ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 10 , October 2020

Calculation of the Speed of the Carriage in Different Sections of the Hump

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ABSTRACT. In the article, to calculate the speed of a carriage in different sections of the hump, a formula derived from the theorem on the change in kinetic energy for a non-free material point in a final form was used. By calculation examples, it is noticed that in the intermediate section of the hump before the separating arrow, the relative calculation error is 10.3%, in the section of the arrow zone of the hump of the second separating arrow -δv6c2 ≈ 9.0%, in the section of the first sorting track -δv7 ≈ 16.1 %.

KEYWORDS*:* Railway, station, marshalling hill, carriage, hill profile, results of calculations of the speed of the carriage on different sections of the hill.

I. INTRODUCTION

This article, as well as works [1 - 13], is devoted to the discussion of the correctness and / or incorrectness of the expanded universal form of formula (2) in [4], as part of the existing theoretical provisions of hump structural and technological calculations of the projected sections of the hump [14 - 21].

Note that in [4], in order to actually take into account the operating conditions of the humps, it is recommended to use the parameters of the specific resistance to movement w, which reflect the generalized characteristics of the modern car fleet and sorting tracks. Taking this factor into account, formula (2) is given in [4], supposedly having an expanded universal form:

$$v_{\text{к}}^2 = v_{\text{н}}^2 + 2g'(i - w)10^{-3} \cdot l - 2g'h_{\text{т}}. \quad (1)$$

However, formula (1) contains a number of inaccuracies and gross errors in its components, the main of which are noted in the form of counterexamples in [3, 9].

II. RELATED WORK

We will try to reveal these shortcomings, which also apply to formula (1).

Unfortunately, formula (1) is mathematically written irresponsibly and undeniably erroneous, although the authors of [4] dwelt on the fundamentally important questions of counter-arguments in [3] (see the first paragraph of the first column on page 36 in [4]).

So, for example, it, as noted in [5], contains two completely incomparable mathematical expressions describing the movement of the car on different sections of the hill, where the reduced ones are valid for imperfect connections, and the subtracted one, as a formula for determining the speed of the body rolling along an ideal plane (connections) (see formula (3) in [7]).

III. LITERATURE SURVEY

This approach, as noted in [9], contradicts the elementary principles of solving engineering problems in theoretical mechanics:

firstly, either for simplicity it is necessary to solve the problem for an ideal connection that is not of scientific value and practical usefulness;

secondly, either for an imperfect connection of scientific and practical interest.

Otherwise, the error of the mathematical notation of formula (1) lies in the fact that it cannot be given a universal form, as if "mechanically" and / or "superficially" uniting the diminished and the subtracted [5].

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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At the same time, realizing the impossibility of performing any hump constructive calculations by formula (1), contrary to the opinion of the authors of article [4] (see the second and third paragraphs of the last column on page 36 in [4]), for the convenience of analysis, we present in it separately diminished and subtracted in the form:

$$v_{\text{к}i}^2 = v_{\text{Н}i}^2 + 2g'(i_i - w_i)10^{-3} l_i ; \tag{2}$$

$$v_{\text{КТ}i}^2 = v_{\text{Н}i}^2 - 2g'h_{\text{т}}, \tag{3}$$

Where

$v_{\text{нт}i}$=[$v_{\text{вх}i}$] = [$v_{\text{вз}i}$]–the maximum permissible speed of a carriage entering the carriage retarders [22];

$h_{\text{т}i}$ – power of the braking positions (according to Table 2 in [23], the power of the braking means $M_{\text{тс}}$) from the hump of the hill to the park braking position, depending on the type and number of retarders.

The length $l_{\text{max.г}}$ and the height Δh of the downhill part of the hill and the power of the braking means $M_{\text{тс}}$ from the hump of the hill to the park braking position (3TP), according to table. 2 in [23], “rigidly” fixed values.

For example, for an automated slide$l_{\text{max.г}}$ = 320 m, Δh = 4,38 mand$h_{\text{т}}$ = $M_{\text{тс}}$ = 7,2 m.e.w .; for mechanized slide$l_{\text{max.г}}$ = 260 m, Δh = 3,6 mand$h_{\text{т}}$ = $M_{\text{тс}}$ = 5,2 m.e.w .; for mechanized slide и$l_{\text{max.г}}$ = 211 m, Δh = 2,57 m, $h_{\text{т}}$ = $M_{\text{тс}}$ = 4,4 m.e.v (see Table 2 in [23]).

With such fixed data ($l_{\text{max.г}}$, Δhи $h_{\text{т}}$ = $M_{\text{тс}}$) wagon speed$v_{\text{кт3}}$at the end of the parking braking position (3TP), regardless of whether any calculations are performed or not, should not exceed 1.38 m / s (5 km / h) in order to prevent a collision of a carriage with a group of standing cars »At the sorting yard.

Hence, it is obvious that the profile of the hump along its entire length (length$l_{\text{max.г}}$and height Δ$h$the downhill part of the hill) was accepted without justification (i.e. not supported by the results of any calculated data) associated with the speed of approach of the car$v_{\text{кРТ}}$to the design point (PT).

Otherwise, a carriage, dismantled from the hump of a hill with a thrust speed$v_{н}$ (for example, 1.7 m / s) at the received power of the braking means$M_{\text{тс}}$, as if “forced” and / or “forced” to arrive at the end of the park braking position at a speed$v_{\text{кт3}}$no more than 1.38 m / s (5 km / h).

