ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 11 , November 2020

About One Method of Solving the Problem of Motion of the Car on Localytes of the Braking Position from Marshalling Hump

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ABSTRACT: In the article on the basis of theorems on the motion of the center of the mass of the system of material points of theoretical mechanics, formulas for determining the time and the braking path at the time of stopping the car in the braking zone on the sections of the brake position of the sorting slide are derived. Thus in the beginning it is necessary to define time of braking, and then on its size length of a way of passing of the car of a locality of braking. The results of the calculation examples made it possible to note that at the same initial velocity values, the formulas obtained by us give the results acceptable for engineering calculations.

KEYWORDS: Railway, station, marshalling hump, car, the input speed of the car in the area of braking time and the stopping.

I. INTRODUCTION

The relevance of the problem. It is well known [8 - 21] that the existing method of hump calculations of sorting hills is mainly aimed at determining the height of the slide from its top to the calculated point. Moreover, such kinematic parameters of the car’s movement as the acceleration and time of the car’s movement in the braking zone are not taken into account at all. In [1–7, 22], materials were presented on a public discussion of the correctness (see [1]) and / or incorrectness (see [1–7, 22]) of the formula for the free fall rate of a body, taking into account the mass of rotating parts (wheel pairs) of a car to determine the speed carriage movements in all sections of the hill, including sections of brake positions. From this, the urgency of the problem of designing a sorting slide and, in particular, studying the movement of a car in the braking zones at the brake position sections, becomes obvious.

II. PURPOSE OF THIS ARTICLE

Using the basic principles of theoretical mechanics, construct mathematical models of the movement of the car and derive a formula for determining the braking time $t_{\text{т}i}$ at the time the car stops, when $v_{\text{т}i} = 0$.

III. TASK STATEMENT

With the examples of calculated data, confirm the correctness and applicability of the constructed mathematical models as applied to the braking zone (ST) of the car in all sections of the brake positions.

IV. METHODS FOR SOLVING THE PROBLEM

The problem is solved on the basis of a theorem on the motion of the center of mass of a system of material points (see [23], § 107 in [24]).

The mathematical description of the solution to the problem
According to the formula (4) in [6], obtained on the basis of the theorem on the motion of the center of mass of the system of material points, we give a mathematical description of the movement of the car in the braking zone at the sections of the brake position (TP) of the sorting slide in the form (see formula (12) in [4]):

$$\frac{G}{g}\ddot{x}_{\text{Св}i} = G\sin\psi_i - f_{\text{т}}G\cos\psi_i ,$$

or, after conversion, similarly to formula (13) in [29],

$$\ddot{x}_{\text{Св}i} = g(\sin\psi_i - f_{\text{т}}\cos\psi_i) , \tag{1}$$

where
i - as before, the numbers of sections of the track profile (i = 1, ... 9);
ft = 0.25 - coefficient of friction of the wheels of a railway car on rail threads [25].

Integrating the last equation, taking into account the fact that at the initial moment t = 0, $\dot{x}_{\text{Св}i} = v_{\text{н.т}i}$, so constant integration C1 = vн.тi.

Therefore, the sliding speed of the car when it is braked will be found according to:

$$\dot{x}_{\text{Св}i} = v_{\text{н.т}i} + g(\sin\psi_i - f_{\text{т}}\cos\psi_i)t_{\text{т}i} , \tag{2}$$

or, given that $\dot{x}_{\text{Св}i} = v_{\text{кт}i}$, will have:

$$v_{\text{кт}i} = v_{\text{н.т}i} + g(\sin\psi_i - f_{\text{т}}\cos\psi_i)t_{\text{т}i} , \tag{3}$$

where
vнтi = vвх.тi – the initial speed and / or speed of entry of the car into the braking zone in the TP sections (the value taken from the results of calculations of the previous sections of the slide).

We note that the latter expressions are similar to formula (18) in [4] for determining the velocity of a body along an imperfect (with friction) inclined plane, obtained according to the d'Alembert principle.

