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Impact of Roughness of Interacting Surfaces of the Wheel-Rail Pair on the Coefficient Of Friction in Their Contact Area

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Abstract

Theoretical and practical research of conditions of interactions of work surfaces of open-quarry locomotives with rails were conducted, rational roughness values for rail profiling were defined to reduce the run-in period for wheel-rail pair to improve the period of the efficient operation of open-pit railway transport.

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The concept of the coefficient of friction was first introduced by Leonardo da Vinci (1508). In about 200 years (1699), the coefficient of friction was researched by Amonton. The law of friction is often called the law of Coulomb who provided an experimental proof that the force of friction is equal to the product of the coefficient of friction and the value of normal response of base surface. According to the classical mechanics "the force of friction does not depend on the area of contact of conjugated surfaces in fairly broad limits".

The modern friction science called TRIBOLOGY developed in work of I.V. Kragelsky, A.V. Chichinadze, D.N. Garkunov, N.B. Demkin [1,2] and their students states that the force of friction depends on many physical and chemical properties of conjugated surfaces including actual area of contact of conjugated surfaces and their roughness.

To simplify evaluation of surface roughness impact, the scientific literature introduces the concept of complex roughness value Δ:

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$$\Delta = \frac{h_{\max}}{Rb^{\frac{1}{\nu}}} , \tag{1}$$

where R is the design curvature radius of the asperity tips defined as average value of curvature radius of uneven areas in longitudinal and lateral profile charts, $R = \sqrt{r_{prod} \cdot r_{pop}}$; h_{max} — is the elevation of the greatest asperity; *b* and ν - parameters of asperity base curve; r_{prod} and r_{pop} vertex radius of profile in longitudinal and lateral direction accordingly.

According to molecular mechanics friction theory of I.V. Kragelsky [1], the coefficient of friction of solid bodies has two components– molecular component (f_{mol}) depending on molecular impact in contact zone of work surfaces of the wheel – rail system and deformation component (f_{def}), which is currently not possible to evaluate in terms of molecular impact due to complex structure of bodies [4]. Therefore, it is defined with special experiments and known information about the nature of substance:

$$f = f_{mol} + f_{def} \tag{2}$$

As it has been noted above, surface roughness is characterized with complex roughness value Δ. When this value is low, i.e. when surfaces have high purity ratio, the molecular component of the force of friction is the dominating factor. Elastic deformations are prevalent in contact zone [1], and therefore the mechanical component of the force of friction is low as compared to the molecular component and amounts about 5% of the total coefficient of friction [3]. When Δ is increased, plastic deformations are prevalent in contact zone, the molecular component of the forces of friction becomes lower and the main coefficient of friction is provided by mechanical (also called deformation) component of the forces of friction. Therefore, it should be noted that purities of similar classes with different processing (difference of Δ) have different value of the coefficient of friction [3].

Depending on Δ value, contour load p_c and physical and mechanical properties of contacting materials (μ – Poisson ratio, μ =0.3; *E* – elastic modulus, $E = 2.1 \cdot 10^5$ MPa), the references [1] provide formulas to identify the nature of deformation in contact zone:

- of elastic non-saturated contact

$$0 \le \frac{p_c\left(1-\mu^2\right)}{E} \le 6 \cdot 10^{-2} \Delta^{1/2} ; \tag{3}$$

- for plastic saturated contact

$$0,0625 \le p_c / HB \le 0,32\alpha HB , \tag{4}$$

where α is the coefficient of hysteresis losses for single-axis strain (stress). For tampered steel α = 0.02 [1].

Contour load is calculated with the following formula

$$p_c = N / A_c , \tag{5}$$

where *N* – load on one wheel of locomotive, H; A_c – contour area of contact of wheel with rail. According to experimental data [5], for the load of 135 000 N (with axial load of 270000 N typical for open pit locomotives) A_c = 390 mm^2, then p_c = 346.2 N/mm^2.

The author's calculations show that for surface purity class R_z6.3 (∇ 7) and higher deformations have elastic non-saturated nature and for roughly treated surfaces of purity class R_z 20 (∇ 5) and lower interaction has the indications of plastic saturated contact. Therefore, coefficients of friction for elastic non-saturated contact and plastic saturated contact are calculated with the below formulas accordingly [1]: