SCIENTIFIC PAPERS
OF THE UNIVERSITY OF PARDUBICE
Series B
The Jan Perner Transport Faculty
15 (2009)

VEHICLE GUIDING BEHAVIOR AND CONTACT CONDITIONS WHEELSET/TRACK

Martin KOHOUT

Department of Transport Means and Diagnostics

1. Introduction

A vehicle and a track are parts of the inseparable couple, which could be judged as a complex. Characteristics of a wheelset/track coupling influence an operation safety, a ride comfort and forces effects between vehicle and track, which are connected with operational and maintenance costs.

2. Assessment of vehicle/track interaction

The mutual interaction between a vehicle and a track is determined at the vehicle running test [2], [4], which is a part of the approval process of the new, reconstructed or modernized vehicles. The aim of this test is determination of the running behaviour in the straight (through measurement of the lateral and vertical acceleration on the vehicle body and on the bogie frame, and the sum of the guiding forces) and the guiding forces in curves (through the quasistatic wheel and guiding forces and the ratio Y/Q).

The gradual progress in understanding of the vehicle/track interaction and growth of requirements on new vehicles (cant deficiency, operational speed, mass per axle) lead to the revaluation of the limit values in norms and standards (limit value of the quasistatic guiding force in curves, ratio Y/Q) or supplementation of another quantities, which should be measured or evaluated during the running tests (the quasistatic track loading force, the equivalent conicity in straight, the radial steering index in curves of a small radius).

3. Characteristics of contact geometry wheelset/track

Characteristics of the wheelset/track coupling have a marked influence on the resulting running and guiding behavior.

The characteristic between a free wheelset and a track can be described with the characteristics of the contact geometry wheelset/track [1] in case that a wheel and a track are considered as rigid bodies, track is considered without lateral and vertical deviations from the theoretical position and the creep in contact patches between a wheel and a rail are neglected. The most important functions are:

- **Function *Δr***, which is defined as a difference of actual rolling radii of the wheel in dependence on the lateral displacement *y*d in the track (*Fig. 1*). This difference causes centering of the wheelset in straight track and compensates partially the difference in the moved distances of each wheel in a curve.

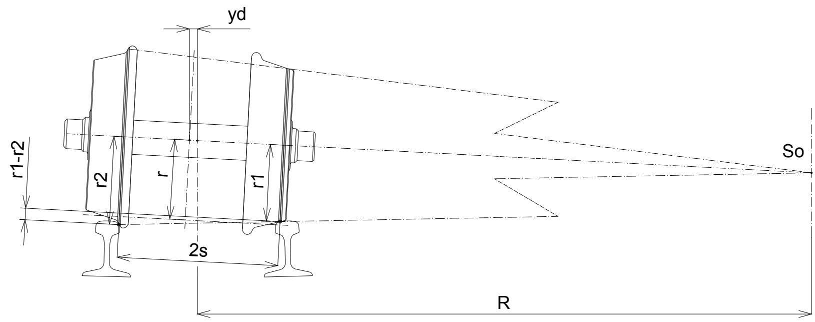

Fig. 1 *Wheel rolling radii in curve*

- **Equivalent conicity** λ_{ekv}, which characterizes a periodic wave motion of the free wheelset in the straight track. This function depends on the amplitude y_0 of the motion (conventional value is 3 mm) and it is evaluated during the vehicle running tests in reference to the stabile motion of vehicles at a higher speed. Higher value of the equivalent conicity indicates the shorter wavelength and the stronger kinematic coupling of the wheelset to the track.

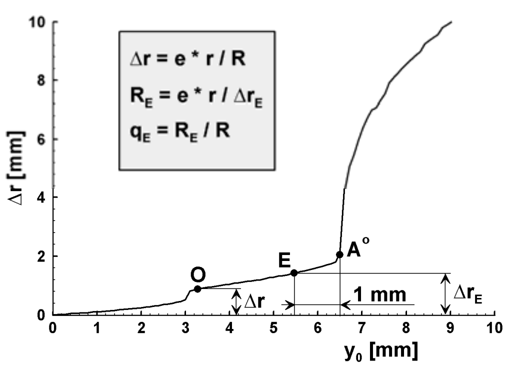

Fig. 2 *Definition of the radial steering index.*

In the new standard UIC 518:2009 there is the **radial steering index** q_E [4] (Fig. 2) in addition, which represents a wheelset steering possibility in the actual passed curve (radius R) and proceeds from the slope of function Δr.

