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Numerical calculation of temperature in the wheel–rail flange contact and implications for lubricant choice

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ABSTRACT

The realization of movement by railway vehicles creates a problem that is connected to the wear process for elements of a tribological wheel–rail system. Wheel–rail wear is a complex phenomenon that depends on many factors. One of the main wear zones is the contact area between a wheel flange and a rail gauge. As is well known, wear in this contact zone occurs when a railway vehicle moves on curved parts of track, realizes tractive, braking efforts or moves in a high-speed mode. In this case, the solution of this kind of wear problem can be found by means of lubricant implementation. The choice of a lubricant requires information about contact characteristics at the moment of a vehicle's movement. This paper focuses on the modeling of the temperature process in the contact between a wheel flange and a rail gauge. Examples of temperature calculation with some experimental data as input for this computation are presented. The obtained values of the temperature allow for making the correct choice of lubricant type.

1. Introduction

In the process of realization of tractive efforts by a railway vehicle with a slip presented between contact surfaces of a wheel and a rail, interaction forces between surfaces are acting, accompanied by release of heat energy in the contact zone. The energy processes act by means of using big specific loads on small contact surfaces, which provides a high concentration of energy and gives a jump in temperature. If compare the wheel–rail head contact and the wheel flange/rail gauge contact, it is possible to see that the values of slip velocities are higher for the second contact and the values of temperatures are less for the first contact, it also explains a jump in temperature. The similar temperature behavior was discussed by Sundh and Olofson [1]. As a result, the temperature in the contact area can reach hundreds of degrees Celsius.

Ertz and Knothe [2], in the field of temperature calculation by means of semi-analytical and numerical methods, give an approach based on Hertzian contact. In their work, the heat conduction from the wheel to the rail is also considered. The further work of these authors is presented in [3], which presents only an approximate analytical solution for a line contact model. The paper [4] also was published with the participation of these authors. For the calculation of adhesion coefficient an approximate solution for the normal stress and the average contact temperature based on Hertzian line contact was used. In all these studies, the authors pay attention to the rolling contact between a wheel and a rail.

Evtushenko et al. [5] obtain expressions for the maximum contact temperature for the friction surface in the deceleration and acceleration modes of a rail vehicle's movement. The paper [6], which continues the investigation by Evtushenko et al., provides an approximate solution of a two-dimensional quasi-stationary problem of heat conduction for a surface with a rapidly moving distributed heat flow. Papers [5,6] consider the contact between a wheel and a rail as the contact of a circular cylinder over the surface of a semi-infinite body.

Fisher et al. [7] present an analytical solution for the temperature field by means of applying the Laplace transform technique. The other paper [8], with the participation of Fisher et al., describes a new heat-partitioning factor for the case of frictional heating and heating due to plastic deformation. However, the authors only consider the rolling contact.

Kennedy et al. [9] examine a number of theoretical solutions for the temperature field by comparing them to the results of a finite element analysis. In this case, they also simplify the problem by assuming that the problem is two-dimensional and ignoring the curvature of the wheel.

The application of temperature calculation for wheel steel development is shown in paper [10], which also considers a sliding wheel–rail system with a one-point rolling contact.

As a result, almost all the studies mentioned above do not consider how to determine the temperature in the contact zone between a wheel flange and a rail gauge. Sundh and Olofson [1] try

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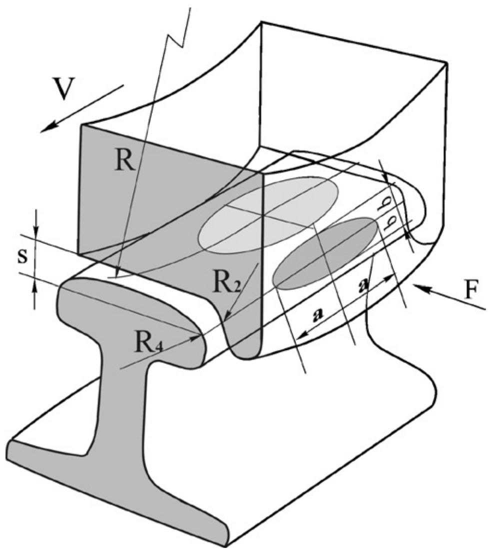

Fig. 1. Two-point wheel–rail contact.

to represent experimentally a contact between a wheel flange and a rail gauge a calculation with using a test method of ball-on-disc type at different sliding velocities, contact pressures and lubricants. The temperature in the contact was calculated based on the theory presented in [11]. However, this approach does not allow simulating a real contact

