Interaction of Elastic Wheelsets and Elastic Rails: Modelling and Simulation

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INTRODUCTION

Today, the simulation of the running behaviour of railway vehicles is usually carried out on the base of a multi-body system approach and under the assumption that the wheelsets and the rails are rigid bodies. Considering the strongly nonlinear characteristics of the wheel-rail contact which can be very sensitive even to small relative shifts, the question arises, whether elastic deformations of the wheelsets and the rails can have an influence on this contact and thereby on the running behaviour of the entire vehicle. Moreover, for a description of the vehicle-track interaction in the higher frequency range in which phenomena like noise and wear are located, the consideration of the structural dynamics of the wheelsets and the rails is essential.
First, a simulation model of a railway vehicle is presented with special focus on the modelling of the wheelsets and rails as elastic bodies and their coupling by a nonlinear wheel-rail contact. Finally, the impact of these structural elasticities on the running behaviour of the vehicle is investigated; as an example, their influence on the critical speed and the limit cycle behaviour is presented.

1. MODELLING

The mechanical model of vehicle and track is based on a multi-body system approach and represents a passenger coach running on a straight track. The bodies this model consists of are shown in Fig. 1. Wheelsets and rails, i.e. the dark bodies, are modelled as elastic bodies, all other bodies are considered to be rigid.

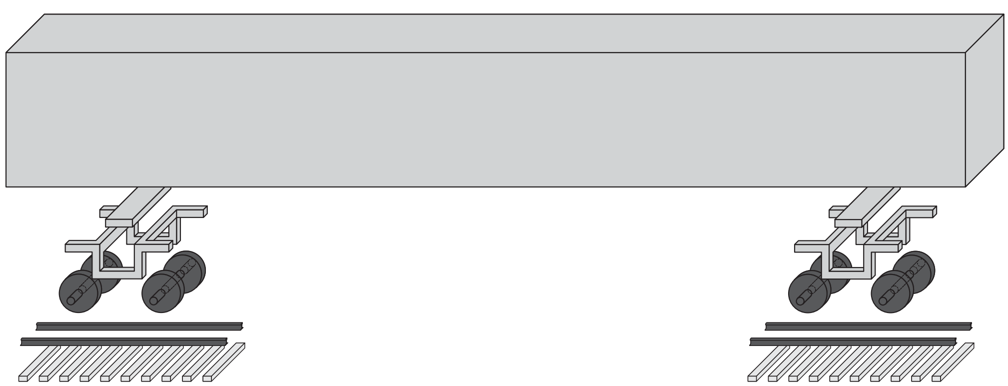

Fig. 1. Mechanical model of the vehicle-track system

1.1 Modelling of the vehicle

The vehicle consists of a carbody and two bogies; each bogie consists of a frame, a bolster and two wheelsets. To describe the suspension system, all the bodies of the vehicle are connected by linear viscoelastic force elements. Additionally, two nonlinear friction elements act between each bolster and the carbody.
To describe the deformations of the wheelsets, a three-dimensional Finite Element calculation is performed which yields their structural eigenmodes. These eigenmodes are used as shape functions for a modal

synthesis; deformations described by the modal synthesis are superimposed on the rigid body motions. Gyroscopic effects due to the rolling motion of the wheelsets are considered by additional terms. The lowest eigenfrequencies of the free wheelset occur at 74.1 Hz (antimetric torsion), 84.2 Hz (symmetric bending) und 147.2 Hz (antimetric bending); the two bending modes are depicted in Fig. 2.

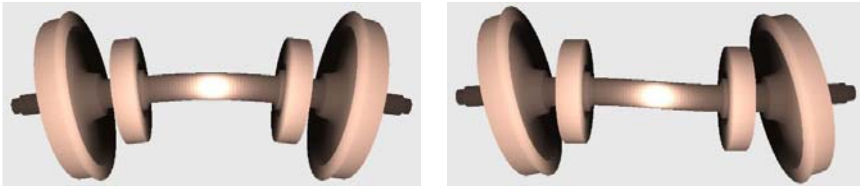

Fig. 2. Symmetric (left, 84.2 Hz) and antimetric (right, 147.2 Hz) bending modes of the wheelset

1.2 Modelling of the track

The track consists of two elastic rails supported by rigid sleepers via viscoelastic pads. The underground is also represented by viscoelastic elements. For each bogie, one separate track is used.

For the rails, a three-dimensional model is used, analogously to the one of the wheelsets; thus, also the deformations of their cross sections are taken into account. An important type of cross sectional deformations are inclinations of the rail's head against the rail's foot as shown in Fig. 3, because they can have an impact on the contact geometry between wheel and rail and thereby on the running behaviour. Such eigenmodes cannot be obtained with the usual beam approach.

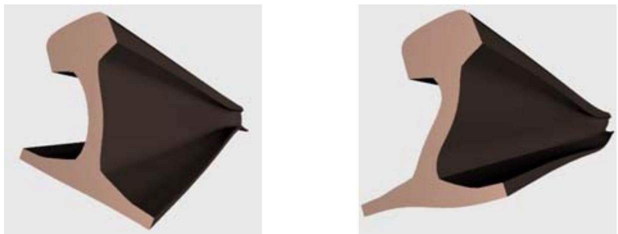

Fig. 3. Eigenmodes of the rail with distinct deformations of the cross section, wavelength: 1.2 m, eigenfrequencies: 1533 Hz (left), 4241 Hz (right)

1.3 Coupling of the vehicle and the track

The forces acting between the wheelsets and the rails are modelled by force elements representing the wheel-rail contact. The connection of this wheel-rail contact element to the elastic wheelset is shown in Fig. 4.