Motion characteristic of a free wheelset in a straight and in a curve is determined by the wheelset back to back distance, the track gauge and the railhead and wheel profiles. The shape of the wheel profiles undergoes the long development from an original cylindrical profile, through a conic profile to the present used "worn" wheel profile ORE S1002 (generally a curve profile). The conical profile generally enables self centering of the wheelset, which is desirable in the straight track (better reaction on lateral track deviations) and in curve too (force interaction, derailment safety).

4. Rail vehicle in curve

The vehicle running through a curve performs two contemporary motions, rotational motion ω_M around the centre of the vehicle rotation M and the translational motion ω_R along the circular way in the curve.

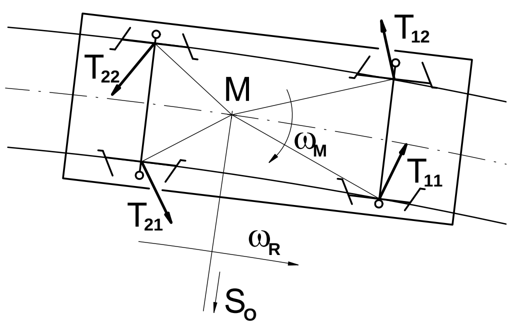

Fig. 3 *Creep forces in contact patches at vehicle running through curve*

The rotational movement causes formation of the creep forces T in contact patches (Fig. 3), which are proportional to relative creep (creepage) between a wheel and a rail. The relative creep in lateral and longitudinal direction are defined by equations (1), (2)

$$\vartheta_{x2} = \frac{\dot{x}_d \cdot \left(\frac{R + \left(s + y_{BD2}\right)}{R} \right) + \dot{\varphi}_d \cdot \left(r + \Delta r\right) + \dot{\xi}_d \cdot \left(s + y_{BD2}\right)}{\dot{x}_d}, \tag{1}$$

$$\vartheta_{y2} = \frac{\dot{y}_d - \dot{y}_k - \xi_d \cdot \dot{x}_d \left(\frac{R + \left(s + y_{BD2}\right)}{R} \right) - \xi_d \cdot \dot{\xi}_d \cdot \left(s + y_{BD2}\right)}{\dot{x}_d \cdot \cos\gamma}, \tag{2}$$

where:

x_d .... coordinate of wheelset (longitudinal direction),

ξ_d .... coordinate of wheelset (rotation around z-axis),

φ_d .... coordinate of wheelset (rotation around y-axis),

s .... half distance on wheelset (750 mm),

y_{BD} .... coordinate of contact point on wheel (lateral direction),

r .... nominal wheel radius,

Δr .... change of nominal radius in contact point,

γ .... inclination of contact plane.

At the vehicle running through a curve, a wheel flange of the leading wheel attacks an outer rail in addition. This situation is in many cases connected with the two-point contact wheel flange/rail. Resulting value of the advance of the contact point on wheel flange influences negatively contact conditions between the wheel and the rail and leads to an intensive wear of the wheel flange and the outer rail. The trailing wheelset take a general position in the track.

5. Rail vehicle guiding behavior in curves of small radius

The tuned lateral and longitudinal stiffness of the wheelset guiding, use of yaw dampers, use of “worn” wheel profiles and special “low” conicity railhead profiles enable achievement of the excellent running behavior of rail vehicles in the straight track at higher speeds. Contrariwise the desired stiff wheelset guiding in the longitudinal direction together with the low slope of the function Δr leads to the intensive side wear of the outer rail and the corrugation formation on the inner rail through the slip forces in contact patches in curves. Its amount is influenced by the geometry of the wheelset and track and by railhead and wheel profiles. In consideration of the guiding performance, the function Δr is the most important among the kinematical characteristics wheelset/track.

The function Δr should reach an amount of 2,5–2,8 mm for a wheelset freely rolling through a curve of small radius (250÷300 m). In case of a wheelset bound in a running gear, a higher amount is needed for decrease of the striking angle by the longitudinal creep forces. Insufficient slope of the function Δr results in the higher guiding forces on the leading wheels and in higher amounts of the striking angle.

The function Δr for the commonly used wheel profile ORE S1002 and rail head profile 60E2 is, however, unsatisfactory. Moreover, an unsuitable combination of profiles often results in occurrence of a **two-point contact** of the guiding wheel and the outer rail. Creep velocity at the second contact point, determined by the advance of this point, is accompanied by an intense wear of the wheel flange and the rail head (eq. 3). In case of the worn wheel and rail head profiles, the situation is still worse by the influence of size of the contact area and spin.

$$v_{sl} \approx r_s \cdot \tan\alpha \cdot \tan\beta \cdot \omega_w , \qquad (3)$$

where:

v_{sl} .... slip velocity in wheel flange contact point,

α .... striking angle,

β .... inclination of the contact plane,

ω_w .... angular velocity of wheelset.

