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Influence of uneven distribution of coupling mass on locomotive wheel pairs, its tractive power, straight and curved sections of industrial rail tracks.

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Abstract. This article deals with the problems of unloading the axes of wheel sets of locomotives of industrial railway transport by the example of exploitation in conditions of open chasing works. Studies have established that the displacement of the center of mass of an open-pit locomotive depends primarily on the height of the center of gravity, the height of the location of the hook of the locomotive coupling over the rails and the slope of the track. Therefore, to increase the coefficient of utilization of the adhesive weight and to ensure rational operating conditions, it is necessary to provide an adjustable displacement of the locomotive's center of mass taking into account the actual operating conditions, including when driving on rectilinear and curvilinear sections of the track. Analysis of calculation results showed that for the traction unit OPE1 when driving in traction mode in close to the extreme operating conditions, it is necessary to provide a constructive solution for displacement of the center of mass of the locomotive up to 0.5 m in the course of movement of the locomotive's center of mass.

1. Introduction

The effectiveness of the interaction of traction wheels with a rail is determined by the traction ability of the locomotive. A number of works [1-6] have been devoted to the investigation of the problem of interaction between the wheel-rail system of industrial rail transport [1-6]. But in the works mentioned, the problem of the influence of the unevenness of the locomotive traction distribution on the wheel pairs on its traction capacity is not sufficiently illuminated.

If the traction force is applied to the trolley locomotive coupling, then moments of forces acting on the body and the trolley appear, which unload the front wheels and load the rear wheel pairs. The reaction forces generated by the operation of the traction motors are applied to the trolleys and also cause a **redistribution** of the vertical loads to the wheel sets due to the coupling mass of the locomotive. The degree of use of the coupling mass is estimated **by the coefficient of its utilization η** [7]. In electric locomotives, $\eta = 0.86 ... 0.94$ on average [3, 8, 9].

Materials and methods. It should be noted that the front wheel pair of the locomotive is usually more prone to skidding. This is due to the redistribution of loads from wheel sets to the rails when the traction force is realized. The traction force acting at the level of the railhead and the force of resistance to movement of the composition acting at the level of the automatic coupler form a pair of forces with a shoulder equal to the height of the automatic coupler axis above the rail head, or the so-called tipping moment, overloading the rear wheel pairs and unloading the front wheels. Therefore, the front, most unloaded wheel pair of the locomotive, before the others, will lose grip with the rails. Figure 1 shows the distribution diagram of the cases of slippage of six wheel sets of a locomotive TEP (diesel-electric locomotive) 75 - 0002 when starting from a place [8].

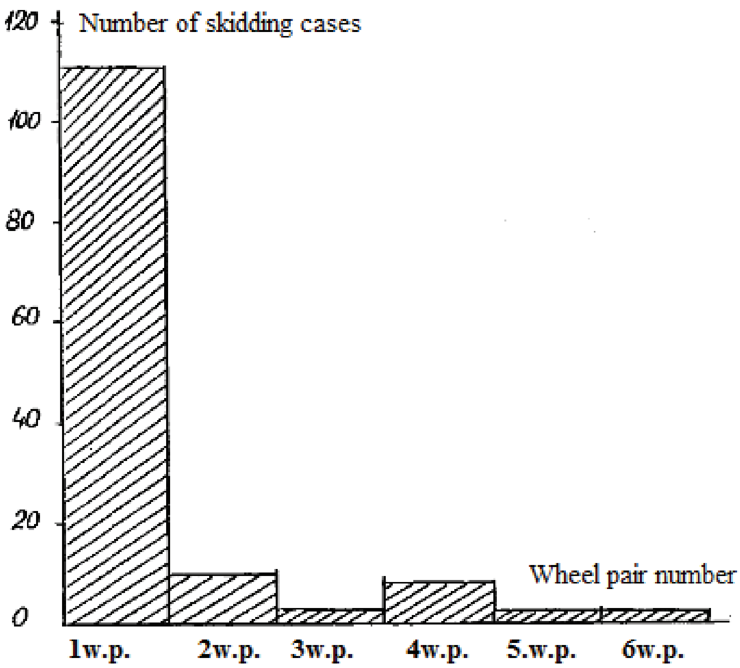
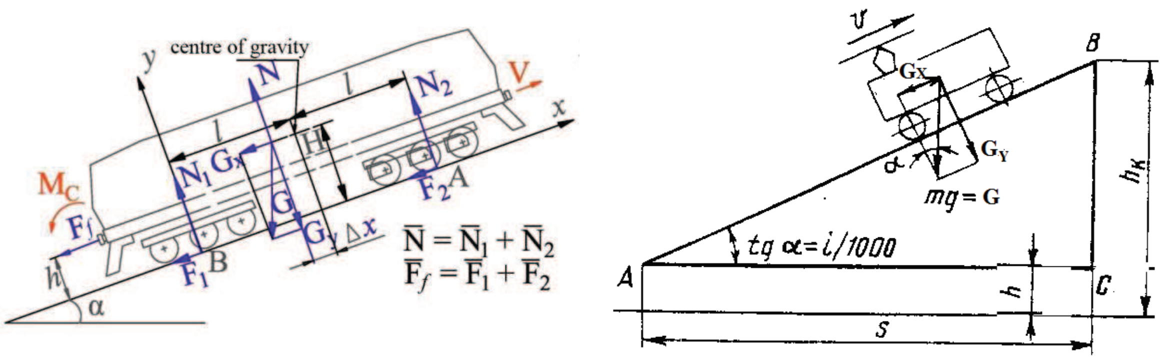


Figure 1. The diagram of the distribution of cases of skidding of wheelsets of diesel locomotive TEP 75 - 0002 [8].