We also make a reservation that formula (3) for determining the sliding speed until the car stops (t <tTi, where t is the current time) in the generally accepted notation, in accordance with formula (5) in [22], we present the form:

$$v_{\text{кт}i} = v_{\text{н.т}i} + a_{\text{т}}(i_{\text{тх}i} - |w_{\text{т}i}|)t_{\text{т}i} . \tag{4}$$

Here we use the same notation as in formula (5) in [7].

From formula (4) it follows that subject to the condition | wтi | > ixi, the movement of the car in the braking zone in the area of the brake positions at vnti> 0 will be uniformly slowed down.

Note that equation (1) allows you to find the travel time tti of a braked car. So, for example, to find out how long the duty officer on a slide should keep the lever switch in the on position to achieve a complete stop of the car, i.e. $\dot{x}_{\text{Св}} = 0$, we rewrite equation in the form:

$$0 = v_{\text{н.т}i} + a_{\text{т}}(i_{\text{тх}i} - |w_{\text{т}i}|)t_{\text{т}i} .$$

From here, after elementary transformations, the stopping time of the inhibited car tti is obtained (see formula (4.80) in [29]):

$$t_{\text{т}i} = \frac{v_{\text{н.т}i}}{g(f_{\text{т}}\cos\psi_i - \sin\psi_i)} . \tag{5}$$

Taking into account formula (5) in [22], we represent the last formula in the form:

$$t_{\text{т}i} = \frac{v_{\text{н.т}i}}{a_{\text{т}}(|w_{\text{т}i}| - i_{\text{тх}i})} . \tag{6}$$

As you can see, the car braking time tti at the moment the car stops, when vti = 0, increases in proportion to the initial speed vnti.

Analyzing the last formula, we note that it strictly observes the fulfillment of the condition $f_{\text{т}} \cos\psi_i > \sin\psi_i$ and / or | wti | > itxi when the car moves with sliding along the slope of the hill in the braking zone, which confirms the correctness of its conclusion.

Note that the car braking time tti, calculated according to formula (5) and / or (6), can have a negative sign, which means slowing down and tti <t (t is the current time) (see formula (4.80) on p. 319 in [26]).

Repeatedly integrating (2) at t = 0, and bearing in mind that at the moment of the start of braking, the center of inertia Cв of the car coincided with the beginning of the moving coordinate system Cвxyz (see Fig. 2 in [6]), we have xCвi = 0, whence we get the constant integration C2 = 0. Therefore, the equation of motion of the car in the zone of braking of brake positions has the form:

$$x_{C\text{в}i} = v_{\text{н.т}i} t_{\text{т}i} + \frac{1}{2} g\left(\sin\psi_i - f_{\text{т}} \cos\psi_i\right) t_{\text{т}i}^2 .$$

Hence, by reassigning xCвi by lTi, it is possible to determine the braking path of a car of a braked car (see pages 309 - 318 in [26]):

$$l_{\text{т}i} = v_{\text{н.т}i} t_{\text{т}i} + \frac{1}{2} g\left(\sin\psi_i - f_{\text{т}} \cos\psi_i\right) t_{\text{т}i}^2 . \tag{7}$$

In accordance with formula (5) in [7], the last formula can be given the following form:

$$l_{\text{т}i} = v_{\text{н.т}i} t_{\text{т}i} + \frac{1}{2} a_{\text{т}} \left(i_{\text{т}0xi} - \left|w_{\text{т}i}\right|\right) t_{\text{т}i}^2 . \tag{8}$$

Formula (7) and / or (8) is valid only until the time tti <t (t is the current time) the car stops in the braking zone, determined by formula (5) and / or (6).

From this, the conclusion becomes obvious that in order to solve the problem of car braking in the brake areas, the following are necessary:

firstly, the assignment of forces, for example, according to the explanation of formula (2) in [17], in the form Fxi = Gsinψi + Фвxi (if the projection of the tailwind force Fвxi = 0 is not taken into account), under the influence of which the car moves, and all kinds of resistance forces | Fci | = - Fti (resistance to the friction force of the rim of the wheelset on the compressed brake tires, the main (running) resistance, resistance to air and wind, from snow and hoarfrost);

secondly, the task of the initial position xCv and the initial speed vн. ti of the car at t = 0, bearing in mind that vn.ti is always known as the speed of entry of the car vin.ti into the braking zone, i.e. vn.ti = vin.ti.