The transitional area between the wheel flange and the wheel tread should, therefore, have the less curvature than the leading edge of the outer rail head fillet to prevent the occurrence of two-point contact between wheel and rail. The difference has to be appropriately larger with an increasing striking angle.

8.1. Leading wheelset

Sinking of the striking angle of the leading wheelset through the action of the longitudinal creep forces is possible only in case of the high slope of the function *Δr* and soft wheelset guiding. The stiffer the wheelset guiding is the sharper slope of function *Δr* is required. The sinking of the striking angle is not possible in case of a very stiff longitudinal wheelset guiding and the resulting longitudinal creep forces produce a higher wear of wheels and railheads.

8.2. Trailing wheelset

Trailing wheelsets take mostly the static position in the curved track characterized by a low striking angle and low lateral shift of the wheelset in the track, which results in the insufficient value of the function *Δr* and high longitudinal creep forces (support rail corrugation development).

6. Special railhead profiles

The problems like the side wear of outer rails and railhead corrugation on inner rails occur even if the main track lines were modernized. It is the reason, why is looked for some ways to eliminate them. There are especially the railhead and the wheel flange lubrication, the railhead hardening, which are use for reduction of resulting effects, and change of the contact conditions wheelset/track.

The modification of the characteristics of the contact geometry wheelset/track can influence the guiding behavior of the rail vehicle. In curves of small radius is not possible to ensure the sufficient difference of the wheel rolling radii only by a lateral displacement of the wheelset in the track because of very flat the function *Δr* for the standard combination of the wheel profile ORE S1002 and rail 60E2. Any changes of wheel profiles are not possible too because they could influence the vehicle running behavior in the straight track.

The special railhead profiles represent the possibility to influence the coupling wheelset/track only in the chosen track sections (curves of small radius). The idea consists in the change of the contact position between wheel and rail and related slope of the function *Δr* through modification (realized by grinding) of the outer and inner railhead (*Fig. 4*).

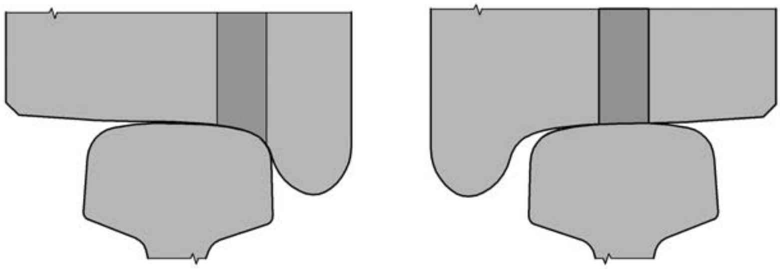

Fig. 4 *Special railhead profiles (right curve)*

8.3.2. Two-point contact

The special railhead profile should be so designed that in a combination with standard wheel profiles can not be:

• decreased the derailment safety.

• increased the guiding forces at leading wheels.

• exceeded the limit stress in the contact patches.

• increased possibility of the two point contact.

7. Realization

One of aims of the theoretical and research work at the Transport Faculty Jan Perner was finding possibilities (through computational simulation of vehicle running) for wear minimization of outer rails and corrugation grow on inner rails through affect the contact geometry wheelset/track. The solution with design and operational verification of special asymmetrical railhead profiles was chosen by reason that they could not influence the good running behaviour of vehicles in straight.

The own designed railhead profiles in combination with the wide used wheel profile ORE S1002 (wheel profile ZI-3 is utilized only on few passenger coaches and locomotives with limitation on the area of the Czech Republic) in comparison with the standard railhead profile prove in curves of small radius:

- Suitable contact conditions between the leading wheel and the outer rail. In case of the two-point contact, the resulting lower advance of the wheel flange contact point enables marked sinking of the sliding speed on wheel flange and wear of railhead and wheel by it.
- Sharper slope of the function *Δr* causes on the leading wheelsets rises of the longitudinal forces, which is well-marked by the vehicles with the softer wheelset guiding or with clearance in guiding as sinking of the striking angle and the guiding forces on the leading wheels. On trailing wheelsets (normally in the static position in gauge clearance), the sharper slope of the function Δr

is used for sinking of the longitudinal slip forces, which participate on the corrugation grow.

