Modelling of rolling friction with sliding

Irina Kirichenko, Alexandr Kashura, Marina Morneva, Sergey Popov

Volodymyr Dahl East-Ukrainian National University
Molodzhny bl., 20a, Lugansk, 91034, Ukraine,
e-mail: i_kir@ukr.net, kashure@mail.ru, morneva@gmail.com

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Summary. The article proposes a mathematical model of the process of rolling friction with slip at the point of contact with the rail wheels of the locomotive in the implementation of thrust.

Key words. The friction force, the force of adhesion, the contact, the contact area, rolling friction, sliding friction.

RESULTS

The problem of interaction of a rolling stock and railway way concerns to number of the major in a transport science [2, 9, 18, 22, 23].

The urgency of the numerous researches devoted given problem, is caused by what from the processes occurring in contact of interaction of a wheel and a rail, safety and technical and economic parameters of a traction rolling stock of railways (speed of movement, the losses connected with overcoming of resistance to movement, deterioration of wheels, rails, etc.) depend [3, 27].

Long-term operation of a rolling stock shows, that the resource of bandages of wheel pairs is defined by hire and, in a greater measure, deterioration of crests. The numerous publications testify to it, devoted to above permitted standard wear process of crests of wheel pairs and a lateral surface of a head of a rail. So, for example in [1] diagrams of structure of turnings of wheel pairs on operational park of locomotives on a network of railways of the Russian Federation 2012 which Analysis are presented shows, that made turnings of bandages of wheel pairs on admissible size of hire make 4 % while on
deterioration of a crest their value reaches 65%.

With the purpose of decrease in intensity of wear process of wheel pairs and rails up to comprehensible values last years a number of actions of technical and organizational-technological character [8] (lubrication, improvement of a design of a way and locomotive servicing of a rolling stock, perfection of geometry of a structure of a surface of driving of wheels and rails, monitoring in system a wheel – a rail, etc.) is spent. From all listed directions of works most quickly introduction in a zone of contact of the third body with the set characteristics is sold.

The choice of the materials applied to cooling and greasing of contacting surfaces of crests of wheel pairs and rails, should be carried out in view of temperature conditions of interaction of the considered pair friction. How the temperature developing at friction, causes heating thin superficial layers of the interfaced bodies and a layer of greasing dividing them, it is one of the most important factors influencing all complex of service properties of lubricants, defining their antifriction properties.

During friction of a lateral surface of a crest of a wheel about a rail depending on loading, high-speed and temperature modes various modes of friction are realized: dry, boundary and полужидкого friction. Change of modes of friction including formation of the mixed greasing, can be considered on diagram Hersy (fig. 1), showing dependence of factor of friction on the characteristic of a mode of greasing [25]. The dimensionless size is defined under the equation:

$$\lambda = \frac{\mu \cdot V}{P} \quad \text{or} \quad \lambda = \frac{\mu \cdot \omega}{P}, \quad (1)$$

key parameters enter into it defining a mode of friction (viscosity of oil, speed, loading).

This curve has two characteristic branches: left, falling for area of boundary greasing and right, increasing, for area of liquid greasing. Between them there is the transitive site corresponding area semi fluid greasing (area). At transition in area unstable semi fluid greasing change of any parameter promoting decrease $\lambda$ (reduction of viscosity, increase in loading, increase in speed of sliding), leads to increase of factor of friction and working temperature tribosystem. Growth of factor of friction in the given area occurs due to increase of a share of boundary greasing down to formation cleanly boundary greasing (area).

![Diagram Hersy](image)

Modeling of thermal processes in pair friction a crest of a wheel-rail definition of power and geometrical conditions контактирования is carried out according to with described in [4] sequence.

At interaction of a crest of a wheel with a lateral surface of a head of a rail at presence between them a lubricant the factor of boundary friction can be calculated under the formula resulted in work [8]:

$$f_{mc} = f_{mp} - k \frac{\eta_{cm} \cdot v_{oc}}{P_{noc}}, \quad (2)$$

where: $f_{mp}$ - factor of friction of not greased surfaces, $\eta_{cm}$ -dynamic viscosity of oil, $v_{oc}$ -speed of sliding, $P_{noc}$ - running loading, $k$ -factor of proportionality.
Modeling modes of friction considered tribosystem it is necessary to mean, that at dry friction the second member of the equation (1) can not be considered. The second part of the equation (1) generally is function of the characteristic of a mode of greasing. From the equation (1) it is visible, that three factors influencing a mode of greasing are speed, loading and viscosity of oil.

The factor of friction \( f_g \) depends, from actual (working) viscosity of greasing at temperature \( T \) on a surface of contact, instead of from the rating value defined in вискозиметр at conditional temperature and atmospheric pressure.

For the calculation of temperature on the surfaces of wheel and rail, it is necessary to define a form and size of spot of contact. We will represent the touch of wheel and rail, as a contact of cylinder with toroid with perpendicular axes. Sizes of spot of contact of wheel and rail is possible to define on the equations of theory of elasticity \[24\]:

\[
a = 1.397 n_a \sqrt{\frac{P_e}{E} \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} - \frac{1}{R_4} \right)},
\]

\[
b = 1.397 n_b \sqrt{\frac{P_e}{E} \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} - \frac{1}{R_4} \right)},
\]

where: \( n_a, n_b \) - coefficients values of which are determined on tables; \( R1, R2, R3, R4 \) – radiuses of curvature of contacting bodies, \( E \) – the elastic module.

