

## A NUMERICAL 3D MODEL OF RAIL WHEELSET DYNAMICS

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### ABSTRACT

The forces that arise in the contact area between the wheel and the rail heavily influence the dynamics of a train during its run. In this work the authors describe a new tridimensional wheel/rail contact model. Along with dynamic equations, the proposed model allows to simulate wheelset motion.

First it is necessary to find the number and position of contact points between wheel and rail; such values are numerically computed using Simplex method. The creep forces in the contact area are computed using the Kalker theory for tangential stress and an elastic approach for the normal force. The obtained numerical results show a good agreement with experimental data and simplified theoretical models available in literature (e.g. Klingel theory).

### INTRODUCTION

In the contact area between wheel and rail the creep forces arise, these forces influence the wheelset dynamic and depend on the contact point between the bodies.

The authors have realized a numerical contact model, with the following features:

- 1) It has to run in real time conditions, in order to be implemented in the HIL (Hardware in the Loop) application;
- 2) six degree of freedom are considered for each wheelset;
- 3) Multiple contact point can be considered;
- 4) Generic contact;
- 5) Model Robustness with respect to geometric and physical parameter variations

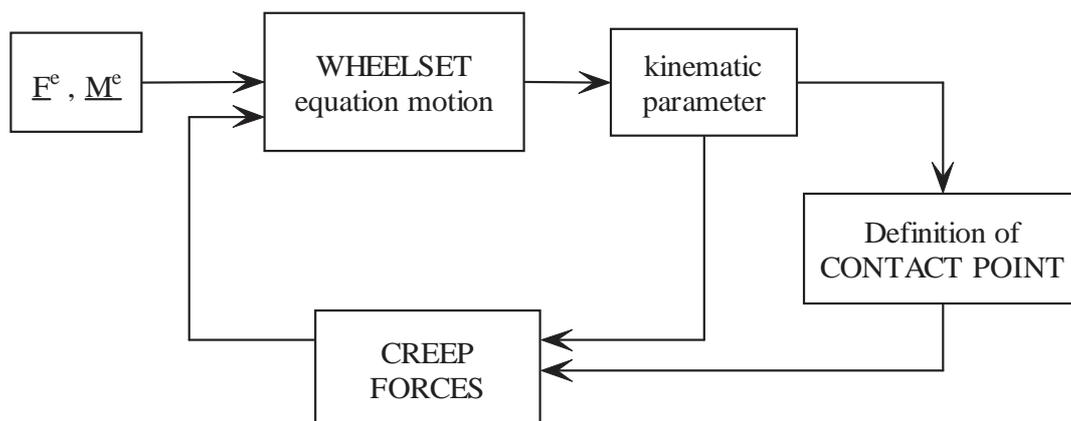


Figure 1: block diagram of the procedure.

### CONTACT POINT BETWEEN WHEEL AND RAIL

From realistic data relative to “normal” and “worn” profiles, the wheel and rail profiles were recreated on a MATLAB program: the wheel is generated as a revolution surface, while the rail as an extrusion in the longitudinal direction.

Once the user has defined the relative displacement, a Matlab procedure finds the contact points as the minimum values of difference surface between rail and wheel; calculations are performed using the Simplex method.

Using the Hertz theory the contact area is defined at the contact point, its dimension depends on the normal force, the material properties and the geometry in this point.

