

AN INFLUENCE OF ADHESION MODEL ON THE RESULTS OF LOCOMOTIVES DYNAMICS SIMULATION

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Summary: The results of the locomotive dynamical behavior modeling with different wheel – rail contact sub – models are presented. It is shown, that the choice of wheel-rail contact model has significant impact on the simulation of locomotive motion in traction regime with high creep values, even when it’s running on the straight track.

Key words: wheel, rail, contact, creep, traction, dynamics

INTRODUCTION

A study on the wheel – rail frictional interaction brought the “adhesion coefficient (force) characteristics” concept – the dependence of the adhesion coefficient (force) on the creep vector inside the contact area. However the term “creep”, its calculation method and its value is different in various sources.

The creep in wheel – rail contact arises by two different reasons:

- as the reaction on the tractive (braking) moment applied to the wheelset axle;
- kinematical parameters of movement

It is often met that the first term is ignored in the locomotive dynamics simulation, and this can lead to significant errors.

OBJECTS AND PROBLEMS

The scheme of wheelset running on the track is shown on fig. 1. Wheelset is moving with linear speed V , left and right wheels are rotating with angular speeds w_{left} и w_{right} thereafter. Let’s denote by r_0 mean rolling radius of the wheel, and by r_{left} и r_{right} - left and right wheel contact radius.

The distance between initial contact points is denoted by d .

The creep components are usually defines as ratio of projections of the relative movement speed of the wheel and rail points to the linear movement speed:

$$\begin{aligned} \xi_x^i &= \frac{\text{Pr}_x(\bar{V} - \bar{w}_i r_i)}{\bar{V}} \\ \xi_y^i &= \frac{\text{Pr}_y(\bar{V} - \bar{w}_i r_i)}{\bar{V}} \\ \varphi^i &= \frac{\text{Pr}_z(\bar{w}_i r_i)}{\bar{V}} \end{aligned} \quad (1)$$

where: ξ_x - longitudinal creep, ξ_y - lateral creep, φ - spin, r - contact radius, $i = left, right$

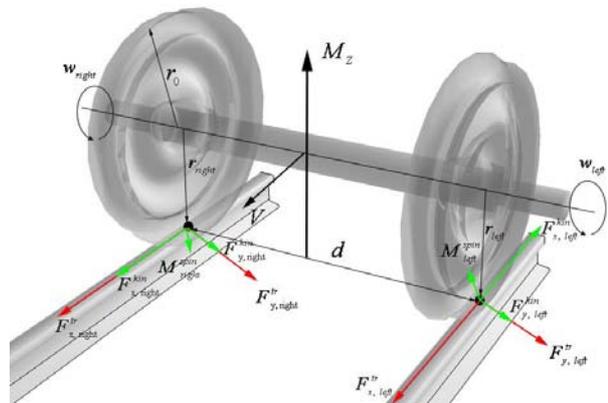


Fig. 1. Wheelset movement scheme

It is often met that creep, calculated with expression (1) is expressed in percents.

The schematic representation of adhesion characteristics is shown on fig. 2.

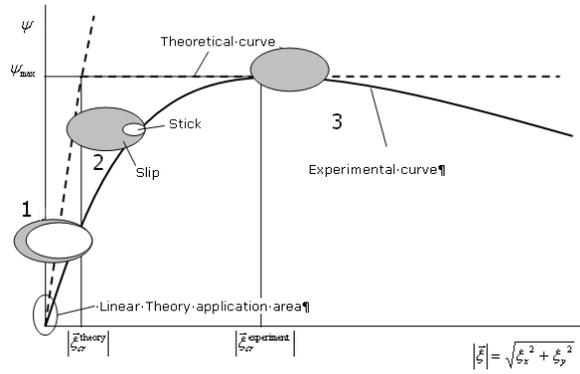


Fig. 2. Creep – adhesion coefficient curve

As it can be seen from fig. 2, creep force characteristics has maximum, which is reached at some value of creep – critical creep $\bar{\xi}_{cr}$. When the creep is lower then $\bar{\xi}_{cr}$, the adhesion process is stated as normal, and when the creep is higher then $\bar{\xi}_{cr}$ boxing is progressing.