If we keep in mind that for small angles (less than 5º): sinψi ≈ ψi = ii, cosψi ≈ 1, then formulas (5) and (7) respectively will take the form:

$$t_{\text{т}i} = \frac{v_{\text{н.т}i}}{g\left(f_{\text{т}} - i_i\right)}; \tag{9}$$

$$l_{\text{т}i} = v_{\text{н.т}i} t_{\text{т}i} + \frac{1}{2} g\left(i_i - f_{\text{т}}\right) t_{\text{т}i}^2 . \tag{10}$$

where

ii - the slope of the track profile, which in the 1TP section of the sorting slide reaches 0.015 ‰ [16, 19, 20, 27].

Thus, if we use the theorem on the motion of the center of inertia of the system of material points [23], then in the braking zones of the car on the TP sections, first, using the formula (5), one should determine the braking time tzati (and / or tti), and then the path length from it the passage of the car braking area lzati (and / or lti) according to the formula (7).

Moreover, to determine the braking time tti, the following options are considered:

a) direct entry to the area of the brake position of the first wheelset, or wheelsets of the front trolley;

b) the entrance of the car to the site for the length of the base of the car lv.

Calculation example. For example, we examine the plot of the first brake position (1TP) of the slide. The initial data are the same as in the calculation example in [2]: $\sin\psi 1t = 0.014$ and $\cos\psi 1t = 1$ - path profile slope, rad., Or i1t = 14 ‰; G = 650 gravity load of the car, kN; G1 = 794 - gravity force of a wagon with a load together with non-rotating parts (wagon body, trolley), kN; FT1x = 14.31 - taking into account the strength of the tailwind of small size (Fin = 3.2 kN), kN; | Fst1 | = - Fst1 ≈ - 222.84 - modulus of the resistance force of all kinds (taking into account the pressing force of the brake pads of car moderators KZ-3 or KZ-5 on the rim of the car's wheels at the speed of entry of the car into the braking zone vvh.t = 8.5 m / s: Ftorm = 23.75 kN (according to [28]: Ftk = 90 or 100 kN); the sliding friction force of the wheel pairs on the compressed brake tires, as the main resistance: Fot1 = 0.25G1 = 198.5 kN; from the air and wind Fсв = 0,0005G1 ≈ 0.4 kN; from snow and hoarfrost: Fc = 0,00025G1 ≈ 0.2 kN), kN; MVg = 6.624 · 104 - mass of a wagon with a load, kg; Mt = 1,468 · 104 - the mass of two carts, kg; Mpr0 = 8.869 · 104 is the reduced mass of the wagon with the load together with non-rotating parts, calculated by the formula (3) in [6], kg.

The results of calculations [29]. 1) for given initial data of the problem, the braking time tzat1 = tt1 calculated according to formula (10) in [17], s: tt1 = 3.37. 2) The car braking time tzat1 = tt1, calculated by the formula (5): tt11 = 3.423 s, and by the formula (6): tt21 = 3.751 s. Here we make a reservation that in the formula (6) the acceleration of the carriage movement in the area of the slam braking at is calculated according to the formula (6) in [7], m / s2:

aт = G1·103/Mпр0 = 794·103/(8,869·104) = 8,953.

The relative error in calculating the braking time tzat1, made on the basis of formulas (5) and (10) in [2], is ≈ 1.55%, and found by formulas (6) and (10) in [7], is ≈ 10, 1%, which is not enough for the accuracy of engineering calculations (≈ 5%).

Note that the moment of car braking t seconds is less than tat1 (i.e. t <tat1, where t is the current time), at which vk.tat1 ≠ 0, the speed can be calculated using formula (9) in [2]. For example, with tt1 = 1.5 s: the speed of the carriage with a clean sliding of the wheels until the stop is equal to vk.pat1 = 4.397 m / s; and at tt1 = 2.5 s: vk.tat1 = 2.046 m / s, and at tt1 = 3.0 s: vk.tat1 = 0.87 m / s and, finally, at t = tt1 = 3.37 s : vc.tun1 = 0 m / s.

