Modeling of Wheel-Rail Contact Dynamics: From Contact Geometry to Damage Prediction

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Accurate prediction of wheel-rail contact dynamics is crucial for vehicle design and performance evaluation of railroad vehicles. For this purposes, various approaches have been proposed and utilized for general multibody dynamics computer algorithms [1]. The contact geometry is essential to the wheel-rail contact analysis, for which accurate surface description is required to obtain the geometric parameters that directly enter into the contact force calculation. In a railroad switch section, in particular, the rail profile varies along the track to enable smooth transfer of contact from one rail to another. The wheel is then subjected to not only the tread and flange contact, but also the back-of-flange contact for guiding the wheel. The top-of-flange contact can also occur in a single-blade tramway turnout. For these problems, a numerical procedure developed for the analysis of vehicle-turnout interaction, including the single-blade tramway turnout, is presented to discuss how complex wheel-rail contact geometry problems in the switching and crossing section can be incorporated [2] in the railroad vehicle dynamics simulation framework.

Another type of complexity resulting from profile geometry is wear, for which slight change in the profile geometry results in significant impact on the contact geometry characteristics of wheel and rail, thereby altering the dynamic performance as well as derailment safety of railroad vehicles. For severely worn wheel and rail profiles involving plastic material flows, two profiles conform closely, posing a conformal wheel-rail contact problem in the context of railroad vehicle dynamics simulation. Since existing point-contact approaches are not applicable to these problems, modeling of the conformal contact has been an active research area in this field. For this purpose, the conformal contact patches predicted by the finite element analysis are converted to the equivalent multiple Hertzian contact patches for use in railroad vehicle dynamics simulations [3]. With this approach, effect of severe wear on the derailment coefficient in small radius curved tracks is discussed, along with the comparison with on-track test data. It is shown that the derailment coefficient decreases as the wear progresses, as demonstrated by the test data.

This, however, does not mean that the profile wear is preferable since increase in the difference in rolling radii results in higher longitudinal creepage (slip) that accelerates flange wear. Furthermore, wear is strongly tied with the rolling contact fatigue (RCF). It is important to note that surface-initiated cracks are removed if the wear progression rate is higher than the crack propagation rate. This, however, leads to frequent re-profiling and replacement of wheels due to higher wear progression rate. Although raising the material hardness can decrease the wear rate, loss of material ductility results in cracks being initiated more frequently. Flange lubrication is another operational practice that helps decrease flange wear. However, flange lubrication not only deteriorates the self-steering ability of the wheelset due to a decrease in the longitudinal creep forces being generated during curve negotiation, but also accelerates the crack propagation due to the entrapment of fluid inside the crack. Therefore, well-balanced mitigation of wheel wear progression and rolling contact fatigue (RCF) is highly desired from the maintenance and operation perspectives.

To address this issue, profile design optimization has been pursued, for which a wear index (WI) and a surface fatigue index (SFI) are generally introduced to minimize wear and surface-initiated fatigue. Minimization of WI (i.e., Tγ value) indicates minimization of frictional power due to creep forces at each contact point. However, the contact geometry characteristics are altered as wear progresses [3], thus an optimized new profile is not necessarily optimum any more once noticeable profile wear occurs. Such a history-dependent profile alteration is not considered in existing WI-based profile optimization procedures. For this reason, the wheel material loss, which is predicted by the wear simulation capability for wheel and rail contact problems [4], is introduced to the optimization problem to account for the effect of wear history in the optimization process. Furthermore, it will be discussed in the presentation that minimization of Tγ value of flange contact does not always reduce wear since the flange wear rate plateaus in severe wear regime regardless of the frictional power density Tγ/A, where A is the contact area. Furthermore, it is important to note here that, for accurate prediction of the wheel material loss due to wear in the optimization process, the wear rate function must be determined experimentally as a function of the Tγ/A value. For this purpose, two-roller wear test is commonly used due to its easiness in controlling test conditions for collecting a wide range of test data and the wear rate function identified is used for predicting wheel profile wear using multibody railroad vehicle dynamics simulation [5-6]. It will also be discussed in the presentation that use of the two-roller wear rate function can lead to an underestimate of severe flange wear in the wear simulation. Furthermore, the numerical procedure for the profile optimization for mitigation of wheel wear and RCF will be discussed.

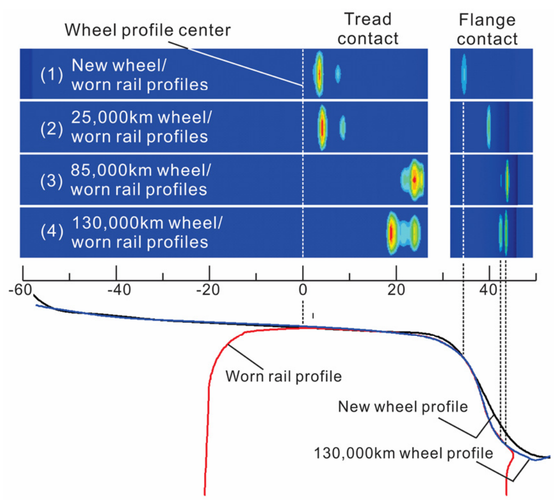

Fig. 1: Contact patches of severely worn wheel and rail

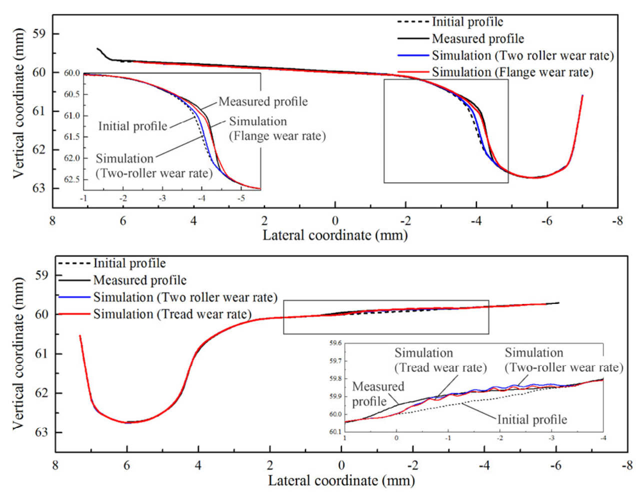

Fig. 2: Wear prediction and comparison with the test data

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