An overwhelming majority of adhesion mathematical models, that explains the adhesion characteristics development, are based on the Osborne Reynolds “On Rolling-Friction” work, published in 1876. He has determined, that when the roller is rolling over the plain, the way passed by the center of the roller during one turn differs from it circle length. Osborne made a assumption that contact zone is split into stick area, where true slip is zero, and slip area, where true slip is higher then zero.

The followers of this approach [Chollet 2007, Kalker 1967, Kalker 1973, Kalker 1982, Kalker 1990, Kalker 1989, Pascal 1993, Piotrowski 2005, Piotrowski 2008, Polach 1999, Popovici 2010, Quost 2008, Vollebregt 2011 and others] state that with a small relative sleep ($\bar{\epsilon} \ll \bar{\epsilon}_{cr}$) almost all the contact zone is stick zone (see fig.2, first position). While the relative sleep grows, stick area becomes smaller, and the slip zone becomes bigger. (see fig.2, second position). When the $\bar{\epsilon}$ exceeds $\bar{\epsilon}_{cr}$, the whole contact area will be slip.area (see fig.2, third position).

A linear theory of the J.J. Kalker [Kalker 1967] is the most widespread rolling friction theory:

$$\begin{bmatrix} F_{tx} \\ F_{ty} \\ M \end{bmatrix} = -Gab \begin{bmatrix} C_{11} & 0 & 0 \\ 0 & C_{22} & \sqrt{ab}C_{23} \\ 0 & -\sqrt{ab}C_{23} & abC_{33} \end{bmatrix} \begin{bmatrix} \xi_x \\ \xi_y \\ \phi \end{bmatrix} \quad (2)$$

where: $C_{11}, C_{22}, C_{33}, C_{23}$ are Kalker coefficients;

a, b – contact ellipse semiaxis;
 G – shear modulus.

$C_{11}, C_{22}, C_{33}, C_{23}$ coefficient values for different a/b ratios and elastic properties of the materials can be found in [Kalker 1967]. This solution has high computational speed, but it is limited by the vanishingly small creep (see fig.2). It is assumed, that $V \approx w_{left}r_{left} \approx w_{right}r_{right}$. Then the expressions (1) are then look like [Iwnicki 2006]:

$$\begin{aligned} \xi_x^{left} &= -\xi_x^{right} = -\frac{\Delta r}{r_0} \\ \xi_y^{left} &= \xi_y^{right} = -\alpha \\ \varphi^{left(right)} &= \frac{\sin \gamma^{left(right)}}{r_0} \end{aligned} \quad (3)$$

where: α - wheelset yaw angle, γ - wheel profile conicity; $\Delta r = r_{left} - r_{right}$ - rolling radius difference.

Another popular model of J.J. Kalker is simplified theory and it's program realization FASTSIM [Kalker 1982]. This model is used as standard for wheel - rail interaction simulation. It is widely used in railway vehicle dynamics simulation, including locomotive dynamics simulation. The last one is totally unacceptable, since the simplified theory is developed on the base of linear one, which has area of application limited by the vanishingly small creep as it was mentioned above.

For all the models mentioned above a critical creep values are lower the tenth of percent, and that is much less than experimentally measured once.

A review on the experimental studies given in work [Kostyukevich 1991], has shown that the critical creep, measured by different researches, is varying for 1 to 15% and even to 20%, depending on the frictional contact conditions.

Thus the usage of adhesion models, based on Reynolds theory, in locomotive dynamics simulations, especially in traction (braking) regimes can cause significant errors.

Having the aim to investigate the influence of friction model choice on the dynamical behavior of the locomotive, let's examine a model of six axle locomotive (TE116), explicitly defined in [Gorbunov 2002]. The design model is shown on fig. 3.