Change of temperature on the surface of friction of wheel flange with the head of rail in time, it is possible to define, deciding the unstationary task of heat conductivity which, in the case of independence of thermo physical properties of materials of contacting bodies from a temperature, is described by differential equalization of heat conductivity, which has a kind \[31\]:

\[
\lambda \left( \frac{\partial^2 T}{\partial t^2} + \frac{\partial^2 T}{\partial j^2} + \frac{\partial^2 T}{\partial k^2} \right) \pm q = c_p \frac{\partial T}{\partial t},
\]

where: \( \lambda \) - coefficient of heat conductivity, \( c_p \) - heat capacity of materials by volume, \( q \) - thermal thread through a surface, \( T \) - temperature; \( t \) - time.

Normal loading \( P(x,y) \) we will define as work of pressure in every cell of spot of contact on the area of cells:

\[
P(x,y) = \sigma(x,y) \cdot F.
\]

For determination of pressure \( \sigma(x,y) \) in every point of contact ground the equation of cycle per a second was used:

\[
\sigma(x,y) = \sigma_{max} \sqrt{1 - \left( \frac{x}{a} \right)^2 - \left( \frac{y}{b} \right)^2},
\]

where: \( \sigma_{max} \) - maximal value of pressure in the center of spot of contact. At the accepted chart of contact of wheel flange with the lateral surface of head of rail, value of maximal pressure, it is possible to define on the equation (8):

\[
\sigma_{max} = 0.245 n_p \sqrt{P_e E^2 \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} - \frac{1}{R_4} \right)^2},
\]

where: \( n_p \) - coefficient, the value of which is determined on tables \[26\].

Viscosity of all drop liquids and their mixes with rise in temperature decreases. For recalculation of viscosity from one temperature on another the equation (9) is recommended:

\[
\eta_T = \eta_\text{u} \left( \frac{t_\text{u}}{t_T} \right)^n,
\]

where: \( \eta_T \) – required viscosity of oil at temperature \( t_T \), \( \eta_\text{u} \) – Resulted in tables of GOST viscosity (in Nsm/m\(^2\)) at temperature of test of oil, \( t_\text{u} \) – Temperature of test of oil on definition of its viscosity, \( t_T \) – temperature for
which count viscosity, \( n \) – factor – an exponent for each grade of oil. Value of factor can be accepted under tables [23].

Results of calculation of parameters considered tribosystem at presence between them a lubricant are presented on fig. 2-5.

Fig. 2. Dependence of the attitude \( f_{mc}/f_{mp} \) from size of lateral force in contact of a crest of a wheel to a lateral surface of a rail (\( f_{mp} \) and \( f_{mc} \) – factor of friction of not greased surfaces and at boundary friction)

Fig. 3. Dependences maximal (a curve 1) and average (a curve 2) relative temperature in contact of a crest of a wheel to a lateral surface of a rail from size of lateral force (\( T_{sm,max}/T_{max} \) - curve 1, \( T_{m.cm.}/T_{m.} \) - curve 2)

Proceeding from data of calculation of temperature on a spot of contact at presence of a lubricant layer the processes proceeding on a surface of friction, it is possible to present in a following kind. So, at constant speed of sliding and accruing loading there is a gradual increase in intensity of allocation of heat of friction fig. 3 and, hence, rise in temperature of a layer of the oil dividing rubbing surfaces. Apparently from fig. 2, in a zone of force of interaction of contacting bodies 3 … 25 kN

Fig. 4. A field of temperatures (\( t, ^\circ C \)) on a surface of contact of a crest of a wheel with a rail at presence between them greasings MC-20, (speed of movement \( V_{line}=60\text{km/h}, \) sliding \( \varepsilon=10\%, P=65\text{kN} \)
there is an excess. It is possible to explain presence of an excess change of a physical and chemical condition of greasing due to a thermal emission in contact. To the further growth of temperature leads to that the oil layer loses protective properties and factor of friction becomes same, as for not greased surfaces.

Fig. 5. Dependence of the attitude capacities of friction in contact of a crest of a wheel to a lateral surface of a rail at presence of greasing and without it from size of directing energies.

The similar result is received in works [20] where the spasmodic increase in factor of a sliding friction was observed at rise in temperature in a zone of contact due to relative friction.

By means of the given calculation it is possible to estimate possible temperature in contact of interface under the heaviest conditions of its work and to pick up a lubricant with demanded operational properties.

For an estimation of influence applied at lubrication materials on conditions контактирования in considered a feather of friction we shall take advantage of power criterion of deterioration [9, 10]. Quality standard of deterioration we shall make calculation of capacity of forces of friction in a zone of contact for a series of oils, according to the described calculation.

Results of calculation of capacity of force of friction on a surface of contact of a crest of a wheel with a rail at presence between them greasing MC-20, (speed of movement $V_{line}=60$km/h, sliding $\dot{\varepsilon}=10\%$, $P=65$kN are shown on fig. 5.

CONCLUSIONS

1. The analysis of the received results shows, that the effect from drawing greasing on rubbing surfaces is observed at rather small values of directing energies up to 10kN. In these conditions rather insignificant deterioration is observed.

2. Decrease in intensity of deterioration and a temperature mode with growth of value of directing energies can be reached at the viscosity of oil corresponding to temperatures considerably smaller than settlement temperature in a zone of friction.

REFERENCES


МОДЕЛИРОВАНИЕ ПРОЦЕССА ТРЕНИЯ КАЧЕНИЯ СО СКОЛЬЖЕНИЕМ

Ирина Кириченко, Александр Кашура, Марина Морнева, Сергей Попов

Аннотация. В работе предложена математическая модель процесса трения качения с проскальзыванием в точке контакта колеса локомотива с рельсом при реализации силы тяги. Ключевые слова: сила трения, сила сцепления, контакт, площадь контакта, трение качения, трение скольжения.