poor quantification of their severity can lead to erroneous maintenance decisions being made which can pose considerable concerns over the safety of high-speed train operations.

Hence, there is an increasing need to move away from conventional inspection procedures which are currently the norm and move towards a remote condition monitoring regime that allows the efficient evaluation of critical railway assets in real-time [8]. This paper discusses some of the key results obtained by the authors using acoustic emission and vibration analysis under laboratory and field testing conditions.

Laboratory experiments on rail samples

Standard three-point bending samples with a geometry of 120mm (L) x 10mm (W) x 20mm (thick) were cut off from the web of used rails provided by Network Rail in order to carry out fatigue tests. A v-shaped notch 2mm deep and 30° angle was spark eroded using a 0.1mm diameter wire. A 20kN Amsler high loading frequency vibrophore was employed for pre-cracking the all the samples. A load range of 0.85-8.5kN (R=0.1) was applied at a frequency of approximately 100Hz using a three-point bending configuration. The initiation and subsequent propagation of fatigue cracks was confirmed using replicas at different times. The initial crack lengths were subsequently measured using a Karl Zeiss optical microscope for each of the samples and ImageJ software.

Three-point bending fatigue testing of the pre-cracked samples was performed using a DARTEC 50kN servo-hydraulic universal test machine. The machine was set to provide a sinusoidal loading sequence at 5Hz. AE activity was recorded using a commercial PAC system and sensors. The AE amplifiers were set to 40dB, the data acquisition threshold was set to 50dB. Two different AE sensors were used to monitor the AE activity. One wideband and one R50a AE sensor procured from PAC were used for comparative purposes. A DCPD instrument was used to monitor the crack length with time. The DCPD measurement was plotted against the cumulative AE energy until each sample finally failed. The experimental configuration is shown in figures 1 and 2.

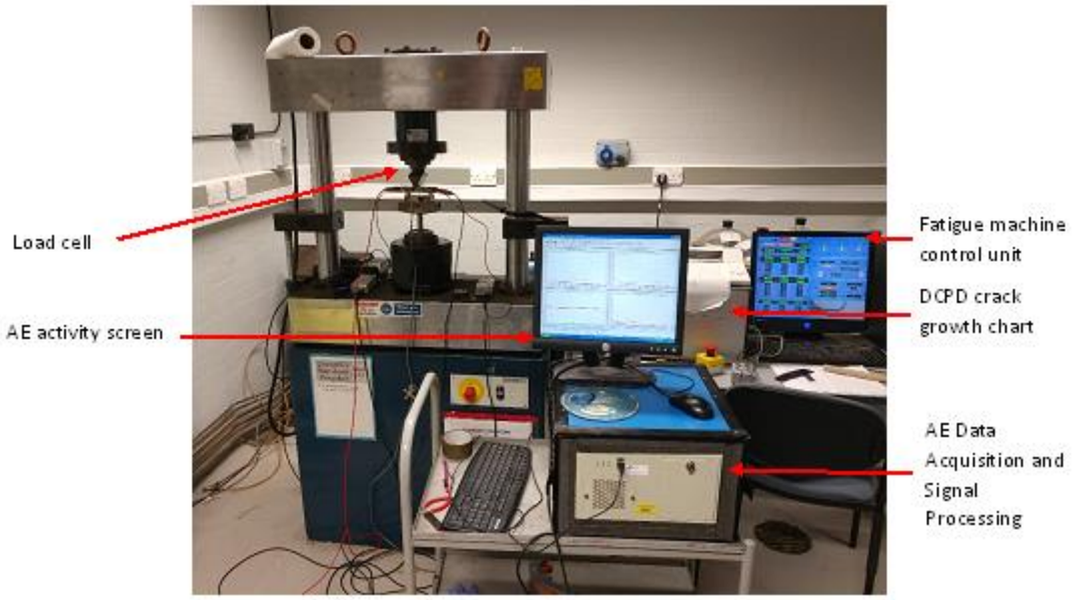

Figure 1: Photo showing the setup of equipment used for fatigue testing. It is shown with a sample in 3 point bend test.

