A NEW METHOD OF CALCULATING TIME AND SPEED OF A CARRIAGE DURING ITS MOVEMENT ON THE SECTION OF THE FIRST BRAKE POSITION OF A MARSHALING HUMP WHEN EXPOSED HEADWIND

НОВЫЙ МЕТОД РАСЧЕТА ВРЕМЕНИ И СКОРОСТИ ПЕРЕВОЗКИ ВО ВРЕМЯ ЕЕ ДВИЖЕНИЯ НА УЧАСТКЕ ПЕРВОГО ПОЛОЖЕНИЯ ТОРМОЗА МАРШАЛИНГОВОГО ПОБОРА ПРИ НАПРАВЛЕНИИ ЛЕТНЕГО ВЕТРА

УДК 656.21.001.2

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Annotation

In this article the time during which the car moves along the entire length of the first braking position of a marshalling hump under the influence of scant headwind was calculated using the previously obtained mathematical models. Using the known value of time of the car movement with acceleration along the considered section of the hump its speed was calculated. Graphical dependences of the speed and distance of the car with acceleration depending on time were also built.

Аннотация

В данной статье с использованием ранее полученных математических моделей рассчитано время, в течение которого автомобиль движется по всей длине первого тормозного положения сортировочной горки под действием слабого встречного ветра. По известному значению времени движения автомобиля с ускорением по рассматриваемому участку горки была рассчитана его скорость. Также были построены графические зависимости скорости и расстояния автомобиля с ускорением от времени.

Key words: marshalling hump, car, headwind; a new methodology, time and speed of the car; movement of the car with acceleration along the entire length of the first brake position of a hump.

Ключевые слова: сортировочная горка, автомобиль, встречный ветер; новая методика, время и скорость автомобиля; движение автомобиля с ускорением по всей длине первого тормозного положения горки.

The urgency of the problem

A critical analysis of research on the dynamics of rolling a car down a marshaling hump, carried out in [1], contributed to the creation of the beginning of a new scientific direction in the calculation and design of a hump. So, for example, in

[2 - 4] the movement of a car along the slope of a hump under the influence of a lightheadwind was investigated on the basis of the d'Alembert principle in coordinate form [5]. In [6, 7], the correctness of the results of analytical studies carried out in [2–4] was confirmed by examples of calculating the time and speed of rolling a car on high-speed sections of the hump. However, there is still no example of calculating the time and speed of a car when it moves along the entire length of the 1TP section (hereinafter - 1TP) of the hump under the influence of a scant headwind.

This article is a continuation of a series of articles [1 - 4, 6 - 8] on the dynamics of rolling a car down a marshaling hump, calculated using the d'Alembert principle in coordinate form [5]. We especially note that in this case, many datafrom the previously developed methods for calculating the time and speed of rolling a car down the profile of the hump, set forth in [6 - 8], will be used.

Purpose of this article

To develop a method for calculating the time and speed of a car when it moves along the entire length of the 1TP section of the hump when exposed to a scant headwind. This makes it possible to preventhalting of the carriage on the marshalling hump, as well as to ensure traffic safety and solve the problems of timely following the cars to the target position.

Statement of the problem

It is required to give an example of calculating the time and speed of a car during its movement along the entire length of the 1TP section of the hump under the influence of the headwind according to a new method, where, using the known value of the entire length of the 1TP hump $l_{1tp}= x(t_t)$, one could find the time ttp, during which the movement of the car with a given initial speed to the end of the given section of the hump occurs, and, in turn, knowing the time t_{tp} – to calculate the speed of the car v(tt)[10].

General approach to solving the problem of the car moving along the entire length of the 1TP section of the hump under the influence of a scant headwind

The general approach to solving the problem when the car moves along the entire length of the 1TP section of the hump under the influence of a headwind, as in [8], is as follows.

1. To solve the problem, the classical provisions of theoretical mechanics were used: the basic principle of d'Alembert in coordinate form [5], as well as the basic concepts of differential and integral calculus [9].

2. Under the conditions of the task and the underlying data, the case [2 - 4] was considered, when the car along the slope of the hump enters section 1TP progressively with a given initial speed v0 usually 6 or 8.5 m / s, depending on the design of the braking devices [10, 15, 18, 20]). When a single car (or a set of cars) enters 1TP section of the hump, in contrast to [8], we consider that the car will experience mainly external forces in the form of an aerodynamic resistance effect of the headwind of a constant value Fr.in, as well as the force of rolling friction of the wheels on the rolling surface of rail threads F_τ = Fr.f.