In our opinion, this is one of the reasons for the systematic collision of a carriage with a “group of standing cars” in the sorting yard.

IV. METHODOLOGY

At the same time, let us make a reservation [9] that formula (2) is necessary to determine the speed of the car on the high-speed sections of the hill profile, and (3) - for sections of braking positions (TP). Although, it is known that the derivation of formula (2) and / or formula (2) in [4] on the basis of the kinetic energy change theorem is well known (see formula (30) on p. 142 in [15]).

However, in the reduced formulas (2) and / or (2) in [4], the unit for measuring the slope of the track profile i in ‰ is equated to the unit for measuring the specific resistance of movement w of the off-system unit of measurement in kgf / t (i.e. т.е. = kgf / m) (see p. 141 in [15], p. 9 in [16]), which is unacceptable in theoretical and engineering mechanics [24 - 32].

It is interesting to note that in recent years in scientific articles [2, 4], official regulatory and technical documents of JSC "Russian Railways" [18, 23] and, as before, in textbooks and teaching aids for students of higher educational institutions of railways. transport [14 - 17, 19 - 21] when performing hump structural and technological calculations, unfortunately, not only non-systemic units of measurement are widely used, but also "pseudoscientific" units of measurement when solving problems of vehicles.

So, for example, in [23] the maximum number of cars on the section $K_{\text{т}}$, from which it is possible to lower one cut, taking into account the provision of a safe connection with the previous cuts at a speed vk not exceeding 5 km / h (permissible collision speed) is calculated by the formula (see p. .3 in [23]):

$$K_{\text{т}} = \frac{2M_{\text{тс}}K_{\text{тс}}l}{\left(v_{\text{н}} + \sqrt{2g\Delta h}\right)^2 - v_{\text{к}}^2}, \tag{4}$$

Where

$M_{\text{тс}}$– the total power of the brake means of the slide along the rolling route, mew (meter of energy height);

$K_{\text{тс}}$ = 0,67 – the coefficient of use of braking means associated with the location of braking positions on the hill and the features of braking long cuts to exclude the possibility of squeezing out the wheel pairs from the retarders;

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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$\boldsymbol{l}$– length of the downhill part of the slide (distance from the hump of the hill to the end of the nearest park braking position), m;

$\boldsymbol{v_н}$– thrust speed, m / s;

$\boldsymbol{M_{тс}}$– the total power of the brake means of the slide along the rolling route, m.e.

$\Delta\boldsymbol{h}$– slide height equal to the maximum difference in the height of the slide hump and the park braking position, m;

$\mathbf{g}$ = 9,8 – free fall acceleration, m / s^2;

$\boldsymbol{v_к}$– the estimated speed of the exit of a long loaded cut from the park brake position of the cut, m / s.

Transforming the last formula, we will have:

$$K_т = \frac{2M_{тс}K_{тс}l}{(v_н + v_h)^2 - v_к^2}, \tag{5}$$

Where

$\boldsymbol{v_h}$– speed of movement of a long loaded cut from the height of the hump to the park braking position, m / s:

$$v_h = \sqrt{2g\Delta h}\,. \tag{6}$$

The last formula is equivalent to formula (3):$\boldsymbol{v_h}$ = $\sqrt{2g'h}$ (see p. 186 in [14] and formula (129) in [26]) for an ideal connection.

Analyzing the numerator of formula (4) and / or (5), we note that it has the dimension m^2 (meter squared), and the denominator in the form $(v_н + v_h)^2 - v_к^2$ – dimension in (m / s)^2.

As a result, formula (4) and / or (5), intended to determine the maximum number of cars on the section Кт, instead of the unit of measurement of "cars", has, oddly enough, in c2 (seconds squared).

So, for example, according to Appendix 2 and table. 2 in [23],

at$\boldsymbol{l}$ = 320 m, $\boldsymbol{M_{тс}}$ = 7,2 m.e. in,$\boldsymbol{K_{тс}}$ = 0,67, $\boldsymbol{v_н}$ = 1,9 m / s, $\Delta\boldsymbol{h}$ = 4,38 m, $\boldsymbol{v_к}$ = 1,38 m / s maximum permissible number of wagons in a cut, wagons:

$$\boldsymbol{K_т} = 25{,}04 \approx 25;$$

при$\boldsymbol{l}$ = 260 m, $\boldsymbol{M_{тс}}$ = 5,2 m.e. in,$\boldsymbol{K_{тс}}$ = 0,67, $\boldsymbol{v_н}$ = 1,67 m / s, $\Delta\boldsymbol{h}$ = 3,6 m, $\boldsymbol{v_к}$ = 1,38 m / s maximum permissible number of wagons in a cut, wagons:

$$\boldsymbol{K_т} = 18{,}3 \approx 18;$$

at$\boldsymbol{l}$ = 211 m, $\boldsymbol{M_{тс}}$ = 4,4 m.e. in,$\boldsymbol{K_{тс}}$ = 0,67, $\boldsymbol{v_н}$ = 1,38 m / s, $\Delta\boldsymbol{h}$ = 2,57 m, $\boldsymbol{v_к}$ = 1,38 m / s maximum permissible number of wagons in a cut, wagons:

$$\boldsymbol{K_т} = 17{,}6 \approx 18,$$

instead of c2 (seconds squared).

