Calculation of the speed of movement of the car along the entire length of the path profile with different inclines of the sorting slide

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Abstract. In the article, a formula derived on the basis of the kinetic energy change theorem for a non-free material point in a finite form is used to calculate the speed of movement of the car on various sections of the sorting slide. Examples of calculations show that in the intermediate section of the sorting slide to the dividing switch, the relative calculation error is 10.3%, in the section of the switching zone of the sorting slide of the second dividing switch – δv6s2 ≈ 9.0 %, in the section of the first sorting path – δv7 ≈ 16.1%.

1 Introduction

As it is known [1 – 10], the existing theoretical provisions of the design and technological calculations of the designed sections of the sorting slide [11 – 18] are not devoid of inaccuracies. In [4], in order to really take into account the operational conditions of the sorting slides, it is recommended to use the parameters of the specific resistance to movement ***w***, which reflect the generalized characteristics of the modern wagon fleet and sorting paths. Taking into account this factor, the formula (2) in [4] is given, supposedly having an expanded universal form:

$$v_e^2 = v_i^2 + 2g'(i-w)10^{-3} \cdot l - 2g'h_b \tag{1}$$

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

At the same time, for the convenience of analysis, we present separately the reduced and subtracted in (1) in the form:

$$v_{ei}^2 = v_{ii}^2 + 2g'(i_i - w_i)10^{-3} l_i \tag{2}$$

$$v_{ebi}^2 = v_{ii}^2 - 2g'h_b \tag{3}$$

Where $\boldsymbol{v_{ibi}} = [\boldsymbol{v_{eni}}] = [\boldsymbol{v_{cdi}}]$ – the maximum permissible speed of the entrance of the car to the car decelerators [23];

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$\boldsymbol{h}_{\mathbf{b}i}$ – the power of the braking positions (according to Table. 2 in [20] the power of $\boldsymbol{M}_{\mathbf{bm}}$ braking means) from the hump of the slide to the park braking position, depending on the type and number of retarders.

Note [9] that formula (2) is necessary to determine the speed of the car on the high-speed sections of the slide profile, and (3) – for the sections of the braking positions (BP). Although, it is known that the derivation of formula (2) and/or formula (2) in [4] based on the kinetic energy change theorem is well known (see formula (30) on page 142 in [12]).

However, in the reduced formula (2) and/or (2) in [4], the unit of measurement of the incline of the profile of the path $\boldsymbol{i}$ in ‰, is equated to the unit of measurement of the resistivity of the movement w of the off-system unit of measurement in kgfpt (i.e., ‰ = kgfpt) (see page 141 in [11], p. 9 in [12]), which is unacceptable in theoretical and engineering mechanics [21, 22].

1.1 The purpose of this article

The results of calculations of the rolling speed of the car on the intermediate section, the switch zone after the second switch, the first sorting path of the slide prove that the formula (2) describing the movement of the car on the high-speed sections of the slide, presented in a universal form in [4], is not applicable for sections of the slide with a small incline.

1.2 Problem statement

With the calculated data, check the applicability of formula (2), as part of the universal form formula in [4] on various sections of the sorting slide (except for brake positions).

1.3 Research method

The practical problem of determining the speed of the carriage along the incline of the sorting slide is solved on the basis of the theorem on the change of kinetic energy for a non-free material point in a finite form [21, 22].

2 Example of performing hill calculations

To determine the limit and/or the limit of applicability of formula (2) (without incorrectly included deductible) in [4] or formula (2) for the entire length of the path profile with different inclines, we present below the results of studies to determine the kinematic parameters of the car on various sections of the slide. So, for example, we determine the speed of the car on the first intermediate section of the slide (IN) to the dividing switch (S), the switch zone (SZ) of the second switch (S2), as well as on the first sorting path (ST1) by formula (2), as a subtractible formula (2) in [4].

