Controlling the Tribological State of Contact Surfaces between Rolling Stock Wheels and Rails

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Abstract. Based on the analysis of Russian and foreign works on the theory of the rolling stock and track interaction and studies in the field of reducing wheel and rail wear, rational friction coefficients on contact surfaces between rolling stock wheels and rails to lubricate rails depending on the conditions of applying rolling stock traction and brake have been defined. The computer simulation of nonlinear 3D vibration of rolling stock and track interaction has been used as a method of the study, which allows to take into account various tribological states of contact surfaces between rolling stock wheels and rails. The effect of reducing the rolling stock lateral impact on the track by reducing the friction coefficient between the rolling stock wheels and the low rail running surface and the high rail head lateral surface in curves of a railway track is proved. On the basis of the computer simulation the results are obtained that make it possible to formulate technical solutions in the field of the friction control at the wheel and rail contact, providing the reduction of energy costs for trains traction, operating costs to replace rails and to turn rolling stock wheelsets.

1. Introduction
The most important factor for the system improvement of the wheels and rails interaction parameters is the increase of the control effectiveness of the tribological state of the contact surfaces between the rolling stock wheels and the rails. The uncontrolled interaction leads to unsatisfactory guiding of vehicle in curves, as a result the values of the lateral forces increase, and this, in its turn, causes the increase of fuel consumption for traction and wheels and rails severe wear.

The change in the tribological state of the contact surfaces between the wheels and the rails as a result of the application of a lubricant on the rails contact surfaces, i.e. the lubrication of the wheel-rail contact area, is an integral part of the measures to ensure sustainable interaction in the wheel-rail system, the resource and energy saving, an integral technical part of the transportation process and one of the main directions for reducing the wheelset tires wear, the rolling stock solid wheels wear, the rails lateral wear.

2. Problem statement
As a result of the conducted analysis of Russian and foreign studies, the rails lubrication by means of a train was defined as an advanced direction in this field [1–5]. Mathematical models of nonlinear 3D vibration of the rolling stock and track interaction have been developed, allowing to take into account different tribological states of the contact surfaces between the rolling stock wheels and rails. According to the results of the computer simulation using these models, the dependences of the effect of the tribological state of the contact surfaces between the rolling stock wheels and the rails on the
rolling stock wheels and the rails interaction are obtained. As a part of the study a variant of the tribological state of the contact surfaces between the rolling stock wheels and the rails in curves, ensuring the most effective interaction of the rolling stock wheels and the rails by the criteria of reducing the rolling stock wheels lateral effect on the rails and the wear factors, is defined – by simultaneous decrease of the coefficient of sliding friction of the oncoming wheel flange along the lateral surface and the high rail fillet and on the thread of the running down wheel along the low rail, and rational values of friction coefficients on the contact surfaces between the rolling stock wheels and the rails in curves under conditions of realization of the rolling stock traction and braking are offered (Figure 1):

- on the side edge of the high rail head after applying the lubricant – in the range 0.1–0.25;
- on the running surface of the low rail head after applying the lubricant – in the range 0.18–0.25.

Figure 1. The proposed technology of rail lubrication in curves with radius less than 800 m: 1) lubrication of the high rail head lateral surface by means of a railcar-lubricator with a lubricant with the resistance of more than 15,000 axles of the rolling stock, the friction coefficient between the oncoming wheel flange and the rail head lateral surface is in the range from 0.1 to 0.25; 2) lubrication of the low rail running surface behind the locomotive, hauling a train, with a friction modifier with a resistance from 250 to 280 axles of the rolling stock, the friction coefficient between the car wheels thread and the rail running surface is in the range from 0.18 to 0.25.

3. Method of the study
To justify rational friction coefficients at the points of contact of the rolling stock wheels with the rails, the computer simulation was performed using the Universal Mechanism software package, which provides for setting both variable and constant friction coefficients at the “wheel – rail” contacts [6, 7]. To calculate the forces at the “wheel – rail” contact, the Fastsim algorithm was used, based on the linear theory of Kalker creep forces [8].

For each rail two main friction coefficients were introduced: on the rail running surface and on the rail head side edge.

A variant is considered in which simultaneous lubrication of the high rail head side edge and the low rail running surface in a curve is performed.

The friction coefficient on unlubricated rails was taken as 0.5. The minimum value of the friction coefficient of the lubricated rail sections was assumed to be 0.1, some intermediate values of the friction coefficient, equal to 0.25, 0.2, and 0.15, were also considered.

4. Study results
Figures 2 and 3 show, in the form of graphs, the results of scanning the dynamics of a freight diesel locomotive section in the mode of traction and a freight car in a curve with a radius of 300 m.
The influence of different ratios of friction coefficients at the points of contact of the rolling stock wheels with the rails on the total creep forces and the sliding friction forces of the corresponding wheels at these contact points was studied.

If the values of the sliding friction forces $T_{ijn}$ over the wheels are greater than the corresponding total creep forces $F_{ijn}$, then there is an adhesion margin, i.e. the rolling stock wheels run on the rails without spinning (sliding) [9].

Sliding and, as a consequence, the loss and deterioration of the rolling stock braking conditions will occur with negative values of comparing the total creep forces with the sliding friction forces of the corresponding wheels $\Delta (\Delta = T_{ijn} - F_{ijn})$.

**Figure 2.** Graphs of the comparison of the total creep forces with the sliding friction forces of the corresponding wheels $\Delta (\Delta = T_{ijn} - F_{ijn})$ for the first wheelset of the freight diesel locomotive when running in a curve with a radius of 300 m at a speed of 30 km/h in the mode of traction.

