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Health condition monitoring of insulated joints based on axle box acceleration measurements

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ABSTRACT

This paper presents a health condition monitoring system for insulated rail joints (IRJs) based on axle box acceleration (ABA) measurements. The ABA signals from all the wheels of the measuring train are processed to extract those characteristics that better represent the quality of the IRJ. Then, different indicators are used for damage assessment, the most relevant being a set of frequency bands in the ABA power spectrum. A detection algorithm is proposed based on the derived frequency characteristics of the ABA signal. We compared the responses of IRJs in good condition with those in poor condition. Track inspections were performed to validate the health condition monitoring methodology in different IRJs of the Dutch railway network. The hit rate of IRJs detection was 84% for two validated tracks. The damage assessment procedure allowed to prioritize the IRJs that require maintenance. This information is useful for the railway inframanagers as it allows to predict where safety compromises will be faced.

1. Introduction

Insulated Rail Joints (IRJs) are critical components in the railways infrastructure as they are the core of signalling systems, in which the railway network is divided into electrically isolated sections of tracks. When a train is running over a section, a short circuit is created and the signalling system switches from green to red, indicating that the track is occupied. Thus, the failure of IRJs affects the safety of the railways, because the malfunction of the signalling system can lead into a severe accident. Consequently, maintenance measures should be taken if an IRJ is found in a bad condition. In a late stage of degradation, these measures are expensive and time consuming because usually the IRJ has to be replaced. Moreover, the maintenance measures are carried out up to 5 times more frequently at an IRJ than at other track components [30] as IRJs are a weak link in the track structure.

An IRJ constitutes a discontinuity to the track, see Fig. 1. The rail ends are connected with two joint bars, placed on both sides of the rail web, and the gap between the rail ends is filled with an isolating component called endpost. The joint bars are attached to the rails by bolts and epoxy adhesive. The IRJs are characterized by high impact dynamic forces at the wheel/rail interface [40], caused by the combination of two factors: lower bending stiffness of the joint bars comparing to that of the rail, leading to larger deflection [10,13]; and lower values of the Young's modulus of the endpost comparing to the one of the steel [2]. The impact dynamic forces may have several consequences on the state of an IRJ, such as the resulting high stress concentration producing plastic deformation of the rail surface [11]; "cavity-like" damage appearing in the rail head after the gap [34]; the high maximum shear stress leading to the partial loss of the bond between the joint bars and the rail [9], and the contribution to the growth of cracks starting from the holes in the rail [22].

The existing studies have focused on understanding the influence of vehicle and track components on the degradation of IRJs to eliminate or lighten the dynamic response between the wheel and the track [10,22,41,30,4,9,14,35,6,21,19,20]. The speed of the train has a significant effect on the wheel/rail contact forces [10,40]. For tracks, the misalignment between the rail ends at a joint and the track parameters that increase the flexibility of the IRJ are the most important factors [41,31,9,14,43].

Currently, the monitoring of the IRJs health condition is mainly based on visual inspection [42], which is dangerous for the operators and the resulting assessment may contain subjectivity introduced by the human factors. Visual inspections are supplemented with eddy current [28] and ultrasound measurements [1] for detection of cracks. However, some conditions of IRJs can still not be detected by these three methods. For example, the cracks in the rail web hidden by the joint bars can only be detected at a late stage when the immediate replacement of the IRJ is the only possible measure. Another example is the partial loss of the bond between the joint bars and the rail which may be the beginning

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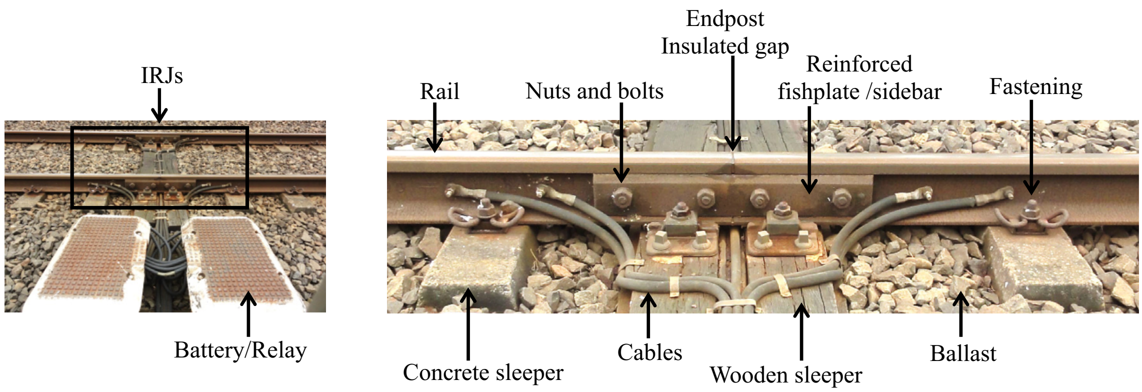

Fig. 1. Picture of an IRJ and its main components.

of the mechanical failure [5] or an electrical failure as water can get in and short-circuit the two rail ends.