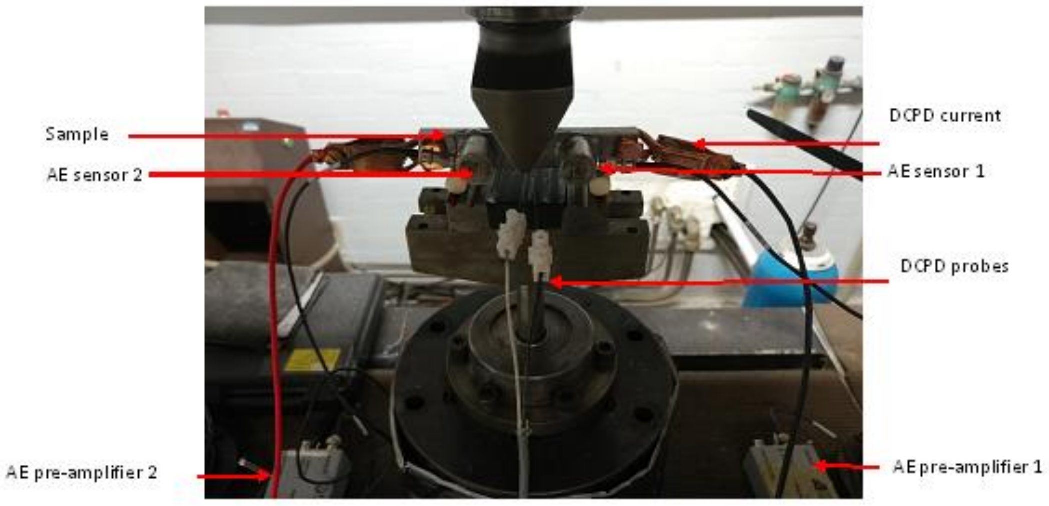

Figure 2: Sample configuration with DCPD crack growth measurement and AE sensing.

Laboratory experiments on wheel defect detection

Laboratory-scale tests were carried out on a railway wheel using a railway trolley that was pushed along a test track at the Birmingham Centre for Railway Research and Education. Tests were carried out so as to simulate both good and defective (wheel flat and metal build-up) conditions.

Figure 3: Experimental setup for trolley tests.

Field trials

Experiments to detect faulty wheels and axle bearings on freight rolling stock were carried out under full scale operational conditions at the Long Marston test track. Both onboard and wayside measurements were carried out using acoustic emission and vibration analysis. Artificially induced defects were considered including wheel flats, lubricant contamination, race and roller defects. Tests were carried out up to a maximum speed of 50km/h. The freight wagons used in the experiments were pulled over a straight section of track a few hundred metres long as shown in figure. The sampling rate for AE signals was set at 500kS/s and vibration at 25kS/s. The duration of the acquisition was 10s for the onboard tests and 12-24s for the wayside tests depending on the number of freight wagons used during testing. Between one and four wagons were used during the various set of trials. Ultrasonic coupling of the AE sensor was achieved using vaseline. A customised acoustic emission and vibration analysis system developed jointly by the University of Birmingham and Swiss Approval Advanced Inspection and Development Limited was used to carry out the measurements.

Results on rail sample experiments

The results presented in this section show the effectiveness of the AE technique in detecting damage propagation. It is clear that the AE activity increases in accordance with the crack growth and maximum activity is recorded close to the final fracture event. The analysis of the AE data has also been based on microscopic observation of the fractured surfaces using optical and scanning electron microscopy. At the times where a sharp increase in the cumulative AE energy is observed, the related AE events correspond to features on the fractured surfaces which appear to have caused an instant increase in the crack growth rate. Figure 4 shows the cumulative AE energy with respect to the measured crack length using DCPD for one of the tested samples. Figure 5 shows the fractured surface of the sample observed microscopically after the completion of the fatigue test.