The next premises were are made before the construction of the model:

- All bodies of the system (locomotive body, bogies' frames, traction motor, wheelsets and wheel treads are considered perfectly rigid.

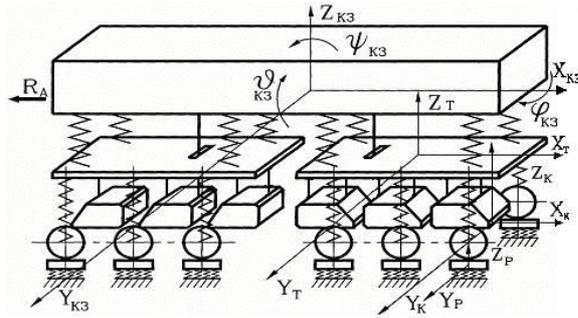


Fig. 3. Design model of six axle locomotive

- Nonlinearities in axleboxes during the lateral run of wheelsets, in pivot units according to the lateral displacements of the bogies, in the support of the locomotive body during the yawing are considered

- The action of the hydraulic and frictional oscillation dampers in axlebox suspension and in the bodie – bogie links

- Train and locomotive running resistance forces are considered

- The simulation is performed in the locomotive traction, braking and stopway regimes

- A traction force value is determined for each wheel separately, depending on the linear velocity of the vehicle, sliding speed of the contacting bodies, frictional condition, wheel – rail profiles and their orientation.

- The longitudinal velocity of the locomotive is determined in the process of the motion differential equations integration and no limitation is put on it.

- A railway track is considered as discrete inertial beams of infinite length, which are laying on the elastic – dissipative or visco - elastic foundation and are under the influence of the vertical and lateral forces, applied at the wheel- rail contact points.

- Wheel tread and rail can have new or worn profiles.

- A wheel flange – rail friction is considered when the once flangeway clearance is exceeded.

- The electrodynamic processes in the engine action are considered.

- During the running process the longitudinal vibrations of the train are considered

- Torsional stiffness of the wheelset axle is considered.

Models [Kalker 1982] and [Golubenko 2012, Golubenko 2011, Gorbunov 2011] were used as sub - model of the adhesion.

A contact model [Golubenko 2012] is formulated in the next way: to find reaction from

the foundation (rail) with the prescribed frictional conditions; relative orientation of wheelset and track, vertical load on the wheel, form and elastic properties of the bodies, rigid slip vector.

This model is formulated without traditional separation of the contact problem into normal and tangent, allowing to take into account the mutual influence of normal and tangent stresses, and that is important in case of conformal contact surfaces of wheel and rail (contact in the flange zone for example).

Another feature of the model [Golubenko 2012] is using the empirical dependence of the rolling with sliding friction coefficient on the temperature in the contact zone under the different frictional conditions. The examples of this dependence can be found in [Kostyukevich 2011].

On fig. 4 the adhesion characteristics, obtained with the use of model [Golubenko 2012], for different frictional conditions specific for mines are shown.

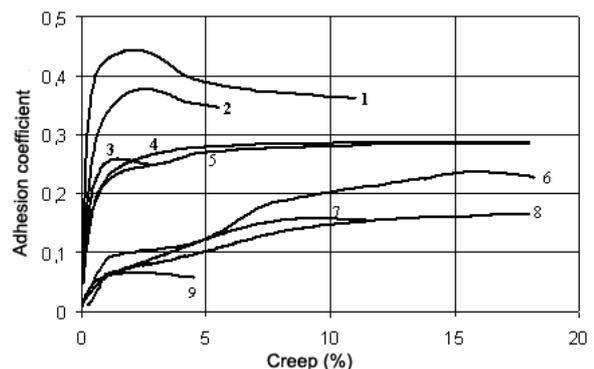


Fig. 4. Adhesion characteristics for different wheel – rail frictional conditions: 1 – thin layer coal dust; 2 - thin layer rock dust; 3- clean dry rail; 4 – thick layer rock dust; 5 – thick layer coal dust; 6- wet rail; 7 – liquid - coal – rock blend; 8 – watery coal - rock blend; 9- motor oil

In the current paper a locomotive motion in the traction regime is studied. Locomotive is running on the straight horizontal track with maximum power and 20 m/s velocity. A flangeway clearance is ± 7 mm. Adhesion coefficient is equal to 0,26. The critical creep for a model [Kalker 1982] – 0,1%, and for a model [Golubenko 2012] – 1.56%.

