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Rolling contact fatigue of three crossing nose materials—Multiscale FE approach

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ABSTRACT

In this work finite element models at different length scales are applied to predict the performance of three different crossing materials (Manganese steel, Hardox and Marage 300) in view of the development of rolling contact fatigue (RCF) cracks. A model of the whole crossing (crossing model) is used for the calculation of the dynamic forces and movements of wheel and crossing. For the prediction of RCF repeated loadings have to be calculated, but only a reduced model permits a sufficiently fine mesh and reasonable computing times. Therefore, a simplified model of the wheel and the crossing nose (impact model) is developed, which uses the dynamic movements of the crossing model as boundary conditions. The accumulation of plastic strains in the crossing, the build-up of residual stresses and the geometric adaption of the crossing to the loads is studied for 81 load cycles. The contact pressures, shear stresses and residual stresses of the impact model with the adapted geometries of the 81st cycle are applied to a two-dimensional model with a surface crack (crack model). Using data from measured crack growth curves, the three materials can be compared in terms of crack development and growth.

1. Introduction

In the railway track structure, turnouts allow trains to change from one track to another. In contrast to the rails with a constant profile in the running direction, the profile of the crossing nose and the wing rail changes throughout the turnout. In the crossing panel the rail is discontinuous but under normal operations the wheel stays in contact all the time either with the wing rail or the crossing nose or both. As the wheel runs onto the crossing nose, it has to change its velocity vector in vertical direction and this causes a vertical impact. Due to geometric restrictions, the crossing nose has a small radius at its tip. For the facing move (the wheel runs initially on the wing rail and impacts on the crossing nose) the small radius of the crossing nose together with the impact produces very high contact pressures. In addition, the different rolling radii of the wheel on the wing rail and the crossing nose cause slip during the time of the impact.

The high contact pressure can cause severe cyclic plastic deformation. Contact pressure and slip are the driving forces for wear and rolling contact fatigue (RCF) described for the wheel/rail contact in [1], which limit the service time and the lifetime of crossings. In Fig. 1, a crossing nose with such surface cracks is shown. Generally, the ideal crossing material should have a high wear resistance and a high resistance to crack initiation and growth.

The process of a wheel passing a crossing is highly complex. The parameters are the passing direction, the axle load, the train speed, the wheel profile, the bogie design and of course the geometry and bedding of the crossing. There are some approaches to capture the dynamics of this process with numerical models. One way is the use of multibody system dynamics with the ability to describe a whole train as it runs over a turnout [2,3]. Another possibility, developed by the authors of this work, is using an explicit finite element code to model one wheel and three meters of the turnout (including the crossing). A simplified case with this explicit FE method is reported and validated in [4]. In [5] the same method is used for an impact calculation on a rail. In the presented model some assumptions are made concerning the movement of the wheel over the crossing, which means that it disregards some effects of the bogies and the whole train's movement. On the other hand, it provides a practical tool to study and understand damage relevant effects in detail.

In previous works by the authors [6–8], two important mechanisms have been identified: First the vertical movement of the wheel and the crossing (involving the impact), and second the change in the angular velocity of the wheel set resulting in slip. The effect of the crossing's bedding, the train velocity and the axle

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Fig. 1. A crossing nose with RCF cracks. With longitudinal slip, they are perpendicular to the running direction of the wheel.

load are further parameters of the investigations. Using a similar model, the effect of the plastic adaption on the impact loads has been studied with simplified geometry and without crack calculations [9].

The dynamic process of a wheel running over a crossing nose is determined by the crossing geometry that is dependent on the crossing material′s plastic deformation of previous loading. In this work three materials are selected for which the loading of a surface crack will be described. These materials are a 13% Manganese steel, in the literature referred to as Hadfield steel [10] ("Mn13"), a maraging steel that is defined in the ASTM norm as "Marage 300" ("Marage") and a steel with a hardness that lies in between Mn13 and Marage ("Hardox").

A similar approach for predicting damage in crossings was presented by Johansson et al. [11] and is applied for a crossing optimization in Ref. [12]. It's main aim is predicting the change in the crossings shape due to plastic deformation and wear. It uses a model for RCF crack initiation but does not investigate loads on an existing crack. There are several papers in the literature that deal with the loading of RCF cracks like [13] which uses a 2D model with one crack and even three-dimensional models of a RCF crack are reported [14]. One aim of these papers is to predict the propagation direction and propagation velocity of cracks. In a more recent work even an anisotropic propagation law has been used [15]. Those crack models, however, often use simplified loads such as a moving contact pressure distribution.

