DECREASE OF ROLLING RESISTANCE AND DAMAGEABILITY OF WHEELS AND RAILS IN CURVES

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Rolling resistance of wheel on a rail mainly depends on friction forces between a wheel and a rail. The energy loss due to friction of a wheel on a rail can reach about 24 % of full energy consumption on the traction [1] which is basically consumed on the overcoming of friction forces between wheels and rails especially in curves. For the heavy loaded frictional contact of wheels and rails, the variable values of friction forces, vibrations, noise and various kinds of destruction are characteristic. Therefore the control of friction between a wheel and a rail is necessary. **Damage accumulation because of wear, fatigue and plastic deformation significantly reduces the service life of the railway wheels and rails. Therefore there are many works devoted to durability of wheels and rails and traffic safety [2-6 and references on their].** ***At the rolling of a wheel on a rail the value of creepage and wear rate of wheels and rails considerably depend on geometry of working profiles, tribotechnical characteristics of wheels and rails and location of wheels relative to rails. In the present work the reasons of energy loss on a friction are considered and correction of a wheel profile for their reduction is offered.***

Kay words: ***wheel, rail, friction, wear, fatigue, friction modifier***

1. Introduction

At interaction of wheels and rails the following main demands should be satisfied:

- **Avoid rise of a wheel on a rail and derailment;**
- **Decrease energy consumed on traction, energy losses on friction and damage rate of wheels and rails;**
- **Decrease the environment contamination by vibrations and noise.**

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 MPa and the contact area - 1 square centimeter, the average temperature on the tread surfaces - 400^0C, on the flange - 800^0C 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 a 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 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 produces 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.

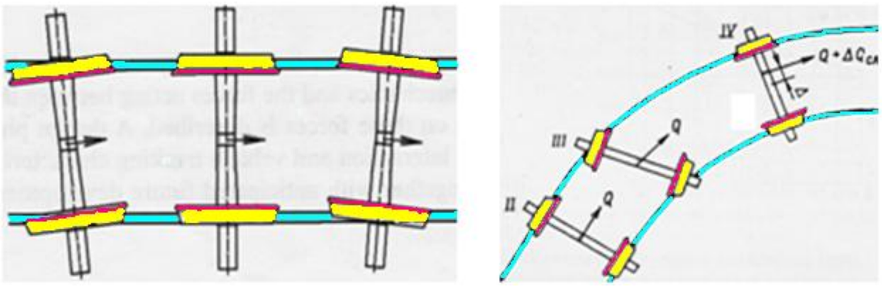


Fig. 1. Movement of a wheel-set in the straight and curve

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.

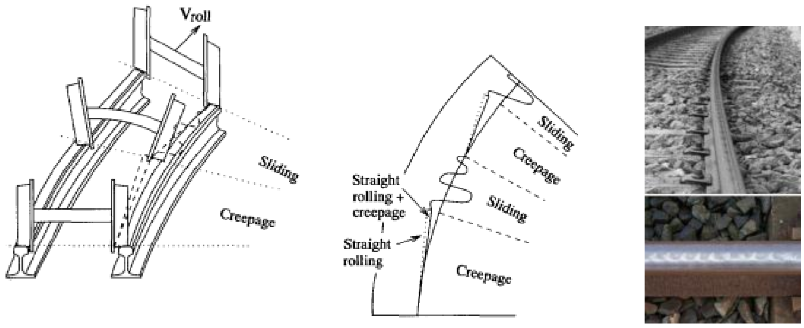
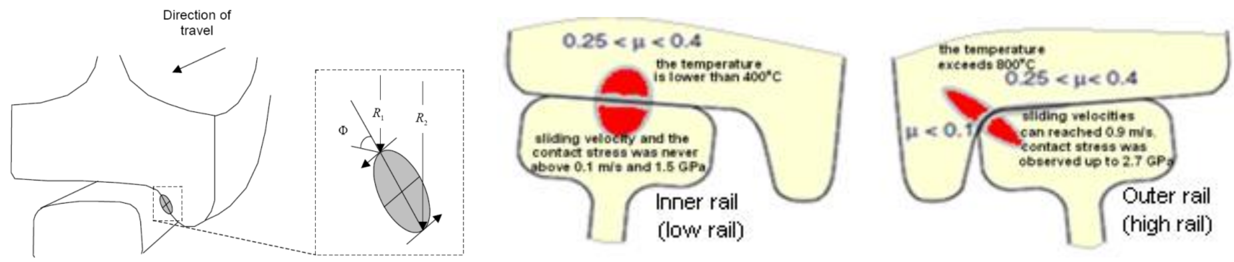


Fig. 2. **Movement of a wheel-set on the track in the curve and a corrugated inner rail** [7]

In the Figure 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.



a b

Fig. 3. Schematic view of various radii inside of the contact zone on the wheel flange [11] (a), desired values of friction coefficients of the contact zone [8] and the thermal loading, stress distribution and sliding velocities of profiles (b)

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 rails and on the tread surface of the inner rail 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.

The wheel–rail contact is a rolling and sliding contact, which can be divided into stick (no slip) and slip zones. The sliding zone of the contact of the tread surface is related to the tractive force, creep, and geometry of the contact. The slip rate increases when travelling in the curves, braking, and accelerating.

Different parts of interacting surfaces of wheels and rails need to have different properties. The friction factor for wheel flange and rail gauge face should be as low as possible - less than 0,1 or 0.2 (for a friction factor and adhesion factor in the literature there are various data [9,10,11]. Excessively high friction on tread surfaces causes severe wear, plastic flow and fatigue and low friction can cause poor traction and braking. But 0.1 – 0.7 is the typical range of the friction factor of interacting surfaces. For tread surfaces of a wheel and a rail and the friction factor should not be less than 0.25, and no greater than 0.4; optimal value of friction factor for tread surfaces is 0.35 [10,11,12]. This is one of the required conditions for normal interaction of wheels and rails.

Not for only 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 [13, 14]. 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 be changed.

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 raising 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}, $F_f = \psi(\sum \tau Aasp)$ [15], where τ is effective shearing strength of the contacting bodies.

The existing 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 take place in steering mainly in the curves and protecting the wheel-set from derailment) and rolling-steering surfaces (flange root and rail corner which 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. Therefore they must have corresponding properties and modifiers. Besides, transition of tread surface into flange root and next into the flange promote mixing of friction modifiers for tread and flange surfaces.

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 loading in the contact of superficial layers, generating vibrations, typical noise and the most dangerous type of wear - scuffing.

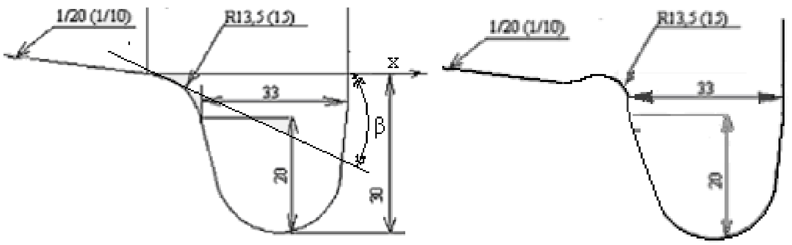


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Fig. 6. Fragments of the existed (a) and suggested (b) wheel profiles

The existing wheel profile is given in the Fig. 6,a. For separation of tread and flange surfaces, avoiding of interaction of the flange root and the rail corner and decreasing the probability of mixing of friction modifiers we suggest to make a recess in the place of transition of tread surface into flange root (fig. 6,b).

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 a special recess.**

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