wheel profile; rail fastening; rolling; sliding; wear

George TUMANISHVILI*, Tengiz NADIRADZE, Ioseb TUMANISHVILI
Georgian Technical University
77 Kostava str. O175 Tbilisi, Georgia
Corresponding author. E-mail: ge.tumanishvili@gmail.com

IMPROVING OF OPERATING ABILITY OF WHEELS AND RAIL TRACKS

Summary. The high cost of wheels and rails due to wear and rolling contact fatigue is one of the main problems in the railway transport. The values of creepage, sliding distance and wear rate of wheels and rails at rolling of a wheel on the rail greatly depend on geometric characteristics of working profiles of wheels and rails and location of wheels relative to rails. In the present work the functional requirements of various parts of profiles of wheels and rails and dominating kinds of their damage in various operating conditions are considered and a new profile of a wheel and device for fastening of rails are offered.

СОВЕРШЕНСТВОВАНИЕ ЭКСПЛУАТАЦИОННЫХ СПОСОБНОСТЕЙ КОЛЁС И РЕЛЬСОВЫХ ПУТЕЙ

Аннотация. Высокая стоимость ремонтно-профилактических работ колес, из-за износа и усталостного повреждения является одным из главных проблем на железодорожном транспорте. При качении колеса на рельсе величина относительного скольжения и интенсивность изнашивания колес и рельсов значительно зависят от геометрических особенностей рабочих профилей колес и рельсов и взаимного расположения рельсов относительно колес. В данной работе рассматриваются функциональные требования различных частей профилей колес и рельсов и доминирующие виды их повреждения при различных условиях работы и предложены новые профили колес и устройства закрепления рельсов.

1. INTRODUCTION

At interaction of wheels and rails the following main demands should be satisfied:
- Avoid a rise of a wheel on the rail and derailment;
- Decrease energy losses on friction and damage rate of wheels and rails;
- Decrease the environment contamination by vibrations and noise.

But until recently, despite a considerable quantity of works, devoted to investigations of dependences between wheel/rail forces and their durability, as well as rail cant and wheel profiles [1-5], expected decisions are not received yet. The energy loss due to friction of a wheel on a rail can reach about 24% of full energy consumption on the traction [6], which is basically consumed on the overcoming of friction forces between wheels and rails especially in curves. Besides, power and thermal loads on the contact zone are very high which causes high rate of the wheels and rails damage. For example, the contact stress at initial point contact of wheels and rails (or at initial linear contact of

worn-out wheels and rails) can reach 3 GPa (theoretically, without plastic stress) and the contact area - 1 square centimeter, the average temperature on the tread surfaces - 4000C, on the flange - 8000C [7] and on the brake shoe - melting temperature of metal. The ways of reduction of these loads are shown in the work.

2. PECULIARITIES OF MOVEMENT AND LOADING OF A WHEEL ON THE RAIL

In the straight a wheel-set performs a zigzag movement close to the sinusoid, which is accompanied by creeping. In curves the inner wheel passes the shorter distance, which causes deviation of the wheel set axis from radial disposition (Fig. 1). It leads to increase of the angle of attack, lateral force and rolling resistance of outer wheel of the front wheel-set of a bogie. In such conditions, to return the wheel-set into initial position it is necessary that one of the wheel of the wheel-set slide on the rail in the longitudinal direction. The intermittent slipping of one of the wheel of the wheel-set can produce the torsional vibrations of the wheel-set and the longitudinal vibrations of the unsprung masses of the vehicle and the respective wear of wheels and rails, like to corrugation. In this case, rutting corrugation can appear if the frequency of a torsional resonance of the wheel set corresponds to the frequency of the bouncing of the unsprung masses of the vehicle.
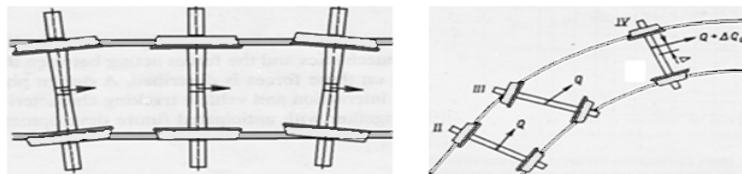