So, according to [23], the unit of measurement for "cars" is equivalent to "c^2 (seconds squared)", ie wagons = c^2, which can only take place in pseudoscientific works where the principles of units of measurement are not observed when solving engineering problems, even if even off-system units of measurement are widely used in traction calculations of train traffic [33] (see p. 23 in [2]) ...

Based on this, we note that the formula (4) and / or (5) cannot be theoretically justified, i.e. is a deceitful and / or pseudoscientific mathematical expression, despite the fact that formula (4) is recommended for use on the basis of R&D 4.035.P "Development of instructions for the maximum allowable cut lengths when breaking up on humps" [23].

At the same time, the wide application of formula (4) for educational purposes for students of higher educational institutions of railway transport is not excluded, which is irreparably harmful for the higher education system.

In our opinion, it is unlikely that now there will be any objections to the units of measurement of the hump profile parameters from the authors of the article [2, 4]. The authors of the article [2] (see p. 23 in [2]) persistently and / or strongly tried to justify the correctness of the equality of the “strange” and / or “contrived” off-system unit of measurement of the slope i of the track profile in ‰ and the resistivity w in kgf / t [1] (ie ‰ = kgf / t) (see page 9 in [16]). Such a "unification" of the dimensions of units of measurement (see the last column on page 23 in [2]), except for the SI system of units of measurement when solving engineering problems in any branch of technology, is not permissible.

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A. PURPOSE OF THIS ARTICLE

Using examples of calculations to reveal that mathematical expressions describing the movement of a car on high-speed sections of the hill, presented in a universal form in [4], are unacceptable for sections of the hill with a small slope.

B. FORMULATION OF THE PROBLEM

Check the theoretical validity of the derivation of formula (193) as part of the universal formula in [4].

C. RESEARCH METHOD

We present the solution to the engineering problem of the car movement along the slope of the hump on the basis of the application of the theorem on the change in kinetic energy for a non-free material point in the final form [24 - 32].

D. MATHEMATICAL DESCRIPTION SOLUTION OF THE PROBLEM

Let us check the correctness of the derivation of formula (2). As in [30, 31], we write down the theorem on the change in kinetic energy for a non-free material point (which means that restrictions called imperfect constraints are imposed on its motion) in the final form (see mathematical expression (143)) in the form:

$$\frac{G}{2g'}v_{\text{к}ix}^2 - \frac{G}{2g'}v_{\text{н}ix}^2 = A_{1,2ix}. \quad (7)$$

As you can see, the increment in the kinetic energy of the system $\Delta \boldsymbol{E}$ is equal to the sum of the corresponding works of active forces $\boldsymbol{A}^{(F)} = \boldsymbol{A}_{1ix}$ and forces of resistance of all kinds $\boldsymbol{A}^{(Fc)} = \boldsymbol{A}_{2ix}$, including bond reactions $\boldsymbol{A}^{(F\text{тр})}$ (see equality (145), p. 315 in [24], formula (8) in [12]):

$$\Delta E = A^{(F)} + A^{(F_c)}. \quad (8)$$

In the mathematical expression (8), the following designation is adopted:

$\boldsymbol{i}$ –an index showing, as before, the numbers of the calculated sections and sections of the brake positions of the hump;

$\boldsymbol{x}$ –an index that means that the projections of speed and force on the directions of the rail lines are investigated here;

$\boldsymbol{G}$–the force of gravity of a wagon with cargo;

$\boldsymbol{A}_{1ix}$–work of the gravity force of a wagon with cargo as a driving force:

$$A_{1xi} = G_{xi} l_i = G \sin \psi_{ix} l_i \quad (9)$$

considering that it contains

sinψ_{ix}–sine angle ψ_{ix}, characterizing the bias of the investigated $\boldsymbol{i}$ section of the slide;

$\boldsymbol{l}_i$–the length of the calculated $\boldsymbol{i}$ section of the slide;

$\boldsymbol{A}_{2ix}$–work of the force of resistance of all kinds:

$$A_{2ix} = |F_{cix}| l_i , \quad (10)$$

taking into account that it

$|\boldsymbol{F}_{cix}| = -\boldsymbol{F}_{cix}$–according to the explanation to formula (2) in [5], resistance forces of all kinds.

Here is the power $|\boldsymbol{F}_{cix}|$ includes the following forces:

frictional drag $\boldsymbol{F}_{\text{тр}ix}$, as the main resistance $\boldsymbol{F}_{oix}$);

air and wind resistance $\boldsymbol{F}_{\text{св}}$, although in [18] it is, as a specific resistance, a value calculated by the formula (4.2);

resistance from snow and frost within the arrow zone of the beams and on the sorting tracks $\boldsymbol{F}_{\text{сн}}$ [18];

resistance when crossing points (arrows) (from impacts of wheels on points, crosspieces and counter rails) $\boldsymbol{F}_{\text{стр}}$ [18];

resistance appearing when driving along curved sections of the path, depending on the speed of movement, taking into account the sum of the angles of rotation in the curves, including the arrow angles on the section under consideration $\boldsymbol{F}_{\text{кр}i}$[18])in shares of $\boldsymbol{G}$.