Calculation example 1. For example, we examine the intermediate section (IN) to the dividing switch (S) of the slide. The initial data for the section of the IN hill are as follows: vi4 = 1.519 – the accepted value of the speed of entry of the car on the IN section after the car leaves the zone of braking of the car retarder of the second braking position (2BP), mps; g' = 9.635 – acceleration of the free fall of the body taking into account the mass of rotating parts, mps2; l4 = 20,001 – the length of the intermediate section, m; i4Ck = 11 – the incline of the main section, ‰; Fo4 = ko4G = 0,001G = 0,908 – the force of the main resistance to the movement of the car to the dividing switch (S) of the section IN hill (where ko4 = 0.001

– a coefficient that takes into account the resistance from the rolling friction force with sliding of the wheelset, taking into account the tailwind, while ko4 = ωo4 = 0,5 – the main resistivity the movement of a very good runner (VG), kgfpts (see Table 4.2 in [15]), kN; Fra4 = kra4G = 0,0005G = 0,454 – force resistance from the air and wind (where kra4 = 0.0005 – resistance from the environment and wind).

Calculation results [23]. We will perform the calculations in the following sequence.

Calculate the total specific resistance to the movement of the car, taken into account as a dimensionless value:

$$|\boldsymbol{w}_4| = |\boldsymbol{k}_{o4} + \boldsymbol{k}_{ra4}| = -0.0015$$

Note that the rolling speed of the wagon v4, calculated by the formula of elementary physics with the acceleration value a4 = 0,128 mps2, is equal to v4 = 2.723 mps.

Let's calculate the rolling speed of the car to the dividing switch (S) of the intermediate section (IN) of the slide v4 without taking into account the projection of the force of the tailwind Fwx according to the formula (2), mps.

$$v_4 = \sqrt{v_{i4}^2 + 2g'(i_4 + |w_4|)10^{-3} l_4} =$$

$$\sqrt{1.519^2 + 2 \cdot 9.635(11.0 - 1.5)10^{-3} \cdot 20.0} = 2.443.$$

The relative error of calculations in comparison with the data of the formula of elementary physics is δv4S = 10.3 %, which is almost 2 times higher than the accuracy of engineering calculations (5%).

Let's calculate the rolling speed of the car to the dividing switch (S) of the intermediate section (IN) of the vx4 slide according to the formula (2) taking into account the projection of the force of the tailwind Fwx, mps:

$$v_{x4} = \sqrt{v_{i4}^2 + 2g'(i_{x4} + |w_4|)10^{-3} l_4} =$$

$$\sqrt{1.519^2 + 2 \cdot 9.635(14.515 - 1.5)10^{-3} \cdot 20.0} = 2.706.$$

The relative calculation error performed according to the formulas of elementary physics is equal to δvx4s ≈ 0.6 %, which is negligible.

4) It is interesting to note that if we vary the value of the initial speed of the carriage vi4 in the range from 1 to 2.0 mps with a step of Δvi4 = 0.125 at w4 = 1.5 (dimensionless value) and i4 = 11, then the value of the rolling speed of the carriage in the calculated section v4Sk increases from 2.159 to 2.768 mps.

The graphical change v4 = f(vi4) is shown in Fig. 1.

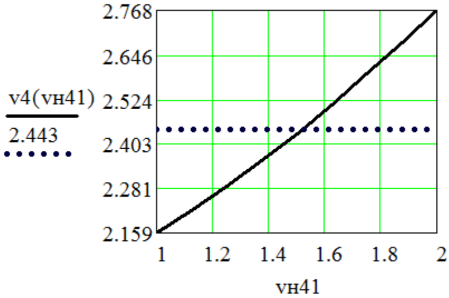

Fig. 1. Graphical change $v_{4S} = f(v_{i4S})$

Note that even if we vary the value of the specific resistance to the movement of the wagon w4 in the range from 0.5 to 3.0 (dimensionless value) with a step of Δw4 = 0.25 at vi4 = 1.529 m/s and i4S = 11, the value of the rolling speed of the wagon in the calculated section v4Ck decreases from 2.521 to 2.332 mps.

The graphical change of v41 = f(w4S) is shown in Fig. 2.

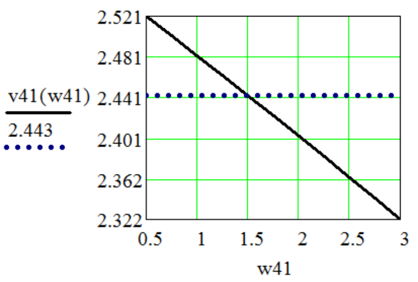

Fig. 2. Graphical change v41 = f(w4)

If we vary the value of the incline of the path i4 in the range from 10.0 to 12.0 with a step of Δi4 = 0.25 ‰ at vi4 = 1,529 mps and w4 = 1.5 (dimensionless value), then the value of the rolling speed of the car on the calculated section v4 increases from 2.363 to 2.521 mps. The graphical change v4i = f(i4) is shown in Fig. 3.