From this diagram it follows that the first in the course of travel wheel is the most prone to skidding.

When the locomotive moves in the traction mode in quarry conditions, the additional force of the G_x resistance acts as a projection of the gravity on the direction of motion (Fig. 2, a), which creates an additional unloading moment M_c on the front (facing the engine) wheel pair.



a) b)

Figure 2. Scheme of action of forces of resistance to movement of rolling stock on a slope.

2. Research of the influence of uneven distribution of traction of the locomotive on its traction ability

The slope of the path profile i is the tangent of the slope angle α of the path profile to the horizon multiplied by 1000, i.e., i = l000tgα. From Figure 2b it follows that the additional resistance to the movement of a train of mass m from the slope is equal to the projection of the gravitational force of the locomotive on the direction of displacement and is equal to:

$$G_X = m\,g\,\sin\alpha, \qquad (1)$$

where mg = G is the gravity (weight) of the train.

Since the gradients (elevation angles) on the actual path profile are small, it is possible to accept sinα tgα and, hence

$$G_X = m\,g\,\mathrm{tg}\alpha, \qquad (2)$$

Let us suppose that the center of mass of the open-pit locomotive is displaced by the value Δx (Fig. 2, a). Let us consider the equilibrium condition of a two-link locomotive moving at a constant speed on a leading slope. Let us write the equilibrium condition as follows:

$$\sum m_B\left(F_K\right) = 0 \qquad (3)$$

$$N_2 2l + F_f h + G_X H - G_Y (l + \Delta x)\cos\alpha = 0\,. \qquad (4)$$

Taking into account that GX = G sinα, after the transformations one will obtain

$$\Delta x = \frac{F_f h}{G_Y \cos\alpha} + H\,\mathrm{tg}\alpha\,. \qquad (5)$$

Due to the fact that the angle α of the inclination of the path profile to the horizon is small, one can take cosα 1, and tgα = i.

Then

$$\Delta x = \frac{F_f h}{G} + Hi\,. \qquad (6)$$

The relation is as follows

$$F_f / G = \Psi_e, \qquad (7)$$

where Ψ_e - the estimated coefficient of adhesion for these operating conditions of an open-pit locomotive; H and h are, respectively, the height of the center of gravity and the height of the location of the hook of the locomotive hitch above the rails. It should be noted that the coefficient of adhesion is a variable and is of a probabilistic nature [10]. The confirmation of this circumstance is the fact that in connection with the redistribution of the coupling weight of the locomotive between the wheel axes, the average value (i.e., mathematical expectation) of the cohesive coefficient realized at the same time also varies.

Taking (7) into account, one will obtain from (6) the following:

$$\Delta x = \Psi_e h + Hi \text{ or } \Psi_e = \frac{\Delta x - Hi}{h}. \quad (8)$$

When driving on horizontal sections of industrial tracks, with i = 0

$$\Delta x = \Psi_e h. \quad (9)$$

It is known that the heaviest conditions are obtained by moving from the place of the laden composition, when it is necessary to overcome the friction of rest [10, 11, 12]. Let us consider the calculated values of the displacement of the centers of mass for some locomotives used in quarries in conditions of open mining operations (according to [13]). Figure 3 shows the dependence of the displacement of the centers of mass calculated by formula (8) for traction units OPE 1 (monophase industrial electric locomotive), PE 2M (industrial electric locomotive) and diesel locomotives TE 10 (diesel locomotive with electric transmission), TEM 7 (shunting locomotive with electric transmission) operating for sections of the angle of recovery of the exit trench at the leading rise of 25 ... 60‰.

In formula (8) instead Ψ_e, the authors used the coefficient of adhesion during starting Ψ_0.

Taking into account the arrangement specifics of open-pit tracks, it is advisable to investigate the influence of the radii of curvature and the magnitude of the leading slope on the displacement of the center of mass of the locomotive to compensate for unloading of the front wheels along the wheel when moving on curvilinear sections. According to building regulations 2.05.07 - 91 for industrial quarries, the limit value of slopes on curved sections is set to 60 ‰ [14]. The radii of curvature rarely exceed 300 m. In most cases, they are within the range of 100 ... 200 m [15]. Their minimum value can be 40 ... 60 m and at some enterprises, the length of the curves is more than half of the entire length of the tracks.