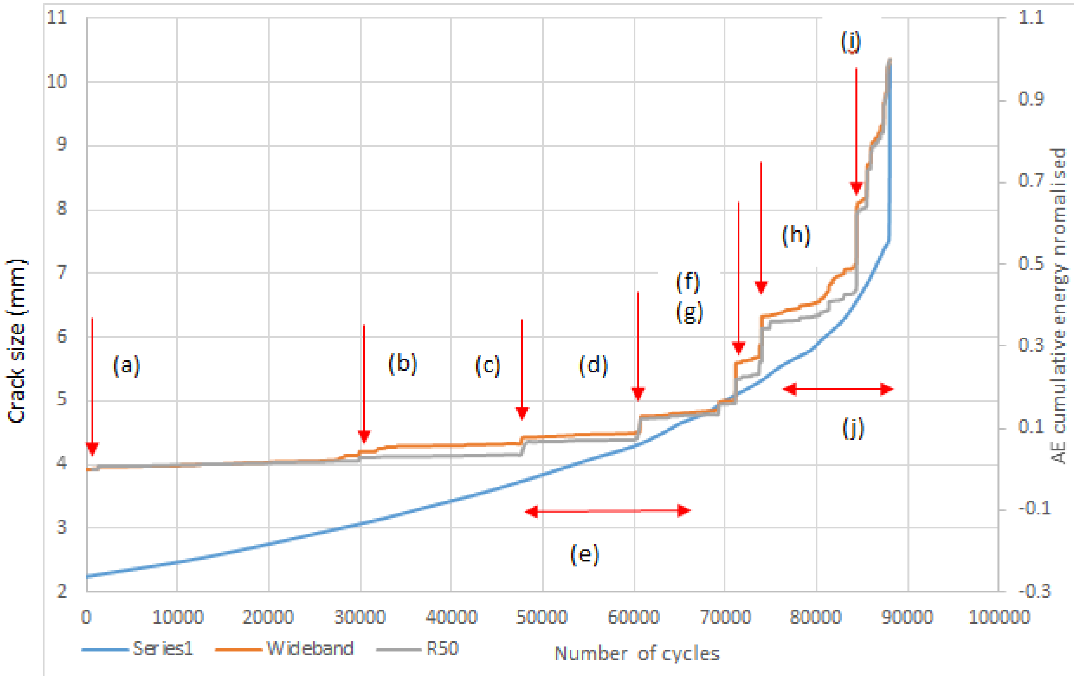

Figure 4: Cumulative AE energy versus measured crack length using DCPD for one of the three-point bending fatigue samples.

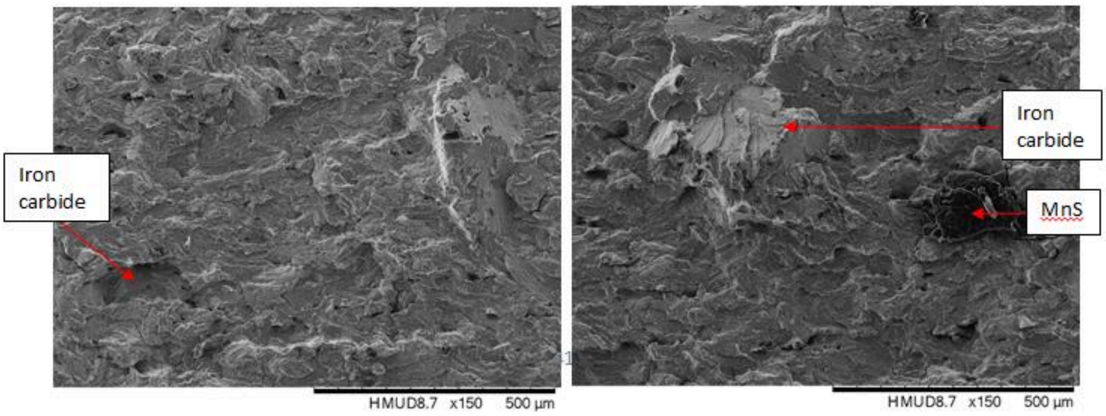

Figure 5: Fractured surface corresponding to points (e) left and (f) right signified on the cumulative AE energy plot shown in figure 4.

