RAILWAY VEHICLE SIMULATION USING NON-ELLIPTICAL WHEEL-RAIL CONTACT MODEL

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Summary An approximate model of wheel-rail contact, which does not lead to stiff equations of motion and can be used for non-elliptical contact area, is considered. An analytical solution of the tangential contact problem for a slice of contact patch in the formulation of Kalker's simplified theory is used in the model. Results of railway vehicle simulation using an algorithm based on the model are given.

INTRODUCTION

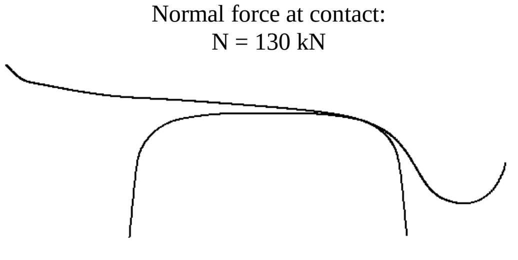
The description of contact between wheel and rail is a necessary condition to obtain reliable results of railway dynamics simulation, prediction of wheel and rail profile wear. The accurate solution of the rolling contact problem is not only a very complex problem even for numerical analysis methods but also a very time-consuming process. Furthermore, mathematical models of the contact forces often lead to stiff equations of motion because of high contact stiffness.
There are numerous methods to solve the contact problem. The choice of them is not easy because it is always a compromise between accuracy and simulation speed for dynamic problems.

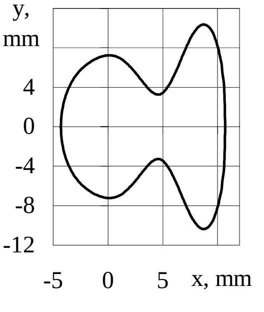
NON-ELLIPTICAL WHEEL-RAIL CONTACT MODEL

Taking into account that the contact patch is often far from elliptical it is necessary to develop a non-elliptical wheel-rail contact model. For that we consider the stationary rolling contact of elastic bodies and suppose that material properties of wheel and rail are the same, i.e. the bodies in contact are quasi-identical. In this case the contact problem can be divided into two independent ones: the normal contact problem and the tangential contact problem [1].

Normal contact problem solution

We use the elastic Winkler foundation model to find the contact patch configuration and the distribution of the normal pressure [1]. It means that the normal pressure at a point of the contact patch is proportionate to the interpenetration of the contact bodies at the point [1]. The foundation modulus is determined with the help of the half space method.
In our rail-track model, rail is considered as a massless body on a visco-elastic foundation and the normal force at the contact point is available from the solution of rail equilibrium equations. The interpenetration of the bodies is only used to solve the normal contact problem, and its small value can be neglected in the dynamic equations. Thus the normal force depends on the quite small vertical and lateral stiffness of the rail-track system and this model is not stiff.
Though solving the contact problem is an iterative process, the convergence of solving requires a small number of iterations if initial values of the interpenetration of wheel and rail are taken from the previous step of integration of equations of motion.
Example of the normal contact problem solution is shown in Fig. 1, where the contact of the rail profile R65 and the wheel profile DMetI, which form is similar to a worn profile, is presented. It is clearly shown in the figure that the contact patch computed by the described method is far from the elliptical one.





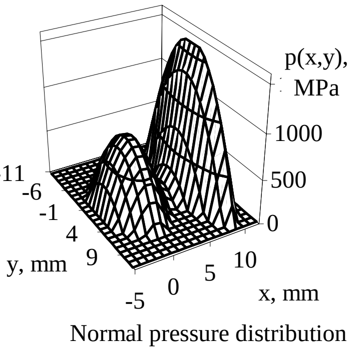


Figure 1. Example of normal contact problem solution.

Tangential contact problem solution

We use the FASTSIM algorithm [1], which was adapted for non-elliptical contact area, to solve the tangential contact problem. To determine the value of flexibility we calculate an equivalent ellipse such that the area of the non-elliptic contact patch is equal to the area of the ellipse [2]. The semi-axis of the ellipse in the rolling direction is set equal to the maximal half-length of the non-elliptical patch.

