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CALCULATION ALGORITHM OF TRACTIVE PROPERTIES AND SAFETY FACTOR OF MINE SECTIONAL LOCOMOTIVE

Introduction. During the rock mass and coal transportation by the mining rail transport along the mining shafts, the rail's functions are not only carrying static loads, but to transmit the dynamical stress and bogie mass to the rail track structure as well. The interaction area between wheel and rail facilitates transmitting braking and tractive forces. In order to increase the productivity of the mining rolling stock, an adhesion weight of the modern mining locomotives increases either and now achieves 10-28 tons. This mass allows hauling heavier mining tub with significantly increased static loads on the rail track on the steeper slopes. Due to the fact, that existing mining rail tracks have been designed for much lower locomotives' weight, increased axial loading on the rail track elements rocketed up to 1,5-2,5 times and for mining tub 7 times more.

However, increased adhesive weight did not solve the problem insufficient friction properties of rolling stock that caused unreasonable energy loss, reduction of its exploitation characteristics. Exploitation indexes of railway transport show, that to overcome friction up to 30 % of all consuming energy is necessary, and loss of material of friction pair amounts 15 % of producing metal [*1.*].

Each of mining drifts has its own climate environment, rail track profile and plan, bending radii, track incline, admissible haulage speed and braking distance etc. All these factors dependence on both economic and exploitation indexes, and on transport system reliability in general. Thus, study of the rail, wheel and their interaction surface as a standalone system elements, wheel-rail interaction control, allow optimizing their work during difficult motion regime.

Modern design methods [2], which base on the scientific simulation and research approaches, facilitate definition of the location and character of arising dynamical loading and prevent their growth during forming within the mining vehicle chassis.

This prevents the following dynamical load transfer on the bolster structure. Thus, the structure selection and selection of mining machines parameters, which bases on the detailed analysis of running processes, might be an essential part of energy-mechanical system and its scheme development during development [2].

The purpose of the paper is to develop guidelines for mining rolling stock development (structural schemes, construction parameters) in order to achieve rational motion regimes with high exploitation characteristics and low energy consumption.

As it is known, the frictional surfaces move across the interaction area with tangential velocities $V1$ and $V2$. The bodies have the components of angular rotation velocity relatively to the base tangent to the surface. Different relations of the wheel set line speed V_1 and speed of rotational motion V_2 is characterized by the sliding velocity δV .

After each wheel's turn on the interaction area resilient and plastic deformations arise. As a result, the friction elements wheel-rail start negotiate through the finite size area. Taking into account existing rail track imperfections and imperfections of contact area, let assume nominal and real contact areas. All force interactions of frictional pair wheel-rail are carrying within the real contact area. Therefore, the tangent reaction Q_{xy} is formed with elementary forces Q_{xyi}, which act on each i-th point of the real contact area (fig. 1). Thus, during analytical research we need to proceed from the elementary contacting area of the interacting bodies.

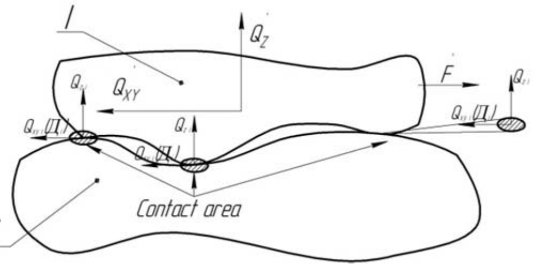


Figure 1 - Real contact areas of interacting bodies

These forces are directed opposite to the sliding velocity of i-th point δV_i in the contact area. In general, the forces' vectors are inclined with an angle α_i to their total force. Q_{xy} (fig. 2). The total force, in the case when μ doesn't independent on δV_i direction, acts in the direction opposite to the wheel's slipping velocity, and their scalar product $Q_{xy}\delta V$ defines the power of dissipative forces in the contact area.

