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Damage tolerances of a railway axle in the presence of wheel polygonalizations

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ABSTRACT

Damage tolerances of a railway axle in the presence of wheel polygonalization are investigated using a comprehensive coupled vehicle/track dynamic model. The model is formulated through coupling a typical high-speed train model and a slab track model, in which the wheelset, axle box and the slab track are treated as flexible bodies using the modal approach to account for the flexible deflections and dynamic stresses caused by the wheel ploygonalization-induced impact forces. The validity of this model is validated by using axle box vertical accelerations obtained from field tests. The dynamic stress in a railway axle is evaluated by using the modal stress recovery method in the proposed dynamic model, which is validated by the Finite Element Method (FEM). Using this comprehensive coupled/slab track dynamic model, the dynamic stresses developed in a railway axle due to the wheel polygonalization-induced impact forces are predicted, and subsequently used in the damage tolerance analyses to determine the residual lifetime of a railway axle in case of initial cracks. The results indicate that the wheel polygonalization can generate high magnitude impact forces at wheel/rail interfaces leading to remarkable increases in the stress states of a railway axle, and subsequently contribute to the propagations of cracks in the axle shaft. Consequently, a reasonable inspection interval for a high-speed train axles should be employed in the presence of wheel polygonalization.

1. Introduction

Railway axles, the most critical component of railway vehicles, are commonly designed with low level of stress states related to the fatigue limits for the objective of the infinite life. However, the railway axle failures still occur in the services due to either the very high cycle fatigue (VHCF) or external damages [1]. In the VHCF with more than 10^8 load cycles, the initial crack may initiate from the non-metallic inclusions, and the sizes of non-metallic inclusions play a crucial role in the initiation of cracks in railway axles [2]. In regard to external damages, the corrosion and ballast impacts are usually referred to the source of initial cracks in a railway axle. Such kind of initial cracks may propagate, and result in the axle fracture accidents under the service load conditions [3]. Through the fracture mechanism method, the damage tolerances of railway axles are thus widely employed to estimate the residual lifetime and to determine the reasonable inspection interval for railway axles.

The railway axles are exposed to alternative load conditions due to wheel rotations which imposes significant influences on the damage tolerances of railway axles with initial cracks. The initial investigation on the damage tolerance of railway axles was performed by August Wohler, then a large amount of investigations have been conducted based on the da/dN-ΔK curve of the material [4]. The recent overview on damage tolerances of railway axles was performed by Zerbst et al. [4–6]. Zerbst Beretta

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[7,8] presented some important failure scenarios caused by fatigue crack initiation and propagation and important influencing factors, which concluded that there are some typical sites where fatigue cracks easily initiate at an axle, including the press fit area and the geometrical transition. In the press fit area, the initial press fit cracks are usually attributed to the fretting fatigue between the press fitted parts, while the stress concentration owing to the notch is referred to the reason of crack initiation at the geometrical transition. Makino et al. [9] reviewed damage tolerances of railway axles in Japan, and conducted comparison analyses in the fatigue design method between the Japan and the European.

Based on the European flaw assessment procedure SINTAP and NASGRO/ESACRACK, Zerbst et al. [10] proposed a damage tolerance concept for railway axles and demonstrated the application of the damage tolerance in the railway axle. Beretta and Carboni [11] presented a probabilistic application of the NASGRO crack growth algorithm to evaluate the propagation lifetime of railway axles, in which the experiments were used to determine the crack growth and threshold data of an A1N steel that enables to establish the random variable models for the estimations of propagation lifetimes. In addition to the fatigue crack growth under the variable amplitude loads, the relevant experimental and analytical researches on a mild steel for a railway axle can be found in [12]. Luke et al. [3,13] studied the influences of variable amplitude loading on the crack propagation behaviors of the axle steel 25CrMo4T (A4T) and the high strength steel 34CrNiMo6. The results concluded that the calculated crack propagation curve significantly underestimates the test data, which may be attributed to the linear-elastic crack propagation approach without considering the crack closure and load sequence effects. Apart from the external damage on the axle, the corrosion at the surface of railway axles also serves as an important source of crack initiations. Through the experimental investigations on the corrosion fatigue of A1N axle steel, Beretta et al. [14,15] suggested the fatigue life of A1N steel is strongly affected by the presence of a mildly corrosive substance such as the rainwater. On the basis of experimental results, a conservative S-N diagram for the A1N steel subjected to artificial rainwater was developed to describe the corrosion-fatigue.