Imagine the strength of all kinds of resistance $|\boldsymbol{F}_{cix}|$ in the form (see formulas (16) in [13]):

$$|F_{cix}| = |w_{ix}| G , \quad (11)$$

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Where

$|w_{ix}| = -w_{ix}$ – *abstract number and / or dimensionless coefficient*, taking into account the share of the force of resistance of all kinds $|F_{cix}|$ from$G$, or in the generally accepted designation and the usual understanding (see the first paragraph on page 23 in [2]) - this is the specific resistance to the movement of the car from the forces of resistance of any kind, ie $|F_{cix}| = f(G)$.

Considering that for small angles:$\sin\psi_{ix} \approx \psi_{ix} = i_{ix}$, we rewrite expressions (9) and (10) taking into account formula (11):

$$A_{1xi} = Gi_{ix}l_i\ ; \tag{12}$$

$$A_{2ix} = |w_{ki}|Gl_i\ . \tag{13}$$

Let us make a reservation that in what follows we omit the index x in the letter notation of formulas.

Substituting the last relations into the mathematical expression (7), after elementary transformations, we obtain the formula for determining the speed of rolling the car along the downhill part of the hill in the final form:

$$v_{\text{к}i}^2 = v_{\text{н}i}^2 + 2g'(i_i + |w_i|)l_i. \tag{14}$$

Formula (14) subject to the condition$v_{\text{н}i}$> 0 andi_i> $|w_{ix}|$ makes it possible to determine the speed of the carriage along the downhill part of the hill with uniformly accelerated movement, and withi_i< $|w_{ix}|$ – evenly slow motion.

Representing in (14), the slope of the path profile$i_i$in glad., and $|w_{ix}|$, as a dimensionless coefficient taking into account the share of the force of resistances of any kind $|F_{cix}|$ from$G$, we obtain formula (2) and / or decreasing in formula (2) in [4] (see formula (30) on p. 42 in [15], p. 10 in [16]), which was required to verify the correctness of the derivation of this formula.

Note that a kind of "cursory" and / or "superficial" comparison of formulas (1) and (2) in [4] (see the last paragraph of the middle column on page 36), formally allows one to obtain a formula similar to formula (16) in [12], to determine the acceleration at uniformly accelerated movement of the car along the slope of the hill in the generally accepted notation and the usual understanding (see formula (16) in [12] and the formula on page 141 in [15]):

$$a_i = 2g'(i_i + |w_i|)10^{-3}, \tag{15}$$

Where

i_i – track slope in ppm (i.e. ‰);

$|w_i|$ – unlike [2, 4], an abstract number and / or a dimensionless coefficient that takes into account the share of the strength of any resistance $|F_{ci}|$from the gravity of a wagon with cargo$G$, т.е. $|F_{ci}| = f(G)$, *for ease of calculation, increased by 10^3 times.*

Here, the “absurdity” of the dimensions in [14 - 21] lies in the fact that in the reduced formulas (2) in [4], the unit for measuring the slope of the track profile i in ‰ is equated to the unit of resistivity to motion w of the off-system unit of measurement kgf / t (ie, ‰ = kgf / t) (see page 9 in [16]), which is unacceptable in theoretical and engineering mechanics [24 - 32].

We make a special reservation that the derivation of formula (2), and / or reduced in formula (2) in [4], was carried out using the theorem on the change in kinetic energy for a non-free material point in the final form [6, 24 - 32].

F. AN EXAMPLE OF PERFORMING HUMP CALCULATIONS

To determine the limit and / or limit of applicability of formula (2) (without the incorrectly included subtracted) in [4] or formula (2) along the entire length of the track profile with different slopes, below we present the results of studies to determine the kinematic parameters of the car in different sections of the hill. So, for example, we determine the speed of the car on the first intermediate section of the hill (PR) to the dividing switch (C), the switch zone (SZ) of the second arrow (C2), as well as on the first sorting track (SP1) according to the formula (2), as deductible formula (2) in [4].

V. EXPERIMENTAL RESULTS

Calculationexample 1. For example, let's examine the intermediate section (PR) to the dividing arrow (C) of the hill. The initial data for the PR slide section are as follows:$v_{\text{н}4}$ = 1,519 – the accepted value of the speed of the car entrance on the PR section of the hill after the car leaves the braking zone of the car retarder of the second brake position (2TP), м/с; g' = 9,635 –free fall acceleration of a body, taking into account the mass of rotating parts, m / s^2; l_4= 20,001 – length of the intermediate section, m;i_{4Ck} = 11 –the slope of the PR section, ‰; $F_{o4} = k_{o4}G$ = 0,001G = 0,908 –the force of the main resistance to the movement of the car to the dividing arrow (C) of the section of the PR of the slide (where$\boldsymbol{k}_{о4}$ = 0,001 – coefficient taking into account the resistance from the rolling friction force with the sliding of the wheelset, taking into account the tailwind, while,$\boldsymbol{k}_{о4}$ = $\boldsymbol{\omega}_{о4}$ = 0,5 - basicspecificresistancetomovementof a verygoodrunner (OX), kgf / tf (seetable 4.2 in [26]),кН; $\boldsymbol{F}_{св4}$ = $\boldsymbol{k}_{св4}\boldsymbol{G}$ = 0,0005$\boldsymbol{G}$ = 0,454 - forceresistancefromairandwind (where$\boldsymbol{k}_{св4}$ = 0,0005–resistance from the environment and wind).

Calculation results [34], according to the calculation sequence [13].