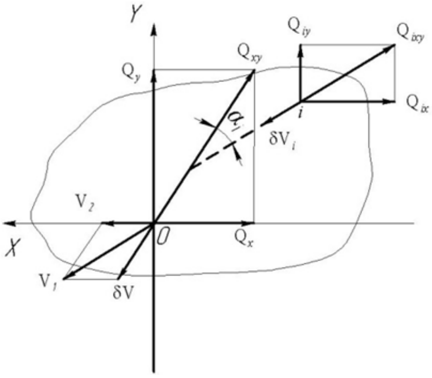


Figure 2 – Calculation scheme of forces and slipping velocities in the i-th point of contact area

Thus:

$$Q_{xy} = \mu \sum_{i=1}^{k} Q_{zi} \cos\alpha_i , \tag{1}$$

where k – amount of the contact points in the slipping area; μ – coefficient of friction limit.

During mining locomotive motion along the mining drifts, the wheel contacts rolls both on the inner and outer rails, which have different curvature and gage width. This fact induces the lateral displacement of the contact area though its width. The worn wheel tread profile represents the total envelope profile of all rails that are contacting with tread [3]. The tread areas, which contact with rails most often, expose to intensive sliding, high contact stress and significant wear in comparison to other tread areas. Mine drifts with big amount of straight track segments lead to wear concentration on the rolling area at the center of the wheel tread. In this case the wear of the flange is minimal. Otherwise, motion on the curvilinear rail track segments (most often case for coalmines) causes significant flange wear.

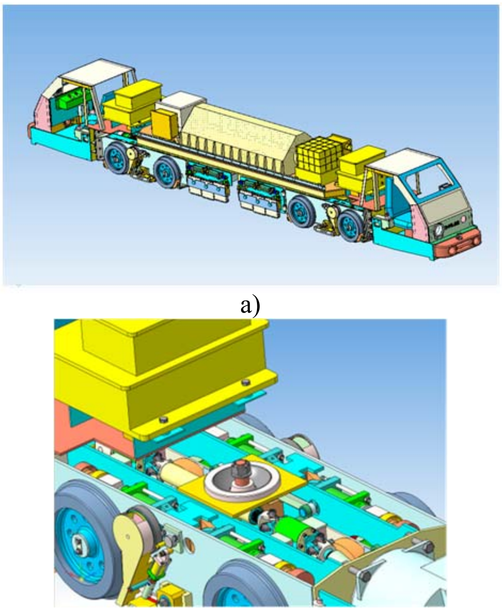
As a result of frictional interaction of the wheel and rail, a clearance between contact surfaces forms. Uncontrollable growth of the clearances provokes additional dynamical forces, acting on the bogie and track, that reduce the exploitation characteristics of the machine.

However, there is possible to revise the machine design and additional kinematical movability either to reduce the duration of nonstationary motion regime. This is essential for mining conditions, which is marked by lots of unfavorable factors [4]. To provide the smooth wear of coupled kinematical members a coupling with local movability can be applied [4].

For example, locomotive of the module scheme, that includes a few sections. It allows for development of the vehicle with different trailing weight, energy supply system and necessary exploitation indexes. The distinguish feature of such locomotives is kinematical coupling between bogie and tractive section (Figure 3).

Such connection provides necessary relative movability and transmits vertical loading from frame to bogie, horizontal lateral forces – centrifugal force, reaction of overrunning rail, which has geometrical imperfections in all surfaces. Movability around the vertical axis is necessary for tractive bogie turn and in order to avoid odd couplings, because the pin does not carry the chassis weight; around lateral axis – for correct weight distribution between locomotive axles and reduction influence on the rail track; longitudinal movability is absent because the tractive effort transmits in this direction.