In this paper, we propose an on-train automatic health condition monitoring system using axle box acceleration (ABA) to monitor the condition of IRJs. The advantage of the ABA method comparing to eddy current and ultrasonic techniques is that ABA is related to the contact force in the wheel-rail interface, and hence, represents the dynamic impact interaction between wheel and rail at an IRJ. High dynamic responses observed in ABA can be a measure of degradation states of IRJ that cannot be assessed with ultrasound and eddy-current measurements, like plastics deformation without cracks, hidden or very small cracks, and loose bolts. In view that the ABA system can detect track defects such as corrugation, welds of poor quality and squats, and assess different deterioration states [17,23], we believe that the condition of IRJs can be monitored, as the impact is significantly higher at IRJs than at short track defects. The other important advantage of the ABA system is that the measurements are performed on-board of a running vehicle, minimizing both the hours of unavailable track due to maintenance and the number of visual inspections required, while the condition of each IRJ is assessed by an automatic decision algorithm.

The process of the health condition monitoring of IRJs with the ABA method includes the detection of the location of the IRJ in the ABA data and subsequent damage classification and assessment. The general methodology of the detection of short track defects was described in [23]; however, in the case of IRJs the characteristic frequencies and deterioration analysis is different than those of short wavelength defects. The main focus of the present paper is the analysis of different damage states of IRJs based on ABA measurements to assess the IRJs health condition.

To investigate the applicability of the ABA measurements to the health condition monitoring of IRJs, a set of real-life IRJs is assessed for two tracks in the Netherlands. IRJs in different conditions are included in the study, such as IRJs in a good state or with visible surface degradation at different states, IRJ with a crack in the fastener, and with damaged insulation layer. The degradation state of IRJs is validated based on the photos taken on the track site. The ABA responses at those IRJs are analysed in both the time and the frequency domains, including frequencies up to 1400 Hz. Based on the results, different indicators are defined to classify the IRJ conditions, where the most relevant are certain frequencies of the ABA signal.

The paper is divided as follows. In Section 2, the theoretical background of the health condition monitoring of IRJs using ABA measurements is discussed. In Section 3, the damaged-IRJ analyses based on ABA and the hammer test are presented. In Section 4, the results of the automatic detection of IRJs are provided and the guidelines for the assessment of the health condition of IRJs are outlined.

2. Health condition monitoring of IRJs using ABA measurements

2.1. ABA measurement system

The ABA measurements were performed on board of a measuring train using a patented ABA technology [15]. The sensitivity of ABA to rail profile deviation was investigated in [16]. It has been shown that even trivial rail surface indentations of 10 mm long and 0.05–0.2 mm deep can be effectively detected by the ABA technology.

The ABA was measured by general purpose accelerometers mounted on the axle boxes of the wheels. Fig. 2 represents a scheme of the whole system IRJ – train. The full set of acceleration measurements for the train i are in the vector $a_i(t)$. The recorded data also included the GPS coordinates $x_i(t)$ and the train speed $v_i(t)$ which was around the normal operational speed of the measuring train (100 km/h). The full measurement vector is denoted as $y_i(t)$, $y_i(t)=[a_i(t)\ x_i(t)\ v_i(t)]$.

2.2. Health condition monitoring of IRJs

The health condition of the railway infrastructure is a distributed parameter system, which is dependent on various factors in both temporal and spatial domain. For instance, the health of an IRJ will be influenced temporally by the tonnage of the trains pass-

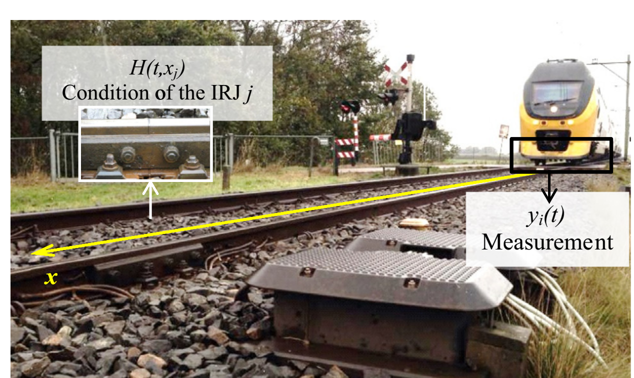

Fig. 2. Track conditions are assessed via signal processing methods using on-board measurements.