1) Let's calculate the total specific resistance to the movement of the car, taken into account as a dimensionless quantity, according to formula (16) in [13]:

$$|\boldsymbol{w}_4| = |\boldsymbol{k}_{о4} + \boldsymbol{k}_{св4}| = -0{,}0015.$$

Note that the rolling speed of the car v4, calculated by the formula of elementary physics (9) in [13] with the same initial data of the problem at the value of the acceleration$\boldsymbol{a}_4$ = 0,128 m / s^2, calculated by formula (1) in [13] taking into account the projection of the tailwind force$\boldsymbol{F}_{вx}$, equals$\boldsymbol{v}_4$ = 2,723 m / s.

2) Let's calculate the speed of rolling the car to the dividing arrow (C) of the intermediate section (PR) of the hill v4 without taking into account the projection of the force of the tailwind$\boldsymbol{F}_{вx}$according to the formula (2), m / s.

$$v_4 = \sqrt{v_{н4}^2 + 2g'(i_4 + |w_4|)10^{-3} l_4} =$$

$$= \sqrt{1{,}519^2 + 2 \cdot 9{,}635(11{,}0 - 1{,}5)10^{-3} \cdot 20{,}0} = 2{,}443.$$

The relative computation error in comparison with the data of formula (9) in [13] is$\delta \boldsymbol{v}_{4C}$ = 10,3 %, which is almost 2 times higher than the accuracy of engineering calculations (5%). For this reason, it is not recommended to use formula (2) and / or reduced in formula (2) in [4] for practical calculations.

3) Let's calculate the rolling speed of the car to the dividing arrow (C) of the intermediate section (PR) of the slide$\boldsymbol{v}_{x4}$according to formula (2) taking into account the projection of the tailwind force$\boldsymbol{F}_{вx}$taking into account the explanations in formula (114) in [13], according to the sequence of calculation [13]., m / s:

$$v_{x4} = \sqrt{v_{н4}^2 + 2g'(i_{x4} + |w_4|)10^{-3} l_4} =$$

$$= \sqrt{1{,}519^2 + 2 \cdot 9{,}635(14{,}515 - 1{,}5)10^{-3} \cdot 20{,}0} = 2{,}706.$$

The relative calculation error, made according to formulas (2) and (9) in [13], is equal to$\delta \boldsymbol{v}_{x4c}$ ≈ 0,6 %, which is negligible.

4) It is interesting to note that if we vary the value of the initial speed of the car$\boldsymbol{v}_{н4}$within the range from 1 to 2.0 m / s with a step $\Delta \boldsymbol{v}_{н4}$ = 0,125 at$\boldsymbol{w}_4$ = 1,5(dimensionless quantity) and$\boldsymbol{i}_4$ = 11 ‰, then the value of the rolling speed of the car on the calculated section$\boldsymbol{v}_{4Ck}$increases from 2.159 to 2.768 m / s.

Graphical change$\boldsymbol{v}_4 = \boldsymbol{f}(\boldsymbol{v}_{н4})$ shown in Fig. 1.

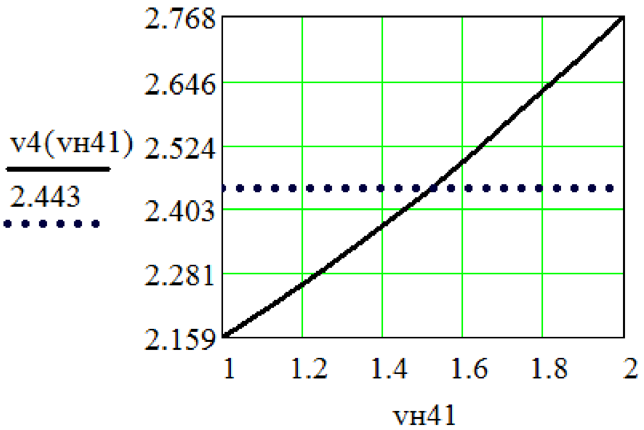

Fig. 1. Graphical change$\boldsymbol{v}_{4C} = \boldsymbol{f}(\boldsymbol{v}_{н4C})$

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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Note that even if we vary the value of the specific resistance to the movement of the car w4 in the range from 0.5 to 3.0 (dimensionless value) with a step Δw_4 = 0,25 at$v_{н4}$ = 1,529 m / s andi_{4C} = 11 ‰, then the value of the rolling speed of the car on the calculated sectionv_{4Ck}decreases from 2.521 to 2.332 m / s.

Graphical change$v_{41} = f(w_{4C})$ shown in Fig. 2.

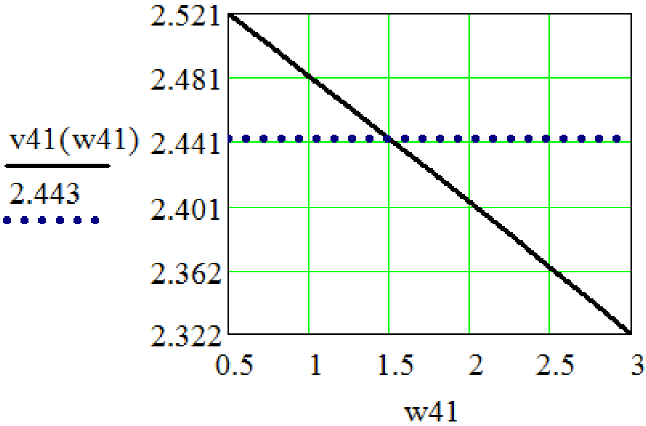

Fig. 2. Graphical change$v_{41} = f(w_4)$

If we vary the value of the slope of the path i_4 in the range from 10.0 to 12.0 with a step Δi_4 = 0,25 ‰ at$v_{н4}$ = 1,529 m / s and w_4 = 1,5(dimensionless value), then the value of the rolling speed of the car on the calculated section$v_4$increases from 2.363 to 2.521 m / s.