Fig. 1. Movement of a wheel-set in the straight and curve
Рис. 1. Движение колёсной пары на прямом и кривом участке

The tread surface of the wheel is conical and is gradually passing into flange surface through flange root. Therefore the differences between diameters of interacting surfaces inside of the contact zone, relative slidings, contact stresses, deformations and temperatures towards the flange are growing. For the heavy loaded surfaces the friction forces depend on the size of contact zone. In operation they will be increased because of wear and for worn profiles of wheels and rails they will be considerably greater. Increase of the friction force on the flange surface and decrease of the angle of inclination of the flange will promote the wheels to climb onto the top of the rail head and then derail. The movement of the wheel-set in the curves is performed by advancing of its inner wheel causing periodical torsion deformations of the wheel-set shaft and by its further backward sliding. In this case various kinds of damage of surfaces can appear: corrugation because of plastic deformations and adhesive wear, fatigue and etc. It can also produce the longitudinal vibrations of unsprung masses of the bogie. In the Fig. 2 is shown the movement of a wheel-set on the track in the curve and a corrugated inner rail.

In the Fig. 3 is shown a schematic view of various radii inside of the contact zone, desired values of friction coefficients of the contact zone and the thermal loading.

As shown from Fig. 3 the power and the thermal loading of tread surfaces are relatively low. At working of wheels in regimes of traction and braking, at lateral movement, at rotation around vertical axis and at skidding, a value of the sliding velocity and sliding distance will grow and they present main reasons of destruction of the third body. The flange root and gauge face have considerably high level of creeping, contact stress and temperatures and the partial or full sliding (creeping) in the contact zone is unavoidable. They can lead to growth of the friction factor, shearing stress and corresponding type of under-superficial or superficial deformations and damage. In all cases, for improvement of working conditions, controlling of friction factor (decreasing of the friction factor on

the flange surfaces of both wheels and on the tread surface of the inner wheel for facilitation a backward sliding of the wheel-set into radial position and retention of the friction factor of necessary value for the tread surface of the outer rail) in the curves is necessary.
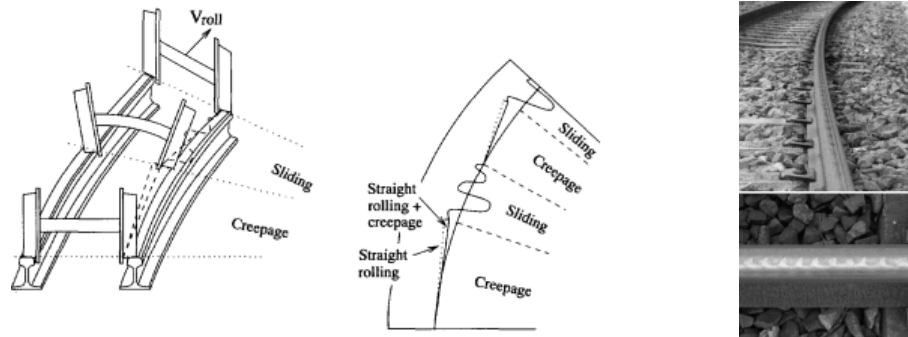