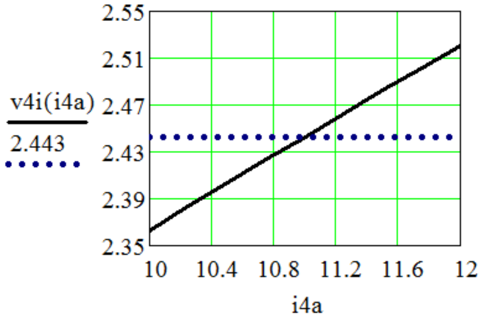

Fig. 3. Graphical change v4i = f(i4)

Example of calculation 2. For an example of calculation, we examine the section of the switch zone (SZ) after the second switch (S2). The initial data of the section of the SZ are as follows: G = 650 – the gravity of the load on the car, kN; G0 = 908 – the gravity of the car with the load, kN; sinψ6s2 = 0.002 and cosψ6s2 = 1.0 or i6c2 = 2 ‰ – the incline of the profile of the path of the slide SZ, rad.; g' = 9.635 – acceleration of the free fall of the body with taking into account the mass of the rotating parts, calculated with a relative calculation error δg ≈ 0.184% at g = 9.81 mps2, n = 4 pcs., Q = G0 = 92.56 ts and/or G = 908 kN (according to Table 4.2 in [15] – this is a very good runner (VG)), γ = 0.00185 (see page 183 in [11]), m/s2; l6s2 = 21.0 – the length of the section of the SZ after the second switch (S2), m; vi6s2 = 2.654 – the accepted value of the speed of the entrance of the car to the section of the SZ after the second switch (S2) of the slide after the exit of the car from the first dividing switch (S1) of this zone, mps; Fm6s2 = km6s2G = 0.001 G = 0.908 – the force of the main resistance to the movement of the car on the section of the second switch (S2) of the slide SZ (where km6s2 = 0.001 is a coefficient that takes into account the resistance from the rolling friction force with sliding of the wheelset, taking into account the tailwind of a small value

Fwx ≈ 3.2 kN), kN; Fsw = kswG = 0.00025G = 0.227 – force resistance at the transition of the curves of the sections of the path (where ksw = 0.00025– resistance from the switchs), kN; Fcur6S2 = kcur6S2G = 0.0002463G = 0.224 – force resistance at the transition of the curves of the sections of the path (where kcur6S2 = 0.0002463 – resistance from the curves), kN; Fra = kraG = 0.0005G = 0.454 – force resistance from the air and wind (where kra = 0.0005– resistance from the medium), kN; Fsn = ksnG = 0.00025G = 0.227 – force resistance from the air and wind (where ksn = 0.00025– resistance from the medium), kN.

Calculation results [23]. 1) Calculate the total resistivity of the movement of the car:

$$|w6S2| = |km6S2 + ksw + kcur6S2 + kra + ksn| =$$

$$= -(0.001 + 0.00025 + 0.0002463 + 0.0005 + 0.00025) = -0.002246.$$

We present the results of calculating the speed of movement of the car according to the formulas of elementary physics, the possibility of using which is analytically proved in [24] (see formulas (16), (19) – (20)).

Let's calculate the time of movement of the car at the initial speed and/or the speed of the entrance of the car to the investigated section of the slide SZ vi6s2 = 2.654 mps and acceleration a6s2 = 0.032 mps2 with equidistant motion, taking into account the projection of the force of the tailwind Fwx: t6s2 = 7.567 s.

Calculate the rolling speed of the car taking into account the projection of the tailwind force Fwx at vi6s2 = 2.654 mps, a6s2 = 0.032 mps2 and t6s2 = 7.567 s:

v6s2 = 2.897 mps and/or v6s2 ≈ 10.43 kmph.