Graphical change$v_{4i} = f(i_4)$ shown in Fig. 3.

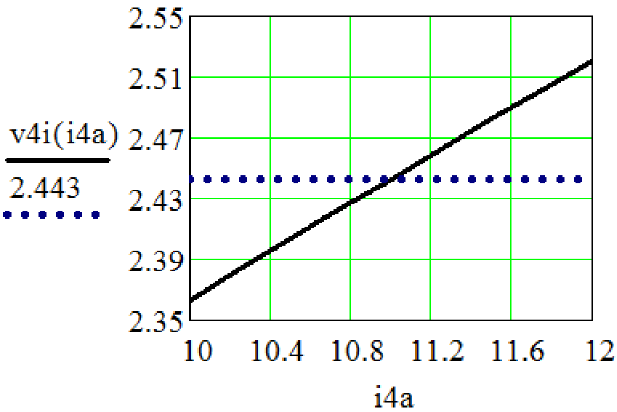

Fig. 3. Graphical change$v_{4i} = f(i_4)$

Calculation example 2. For an example calculation, we examine the section of the arrow zone (SZ) after the second arrow (C2). The initial data of the SZ section are as follows: G = 650 - the gravity of the cargo on the wagon, кН; G_0 = 908 – the force of gravity of a wagon with cargo, кН; $\sin\psi_{6c2}$ = 0,002 и $\cos\psi_{6c2}$ = 1,0ori_{6c2} = 2 ‰– the slope of the profile of the path NW of thehill, glad; g' = 9,635 –free fall acceleration of a body, taking into account the mass of rotating parts, calculated with a relative calculation error$\delta g \approx$ 0,184 % at$g$ = 9,81 m / s^2, n = 4 PCS., $Q = G_0$ = 92,56 TC and / or G = 908 кН(caccording to table. 4.2 in [18] is a very good runner (OX)), γ = 0.00185 (see page 183 in [14]), m / s^2; l_{6c2}= 21,0 – length of the NW section after the second arrow (C2), m;$v_{н6c2}$ = 2,654 – the accepted value of the speed of the car entering the section NW after the second arrow (C2) of the hill after the car leaves the first dividing arrow (C1) of this zone, м/c;$F_{o6c2} = k_{o6c2}G = 0{,}001G$ = 0,908 –the force of the main resistance to the movement of the car in the section of the second switch (C2) NW of the hill (wherek_{o6c2} = 0,001 –coefficient taking into account the resistance from the rolling friction force with the sliding of the wheelset when taking into account the tailwind of a small value$F_{вх} \approx$ 3,2 кН), кН; $F_{стр} = k_{стр}G = 0{,}00025G$ = 0,227 –force resistance at the transition of curved track sections (where$k_{стр}$ = 0,00025–resistance from arrows), кН; $F_{кр6C2} = k_{кр6C2}G$ = 0,0002463G = 0,224 –force resistance at the transition of curved track sections (where$k_{кр6C2}$ = 0,0002463 –resistance from

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

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curves),кН; $F_{св} = k_{св}G$ = 0,0005G = 0,454 –force resistance from air and wind (where$k_{св}$ = 0,0005–resistance from medium), кН; $F_{сн} = k_{сн}G$ = 0,00025G = 0,227 –force resistance from air and wind (where$k_{сн}$ = 0,00025–resistance from the medium),кН.

Calculation results [4], according to the calculation sequence in [13].

1) We calculate the total specific resistance to the movement of the car, according to the formula (16) in [13]:

$$|w_{6С2}| = |k_{о6С2} + k_{стр} + k_{кр6С2} + k_{св} + k_{сн}| =$$
$$= -(0{,}001 + 0{,}00025 + 0{,}0002463 + 0{,}0005 + 0{,}00025) = -0{,}002246.$$

We present the results of calculations by the formulas of elementary physics (9) - (12) in [13], the possibility of using which was analytically proved in [35] (see formulas (16), (19) - (20)).

Let's calculate the time of the car movement according to the formula (12) in [13] at the initial speed and / or the speed of the car entrance to the investigated section of the NW hill$v_{н6с2}$ = 2,654m / s and acceleration$a_{6с2}$ = 0,032 m / s^2 at uniformly accelerated motion, calculated by formula (1) in [13], taking into account the projection of the tailwind force$F_{вх}$: $t_{6с2}$ = 7,567 c.

Let us calculate the rolling speed of the car by formula (9) and / or, which is the same by (11) in [13], taking into account the projection of the tailwind force$F_{вх}$at$v_{н6с2}$ = 2,654m / s, $a_{6с2}$ = 0,032 m / s ^{2}и$t_{6с2}$ = 7,567 s:

$$v_{6с2} = 2{,}897 \text{m / s and / or} v_{6с2} \approx 10{,}43 \text{km / h}.$$

2) Let's calculate the rolling speed of the car after the dividing arrow (C2) of the NW section of the hill according to the formula (2) without taking into account the projection of the tailwind force $F_{вх}$,m / s:

$$v_{6с2} = \sqrt{v_{н6с2}^2 + 2g'(i_{6с2} + |w_{6с2}|)10^{-3} l_{6с2}} =$$
$$= \sqrt{2{,}654^2 + 2 \cdot 9{,}635(2 - 2{,}2246)10^{-3} 21{,}0} = 2{,}635.$$

Here is the result of the calculation$v_{6с2}$ = 2,635 m / s less than initial speed$v_{н6с2}$ = 2,654 m / s, since $|w_{6с2}| > i_{6с2}$.

