INTERACTION OF A WHEEL WITH A RAIL DURING ROLLING

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ABSTRACT

The problem of uneven wear of a wheel set is considered by many scientists of the world, in the works related to car building. New software complexes for mathematical modeling are being created, and each follows its own theory of rolling stock dynamics. In this article the main provisions for deformation and wear of a wheel along the circle of rolling during car movement are considered. In this case, the elastic sliding model is described in more detail. During wheel rolling and in the presence of torque in the contact area, there is always a gripping area that is located at the entrance, and an area of slippage at the exit. It is proved that the coefficient of slippage is equal to deformation in the gripping area. Under certain kinematic and dynamic conditions, a stress distribution graph is plotted in the contact zone. On the basis of the theory of tangential stresses, a displacement formula is obtained, which is transformed into a new formula for the creep coefficient, which retains the physical meaning of the value found.

Keywords: theory of rolling stock dynamics, wheel set, rail, creep coefficient, sliding, gripping, contact spot, wheel rolling, stress distribution.

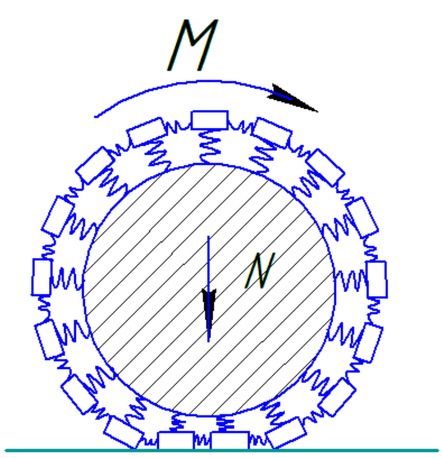
Background. *The wheel set is the most loaded element in operation of running parts of rolling stock of railways, directly interacting with the rail. Due to the twisting motion of wheel sets in the track, their interaction is accompanied by appearance of forces and moments in the horizontal direction. The horizontal forces are strengthened with participation of the frame. Rolling friction occurs between the wheel and the rail. The tangential forces that are detected at the point of contact cause slippage of the wheels along the rail head.*

When the tangential forces are less than the dry friction force, the relative sliding of the wheel along the rail during rolling is considered to be due to the elastic deformations of the wheel and rail materials and is called elastic sliding, or creep: F = ku/v, where k is the creep coefficient, v is the train speed, u is the slippage velocity [2].

Objective. *The objective of the author is to consider interaction of a wheel with a rail during rolling and to suggest a formula of creep coefficient.*

Methods. *The author uses general scientific and engineering methods, comparative analysis, mathematical apparatus, theory of elasticity, tangential stresses, elastic sliding model.*

Results. *Let us consider in more detail the elastic sliding model. In the rolling contact, with minor torques, it is established that a small slippage region initially appears, which then increases with an increase in the positive moment until full sliding occurs [11]. To understand the processes taking place in the contact (wheel–rail), let's take a simplified model of an elastic wheel (Pic. 1).*



Pic. 1. The simplest model of a rolling wheel.

When the wheel is fully rotated, it can be seen that the elastic elements that come into contact with the surface are in a compressed state. When leaving the contact area, where the elements are stressed, and the action of normal force weakens, the balance is broken and the elements relax. As a consequence, the wheel rotates a little more. During wheel rolling and in the presence of torque in the contact area, there is always a gripping area that is located at the entrance. And the slippage area is at the exit. It is easy to determine that the slippage coefficient is equal to deformation in the gripping area in the contact spot:

$$k = \frac{\varepsilon_{xx}}{1+\varepsilon_{xx}} \approx \varepsilon_{xx} .$$

Now it's time to use the known formulas from the theory of elasticity. Let's suppose that the contact spot is a circle with radius a, as shown in Pic. 2a. In this zone tangential stresses act as:

$$\tau\left(r\right) = \sigma_{xx}\left(r\right) = \tau_0\sqrt{1-\frac{r^2}{a^2}} .$$

These forces lead to a displacement in the tangential direction:

$$u_x = \frac{\pi\tau_0}{32Ga}\left[4\left(2-v\right)a^2-\left(4-3v\right)x^2-\left(4-v\right)y^2\right],$$

where G is shear modulus, v – circumferential velocity.