3. When designing the computational model of the car movement along the entire length of the 1TP section of the hump, as in [8], it was assumed that the wheelsets roll along the rail lines with pure rolling of the wheels relative to the rolling surface of the rail lines Fr.f, i.e. Fr.x = F_τ = Fr.f.

4. As in [2 - 4], the method of creating a mathematical model of the car movement along the entire length of the 1TP section of the hump is based on the basic law of the dynamics of the translational motion of a car (or the d'Alembert principle) in coordinate form [5].

5. In the mathematical model of the movement of the car along the entire length of the 1TP section of the hump, the formulas of the speed and distance for the equally slow motion of the body, widely known from the course of physics, are obtained.

Thus, using the d'Alembert principle, the method of separation of variables and tables of simple integrals [9], according to the known value of the entire length 1TP of the hump $l_{1tp} = x(t_t)$, similarly to [8], the time t_{tp}, during which the car moves with a given initial speed up to the end of the considered section of the hump, and, applying the amount of time t_{tp} - the speed of the car $v(t_t)$ are determined.

A new method for calculating the time and speed of a car when it moves along the entire length of the 1TP section of the hump when exposed to a scant headwind

A new method for calculating the time and speed of a car along the entire length of the 1TP section of the hump when exposed to a headwind is applied in the following sequence.

1. When designing a hump, such kinematic parameters as the total length of the section 1TP of the hump l1tp are taken according to the recommendations. For example, l1tp = 29 m.

2. For the rate of the headwind speed, the recommended small values are taken (usually the headwind speed is 2–4 m / s) [2 - 4].

3. The force of the impact of the headwind on the frontal surface of the car is calculated at a constant low speed of the wind (for example, 2–4 m / s) in the form, kN [11, 13, 16]:

$$F_{rin} = 0.5A_t \quad (1)$$

where 0.5 is the specific pressure per 1 sq.m. of area, kN / sq.m.; A_t - the area of the frontal surface of the car with the load, м^2: $A_t = 2B \times 2H$ (where 2B and 2H are the width and height of the windward surfaces of the car with the cargo, m).

1. The rolling friction force $F_{r.f}$ as the tangential component of the bond reaction (rail lines) Fτ is calculated, which, according to Coulomb's law, is

$$F_{f.x} = F_{f.r} = F = f_0 G \quad (2)$$

where f_0 is a certain conditional (or reduced) coefficient of sliding friction, taking into account the number of wheels in bogies, rolling friction (along the bearing rings and the wheel along the rail) (usually f_0 = 0,001) [2 - 4].

2. The forces of resistance to the movement of the car from the environment $F_{env.}$ are found:

$$F_{env.} = k_{env} G \quad (3)$$

where $k_{env.}$ - coefficient that takes into account the fraction of gravity G in condition of the resistance of the environment (usually in the range of 0.0005 ÷ 0.00011 at a headwind speed of 4 to 6 m / s.

6. All the forces acting on the car (set of cars) when exposed to a scant headwind, kN are calculated:

- "shearing" forces $F_{sh.}$:

$$F_{sh.x} = G \sin\alpha \quad (4)$$

based on the impact on the plane of the projection of the gravity force of the car, acting along the entire length of 1 TP of the hump;

– "retentive" forces Fret.x (that is, the forces of resistance to the movement of the car in the form of sliding friction force on the section 1TP of the hump:

$$F_{ret.x} = F_{f.x} + F_{env.} + F_{in} + F_{front} \quad (5)$$

As you can see, in this case, the "shearing" force Fsh.x, equal to the effect of the projection of the gravity force Gsinα, is the shearing force, which enables the car to move with the given initial entering speed v01tp to the considered section 1tp (for example, v_{01tp} = 7.633 m/s [7]), overcoming the rolling friction forces Ff.x, resistance of the environment Fenv, and the force of an impact of headwind Fin [8]).

7. According to the values of the "shearing" $F_{sh.x}$ and "retentive" $F_{ret.x}$ forces, the force F1tp, contributing to the movement of the car on the considered section of the 1TP hump, kN is calculated:

$$F_{1tp} = F_{sh.x} + F_{ret.x} \cdot \quad (6)$$

8. Taking into account (4) and (5), the condition for the movement of the car on the considered section of the 1TP hump is found in the form:

$$F_{sh.x} \geq F_{ret.x} = F_{f.x} + F_{env.} + F_{in} + F_{front} \quad (7)$$

9. From the value of the force F1tp and the mass of the car M, taking into account the inertia of the rotating parts, the acceleration of the car a1tp when moving on the considered section of the hump with acceleration, m / s2 is found:

$$a_{1тп} = \frac{F_{1тп}}{M}. \quad (8)$$

10. The time t1tp (s), during which a rectilinear uniformly retarded movement of the car on the section 1TP of the hump with the length l1tp (m) takes place is calculated:

$$t_{1тп} = \frac{v_{01тп} \pm \sqrt{v_{01тп}^2 - 2a_{1тп}l_{1тп}}}{a_{1тп}}, \quad (9)$$

where v_{01tp} is the initial speed of the car (the speed of the car at the beginning of the 1TP section of the hump, for example, 7.633 m/s [7]), m/s.