Results on trolley experiments

The plot in figure 6 presents the raw AE signal from a test carried out using the test trolley without any wheel defects present. At 2.6s the peak observed in the signal is due to lead break carried out on the rail. The moving RMS plot of the raw signal is also shown. This particular test shows that rail wheels in good condition generate very little background noise and hence a crack growth event in the vicinity of the AE sensors can be easily detected.

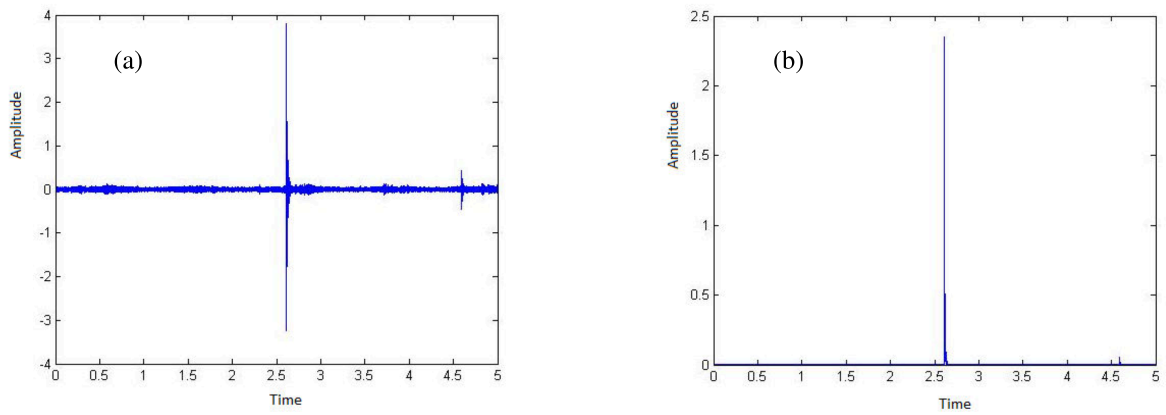

Figure 6 : Simulated AE event during movement of the test trolley using a lead tip break. a) Raw data and b) moving RMS plot.

The plot in figure 7 shows the raw AE signal acquired for the case of a simulated metal build-up defect. The peaks seen in the raw AE signal are arising from the impacts of the area where metal build-up has been simulated on the surface of the rail every time the wheel rotates.

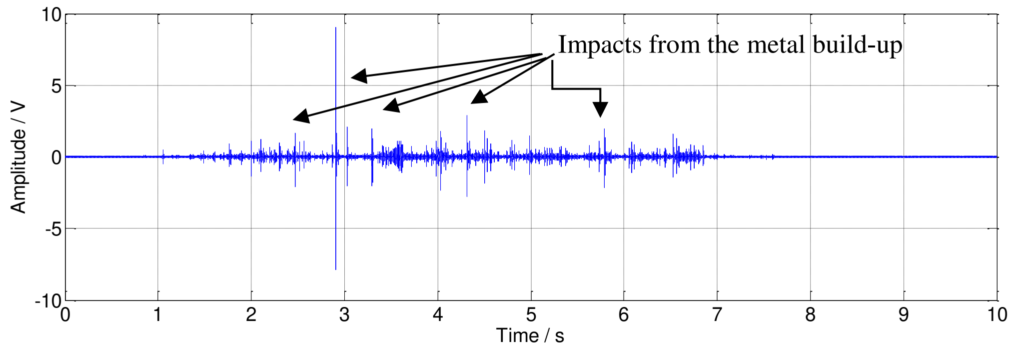

Figure 7: Wheel with metal build-up defect moving with automatic trolley.

Results on field trials

The plots in figure 8 summarise the results from vibration and AE measurements carried out onboard. Due to the limited accelerometer cable length, vibration measurements could not be carried out on the bearings with over 8 mm race and roller defect size. The increase in signal amplitude of the impacts with increasing defect size can be observed in results of the AE measurement. In the case of vibration analysis, it is more difficult to distinguish the differences between the measurements for the healthy and defective bearing without further analysis. The peaks seen in the healthy case are related to joints over which the test train was passing generating impacts each time.