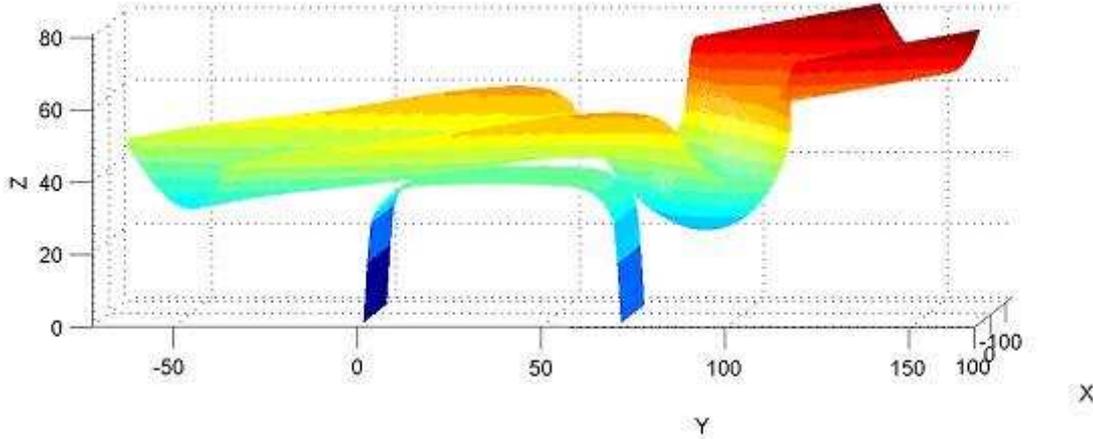


Figure 2: wheel and rail geometry.

### WHEELSET DYNAMIC

The creep forces in the contact area, give the total forces acting on the wheelset by the interaction with the boogie, besides acting torque and the weight.

So the dynamics of the wheelset can be described by means of the following differential equations:

$$\begin{cases} \ddot{M} \underline{G} = \underline{P} + \underline{S} + \underline{D} + \sum_{i=1}^n \left[ \underline{N}_i + \underline{T}_{ix} + \underline{T}_{iy} \right] \\ \ddot{K}(\underline{G}) = \sigma(\underline{G}) \underline{\omega} + \underline{\omega}_s \wedge \underline{K}(\underline{G}) = \underline{M}_m + \underline{M}_S + \underline{M}_D + \sum_{i=1}^n \left[ \underline{M}_{iN} + \underline{M}_{iT_x} + \underline{M}_{iT_y} + \underline{M}_{isp} \right] \end{cases} \quad (1)$$

The creep forces are calculated by Kalker linear theory

$$\begin{aligned} T_x &= -f_{11} \xi \\ T_y &= -f_{22} \eta - f_{23} \varphi \\ M_{sp} &= f_{23} \eta - f_{33} \varphi \end{aligned} \quad (2)$$

where  $f_{11}, f_{22}, f_{33}, f_{23}$  are the linear creep coefficients, calculated as follows:

$$\begin{aligned} f_{11} &= abGC_{11} & f_{33} &= (ab)^2 GC_{33} \\ f_{22} &= abGC_{22} & f_{23} &= (ab)^{3/2} GC_{23} \end{aligned} \quad (3)$$

and the values  $\xi$ ,  $\eta$  and  $\varphi$  for the right and the left wheel are the tree component of the creepage defined as:

$$\underline{\varepsilon} = \frac{\underline{v} - \underline{\omega} \wedge (\underline{G} - \underline{P}^c)}{|\underline{v}|}$$

The tangential Kalker values of creep forces are then saturated at the “adhesion limit”.

The normal force  $N$  is calculated with elasto-viscous approach as sum of a term proportional to the normal penetration between the body, and a term proportional to the surface relative velocities in the contact point.

$$N = -k_1 |p|^{\gamma_1} + k_2 \left| v^c \cdot \underline{n}_b(\underline{P}_b^c) \right|^{\gamma_2} \quad (4)$$

The constant values are calculating in accordance with the common adpted in literature ones [8,9].

So, the system composed by dynamic equations and the creep and normal forces calculations, is solved numerically by a SIMULINK model.

The definition of contact point is characterized by a high computational burden, so it is solved off-line with a look-up table.

The numerical model calculates the kinematic parameters of the wheelset and the whole contact information (creep forces and creepage).