2) Let's calculate the rolling speed of the car after the dividing switch (S2) of the section of the slide SZ according to the formula (2) without taking into account the projection of the force of the tailwind FWx, mps:

$$v_{6s2} = \sqrt{v_{i6s2}^2 + 2g'(i_{6s2} + |w_{6s2}|)10^{-3} l_{6s2}} =$$

$$= \sqrt{2.654^2 + 2 \cdot 9.635(2 - 2.2246)10^{-3} 21.0} = 2.635$$

Here, the resulting calculation result v6s2 = 2.635 mps is less than the initial velocity vi6s2 = 2.654 mps, since |w6s2| > i6s2.

The relative calculation error performed by formulas (2) and by formulas of elementary physics is equal to δv6s2 ≈ 9.0%, which is not small, i.e. almost 2 times exceeds the limits of accuracy of engineering calculations (5%).

If for the main specific resistance to movement, according to Table 4.2 in [15], take ωo1 = 0.5 kgfpts for a very good runner (VG), then the rolling speed of the wagon v6s2o after the dividing switch (S2) on the section of the SZ, mps:

$$v_{6s2o} = \sqrt{v_{i6s2}^2 + 2g'(i_{6s2} + |w_{6s2o}|)10^{-3} l_{6s2}} =$$

$$= \sqrt{2.654^2 + 2 \cdot 9.635(2 - 0.5)10^{-3} 21.0} = 2.766$$

Note that when calculating v1o, the values of ωo1 were taken unchanged, i.e. ωo1 = 0.5 kgfpts.

The relative calculation error performed by formulas (2) and by formulas of elementary physics is equal to δv6s2o ≈ 4.51%, which is not enough.

Let's calculate the rolling speed of the car after the dividing switch (S2) of the section of the slide according to the formula (2), taking into account the projection of the force of the tailwind Fwx, mps:

$$v_{6c2b} = \sqrt{v_{н6c2}^2 + 2g'(i_{x06c2} + |w_{6c2}|)10^{-3} l_{6c2}} =$$

$$= \sqrt{2.654^2 + 2 \cdot 9.635(5.15 - 2.2246)10^{-3} 21.0} = 2.893$$

The relative calculation error performed by formulas (2) and by formulas of elementary physics is equal to δv6s2b ≈ 0.14%, which is negligible.

Calculation example 3. Let's explore the section of the first sorting path (SP1) of the slide. The initial datka of the SP1 section are as follows: vi7 = 3,154 – the accepted value of the speed of the car's entrance to the SP1 section of the slide after the car exits the switch zone (SZ), mps; g' = 9.635 – acceleration of the free fall of the body taking into account the mass of the rotating parts, mps2; l7 = 59.18 – the length of the SP1 section of the slide, m; i7 = 1.6 – slope of the section of the slide SP1, ‰; Fo7 = ko7G = 0,001G = 0.908 – the force of the main resistance to the movement of the car on the section of the slide SP1 (where ko7 = 0.001 is a coefficient that takes into account the resistance from the rolling friction force with sliding of the wheelset taking into account the tailwind Fwx), кH; Fcur7 = kcur7G = 0,00067G = 0.061 – the resistance force during the transition of the curves of the sections paths (where kr7 = 0.00067 is the resistance from the curves), kN; Fr = krG = 0,0005G = 0.454 is the resistance force from the air and wind (where kr = 0.0005 is the resistance from the medium), kN; Fsn = ksnG = 0,00025G = 0.227 is the resistance force from air snow and frost (where ksn = 0.00025 is the resistance from snow and frost), kN.

Calculation results [27]. 1) Calculate the total resistivity of the movement of the car according to the formula:

$$|w7| = |ko7 + kcur7 + kr + ksn| =$$

$$= -(0.001 + 0.000067 + 0.0005 + 0.00025) = -0.001817$$

2) The rolling speed of the wagon v7 on the section of the slide SP1, calculated by the formula of elementary physics with the given initial data of the problem, is equal to: v7 = 3.711 mps.

3) We will calculate the rolling speed of the car on the section of the slide SP1 according to the formula (2) without taking into account the projection of the force of the tailwind Fwx, mps:

$$v_7 = \sqrt{v_{i7}^2 + 2g'(i_7 + |w_7|)10^{-3} \cdot l_7} = \sqrt{3.154^2 + 2 \cdot 9.635(1.6 - 1.817)10^{-3} \cdot 59.18} = 3.114$$

Here, the resulting calculation result v7 = 3,114 mps is less than the initial velocity vi7 = 3,154 mps, since |w7| > i7.