By changing the length of the section 1TP of the hump, $l_{1тр}$, it is possible to build a graphical dependence $t(l_{1tp})$.

11. The speed of the car at the end of the 1TP hump with the disabled car retarder $v_{1тр}$ is calculated according to the classical formula of elementary physics, m/s:

$$v_e(t_{1тп}) = v_{01тп} - a_{1тп}t_{1тп}. \quad (10)$$

Further, if necessary, by changing the time of movement of the car along the entire length of the section 1TP of the hump t1tp, it is possible to construct a graphical dependence $v_{1tp}(t_{1tp})$.

12. If necessary, similarly to [6,7, 9, 12, 17, 19], the distance of the car x1tp (t) at any moment of time of its movement t at the end of the 1TP section of the hump (movement of the car "to the passage") according to the classical formula of physics, m:

$$x_{1тп}(t_{1тп}) = v_{01тп}t - a_{1тп}\frac{t^2}{2}. \quad (11)$$

An example of calculating the time and speed of a car when it moves along the entire length of the 1TP section of the hill when exposed to a scant headwind

For example, let the initial data be: v_{01}= 7.633 – initial speed of the car, m/s;

l_{1tp} = 29 – length of the 1TP section of the hump, m; M = 8.5 · 10^4 – the mass of the car with a load, taking into account the mass of the wheelsets, kg; G = 834 - the force of gravity of a car with a load, taking into account the mass of rotating parts, kN; F_{sh} = 7.58 – "shearing" force, F_{ret} = 217.373 -"retentive" force (taking into account the effect of the headwind, F_{in} = 3.192 kN) and F_{1tp} = -206.373 – the force under the influence of which the car moves along the entire length of the 1TP hump (that is, the difference between the "shearing" and "holding" forces), kN.

Below is a mock-up document obtained in the MathCAD program [12].

1. According to clause 1 of the procedure, the entire length of the 1TP section of the hump is taken according to the recommendations. For example, l_{1tp} = 29 m.

2. According to clause 3 of the procedure, the forces of aerodynamic resistance to the movement of the car are found (see [1]).

Ат = 6.384 – the area of the end windward surface of the car, m2;

Fвт := 0.5·Ат Frbx := Fвт Fвт = 3.192 – force of aerodynamic resistance of a car, kN.

3. According to clause 4 of the procedure, the rolling friction force is calculated (see [2 - 8]). $f0 = 1.036 \times 10^{-4}$ – Certain conditional sliding coefficient, taking into account the rolling friction of bearings in axle boxes, kN.

Fтрск3т := fск·(G0·cos(ψ03) + Frbx·sin(ψ03)) Fтрск3т = 151.599 _ Rolling friction force, kN

4. According to clause 5 of the procedure, the resistance forces of the environment are calculated (see [8 - 14]).

kcp := 0.0003 – Coefficient that takes into account the share of the gravity of the car considering the resistance of the environment.

$Fc := kcp \cdot G$ $Fc = 0.272$ – Resistance force from the air, kN.

5. According to clause 6 of the procedure, the "shearing" force is calculated (see [4]).

$Fсд3 := G0 \cdot \sin(\psi 03)$ $Fсд3 = 7.58$ – "shearing" force, kN.

6. According to clause 6 of the procedure, the "retentive" force is calculated (see [5]).

$Fуд3т1 := Fтрх3т + Fсо3 + Fтрб3$ $Fуд3т1 = 217.373$ – "holding" force considering the force of resistance of the environment, and the effect of cross-wind.

7. According to clause 7 of the procedure, the value of the force, under the influence of which the car moves along the entire length of the 1TP section of the hump with acceleration is found (see (6)).

$F1т := Fсд3 - Fуд3т$ $F1т = -206.373$ – the difference between the "Shearing" and "Retentive" forces, due to which the car moves with acceleration on the considered section of the hump, kN.

8. According to clause 9 of the procedure, the acceleration of the car, at which the accelerated movement of the car along the entire length of the 1TP section of the hump takes place, is calculated (see [8]).