This task can be solved by application of the model proposed in this paper, which also contains the theoretical background of the model. The algorithm proposed in this model can be simulated and it gives the calculated values of temperatures, which are required for lubricant choice. The process of choosing of lubricants depends on the values of their working temperatures, which are recommended to be higher than a maximal value of calculated values of temperature in the contact. For an example, the mineral oils can be applied if the temperature in the contact is less than 80 °C, synthetic oils are recommended to use in the range of 200 °C and above. The temperature depends on additive contents of these oils. The graphite and molybdenum greases can be applied for the temperature range from 600 to 800 °C. It also should depend on in which country the lubricant types are going to apply (requirements from railways, different manufactures, etc.).

2. Wheel–rail contact

If we consider the situation in which the wheelset is moving on different curved parts of track, it is possible to see that a wheel, moving with defined values of an angle of attack, can make contact with a rail at two different points—two-point contact. In this case, two contact spots appear: one is situated between wheel tread and rail head, and the second is between the wheel flange and gauge face of the rail head; the last one is also called flange contact. Both of these contact spots are shown in Fig. 1. Also, it is necessary to say, this kind of contact is possible for high-speed modes of a rail vehicle.

Because a wheel moves on curved parts with some angle of attack, the flange contact area is slightly shifted ahead. Increasing the values of the angle of attack increases the distance between the contact spots and the instantaneous axis of rotation motion of a wheelset. As a result, we have increasing values of relative slip and tangential force. Based on this, it is very important to detect a location, a shape and dimensions of contacts when the contact analysis between a wheel and a rail is made. In the case of modeling, the location of contacts is detected by means of contact element stitching for a specific part of a railway track, because the profiles of cross-sections of wheel and rail can have very difficult configurations.

However, in the common case, the flange contact can be represented as a contact between a cylinder and a toroid with orthogonally related axes. The dimensions of the contact zone for new rolling surfaces of a wheel and a rail, which are formed by means of elastic properties of contact bodies, can be calculated with the following equations from elasticity theory [12]:

$$a = 1.397 n_a \cdot \sqrt[3]{\frac{F}{E_m} \cdot \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} - \frac{1}{R_4}}} \tag{1}$$

$$b = 1.397 n_b \cdot \sqrt[3]{\frac{F}{E_m} \cdot \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} - \frac{1}{R_4}}} \tag{2}$$

where n_a and n_b are coefficients taken from tables [12]; F is a lateral force in the flange contact and can be taken from experimental or theoretical investigation for a specific rail vehicle; $R_1 = R + s$ is the radius of curvature for the needed part of a wheel; R is the rolling radius of a wheel; s is the distance from a rail head to the point of the flange contact (see Fig. 1); R_3 is the radius of rail curvature in the longitudinal direction and equal to ∞; R_2 and R_4 are radii of curvature in the lateral direction; E_m is the modulus of elasticity.

The effectiveness of using Eqs. (1) and (2) for the calculation of dimensions of the flange contact area will be discussed in detail in Section 5.

3. Lubrication in the wheel–rail flange contact

Heat educed in the contact zone between a wheel and a rail, and raising the temperature of the working surfaces, brings a change of structure and mechanical properties of working bodies. It leads to wear of contact surfaces, which contributes to the premature failure of wheel flanges and rails.

One of the ways to reduce wear processes of surfaces in the flange contact is the application of lubrication devices for working surfaces. A good review of tribological aspects connected with this problem is made in publications [13,14].

In work [13], the attention is focused on problems of high friction and solutions as to how to reduce it by means of lubrication. Advantages of lubrication and existing method of applications are present. Also, the given information confirms the efficiency of such systems.

The work [14] does not describe any studies concerning fuel or energy savings due to wheel flange lubrication, though it is important to understand that the technique is useful and an easy way to save energy, as wear on both wheels and rails will be reduced. This work describes obtaining a solution to detect what type of lubrication is required to decrease wear rate. However, lubrication can also result in unwanted effects in this complex system such as, the application of lubricant on the rail ball can lead to problems with traction and on a high gauge face can increase the possibility of derailment. To solve this problem, field tests and laboratory tests were conducted and good results were obtained. As is well known, this kind of research requires good financial and technical support.

Based on the above, this article proposes to use a model, shown in Section 4, to detect the lubrication type or lubricant additive in a contact by means of numerical simulation. If the choice of lubricant type depends on temperature characteristics, it is necessary to remember the requirements to satisfy environmental selection criteria.