The relative calculation error performed by formulas (2) and by formulas of elementary physics is equal to δv7 ≈ 16.1%, which is almost 3 times higher than the accuracy of engineering calculations (≈ 5%).

Hence, it becomes obvious that the calculations of the rolling speed of the car on the sections of the sorting hill with a small slope (i7 = 1.6 ‰) are erroneous without taking into account the projection of the force of the tailwind Fwx (see the second paragraph of the middle column on page 24 in [2]).

If for the main specific resistance to movement, according to Table 4.2 in [15], take ωo1 = 0.5 kgfpts for a very good runner (VG), then the sliding speed of the wagon vo7 on the section of the slide SP1, mps:

$$v_{o7} = \sqrt{v_{i7}^2 + 2g'(i_7 + |w_{o7}|)10^{-3} \cdot l_7} =$$
$$= \sqrt{3.154^2 + 2 \cdot 9.635(1.6 - 0.5)10^{-3} \cdot 59.18} = 3.347$$

Note that when calculating vo7, the values of ωo7 were taken unchanged, i.e. ωo1 = 0.5 kgfpts.

The relative calculation error performed by formulas (2) and by formulas of elementary physics is equal to δvo7 ≈ 9.8%, which is almost 2 times higher than the accuracy of engineering calculations (≈ 5%). For this reason, the values w07 = ωo7 = 0.5 kgfpts are not recommended for performing practical calculations.

5) Calculate the rolling speed of the car on the section of the SP1 slide according to the formula (2), taking into account the projection of the force of the tailwind Fwx, mps:

$$v_{x7} = \sqrt{v_{i7}^2 + 2g'(i_{x7} + |w_7|)10^{-3} \cdot l_7} = \sqrt{3.154^2 + 2 \cdot 9.635(1.6 - 1.817)10^{-3} \cdot 59.18} = 3.702$$

The relative calculation error performed according to formulas (2) and (9) in [13] is equal to δvx7 ≈ 0.25 %, which is negligible.

3 Conclusions

Analyzing the results of calculations of the rolling speed of the car on the intermediate section (IN), the switch zone (SZ) after the second switch (S2), the first sorting path (SP1) of the slide (see examples of calculations 1 – 3), it can be concluded that it is inappropriate to use formula (2) in hill calculations as part of formula (2) (without incorrectly included subtractible) in [4] for all sections of the slide profile, since the relative error of calculations (with the same initial data) δv is compared with by the simplified calculation method of the authors of the article [3], when not taking into account the projection of the force of the tailwind Fwx reach from 4 to 16.1%.

Based on this, the results of the calculations proved the inconclusiveness of the use of formula (2) in hill calculations, as part of formula (2) (without incorrectly included deductible) in [4], for all sections of the slide profile, since:

firstly, in the intermediate section (IN) of the sorting slide to the dividing switch (S), the relative calculation error performed according to formulas (2) compared with the exact formula of elementary physics is equal to δv4 ≈ 10.3%, which is almost 2 times higher than the accuracy of engineering calculations (≈ 5%);

secondly, in the section of the switch zone (SZ) of the sorting slide of the second dividing switch (S2), the relative calculation error performed according to formulas (2) and according to formulas of elementary physics is equal to δv6c2 ≈ 9.0%, which is almost 2 times higher than the accuracy of engineering calculations (≈ 5%);

thirdly, on the section of the first sorting path (SP1), the relative calculation error performed according to formula (2) in comparison with the formula of elementary physics is equal to δv7 ≈ 16.1%, which is almost 3 times higher than the accuracy of engineering calculations (≈ 5%);

Fourthly, on the section of the first sorting path (SP1), the relative calculation error performed according to formulas (2) and according to formulas of elementary physics at the value of the specific resistance to the movement of the car w07 = ωo7 = 0.5 kgfpts is equal to δvo7 ≈ 9.8%, which is almost 2 times higher than the accuracy of engineering calculations (≈ 5 %).

Based on this, it can be argued that the reasoning of the authors of the article [4] that the formula (2) in [4] can be used for calculations on any sections with a slope i of the sorting slides, 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]) raise objections and/or fall under doubt.

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