Though the FASTSIM algorithm is fast, it requires a large number of arithmetical operations. In fact, the algorithm is the numerical solution of a system of ordinary differential and differential-algebraic equations by a method similar to Euler's method, which has low accuracy. We use an analytical calculation of the tangential forces for every slice of the contact patch instead of the numerical computation. This method is exact in an adhesion area and approximate in a sliding area of the contact patch. The diagram of ratio of time required to solve the contact problem using FASTSIM (*Tf*) to solution time for the analytical method (*Ta*) is presented in Fig. 2. The number of slices in the contact patch is taken equal to 10 for both methods while the number of elements (*n*) in a slice is varied for FASTSIM.

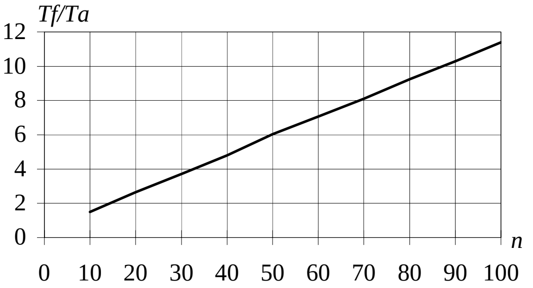


Figure 2. Ratio of required solution time of FASTSIM to time of analytical method.

The detailed description of the wheel-rail contact model can be found in [3].

APPLICATION OF THE DEVELOPED CONTACT MODEL FOR RAILWAY SIMULATION

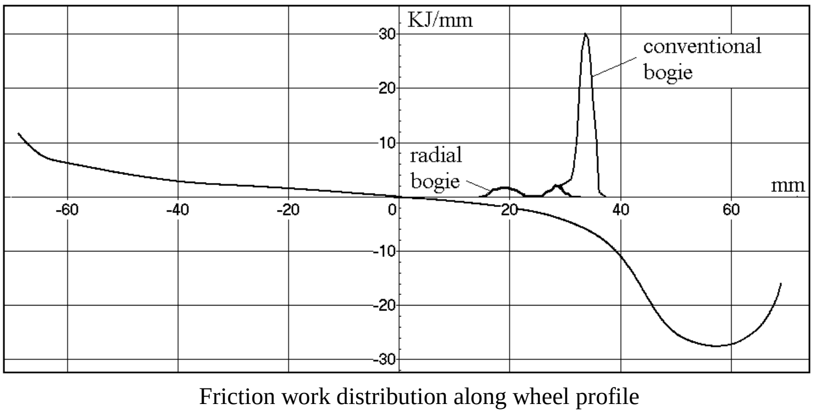
Estimation of effectiveness of radial steering bogie

The effectiveness of the radial steering bogie designed by VNIKTI MPS (Kolomna, Russia) for a six-axle freight diesel locomotive was estimated with the help of the described contact model. The radial steering bogies decrease angle of attack of wheels and correspondingly creep forces that leads to reduction of wheel and rail wear.

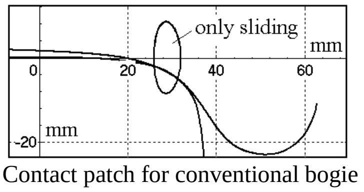
Performances of the vehicle with radial steering bogies and the diesel locomotive TE116 equipped with conventional bogies were compared. Main inertial and geometric parameters of both vehicles are equal. Wheel and rail profiles used for simulation are shown in Fig. 1.

Railway vehicle simulation was performed with the help of the program package "Universal Mechanism" (www.umlab.ru) developed in Bryansk State Technical University.

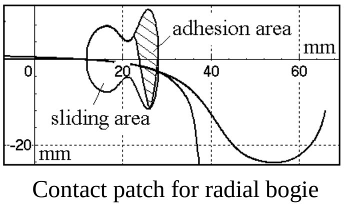
Some results of simulation of both vehicles in even curve R = 300 m are presented in Fig. 3. Contact patches between the first outer wheel and rail are shown on the right part of the figure. It is obvious that the contact patch for the locomotive with conventional bogies is located nearer to the wheel flange because of larger angle of attack. Moreover, as a result of larger values of creep the contact patch has no adhesion area. Curves of the distribution of friction work along wheel profile confirm that wear of wheels of TE116 locomotive will be considerably greater.



Friction work distribution along wheel profile



Contact patch for conventional bogie



Contact patch for radial bogie

Figure 3. Results of railway simulation in even curve.

CONCLUSIONS

The presented algorithm, which computes a non-elliptic wheel-rail contact, can be successfully used for problems of simulation of railway vehicle dynamics and wheel and rail wear prediction. The algorithm is fast enough and does not lead to stiff equations of motion.

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References

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