The relative calculation error, made according to formulas (2) and (9) in [13], is equal to$\delta v_{6с2} \approx$ 9,0 %, which is not small, i.e. almost 2 times exceeds the limits of accuracy of engineering calculations (5%). For this reason, formula (2) and / or reduced in formula (2) in [4] cannot be recommended for engineering calculations.

If for the main specific resistance to movement, according to table. 4.2 in [18], accept$\omega_{о1}$ = 0,5 kgf / tf for a very good runner (OH), then the rolling speed of the car$v_{6с2о}$after the dividing arrow (C2) in the NW section, m / s:

$$v_{6с2о} = \sqrt{v_{н6с2}^2 + 2g'(i_{6с2} + |w_{6с2о}|)10^{-3} l_{6с2}} =$$
$$= \sqrt{2{,}654^2 + 2 \cdot 9{,}635(2 - 0{,}5)10^{-3} 21{,}0} = 2{,}766.$$

Note that when calculating v1o, the values of ωo1 were taken unchanged, i.e.$\omega_{о1}$= 0,5кгс/тс.

The relative calculation error, made according to formulas (2) and (9) in [13], is equal to$\delta v_{6с2о} \approx$ 4,51 %, what little.

Let's calculate the rolling speed of the car after the dividing arrow (C2) of the NW section of the hill according to the formula (2) taking into account the projection of the tailwind force$F_{вх}$and explanations in formula (14) in [13], m / s:

$$v_{6с2b} = \sqrt{v_{н6с2}^2 + 2g'(i_{x06с2} + |w_{6с2}|)10^{-3} l_{6с2}} =$$
$$= \sqrt{2{,}654^2 + 2 \cdot 9{,}635(5{,}15 - 2{,}2246)10^{-3} 21{,}0} = 2{,}893.$$

The relative calculation error, made according to formulas (2) and (9) in [13], is equal to$\delta v_{6с2в} \approx$ 0,14 %, which is negligible.

Calculation example 3. We investigate the section of the first sorting track (SP1) of the hill. The initial data of the site SP1 are as follows: $v_{н7}$ = 3,154 – the accepted value of the speed of the car entering the section SP1 of the hill after the car leaves the switch zone (SZ), m / s; g' = 9,635 –acceleration of free fall of a body, taking into account the mass of rotating parts,м/с^2; l_7= 59,18 – length of the section SP1 of the slide, m; i_7 = 1,6 –slope of the section SP1 of the hill ‰; $F_{о7} = k_{о7}G$ = 0,001G = 0,908 –the force of the main resistance to the movement of the car on the section SP1 of the hill (where$k_{о7}$ = 0,001 – coefficient taking into account the resistance from the rolling friction force with the sliding of the wheelset, taking into account the tailwind$F_{вх}$), кН; $F_{кр7} = k_{кр7}G$ = 0,00067G = 0,061 –resistance force at the transition of curved track sections

ISSN: 2350-0328

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(where$\boldsymbol{k}_{св7}$ = 0,00067 –resistance from curves), кН; $\boldsymbol{F}_{св}$ = $\boldsymbol{k}_{св}\boldsymbol{G}$ = 0,0005$\boldsymbol{G}$ = 0,454 –resistance force from air and wind (where$\boldsymbol{k}_{св}$ = 0,0005 –resistance from medium), кН; $\boldsymbol{F}_{сн}$ = $\boldsymbol{k}_{сн}\boldsymbol{G}$ = 0,00025$\boldsymbol{G}$ = 0,227 –resistance force from air snow and frost (where$\boldsymbol{k}_{сн}$ = 0,00025 –resistance from snow and frost),кН.

Calculation results [34], according to the calculation sequence in [13].

1) Let's calculate the total resistivity to the movement of the car using the formula (16) in [13]:

$$|\boldsymbol{w}_7| = |\boldsymbol{k}_{о7} + \boldsymbol{k}_{кр7} + \boldsymbol{k}_{св} + \boldsymbol{k}_{сн}| =$$
$$= -(0{,}001 + 0{,}000067 + 0{,}0005 + 0{,}00025) = -0{,}001817.$$

2) The rolling speed of the car v7 on the section SP1 of the hill, calculated using the elementary physics formula (9) in [13] for the given initial data of the problem, is: $\boldsymbol{v}_7$ = 3,711 m / s.

3) Let's calculate the rolling speed of the car on the section SP1 of the hill according to the formula (2) without taking into account the projection of the tailwind force$\boldsymbol{F}_{вх}$,m / s:

$$v_7 = \sqrt{v_{н7}^2 + 2g'(i_7 + |w_7|)10^{-3} \cdot l_7} =$$
$$= \sqrt{3{,}154^2 + 2 \cdot 9{,}635(1{,}6 - 1{,}817)10^{-3} \cdot 59{,}18} = 3{,}114.$$

Here is the result of the calculation$\boldsymbol{v}_7$ = 3,114 m / s less than initial speed$\boldsymbol{v}_{н7}$ = 3,154 m / s, since $|\boldsymbol{w}_7| > \boldsymbol{i}_7$.