Fig. 2. Movement of a wheel-set on the track in the curve and a corrugated inner rail [8]
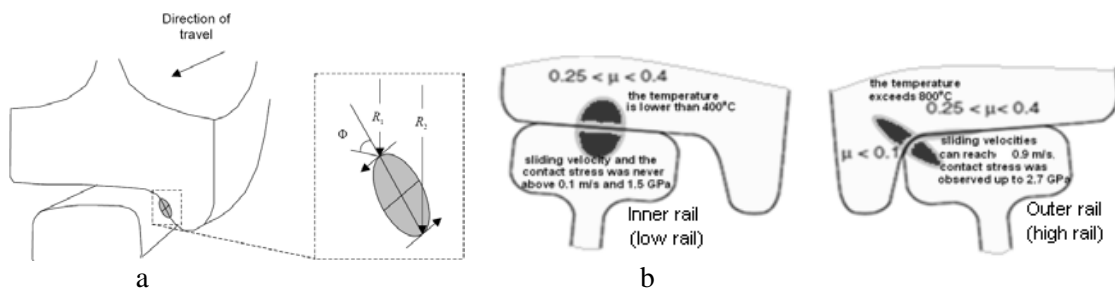Рис. 2. Движение колёсной пары на кривом участке и повреждённый наружный рельс [8]

Fig. 3. Schematic view of various radii inside of the contact zone on the wheel flange [9] (a), "ideal" values of friction coefficients [10, 11] and the thermal loading, stress distribution and sliding velocities of profiles (b)
Рис. 3. Схематический вид переменного радиуса в контактной зоне гребня колеса [9] (a), "идеальные" значения коэффициентов трения [10, 11] и тепловой нагруженности, распределение напряжений и скоростей скольжения профилей (b)

Not only for two point contact or conformal contact but for one point contact, interacting points will be located on various diameters in the contact zone. Therefore the increased relative sliding in all cases can become a reason for raised thermal loading, shearing stresses, destruction of the third body, adhesive wear process and scuffing. Even more, inadequate friction can result in disasters and high friction on the wheel flange - rail gauge contact can cause wheel climb on the rail head and derailment [12, 13]. Due to immediate vicinity of tread, flange root and flange surfaces the friction modifiers for tread and flange surfaces can be mixed and their characteristics can change.

A significant part of the energy consumed in rail transport is due to wheel/rail friction. For heavy loaded interacting bodies at partial or total absence of the third body the moving resistance of interacting surfaces additionally depends on adhesive strength of actual contact areas and its increase can lead to rising of the adhesive component of friction. The friction force F_f between two macroscopic bodies is also the function of the actual area of microscopic contact A_{micro}, $F_f = \psi(\sum \tau A asp)$ [14], where τ is effective shearing strength of the contacting bodies.

The load on the outer rail in the curve mainly depends on the friction force (where two-point or conformal contact takes place that increases actual contact area), angle of attack and centrifugal force. This causes sharp rise of the wear rate (Fig. 4).
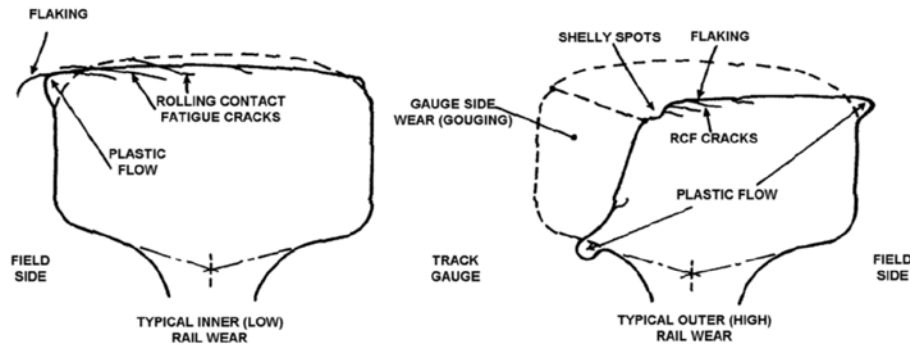

Fig. 4. The typical rail profile changes that arises because of common wheel and rail contact conditions in the curves [15]

Рис. 4. Обычное изменение профиля рельса, которое возникает при взаимодействии колеса с рельсом в кривых [15]