On fig. 5. the dependence of the longitudinal creep (fig. 5,a) , lateral creep (fig. 5,b) and first wheelset lateral displacement (fig. 5,c) on the way passed are presented. For the all plots curve 1 corresponds to the model [Kalker 1982], and curve 2 - model [Golubenko 2012]. As it can be seen from the plots the selection of the adhesion model has significant influence on the locomotive dynamics simulation.

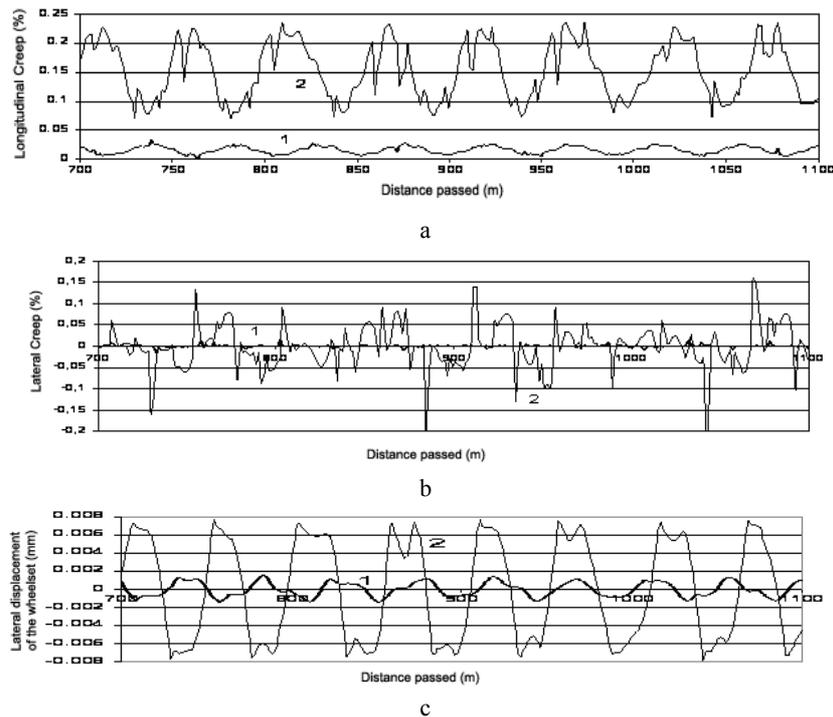


Fig. 5. The dependence of longitudinal creep ξ_x (a), lateral creep ξ_y (b) скользяния, first wheelset displacement (c) on the way passed

CONCLUSIONS

The use of adhesion models, based on Reynolds theory, in locomotive dynamics simulation, can cause significant errors when locomotive is moving in tractive (braking) regime.

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ВЛИЯНИЕ МОДЕЛИ СЦЕПЛЕНИЯ НА РЕЗУЛЬТАТЫ МОДЕЛИРОВАНИЯ ДИНАМИЧЕСКОГО ПОВЕДЕНИЯ ЛОКОМОТИВОВ

*Александр Голубенко, Александр Костокевич,
Илья Цыгановский*

Аннотация: В статье приведены результаты моделирования динамики локомотива с использованием различных подмоделей контакта «колесо - рельс». Показано, что выбор контактной модели существенным образом влияет на результаты моделирования движения локомотива в режиме тяги при больших значениях скольжения даже при движении в прямой.

Ключевые слова: колесо, рельс, контакт, скольжение, тяга, динамика