The relative calculation error, made according to formulas (2) and (9) in [13], is equal to$\delta \boldsymbol{v}_7 \approx$ 16,1 %, which is almost 3 times higher than the accuracy of engineering calculations (≈ 5%). For this reason, formula (2) and / or the reduced formula (2) in [4] is not recommended for practical calculations.

Hence, it becomes obvious that the calculation of the rolling speed of the carriage in the sections of the hump with a small slope is wrong. ($\boldsymbol{i}_7$ = 1,6 ‰) if the projection of the tailwind force is not taken into account$\boldsymbol{F}_{вх}$(see the second paragraph of the middle column on page 24 in [2]).

4) If for the main specific resistance to movement, according to table. 4.2 in [18], accept$\boldsymbol{\omega}_{о1}$ = 0,5 kgf / tf for a very good runner (OH), then the sliding speed of the car$\boldsymbol{v}_{о7}$on the section SP1 slides, m / s:

$$v_{о7} = \sqrt{v_{н7}^2 + 2g'(i_7 + |w_{о7}|)10^{-3} \cdot l_7} =$$
$$= \sqrt{3{,}154^2 + 2 \cdot 9{,}635(1{,}6 - 0{,}5)10^{-3} \cdot 59{,}18} = 3{,}347.$$

Note that when calculating vo7, the values of ωo7 were taken without change, i.e..$\boldsymbol{\omega}_{о1}$= 0,5 kgf / tf.

The relative calculation error, made according to formulas (2) and (9) in [13], is equal to$\delta \boldsymbol{v}_{о7} \approx$ 9,8 %, which is almost 2 times higher than the accuracy of engineering calculations (≈ 5%). For this reason, the values$\boldsymbol{w}_{07}$= $\boldsymbol{\omega}_{о7}$= 0,5 kgf / tf is not recommended for practical calculations.

5) Let's calculate the rolling speed of the car on the section SP1 of the hill according to the formula (2) taking into account the projection of the tailwind force$\boldsymbol{F}_{вх}$and explanations in formula (16) in [13], m / s:

$$v_{х7} = \sqrt{v_{н7}^2 + 2g'(i_{х7} + |w_7|)10^{-3} \cdot l_7} =$$
$$= \sqrt{3{,}154^2 + 2 \cdot 9{,}635(1{,}6 - 1{,}817)10^{-3} \cdot 59{,}18} = 3{,}702.$$

The relative calculation error, made according to formulas (2) and (9) in [13], is equal to$\delta \boldsymbol{v}_{х7} \approx$ 0,25 %, which is negligible.

VI. CONCLUSION AND FUTURE WORK

Analyzing the results of calculating the rolling speed of the car at the intermediate section (PR), the switch zone (SZ) after the second arrow (C2), the first sorting track (SP1) of the hill (see examples of calculations 1 - 3), one can come to the conclusion that it is inexpedient to use when hill calculations of formula (2), as part of formula (2) (without the incorrectly included subtracted one) in [4] for all sections of the hill profile, since the relative calculation error (with the same initial data)$\delta \boldsymbol{v}$compared with the simplified calculation methodology of the authors of the article [3] when the projection of the tailwind force is not taken into account$\boldsymbol{F}_{вх}$reach from 4 to 16.1%.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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Proceeding from this, the results of the calculations proved the inconclusiveness of using formula (2) in hill calculations, as part of formula (2) (without the incorrectly included subtracted) in [4], for all sections of the hill profile, since:

firstly, in the intermediate section (PR) of the hump before the dividing arrow (C), the relative calculation error, made according to formulas (2), compared with the exact formula of elementary physics (9) in [13], is$\delta \boldsymbol{v_4} \approx 10{,}3$ %, which is almost 2 times higher than the accuracy of engineering calculations ($\approx 5\%$);

secondly, in the section of the switch zone (SZ) of the hump of the second dividing arrow (C2), the relative calculation error, made according to formulas (2) and (9) in [13], is$\delta \boldsymbol{v_{6c2}} \approx 9{,}0$ %, which is almost 2 times higher than the accuracy of engineering calculations ($\approx 5\%$);

thirdly, in the section of the first sorting track (SP1), the relative calculation error, made according to formula (2) compared with formula (9) in [13], is$\delta \boldsymbol{v_7} \approx 16{,}1$ %, which is almost 3 times higher than the accuracy of engineering calculations ($\approx 5\%$);

fourthly, in the section of the first sorting track (SP1), the relative calculation error, made according to formulas (2) and (9) in [13] with the value of the specific resistance to the movement of the car$\boldsymbol{w_{07}} = \boldsymbol{\omega_{o7}} = 0{,}5$ kgf / tf is equal to$\delta \boldsymbol{v_{o7}} \approx 9{,}8$ %, which is almost 2 times higher than the accuracy of engineering calculations ($\approx 5\%$).

Based on this, it can be argued that the reasoning of the authors of the article [4] that formula (2) in [4] can be used for calculations on any sections with a slope i of the hump, taking into account the presence of specific values of resistance to movement w (see the first paragraph of the last column on page 36 in [4]) are objectionable and / or questionable.

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