2. Modeling

2.1. The crossing model

A model for the crossing has been developed using the finite element code ABAQUS/Explicit [16] by the authors [8]. In this model, a three meter part of the crossing is modeled, in which the wheel changes from the wing rail to the crossing nose. The mesh of the model can be seen in Fig. 2. The influence of various parameters on the crossing′s loading can be investigated. The calculated results include the maximum vertical contact forces, the wheel movement, the longitudinal position of impact on the crossing nose, the contact pressure, the slip and the plastic strains. Certain assumptions about the boundary conditions are made.

With this *crossing model* that contains about 250,000 elements causing calculation times of 8h on an up-to-date four-core computer, cyclic studies are very time-consuming. The crossing model contains elements with an edge-length of 3 mm in the contacting areas, which is sufficient for a good description of the dynamics and a rough but usually sufficiently accurate description of contact pressure, slip and plastic deformation. However, for a more detailed study of the adaption of the crossing nose (in terms of stresses and strains), the calculation times have to be reduced and the elements in the crossing nose have to be refined.

2.2. The impact model

In the *impact model* only the 0.6 m part of the crossing nose in which the wheel impacts is modeled. The case of the facing moves (wheel initially running on the wing rail and impacting onto the crossing nose) is investigated. Parameters of the investigation consist of a new wheel profile, a train speed of 160 km/h and an axle load of 14.2 t. In Fig. 3 the contact force evolution of the *crossing model* is shown for this case. The corresponding region of the impact model (1.7–2.2 m) is indicated by two lines. Within this distance, it can be seen that the wheel impacts onto the crossing nose. The initial vertical wheel and crossing position and the wheel velocity were subsequently used as initial conditions in the impact model.

Concerning the crossing geometry, a standard crossing of the type 760-1:15 (UIC 60 rails) is used. The unworn profile of an UIC-ORE 1002-type wheel is used as wheel geometry. The mass of the wheel is 1025 kg and the moment of inertia of the whole axle is 135.5 kgm^2. The contact between the wheel and the crossing nose is modeled with a Coulomb friction coefficient of 0.3.

The model uses explicit time integration and is solved with the commercial code ABAQUS/Explicit [16]. In the model of the wheel and the crossing nose, the mesh is refined in the regions where the wheel and the crossing nose contact each other. Tie-constraints connect the parts with different element sizes and these connections are carefully put into areas where they do not alter the stress

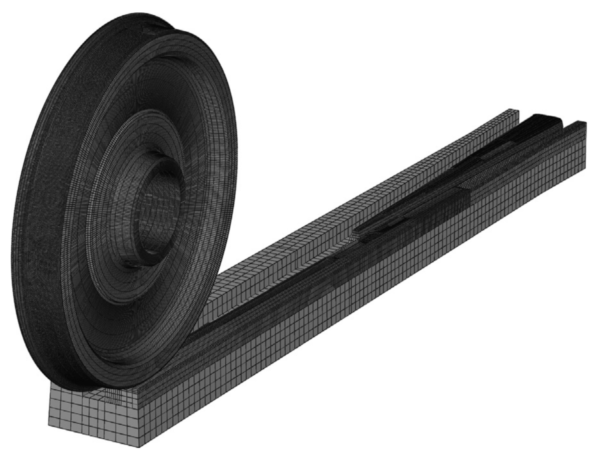

Fig. 2. The crossing model with the wheel, two wing rails and the crossing nose. A total length of 3 m is modeled.

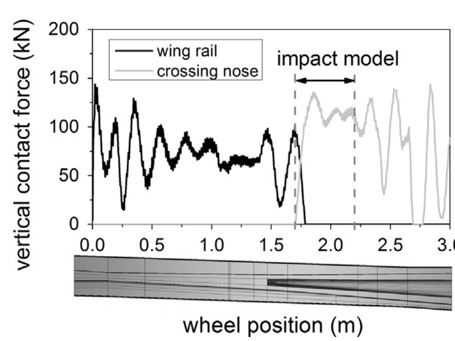

Fig. 3. Vertical contact forces of the crossing model with a train speed of 160 km/h and facing move. The region that is separately modeled in the impact model is indicated by the dashed lines.