ONCE AGAIN ON ADDITIONAL POWER LOSSES OF THE TRAIN IN CURVE

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ABSTRACT

The article analyzes feasibility of the idea of forming trains of motor cars, put forward by I. K. Aleksandrov in the article «The Train in Curve: Additional Power Losses» (Mir Transporta [World of Transport and Transportation] Journal, 2014, Vol. 12, Iss.1, pp. 18–23). It is noted, in particular, that there is no reason for emergence of secondary forces by changing the direction of the locomotive traction and application of Euler's formula for evaluating the efficiency of the train as a «transmission mechanism». According to the authors, there is no evidence to suggest the fact that the use of a motor-car train will reduce power losses while moving on a curve because additional resistance to the movement of trains in the curve does not depend on the types of vehicles, butinstead on the radius of the curve and the value of the unextinguished acceleration.

To prove that, the authors analyze interaction of the rolling stock and of superstructure in curves. Basing on the studies the article notes that the bogie with rigid basis finds «natural» standing, whatever position it is, and if wheelsets are rigidly installed within the frame of the bogie, then one of the wheels of a wheelset is slipping, and another one is rolling. In order to evaluate an additional resistance in the curve, the authors suggest to use the notion of «density of slipping of the surface of wheels» rolling and of their rims and they suggest to evaluate power losses caused by additional resistance by using approach based on density of power of forces of slipping friction.

Keywords: railway, motor-car train, movement on the curve, power losses, Euler's formula, secondary forces, scientific discussion.

Background. *In [1] the author, considering the emergence of secondary forces, creating additional resistance to the movement of the train in a curved section of track, draws a conclusion on a need for a motor-car scheme of a train. The apparatus for this justification was Euler's formula*

$$Q = P \cdot e^{-\mu\alpha}, \quad (1)$$

where P is a force, that extends a rope around a bollard;

Q is a force, holding a rope;

μ is a friction coefficient;

α is an angle of contact of a cylindrical part of a bollard (contact angle of a rope with a cylinder's surface).

The author rightly points out that, despite the centrifugal force compensation with lateral forces arising through constructive canting over an inner rail in some curves, wear of wheel flanges and the lateral surface of rails is still observed. Power contact of flanges with rails requires additional expenditure of energy to overcome the resistance forces occurring at the contact of the wheel flange and the lateral surface of the rail.

The cause of secondary forces, according to I. K. Aleksandrov [1] is the change in direction of traction along the train that if we understand correctly, remains unchanged in magnitude. Thus he makes reference to a picture in his article.

In this picture that we reproduce as Pic.1, the reaction forces, designated as R_{pi}, are applied to the inter-car coupling unit or, to be more precise, to the center sill of the car body. Then these reactions due to their direction towards the center of the curve, contribute to the turn of cars. The values of these reactions diminish from the head end to the rear end of the train, as values of forces between the cars also diminish. By the way, the thrust and forces between cars folloowing a train's movement along the curve change their directions continuously.

Objective. *The objective of the authors is to study the feasibility of forming motor car trains, which is investigated by I. K. Aleksandrov in his article, to demonstrate its disadvantages and to offer another method of train formation.*

Methods. *The authors use analysis, comparative method, mathematical calculations.*

Results. *Changing the direction of the vector of the thrust along the train only partially affects frictional forces (secondary forces) in contact of wheel flanges and rails (hereinafter – FFCWFR).*

The cause of FFCWFR mainly consists in changing the kinematics of motion of the wheel set, due to a change in the geometry of the track: the transition from the traffic on the straight section to the curved section of the track. It is known [2,3] that climbing of the wheel set on the outer rail occurs on curves which radii satisfy the inequation

$$R < R_{\delta} = \frac{r \cdot h}{i \cdot \delta}, \quad (2)$$

where R is a radius of the curve;

r is a rolling radius of the wheel in a central installation;

2h is a half distance between wheel rolling circles;

i is a slope of the rolling profile;

2δ is a half value of a total clearance between wheel flanges and rails;

R_{δ} is a radius of curvature of the centre of a free wheel set.

Table 1 shows the rate of the track laying in curves and radii, in which the condition (2) is met. Starting with the curve of a radius 1580 and less, wheel sets are rolling, climbing with the wheel flange on the outer rail. Contact of a wheel flange with rail occurs ahead of the instantaneous center of velocities and, therefore, the friction force vector is directed not horizontally but at an angle to the horizontal: in the direction of the linear velocity of the wheel in the contact point of a wheel flange with a rail.

As for the value of the frictional force, it is the product of a guiding force to the coefficient of friction: $F_{fr} = \mu \cdot Y$.

Here F_{fr} is a frictional force in the contact area of a wheel flange with a rail; Y is a guiding force, which is a result of the projection of the pressure of wheels on the normal to the surface of a wheel flange in its contact with the rail.

Table 1

R_δ values for existing norms of track laying

Intervals of curves radii	R ≥ 350	349 > R ≥ 300	R ≤ 299
Gauge width, m	1,512		
Distance between the points of contact of wheels with rails, m	1,584	1,596	1,604
Total clearance, mm	12	18	28
Required radius R_δ, m	1254	842	544

Thus assuming the compensation of the centrifugal force with tilting the plane of the track the cause of secondary forces is the pressure of the wheel on the rail, and not the change of the direction of the «vector of the thrust along the length of the train».

We now return to the conditions of application of Euler's formula (1). It is true in the case where the frictional forces are directed strictly along the rope, the holding force is applied to its end and the reaction forces lie in the plane of vectors of the holding and pulling forces.

In the case of movement along the curve of the rear end of the train is free, i. e. holding force is zero. Friction force, as shown above, are directed at an angle to the horizontal, and the reaction forces (guiding forces) are not in the horizontal plane, i. e. not «act strictly in the horizontal plane».