In order to define relations between kinematical and dynamical characteristics of mine rollingstock we need to provide the analysis of rail and wheel interaction, and to evaluate locomotives tractive and safety properties.



a)

b)

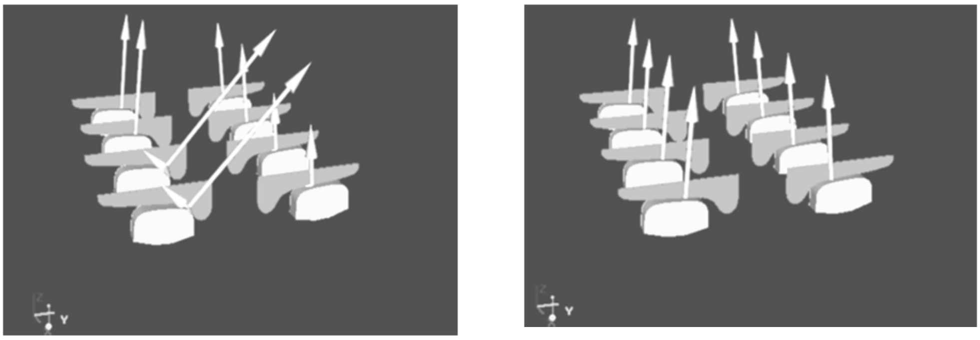
Figure 3 - (a) pin joint locomotive; (b) locomotive joint

The obtained data allows for assessment of the safety index, which is used to describe by safety coefficient [5]:

$$SF = \frac{\operatorname{tg}\chi - \mu}{1 + \mu \cdot \operatorname{tg}\chi}\left(\frac{Q_z}{Q_y}\right) > 1 \tag{2}$$

where χ – angle of wheel flange; μ – friction coefficient; Q_z – normal rail reaction under ongoing wheel, N; Q_y – guiding force on the ongoing wheel, N.

Local and regular rail imperfections lead to additional growth of guiding force Q_y that can cause the derailment at some certain critical value (Figure 4, a). Reduction of guiding force can improve stability and predict derailment (Figure 4, b).



a) **b)**

Figure 4 - The scheme of forces distribution during motion in the bending (a) and on the straight segment (b).

The most complex motion regime is driving through curvilinear rail track with wheel flange climbing by both rear and front axles. This induces the rotation of tractive bogie in relation to mass center (Figure 5). Simultaneously, the middle section rotates around pin joint. At axial displacement of the wheels, a reaction force arises at the point of flange contact, which acts flatwise to motion direction. A sudden growth of these forces appears while wheel misalignment. To reduce reactive forces an additional local movability of kinematical pair coupling is necessary.

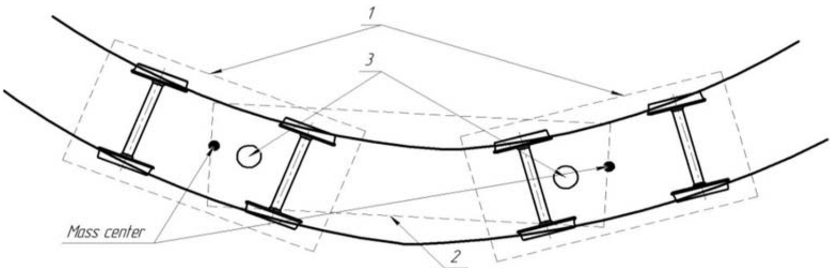


Figure 5 - General scheme of tractive bogie rotation in relation to mass center during wheel climbing (1- tractive bogie; 2 – middle section; 3 – pin joint)

The usage of mathematical simulation facilitates the designing and dynamical interconnection of mine rolling stock. The study of mining vehicle dynamics is provided via developed system of differential equations.

As mentioned above, the characteristics of contact surfaces, and the pressing force define friction properties at the contact point. When the position of the wheel set in the rail track cannot be achieved through the friction forces, there is a two-point contact appears and lateral forces on the flange, which protects the wheel set from derailment (Figure 4 a, b). At the same time, an additional resistance force arises. However, the forces on the flange are connected with frictional components, which may lead to force reduction in the contact area. Thereby it facilitates the wheel climbing on the rail, especially on curved track sections of small radius.