**Figure 3.** Graphs of the comparison of the total creep forces with the sliding friction forces of the corresponding wheels $\Delta (\Delta = T_{ijn} - F_{ijn})$ for the first wheelset of the open car (gondola car) when running in a curve with a radius of 300 m at a speed of 30 km/h in a loaded state.

From the graphs in Figure 2, it follows that sliding occurs on the wheels of the freight diesel locomotive in the mode of traction with the friction coefficient values on the low rail running surface less than 0.18. This conforms with the results of analytical calculations.

As for the freight car, it follows from the figure 3 that sliding will occur when the friction coefficient values on the low rail running surface are less than 0.15.

Based on the results of the computer simulation of a freight locomotive and a car operation, confirmed by fields experiments and technical solutions, developed in JSC “VNIKTI”, for the rails
tribological state control, the technology of the combined rail lubrication by means of a locomotive, hauling a train, is suggested. It differs from the existing ones in that the lubrication of the low rail is carried out in a curve by a traction locomotive in the train on the track sections where the high rail head side edge has already been lubricated by railcar-lubricators. The technology of rail lubrication by means of a locomotive, hauling a train, is shown in Figure 4.

The lubricant is applied in curves with a radius of less than 800 m on the low rail running surface immediately after the locomotive, hauling a train. A friction modifier is used as a lubricant, which allows to regulate the reduction of the coefficient on the contact surfaces between the rolling stock wheels and the rails in the range from 0.18 to 0.25.

The resistance of the friction modifier until it is completely abraded from the low rail surface in a curve by the train car wheels, under which it was applied, should be from 250 to 280 axles of the rolling stock (Figure 4), and the resistance of the lubricant applied to the high rail head lateral surface using the method of rail lubrication by means of a railcar-lubricator – more than 15,000 axles of the rolling stock [10].

![Figure 4](image-url)

**Figure 4.** The rail lubrication technology by the locomotive, hauling a train: 1) the tribological state of the low rail running surface before the lubrication, the friction coefficient \( \varphi > 0.25 \); 2) the lubrication of the low rail running surface by the locomotive, hauling a train, by a friction modifier, the friction coefficient \( \varphi = 0.18 \); 3) the change of the tribological state of the low rail running surface depending on the number of missing axles of the rolling stock, the friction coefficient \( \varphi = 0.18 \ldots 0.25 \); 4) the tribological state of the low rail running surface after 250–280 rolling stock axles missing, the friction coefficient \( \varphi > 0.25 \).

When applying the technology of simultaneous lubrication of the high rail head lateral surface and the low rail surface in curves, the saving of the energy consumption for train traction is 10–13% [11, 12], the lateral impact on the track is reduced to 50% depending on the radius of curves and the type of the rolling stock [13, 14].

As a result of the carried out by JSC “VNIKTI” theoretical and experimental studies on the dynamic negotiation and the rolling stock effect on the track when using the simultaneous lubrication of the high rail head lateral surface and the low rail surface in curves with friction coefficient values \( \varphi = 0.18 \) on the low rail running surface and the high rail head lateral surface \( \varphi = 0.1 \) and, depending on the running speed, the decrease of the resistance to movement up to 10% and the lateral impact on the track of the freight car in a loaded state in a curve with a radius of 300 m to 30% is got.

The lateral impact on the track is decreased by reducing the friction coefficients on the low rail running surface and the high rail head lateral surface, as a result of which there is a proportional decrease of the transverse creep forces at the contact of the rolling stock wheels with the rails. As a result of the decrease of the transverse creep forces, the normal reaction on the oncoming wheel flange reduces, which consequently leads to the decrease of the resistance to movement and, as a result, to the train traction energy consumption decrease, to the decrease of wear of the rolling stock wheel flanges.
and rails in curves. The distribution of creep forces of the first bogie of the loaded car in a curve with a radius of 300 m at a speed of 30 km/h with different types of rail lubrication is shown in Figure 5.

![Figure 5](image)

**Figure 5.** The distribution of creep forces of the first bogie of the loaded car in a curve with a radius of 300 m at V = 30 km/h with different types of rail lubrication: a) the lubrication of the high rail head lateral surface; b) the lubrication of the high rail head lateral surface and the low rail running surface.

5. Conclusions
The use of the technology of simultaneous lubrication in curves of the high rail head lateral surface by means of a railcar-lubricator with a lubricant with the resistance of more than 15,000 axles of the rolling stock and the low rail surface by means of a locomotive, hauling a train, with a friction modifier with the resistance from 250 to 280 axles of the rolling stock in comparison with the technology of lubrication of only the high rail lateral surface in a curve, allows to:

- reduce the values of the moments of resistance (MC) to the rotation of freight car bogies in a curve with a radius of 300 m by 70% at a speed of 30 km/h and by 36% at a speed of 70 km/h and, as a result, reduce energy consumption for train traction;
- reduce the rolling stock lateral impact on the track in a curve with a radius of 300 m to 30% at a speed of 30 km/h and to 10% at a speed of 70 km/h.

The technology of rail lubrication by means of a locomotive, hauling a train, has a great prospect of application on the railway network of the Russian Federation. The costs for equipping locomotives with rail lubricators for applying a friction modifier and manufacturing a friction modifier will pay off by the saving of the energy consumption for train traction, the reduction of the wear of the rolling stock wheel flanges and rails in curves.

6. References
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