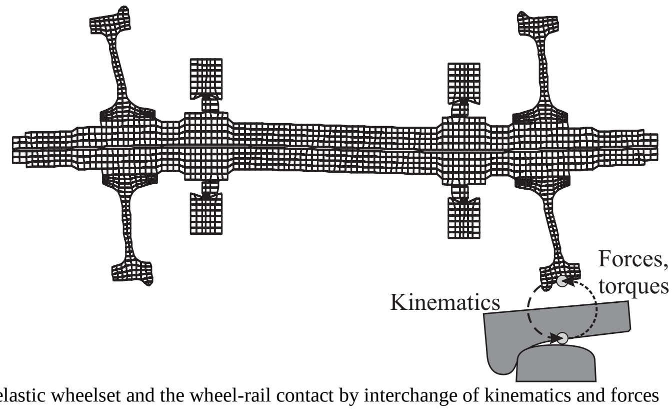

Fig. 4. Connection of the elastic wheelset and the wheel-rail contact by interchange of kinematics and forces

The inputs of the contact module are the kinematics of the wheelset taken at a special point on its surface, the so-called wheel node. Depending on the kinematics, the forces between the wheel and the rail are calculated taking into account the nonlinear geometry of the profiles and the nonlinear characteristics of the normal and tangential forces. The resulting forces are then applied on the elastic wheelset at the wheel node. For the rail, the interchange of kinematics and forces is performed in an analogous way at a corresponding rail node. Both nodes are fixed on the bodies, the shifting of the actual contact is performed internally in the contact element; to describe this shifting, additional contact torques relative to the wheel node and the rail node are used.

2. RESULTS

An important design criterion of a railway vehicle is its critical speed; if the vehicle runs faster than the critical speed, possible lateral motions of the wheelsets induced .e.g. by track irregularities do not decrease, but increase to a dangerous limit cycle. Below the critical speed, no limit cycle oscillations can occur at all.
The question arising in this context is whether the consideration of the structural elasticities of the wheelsets and the rails within the simulation model can influence the computed critical speed and the limit cycle behaviour. To investigate this influence, calculations are performed taking them into account completely, partially or not at all. By a comparison of the different results, the influences can be recognized (oder: the influences become apparent). As an example, the lateral motion of the first wheelset at its centre of mass is compared for different types of modelling in Fig. 5. In the right diagram, the critical speed appears as the left starting point of the curves; it is the lowest speed at which limit cycle oscillations occur.

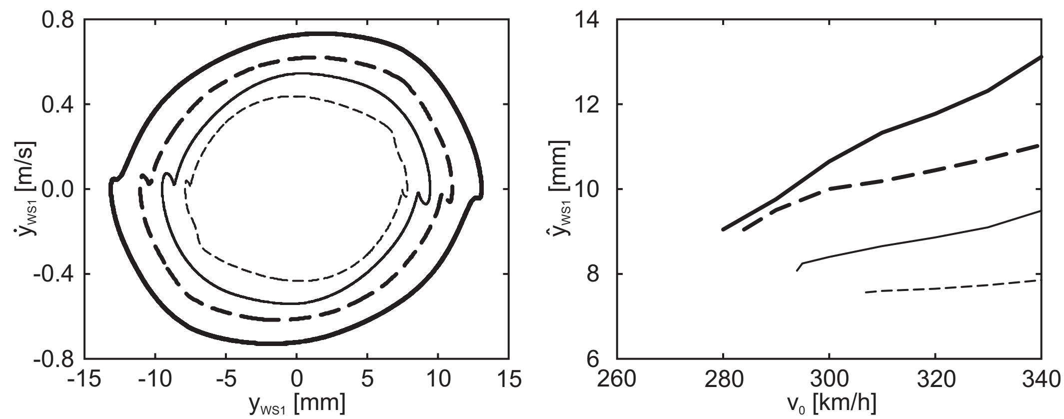

Fig. 5. Phase portrait (left) and amplitude versus travelling speed v_0 (right) of the first wheelset's lateral motion.
Thin lines: Rigid wheelsets, thick lines: Elastic wheelsets, dashed lines: Rigid rails, full lines: Elastic rails.

It can clearly be seen that the structural elasticities of the wheelsets and the rails lead to larger amplitudes of the wheelsets. Furthermore, the critical speed of the vehicle, i.e. the lowest speed where limit cycles can occur, is shifted down to lower travelling speeds by the structural elasticities; for example, the critical speed drops from 307 km/h (rigid wheelsets, rigid rails) down to 280 km/h (elastic wheelsets, elastic rails). It turns out that this effect is mainly caused by the elasticity of the wheelsets; the influence of the rails' elasticity is weaker, but nevertheless cannot be neglected. Furthermore, the support of the rails by discrete sleepers has only an extremely weak influence in this case.

3. CONCLUSIONS

The comparison of the obtained results shows that the structural elasticities of the wheelsets and the rails can have a significant influence on the running behaviour of a railway vehicle. The structural elasticities cause a distinct drop of the critical speed, i.e. the limit cycle oscillations start at a lower travelling speed if the structural elasticities are taken into account. Generally, the influence of the elasticity of the wheelsets is stronger; although the influence of the rails' elasticity is weaker, it cannot be neglected.

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REFERENCES

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