The existent profiles of wheels and rails can be divided into the tread surfaces (which take place in "free" rolling, traction and braking), steering surfaces (flange and side of rail head, which takes place in steering mainly in the curves and protecting the wheel-set from derailment). The flange root and the rail corner can take place in "free" rolling, traction, braking and steering. But traction (braking), "free" rolling and steering demand mutually excluding properties: the raised size of friction factor at traction and braking and the lowered size of the friction factor at steering. And the "ideal" values of friction coefficient (μ <0,1) in the contact zone of the flange root and the rail corner is desirable for steering only. Therefore the tread and the steering surfaces must be well separated and have corresponding properties and modifiers. At movement of the interacting point of the wheel and rail from tread surface towards flange the relative velocity, sliding distance, the scuffing probability, vibrations, noise and wear rate are increased. It should be noted, that decrease of distance between rails from 1524 to 1520 mm in the former Soviet Union lead to rise of probability of interaction of the flange root and rail corner, which is one of the main reasons of rise of the wear rate. Besides, gradual transition of tread surface into flange root and next into the flange promotes mixing of friction modifiers for tread and flange surfaces. It should be noted that similar problems there are also in the railways of other countries [16].

The processes accompanying the interaction of profiles especially at increase of creeping (at increase of the traction force or at shifting of interacting places towards flange) conduce increase of the probability of destruction of the third body and interacting surfaces too. Therefore the preservation of the third body between interacting surfaces has a crucial importance. But the slipping of wheels causes rise of thermal and power loads in the contact of superficial layers, generating vibrations, typical noise and the most dangerous type of wear - scuffing.

3. IMPROVEMENT OF THE WHEEL PROFILE

Due to immediate vicinity of tread, flange root and flange surfaces in order to avoid change of tribotechnical characteristics of interacting surfaces of the tread and flange, it is necessary to avoid mixing of friction modifiers for tread and flange surfaces during working process. The worn-out surfaces of the flange root and the rail corner promote growing the angle of inclination of interacting

surfaces and contact zone till conformal contact which together with growth of friction factor is especially undesirable for rolling resistance of wheels, wheel climb on the rail head and derailment.

Different parts of the wheel working profile have different relative sliding velocities that can lead to different kinds of damage and different damage rate. Therefore, because of high defectiveness of surface and under surface layers, presence of stress concentrators etc., at high normal and low shearing stresses, the durability of materials is defined by subsurface stresses and at high shearing stresses - by surface stresses. Because of high deficiency of superficial and under blankets, presence of pressure concentrators etc., at high normal and low tangents pressure, the durability of materials is defined by fatigue durability under blankets and at high tangents pressure by superficial damages. Since the contact of the wheel flange root and rail corner is characterized by high normal and tangential loads, it is expected on the surfaces both: the superficial and the under-superficial damages.

The processes accompanying the interaction of profiles especially at increasing of creeping (at increasing of traction force or at shifting of interacting places towards flange) conduce to increase of destruction probability of the third body and interacting surfaces too. Therefore the preservation of third body between interacting surfaces has crucial importance. But the slipping of wheels causes rise of thermal and power loads in the contact of superficial layers, generating vibrations, typical noise and the most dangerous type of wear-scuffing. The wheel profile is given in Fig. 6 (a). The flange root (R13.5 (15)) and the rail corner often interact with each other, especially in curves which occur at "free" rolling, traction, braking and steering. The gradual and direct transition of tread surface into flange root and next into the flange can promote mixing of friction modifiers for tread and flange surfaces. For separation of tread and flange surfaces, avoiding interaction of the flange root and the rail corner and decreasing the probability of mixing of friction modifiers a recess in the place of transition of tread surface in flange root (R13.5 (15)) is suggested (Fig. 6 (b)). In addition, this will redistribute power load acting on the flange root on the tread surface and flange. In the Fig. 6 (c) and (d) is also shown geometry of mutual disposition of the wheel and rail for existent and suggested profiles.
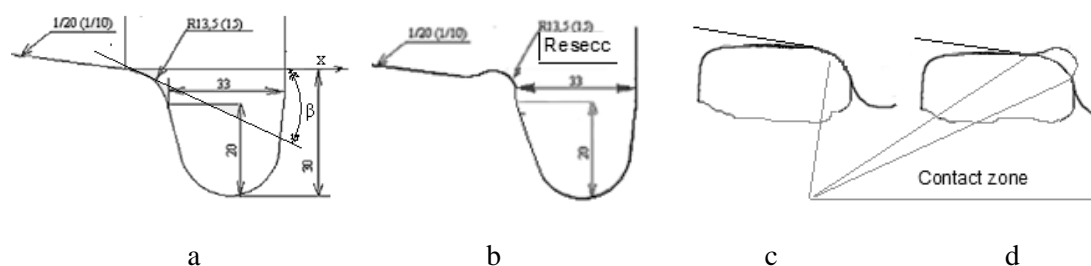