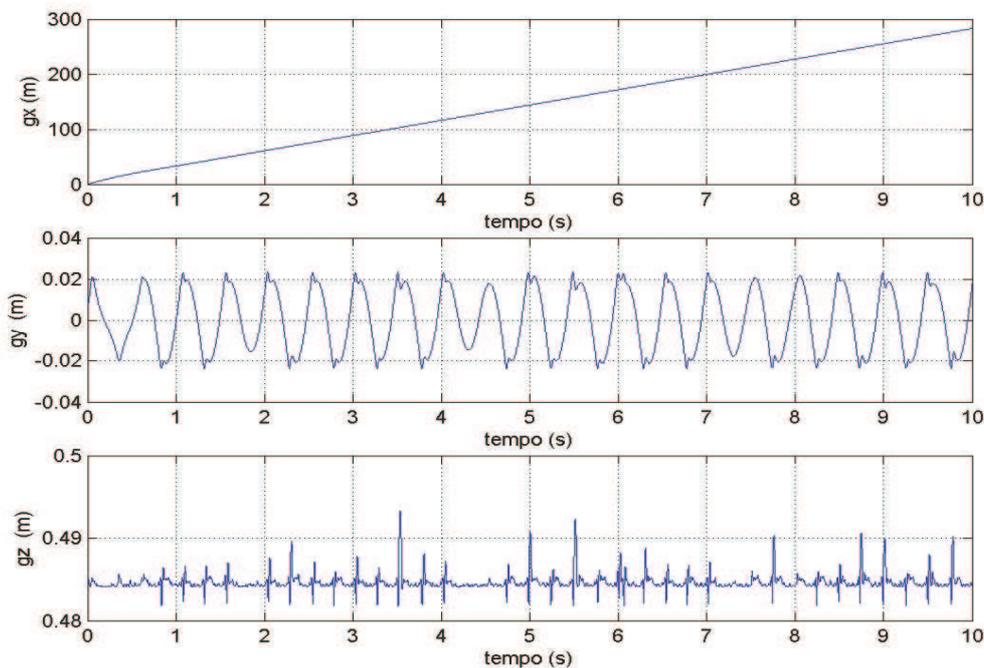


Figure 3: example of simulation results, position of the wheelset center of mass

## CONCLUSIONS AND FUTURE WORKS

In this work a study on a railway wheelset dynamics is shown, starting from the differential equations describing the dynamics a numerical procedure was developed, the wheel/rail contact problem was considered.

In the procedure, first an analysis on the contact area and the contact points research are performed. The contact point is numerically calculated as minimum value of difference rail/wheel surface with the Simplex method.

Then the contact points are inserted in a simulation block of normal and creep forces and spin moment, and then in a Simulink model that simulates the wheelset dynamics.

From the numerical simulation the wheelset motion variable and the contact features can be found. These results can be used also for the analysis of the dynamic stability of the railway vehicle wheelset.

The next target in the development of the model is the implementation of a generic track (with slope and curves), and taking into account the boogie interaction.

## REFERENCES

- [1] **K.L. Johnson**, *Contact mechanics*, Cambridge University Press, 1985.
- [2] **J.J.Kalker**, *Three-Dimensional Elastic Bodies in Rolling Contact*, Kluwert Academic Publishers, 1990.
- [3] **P.J. Vermeulen. K.L. Johnson**, *Contact of Nonspherical Elastic Bodies Transmitting Tangential Forces*, Journal of Applied Mechanics, Transactions of the ASME, June, 1964.
- [4] **E.A.H. Vollebregt, J.J. Kalker, G. Wang**, *CONTACT 93 Users Manual*, VORtech Computing, Industrial and Scientific Computing, July 1992, revised March 1994.
- [5] **S.Iwnicki**, *Simulation of wheel-rail contact forces Bodies*, Fatigue & Fracture of Engineering Materials & Structures, volume 26 Issue 10 Page 887-October 2003
- [6] **B.Liang, S.D.Iwnicki, F.J.Swift** *Simulation of the behavior of a railway vehicle with independently driven wheels*, Manchester Metropolitan University, Manchester M1 5GD, UK.
- [7] **C. Esveld** *Modern railway track*. MRT Productions, 2001
- [8] **A. A. Shabana, J. R. Sany** *An augmented formulation for mechanical systems with non-generalized coordinates: application to rigid body contact problems*. "Nonlinear dynamics", 24, 2001.
- [9] **A. A. Shabana, K. E. Zaazaa, J. L. Escalona, J. R. Sany** *Development of elastic force model for wheel-rail contact problems*. "Journal of sound and vibration", 269, 2004.