$M = 8.502 \times 10^4$ – the mass of the car, taking into account the mass of rotating parts (set of wheels), kg;

$$a1т := \frac{|F1т| \cdot 10^3}{M0} \qquad a1т = 2.671$$

$$a1т1 := \frac{|F1т1| \cdot 10^3}{M0} \qquad a1т1 = 2.715$$

– the acceleration of the car, at which the retarded movement along the entire length of the 1TP section of the hump takes place, m/s^2.

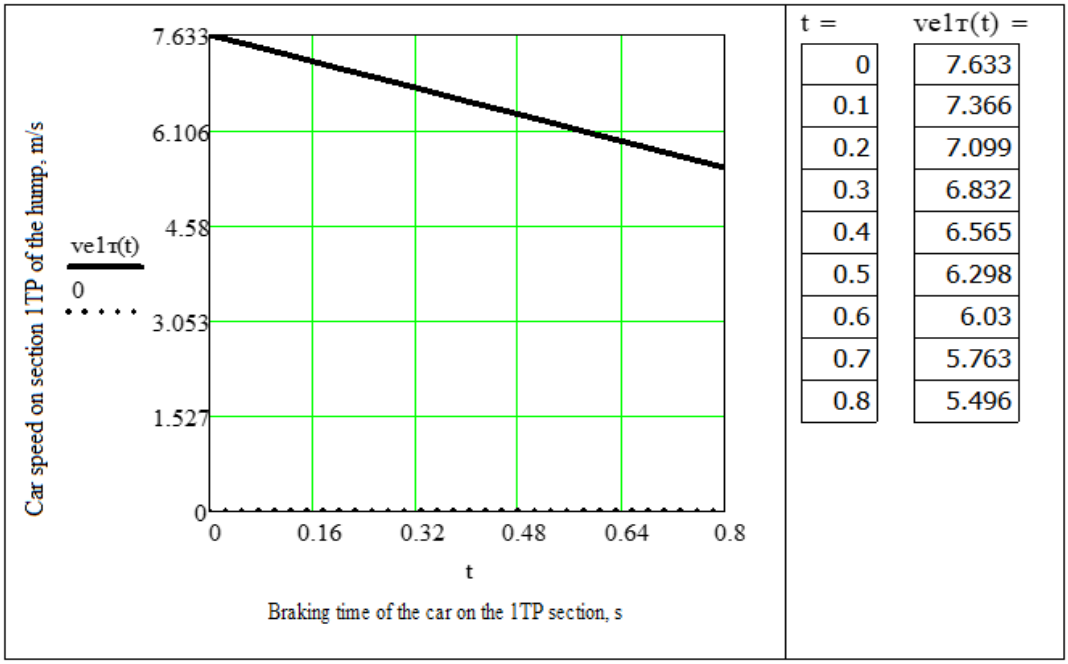
9. Calculation of the time t and the speed of rolling the car along the hump profile

$v01т = 7.633$ $a1т = 2.671$ $v01т1 = 7.623$ $a1т1 = 2.715$

t_{br} = 0,8 – response time of braking devices, (s)

t := 0 ,0.1 .. tзат – variation of the time of movement of the car in the section of the first braking position, (s)

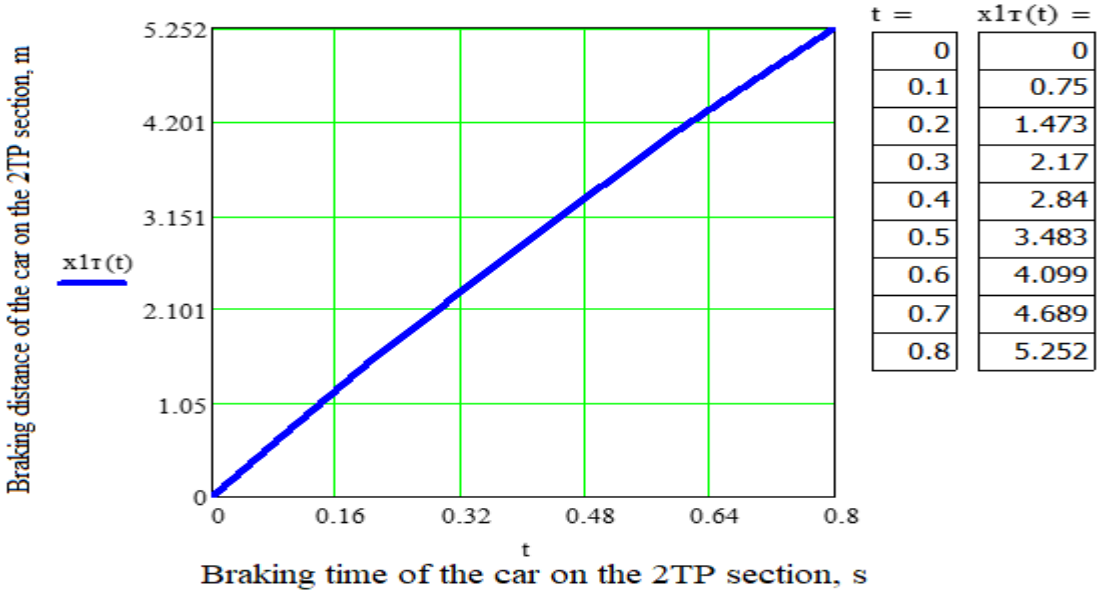
Building the graphical dependence of the car speed on the braking time