Distribution is of a kind

$$\tau\left(x\right) = \sigma_{xx}\left(x\right) = \tau_0\sqrt{1-\frac{x^2}{a^2}}$$

in a strip of width 2a (Pic. 2b), leads to displacement of the surface

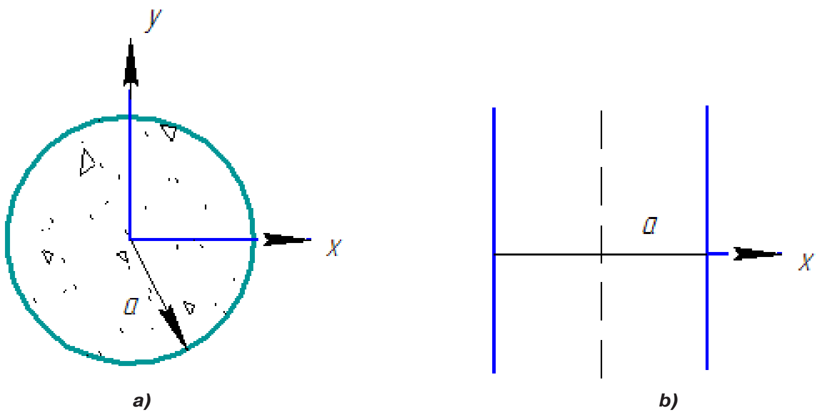
$$u_x = Const - \tau_0\frac{x^2}{aE} ,$$

where E is modulus of elasticity of the wheel material. With the help of these dependencies, it is possible to plot the distribution of stresses in the contact.

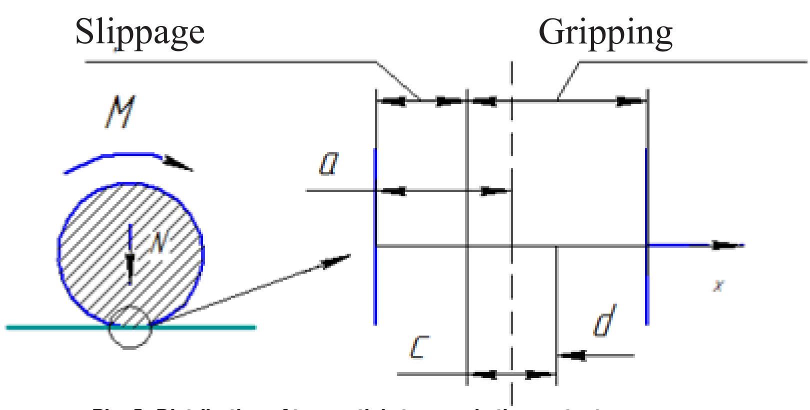
The distribution of normal pressure over the entire contact region is given by Hertz's formula:

$$p\left(x\right) = p\sqrt{\;-\!-\;} .$$

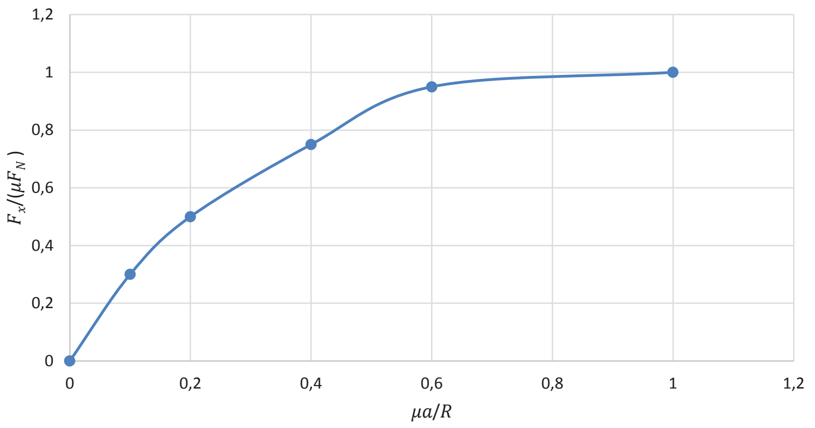
In order to construct a stress distribution for a rolling contact, it is necessary to fulfill certain kinematic and dynamic conditions. According to Pic. 1, the material entering the contact region is deformed. Let us assume that the deformation in the



Pic. 2. Tangentially loaded contact.



Pic. 3. Distribution of tangential stresses in the contact zone.
a – half the width of the contact zone; c – gripping areas.



Pic. 4. Slippage curve in the presence of tangential force.

contact zone is constant. And let us also suppose that the condition (Coulomb's law of friction) must be satisfied in the slippage zone $F_{тр} = \mu N$: $\tau(x) = \mu p(x)$.

Then the formula for calculating tangential stresses in the contact zone is:

$\tau(x) = \tau_1(x) + \tau_2(x)$,

where $\tau_1(x)$ – tangential stress in the gripping area, $\tau_1(x)$ – tangential stress in the slippage area.

As follows from Pic. 3, $d = a - c$.

The formula for calculating tangential stresses allows us to derive the displacement formulas:

$$u_{x1} = Const - \tau_1 \frac{x^2}{aE};$$

$$u_{x2} = Const + \tau_2 \frac{(x-d)^2}{cE}.$$

For a complete displacement, we get:

$$u_x = Const - \tau_1 \frac{x^2}{aE} + \tau_2 \frac{(x-d)^2}{cE}.$$

And the formula for deformation transforms into:

$$\frac{\partial u_x}{\partial x} = -\tau_1 \frac{2x}{aE} + \tau_2 \frac{2(x-d)}{cE}.$$

Substituting τ_1 for the expression of the Coulomb law, we obtain $\tau_1 = \mu p_0$.

Taking into account the fact that the deformation in gripping area is constant, we have the formula:

$$\frac{\partial u_x}{\partial x} = -\frac{2\mu p_0 d}{aE}.$$

The total transverse force in the contact region is calculated by equation

$$F_x = \int_{-a}^{a} L \bullet \tau(x)\,dx \approx L \bullet \left(\frac{\pi}{2} a\mu p_0 - \frac{c}{a}\frac{\pi}{2} c\mu p_0\right) =$$

$$\mu F_N \left(1 - \frac{c^2}{a^2}\right).$$

By transforming the expression d = a – c we obtain d/a = 1 – c/a and, substituting it into the expression for the total transverse force, we find the unknown distance d:

$$d = a\sqrt{\frac{F_x}{\mu F_N}}.$$

Using the formula for deformation in the gripping area, we derive the creep coefficient:

$$k = \frac{\partial u_x}{\partial x} = -\frac{2\mu p_0}{E}\sqrt{\frac{F_x}{\mu F_N}}.$$

We assume

$p_0 = E \cdot \frac{a}{2R}$, *where R is wheel radius.*

We get the final creep formula for the railway wheel:

$$k = -\frac{\mu a}{R}\sqrt{\frac{F_x}{\mu F_N}}.$$

This dependence, as shown in the graph of Pic. 4, corresponds to the slippage curve.

It can be seen from the graph that the total sliding in the entire contact area occurs when $F_x = \mu F_x$. In this case, the creep coefficient (pseudo-slippage):

k = -μa/R.

Conclusion. *Thus, we have obtained a new formula for the creep coefficient, which preserves the physical meaning of the value itself.*

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