a   b   c   d

Fig. 5. Fragments of the existent (a) and suggested (b) wheel profiles and geometry of mutual disposition of the wheel and rail for existent (c) and suggested (d) profiles

Рис. 5. Фрагменты существующего (a) и предложенного (b) профилей колёс и геометрия взаимного расположения колеса и рельса для существующего (c) и предложенного (d) профилей

4. DEVELOPMENT OF THE RAIL FASTENING

Practice has shown satisfactory working capacity of various rail fastenings for straights and curves with radius of more than 500 m [12]. The problem consists in working out of a rail fastening which will be capable of damping the lateral fluctuations and maintain a constant rail cant for different curves. But the dumping is carried out by deflection of the rail in the external direction (Fig. 1), promoting displacement of the contact point on the flange downwards which increases the distance between heads of the rails, difference of diameters of interacting surfaces, the sliding distance and causes other undesirable phenomena. Track design has a significant effect on both dynamical features and durability of the rolling stock and the track. High lateral stiffness is often incompatible with

requirements of dumping of rail vibration level and not always meet dynamic requirement and low lateral stiffness gives raised rail cant variation and needs limitation in the range of rail cant variation. Therefore, the fasteners that provide adequate stiffness to guarantee dynamic requirements and limitation in the range of rail cant variation are desirable.
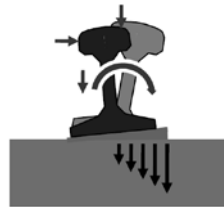

Fig. 6. Variation in rail cant
Рис. 6. Изменение подуклонки рельса

To maintain a constant rail cant and ensure damping of lateral fluctuations and constant distance between heads of the rails, a new design of fastening of the rail was developed (Fig. 7).
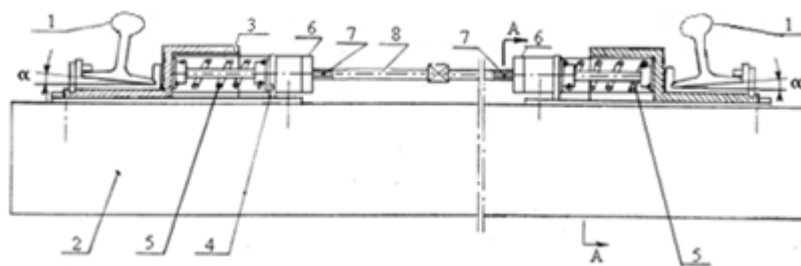

Fig. 7. Device for rail fastening
Рис. 7. Устройство для закрепления рельса

The rail fastening device consists of the rail 1, sleeper 2, base plates 3, 4 and the compression spring 5. The base plate consists of the movable 3 and immobile 4 parts connected with each other by sliding kinematic pair. The rail 1 is fastened on the movable part 3 with optimal angle of inclination □ and the immobile part 4 is fastened on the sleeper 2. An elastic element – compression spring 5 is placed between movable 3 and immobile 4 parts with possibility of preliminary compression by screw pair 6. A connecting rod 8 is connected to left and right movable parts 3 by screw pairs 7, with its two ends on which are made screws 7 of opposite directions. The developed construction ensures constant rail cant and distance between rail heads and also greater lateral displacement of both rails that improves damping quality.