Consequently, the validity of the use of Euler's formula as a model for determining the efficiency of the «gear» is in doubt, as well as the proof of the need for motor-car scheme of the train. If we follow the formula of counting the efficiency given in [1], and take into account that the holding force in the rear end of the train is equal to zero, the efficiency factor of such a mechanism will always be zero.

Let's assume that the motor-car scheme of the train is implemented. We compare the resistance of such a train and a train with a locomotive when moving on a curved section of a track. To do this, we use the guide to the traction calculation, in which there are formulas of additional resistance on the steepness of the track, based on experimental data. Let trains are entirely located on a curved section of track. Then additional resistivity to the motion due to the curvature of the track, for all types of rolling stock is recommended [12] to be determined by the formula:

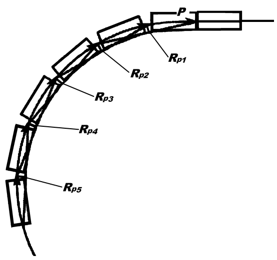
$$w_r = \frac{200}{R} + 1{,}5\tau,$$

where τ is an absolute value of the unextinguished acceleration in the curve; R is a radius of the curve.

It is easily seen, the resistivity does not depend on the type of the train, but only on the radius of the curve for any admissible value of the unextinguished acceleration.

Thus, the use of motor-car scheme of the train does not reduce power losses. But note, without going into details, the motor-car train is much more expensive to be manufactured and to be operated.

Let's consider in more detail the interaction of rolling stock and track superstructure in curved sections. As already mentioned, if the inequation (2) is met wheel sets of the bogie climb on the outer rail, wherein in the steady movement only the first of them climb [4]. The very same bogie with a rigid base occupies a «natural» installation [4,5], in which the axis of the rear wheel pair is oriented along the radius of the curve (Pic. 2). And this installation is quite stable [6].



Pic. 1. Change of the vector of locomotive traction when moving on the curve: P – total traction with additional losses from the actions of secondary forces; R_{p1}, R_{p2}, R_{p3}… – elementary reaction forces of the track.

In [7,8] it was shown that one wheel of the wheel set, enclosed in a rigid frame, rolls, and the other slips. If the load on wheels is the same, the wheel of the driven set of a smaller radius skids, and of a larger radius – rolls. For the driven wheel set on the contrary – the wheel of a smaller radius rolls, and of a larger radius it slides with slipping. In curved sections of the track wheel sets shift to the outer rail and roll in circles of different radii. It is clear that for the driven bogie a front wheel set (hereinafter- WS) slides by a flange of an outer wheel and the inner wheel tread, of a smaller radius. The rear WS being in radial installation can roll without slipping of wheels only when the condition is met:

$$\frac{R+h}{R-h} = \frac{r+i\cdot y}{r-i\cdot y}, \qquad (3)$$

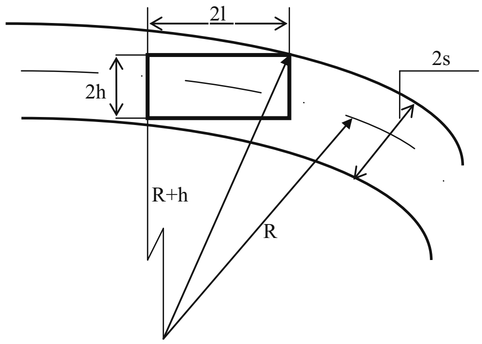
where y is drift of the centre of the rear WS axis [9].

Otherwise the wheel of a smaller radius rolls with sliding. That is, the statement [1] that «due to the taper of the wheel tread we exclude their slipping in turn», is, at least, misleading. Wheel sliding of WS can be eliminated if the wheel set in the curve moves in the radial installation and condition (3) is met.

Thus, the additional power loss when moving on curved sections of the track are not only caused by the friction in the contact of the flange of the climbing wheel and the rail, but also the longitudinal sliding of the wheel tread of a smaller radius and lateral sliding of a climbing wheel [9].

To account for these sliding in [9,10] the notion of sliding density of a four-axle bogie with a rigid base is introduced as a ratio of the length of the track covered by sliding to the distance covered. If we denote dξ – element of the track covered by sliding, du – element of the track covered by rolling with sliding, then the density of the sliding by wheel tread of the bogie is shown by:

$$\frac{d\xi}{du} = \frac{2}{rR}[|Ri\delta - hr| + |Ri(\delta-\eta) - hr|]. \qquad (4)$$



Pic. 2. The natural setting in the curve of a bogie with a rigid base.

The value η, if l is a bogie base, is given by:

$$\eta = \frac{2l^2}{R+h}. \qquad (5)$$

Without going into the details of the derivation, let give the density of sliding of the flange of the climbing wheel of the bogie:

$$\frac{d\xi}{du} = 2(\frac{rh}{Ri\delta} - 1). \qquad (6)$$

Conclusions. *The analysis of the formulas (4–6) leads to the following conclusions: a decrease in the sliding density will decrease the power losses for compensation of additional resistance to movement; with increase of the radii of curves sliding density decreases and tends to sliding density in straight sections of the track; sliding density depends on the radius of the curve, the total clearance between wheel flanges of the wheel set and lateral surfaces of the rails and the geometrical parameters of the contacting wheels and rails; decrease in the sliding density can be done by changing the profile of the wheel tread, as modification of other parameters requires significant investment.*

Any deviation of wheel sets from the central installation (deviation of the wheel set from the track axis) and its turn cause additional resistance, which can be characterized by the power of the sliding friction forces. For such characteristics [9,11] a formula of power density of sliding friction forces and the power per unit length of the track is proposed.

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