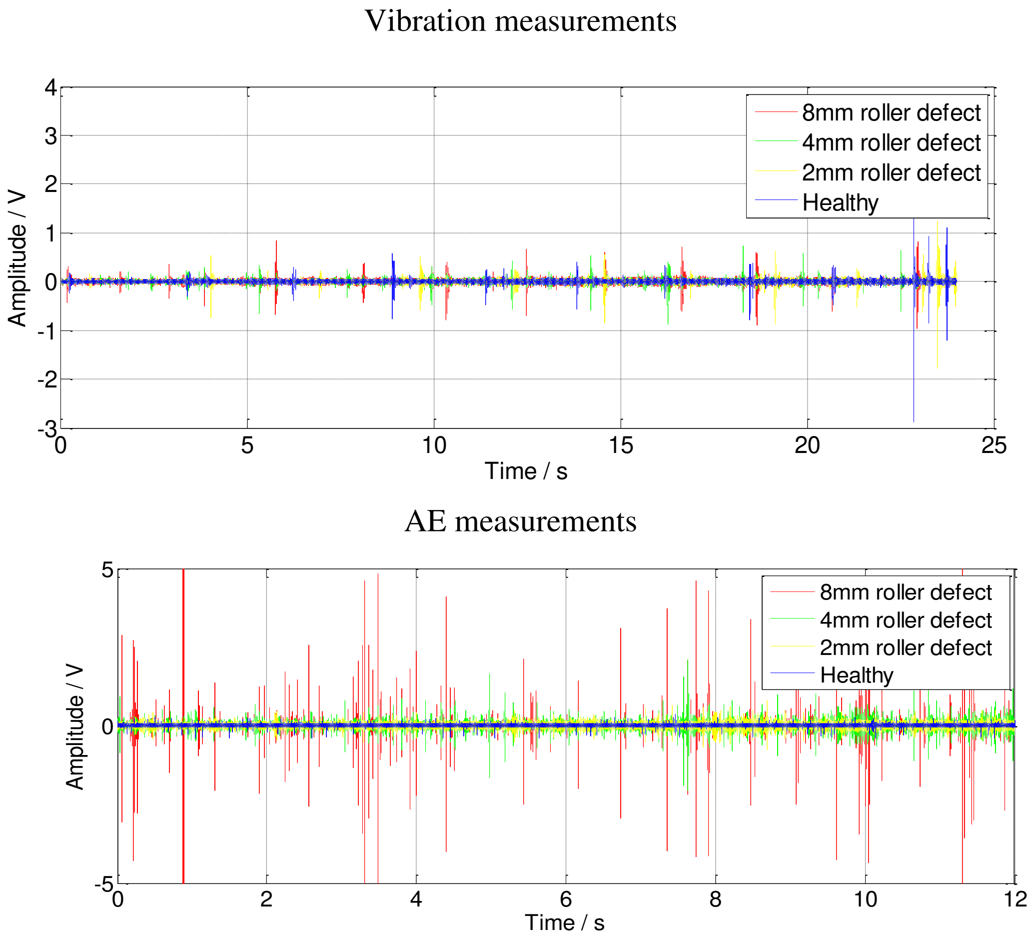

Figure 8: Raw data comparison from a) the onboard vibration and b) AE measurements during tests of bearings with different conditions in Long Marston.

Conclusions

In this paper we have briefly presented some experiments to highlight the possibilities of the application of remote condition monitoring for evaluating in real-time different types of defects in railway infrastructure and rolling stock. Of course the results presented herewith are in no case exhaustive and aim to just provide a brief overview of the usefulness of AE and vibration analysis as an alternative or supplement to traditional inspection approaches. The aim is to use remote condition monitoring date efficiently enough so as to reduce the frequency of inspection campaigns using conventional means and support the transition from corrective and preventive maintenance to condition-based and predictive maintenance approaches.

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