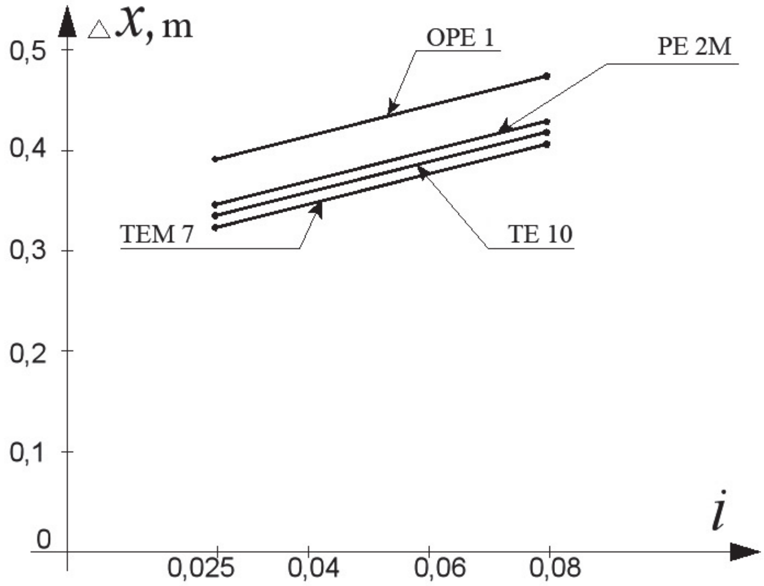


Figure 3. Dependence of the change in the calculated value of the displacement of the center of mass of the quarry locomotives on the angle of the rail track elevation at the start.

For traction units and electric locomotives of all series when driving in curves with radius R <500 m, the calculated coefficient of adhesion can be determined by the formula [11, 15].

$$\Psi_{curv} = \Psi_e \frac{250 + 1.55R}{500 + 1.1R}, \qquad (10)$$

where Ψ_p is the calculated coefficient of traction on the straight sections.

If in formula (10) the Ψ_p is changed by the adhesion coefficient at starting Ψ_0, it is possible to obtain the adhesion coefficient formula for starting a locomotive on a curved section:

$$\Psi_{0curv} = \Psi_0 \frac{250 + 1.55R}{500 + 1.1R}. \qquad (11)$$

Taking into account the fact that according to the formula (7), the thrust force F_{th} for curvilinear sections of the track can be defined by the formula

$$F_{e_{curv}} = \psi_{curv} G. \qquad (12)$$

Substituting the value from (10) in (12), one will obtain:

$$F_{e_{curv}} = \psi_e \frac{250 + 1.55R}{500 + 1.1R} G, \qquad (13)$$

where R is the radius of curvature of the track.
Substituting (13) into (8), one will obtain:

$$\Delta x = \psi_e \frac{250 + 1.55R}{500 + 1.1R} h + Hi. \qquad (14)$$

Figure 4 shows the dependence of the change in the calculated value of the displacement of the center of mass of the traction aggregates on the radius of curvature when the composition is moved on curvilinear sections of the track.

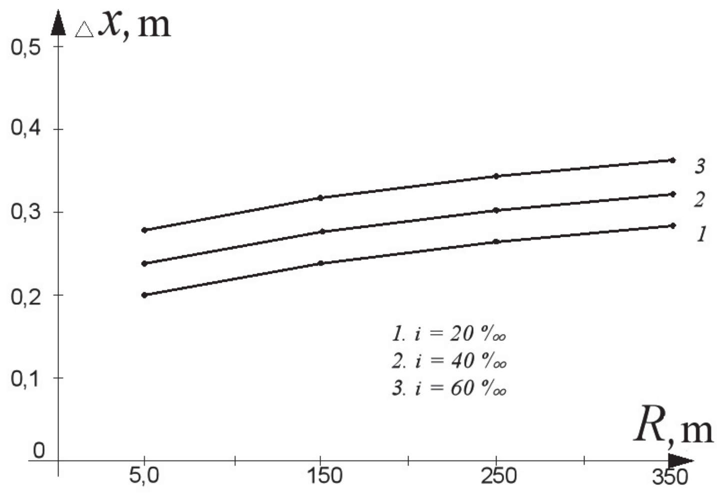


Figure 4. Dependence of the change in the calculated value of the displacement of the center of mass of the traction aggregate on the radius of curvature when the composition is moved on curvilinear sections of the track

The calculations have been performed by formula (14). In this case, the following is customary for the traction unit OPE 1: h = 1 m, H 2.0 m, $\Psi_c = \Psi 0 = 0.35$.

3. Conclusions.

1. The performed studies show that the displacement of the center mass in an open-pit locomotive depends primarily on the height of the center of gravity, the height of the locating of the locomotive's hook over the rails and the slope of the track. Therefore, to increase the coefficient of utilization of the coupling weight and to ensure rational operating conditions, it is necessary to provide an adjustable displacement of the locomotive's center of mass taking into account the actual operating conditions, including when driving on rectilinear and curvilinear sections of the track.
2. Analysis of calculation results showed that for traction unit OPE 1, when driving in the traction mode under operating conditions, close to the limiting ones, it is necessary to provide a constructive solution for displacement of the center of mass of the locomotive up to 0.5 m along the motion of the locomotive's center of mass.

4. Acknowledgements

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