It is known that the stress load cycles in an axle are the driving forces of crack initiations and propagations for railway axles. In the existing researches, damage tolerances of railway axles are usually evaluated by either constant amplitude loads or variable amplitude loads. Through experiments on the British railway axles Watson and Timmis [16] proposed a method to estimate the railway axle stress spectra. The loading of a railway axle can be generally grouped into different components, including static and dynamic axle loads, bending and axial tension at curved track section, crossovers and switches, torsion during traction and braking, high frequency loading due to stick-slip behavior, press fit loading, and residual stresses from manufacturing [5]. The static and dynamic axle loads are mainly caused by the weight of the vehicle associated with different load cases, track irregularities and wheel tread conditions. In EN and JIS standards the vertical and horizontal acceleration coefficients are usually adopted to account for the dynamic effects [17,18].

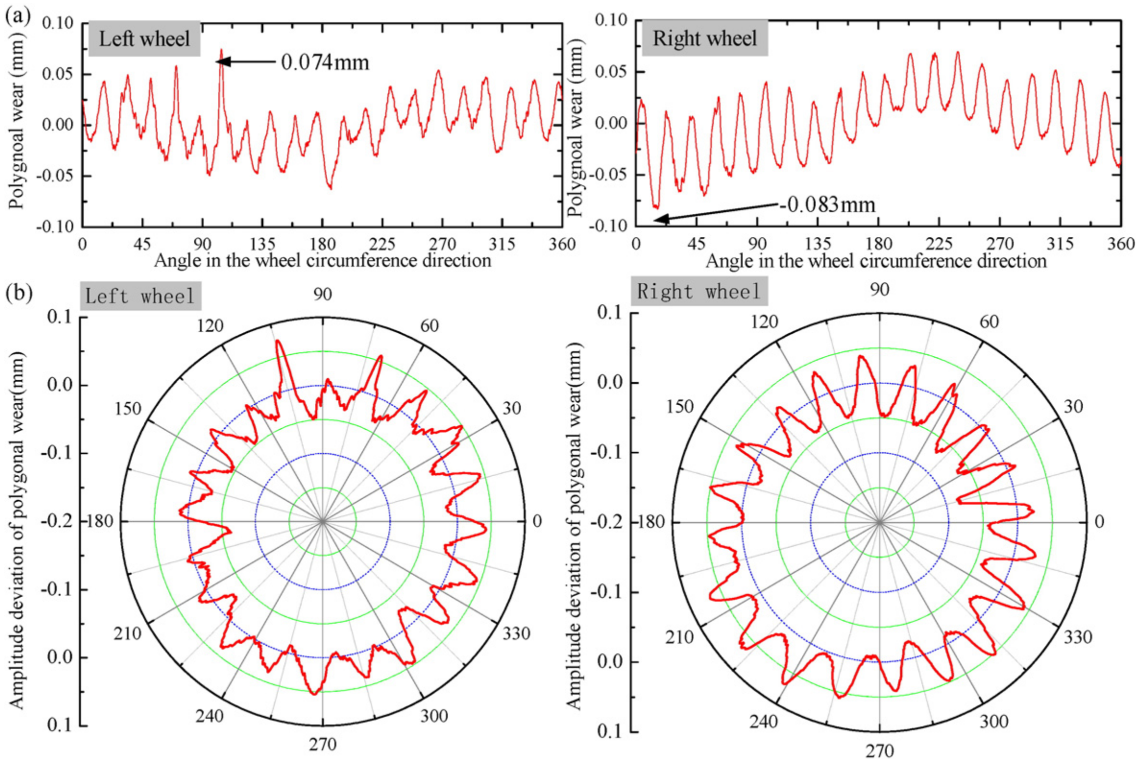

Fig. 1. Typical wheel polygonalization in a high speed train [22].