After the theoretical computational simulation the special railhead profiles were ground in two curves of small radius (260 m < R < 300 m) on the main track, followed by four years monitoring of the track geometry, corrugation formation and wear of rails. The evaluation of the development confirms the theoretical results and shows that:

- Effectiveness as well as financial advantageousness by use of the special railhead profiles depends on a concrete situation (track layout, technology of transport, types of vehicles).
- Correct function of the special railhead profiles is connected with their regular maintenance by grinding. It is useful to grind the outer rail in time of the corrugation removal from the inner rail in order to keep the costs.

The analysis of the numerical simulations and measurement results in operation within this work proved the suitability of the special railhead profiles in case of curves of small radius. The next result of this research [5] was confirmation of a very close coupling between changes in the contact conditions wheelset/track and other track parameters (speed of track geometry parameters and of corrugation depth), which is important findings from the point of view of track maintenance planning and making some strategic decision in a track construction.

8. Conclusion

Even if the changes of the railhead profiles are relatively small in comparison with the wheel and rail dimensions they could influence the resulting force action between vehicles and track considerably.

Acknowledgement

This article was written with the support of VCKV (Research Centre of Rail Vehicles), funded from the project of MŠMT (Ministry of Education, Youth and Sports of the Czech Republic), reg. no. MŠMT 1M0519.

Submited: 20.4.2010

References

1. IZER, J., ZELENKA, J.: *Charakteristiky kontaktní geometrie*. Scientific Papers of the University of Pardubice, Series B, Nr. 39-62, Pardubice, 1996, ISSN 1211 6610.
2. ČSN EN 14363: *Železniční aplikace – Přejímací zkoušky jízdních charakteristik železničních vozidel – Zkoušení jízdních vlastností a stacionární zkoušky*. Czech Standards Institute, 2006.
3. ČSN EN 15302: *Metody stanovení ekvivalentní konicity*. Czech Standards Institute, 2008.

4. UIC518:2009 *Testing and approval of railway vehicles from the point of view of their dynamic behaviour – Safety – Track fatigue – Running behaviour*. UIC, 2009.
5. KOHOUT, M. : *Výzkum kontaktní geometrie dvojkolí kolej při průjezdu vozidel oblouky malých poloměrů*. Dissertation thesis. University of Pardubice, 2009.

Resumé

VODICÍ VLASTNOSTI VOZIDEL A KONTAKTNÍ PODMÍNKY MEZI DVOJKOLÍM A KOLEJÍ

Martin KOHOUT

Příspěvek je zaměřen na problematiku možnosti zlepšení vodicích vlastností vozidel v obloucích malých poloměrů (300 m a méně) modifikací parametrů vazby dvojkollí ke koleji. Z důvodu nevhodných kontaktních poměrů mezi kolem a kolejnicí v těchto obloucích dochází k tvorbě skluzových vln na hlavě vnitřní kolejnice a intenzivnímu opotřebovávání vnější kolejnice. Jedním z možných řešení snížení výsledného silového působení mezi vozidlem a kolejí je využití speciálních příčných profilů hlav kolejnic. Kromě jejich návrhu jsou v článku prezentovány také první výsledky ze zkušebního provozu.

Summary

VEHICLE GUIDING BEHAVIOR AND CONTACT CONDITIONS WHEELSET/TRACK

Martin KOHOUT

The article deals with the possibilities of improvement of the vehicle guiding behaviour in curves of small radius (300 m and less) through the modification of the wheelset/track coupling. Due to the unsuitable contact conditions between the wheel and rail there is a place of the slip-wave creation at the head of the inner rail and intensive side wear of the outer rail. Special railhead profiles could be one of the possible solutions to sinking the force effect between vehicle and track. Except design of the railhead profiles, first results from the operation are presented.

Zusammenfassung

FÜHRUNGSEIGENSCHAFTEN VON SCHIENENFAHRZEUGEN UND KONTAKTBEDINGUNGEN ZWISCHEN RADSATZ UND GLEIS

Martin KOHOUT

Der Artikel beschäftigt sich mit der Problematik der Verbesserungsmöglichkeiten der Führungseigenschaften von Schienenfahrzeugen in den Bogen von kleinen Halbmessern (300 m und weniger) durch die Parametermodifikation der Radsatz-Gleiskopplung. Wegen der ungeeigneten Kontaktverhältnissen zwischen dem Radsatz und dem Gleis entstehen die Schlupfwellen auf der inneren Schiene und kommt es zur intensivem Verschleiß der äußeren Schiene. Eine der Lösungen zur Reduzierung der Kraftbeanspruchung zwischen dem Fahrzeug und Gleis ist die Verwendung der sonderen Schienenkopfrofilen. Außer dem Entwurf von Sondeprofilen werden im Artikel auch die ersten Ergebnissen aus dem Verschuchsbetrieb vorgeführt.