5. CONCLUSIONS

- Properties, working conditions and functions of tread and steering surfaces are different; therefore, use of the flange root and rail corner as a steering surface as well as a tread surface is inadmissible;
- The tread and steering surfaces must be sharply separated from each other to avoid mixing of their friction modifiers;
- A new profile of the wheel is developed where tread and steering surfaces are separated by the special recess;
- A new construction for the rail fastening ensuring a constant value of the rail cant and distance between rail heads is developed.

References

1. Iwnicki, S.D. (ed.) *A Handbook of railway vehicle dynamics*. London: CRC Press. 2006.
2. Gubenko, S. & Sladkowski, A. The influence of the contact stress on the structural changes of railway wheel steel. In: Sladkowski, A. (ed.) *Rail vehicle dynamics and associated problems*. Gliwice: SUT. 2005. P. 135-160.
3. Lewis, R. & Dwyer-Joyce, R.S. Wear mechanisms and transitions in railway wheel steels. *Proceedings of the Institution of Mechanical Engineers. Part J. Journal of Engineering Tribology*. 2004. Vol. 218(6). P. 467-478.
4. Enblom, R. *On simulation of uniform wheel and rail profile evolution in wheel – rail contact*. PhD Thesis. Stockholm: KTH. 2006. 112 p.
5. Dwyer-Joyce, R.S. & Lewis, R. & Gao, N. & Grieve, D.G. Wear and fatigue of railway track caused by contamination, sanding and surface damage. In: *6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003)*. Gothenburg: CHARMEC. 2003. P. 211-220.
6. Stodolsky, F. *Railroad and Locomotive Technology Roadmap*. ANL/ESD/02-6. Center for Transportation Research. Energy Systems Division Argonne National Laboratory. 2002. Available at: http://www.transportation.anl.gov/pdfs/RR/616.PDF
7. Cassidy, D. Wrought Materials May Prolong Wheel Life. *International Railway Journal*. 2001. No. 12. P. 40-42.
8. Collette, C. & Horodinca, M. & Preumont, A. Rotational vibration absorber for the mitigation of rail rutting corrugation. *Vehicle System Dynamics*. Vol. 47. No. 6. 2009. P. 641-659.
9. Thompson, D.J. & Monk-steel, A.D. & Jones, C.J.C. & Allen, P.D. & Hsu, S.S & Iwnicki. S.D. *Railway noise: curve squeal, roughness growth, friction and wear*. The universities center for railway system research. Report: RRUK/A3/1. June 2003.
10. Lewis, R., & Olofsson, U. (Eds). *Wheel-rail interface handbook*. UK: Woodhead Publishing Limited. 2009.
11. Zhu, Y. *Adhesion in the wheel−rail contact under contaminated conditions*. Licentiate thesis. KTH Machine design. 2011.
12. Müller, B. & Jansen, E. & de Beer, F. *UIC Curve Squeal Project WP3*. Swiss Federal Railways. Rail Environmental Center. 2003.
13. Chiddick, K.S. & Eadie, D.T. Wheel /rail friction management solutions. In: *14th Int. Conference on Current Problems in Rail Vehicles "PRORAIL 99"*. Prague. 1999.
14. Yifei, Mo. & Turner, K.T. & Szlufarska, I. Friction laws at the nanoscale. *Nature*. 2009. Vol. 457. P. 1116-1119.
15. Magel, E.E. *Rolling Contact Fatigue: A Comprehensive Review*. NSN 7540-01-280-5500 (Rev. 2-89) Prescribed by ANSI Std. 239-18 298-102 DOT/FRA/ORD-11/24, U.S. Department of Transportation. Office of Railroad Policy and Development Washington. DC 20590. 118 p.
16. Guerrieri, M. & Parla, G. & Ticali, D. A theoretical and experimental approach to reconstructing the transverse profile of worn-out rails. *Ingegneria Ferroviaria*. 2012. Vol. LXVII. No. 1. P. 23-37.