t =	vel1т(t) =
0	7.633
0.1	7.366
0.2	7.099
0.3	6.832
0.4	6.565
0.5	6.298
0.6	6.03
0.7	5.763
0.8	5.496

10. Building the graphical dependence of the distance traveled on the braking time of the car retarder

tret = 0.8

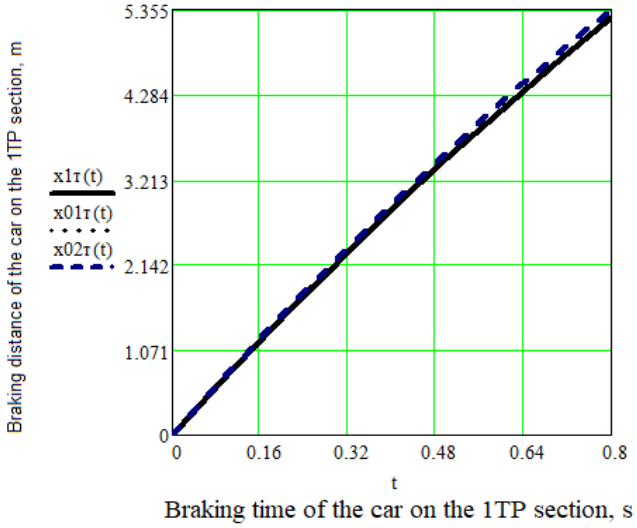


t =	x1т(t) =
0	0
0.1	0.75
0.2	1.473
0.3	2.17
0.4	2.84
0.5	3.483
0.6	4.099
0.7	4.689
0.8	5.252

As you can see, the graphical dependences v(t) and x(t) are linear in accordance with (10) and (11).

Analysis of the graphical dependences v(t) and x(t) shows that during the time t = 3.711 s (see Fig. 1) the car will cover a distance of 29 m (the accepted length of the 1TP section of the hump) and at the same time its speed (see Fig. 2) will reach 7.748

m / s (≈ 27.9 km / h). Taking into account the effect of wind on the side of the car, the time of car movement is t1tp = 3.805 s, and the car speed will decrease to 7.517 m / s (or 27.0 km / h).



t =	x1τ(t) =	x01τ(t) =	x02τ(t) =
0	0	0	0
0.1	0.75	0.749	0.764
0.2	1.473	1.47	1.502
0.3	2.17	2.165	2.212
0.4	2.84	2.832	2.895
0.5	3.483	3.472	3.551
0.6	4.099	4.085	4.179
0.7	4.689	4.671	4.781
0.8	5.252	5.23	5.355

Analysis of the graphical dependences v(t) and x(t) also shows that during the time t = 3.711 s, its speed (see Fig. 2) increases from 7.633 m / s (the speed of entry to the 1TP section of the hump) to 7.748 m/s, and when exposed to wind from the side of the car, it slightly decreases (from 7.633 to 7.517 m / s), in so doing the car will travel a distance of 29.0 m (the accepted length of the 1TP section of the hill).

Conclusions

1. Mathematical models of the movement of a car (set of cars) along the entire length of the 1TP section of the hump under the influence of a scant rear-on wind, described in [5], made it possible to develop a new method for calculating this section, allowing to find the kinematic parameters of the car (time and speed) for a given geometric parameter (length) of the considered section of the hump.

2. The results of calculations to determine the kinematic parameters of the car using the new method made it possible, by the known value of the distance traveled by the car along the entire length of the 1TP section (“to pass”) l1tp, to determine the time t1tp, during which a uniformly accelerated movement of the car will take place on this section of the hump. Using the value t1tp, the speed of the car at the end of the considered section v1tp (t1tp) was found.

The results of the studies performed can be used for the correct solution of problems in the calculation and design of marshalling humps.

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