3) The braking path lt1 calculated according to formula (11) in [17]: lt1 = 13.353 ≈ 13.4 m, calculated according to formula (7): lt11 = 13.56 ≈ 13.6 m, and according to formula (8) : lt12 = 14.71 m. The relative calculation error δlT1 calculated by formulas (11) in [2] and (7) is 1.52%, and calculated by formulas (11) in [2] and (8), it is 9.2%, which is not few.

4) Graphic dependences x1t = f (tt1), lt11 = f (tt1), and lt12 = f (tt1), constructed on the basis of, respectively, the elementary physics formula (11) in [2], formulas (7) and (8) with a variation of tt1 from 1.0 to 4.5 with a step Δtt1 = 1.1 s are shown in Fig. 1.

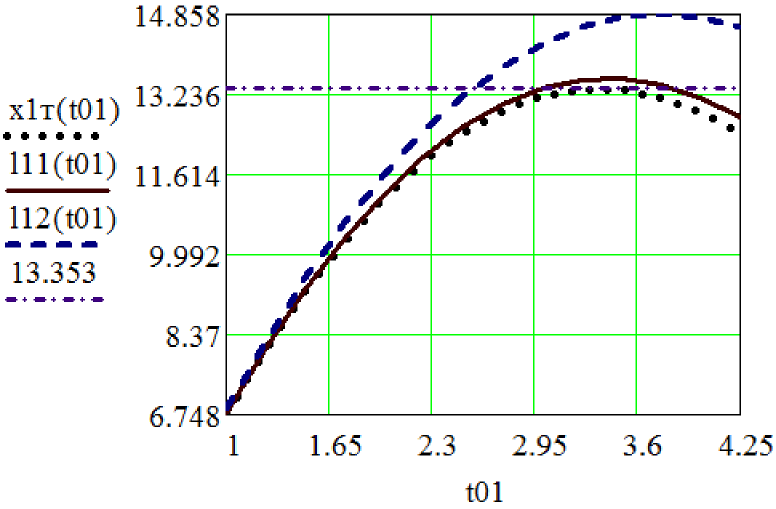

Figure 1. Graphical dependencies x1т = f(tт1), lт1 = f(tт1) и lт01 = f(tт1)

From Figure 1 it is clear that, in accordance with the form of formulas (11) in [2], (7) and (8), the presented graphical dependences have the character of an increasing quadratic dependence until the car stops. The maximum braking distance x1t = 13.353 m corresponds to the braking time tt1 = 3.25 s, and lt11 = 13.56 m: tt11 = 3.423 s and lt21 = 14.86 m corresponds to tt1 = 3.751 s.

Thus, the results of calculating the braking time tzat and the braking path lzat of the car, using formulas (10) in [2], (5), (6) and / or (9) and (11) in [2], (7) , (8) and / or (10), made it possible to note that for the same values of the initial speed, they give results that are acceptable for performing engineering calculations.

This, in turn, confirms the correctness and applicability of the constructed mathematical models in relation to the braking zone (ST) of the car in all sections of the brake positions (2TP and 3TP).

At the same time, we note that the formula for the car braking time (6), in comparison with the time formula (10) in [2], gave a relative error of the order of 1.5%, which is small, but, written according to formula (8), written in the generally accepted designations, according to formula (5) in [7], and according to formula (10) in [2], amounted to ≈ 10.1%, which is not small for the accuracy of engineering calculations (5%). The formulas of the car braking path (7) and (8) compared with formula (11) in [2] gave, respectively, a relative error of 1.52% and 9.2%.

V. CONCLUSION

On the basis of the theorem on the motion of the center of mass of the system of material points of theoretical mechanics, formulas are derived for determining the time and path of braking at the moment the car stops in the braking zone in the brake sections of the sorting slide. The results of the calculation examples made it possible to note that for the same initial velocity values, the formulas obtained by us give results that are acceptable for performing engineering calculations.

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