To enhance the stability and safety, reduce load on the vehicle's chassis and the track and to reduce motion resistance become possible while the usage of a new kinematical design where the kinematical pairs will have an additional local movability. Thus, it will reduce the number of redundant links with shortage of the unnecessary weight. To determine the appropriate value of mobility, providing the necessary performance, we can use modern means of computer simulation interoperability of mine transport and track.

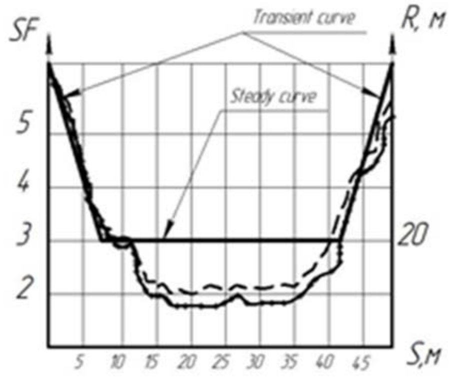


Figure 6 - Safety factor relation to track curvature subject to structural scheme. V=4 m/s
- - - - sectional locomotive;
—— conventional locomotive

Taking into account the denoted above approach of wheel and rail interaction evaluation, the motor torque, reduced to the wheel set with rigid connection between the wheels, as a function of absolute motion velocity V and relative velocity of the boundary layers δV_i of the frictional pair wheel-rail, defines as $M_{\text{дв}} = \sum_{i=1}^{N} Q_{xyi} R$. The value Q_{xyi} for each wheel calculates according to [4].

Figure 7 – Control algorithm

Each point of the grip characteristics is corresponded by its distinguish energy state of interaction process of the pair wheel-rail. Thus, alteration of the grip accompanies by a change of the state. At a constant locomotive speed V alteration of the tangent component Q_{xy} takes place during increase of the boundary layer displacement of frictional pair material δV_i, which leads to energy loss in the contact area and unstable state of the eletromechanical system

The relation between torque and angular velocity of the electric motor DC series excitation, which is the most popular in mine locomotives, has the following form [6, 7]:

$$\omega = \frac{\pi\sqrt{C_M U_C}}{30 C_E \sqrt{C_F M_{\partial в.}}} - \frac{\pi R_2}{30 C_E C_F}, \tag{3}$$

where U_C – voltage; R_2 – winding resistance; $M_{\partial в.}$ – engine torque; C_M – engine constant; C_E – EMF constant; C_F – DC and magnetic flux constant.

Expression (2) converted into the angular velocity of rotation of the wheel set with applied torque, can be written in a simpler form:

$$\omega = C_0 \sqrt{\frac{U_C}{M_{\partial в.}}} - C_1, \tag{4}$$

where C_0 and C_1 – constants of the motor.

Considering, that $V = \omega R - \delta V$ or $\omega = (V + \delta V)/R$, the expression (3) rearranges in the form:

$$M_{\partial в.} = \frac{C_0{}^2 U_C}{(\omega + C_1)^2} = \frac{C_0{}^2 R^2 U_C}{(V - V_{12} + C_1 R)^2}. \tag{5}$$

The critical velocity can be determined by equating the limit values for traction grip and power to each other. The maximum permissible torque, at which there will be no grip disruption, will be defined from the expression of $M_{\partial в.}$ after substitution the relative velocity δV [4]. Using the relation between torque and angular velocity of tractive motor, we can determine the voltage U_C as a function of the speed V for these conditions and formulate requirements for tractive motor control algorithm. (Figure 7).

Conclusions. While constant locomotive speed V variation of the tangential component Qx occurs when the increment speed of the boundary layers of friction pair materials δV leads to energy loss in the contact area and the unstable state of the electromechanical system. To increase stability and safety, reduce the load on the vehicle and chassis, as well as on the rail track, additional movability of the kinematic connection of its members can be used. Basing on the thrust forces equations subject to adhesion and permissible power for definite conditions we can determine the values of engine voltage Uc as a function of the locomotive speed.

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