About the movement of the car on the high-speed sections of the sorting hill

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Abstract. The content of the article is based on the classical provisions of mechanics (the Dalembert principle) for non-ideal communication. The analytical proof is given that the linear acceleration of the car with its equally accelerated movement along the descent part of the sorting slide depends on the force under the influence of which the car rolls down the slope of the slide, the strength of resistances of all kinds, on the reduced mass of the car with the load, taking into account the moment of inertia of the rotating parts. At the same time, the results of calculations proved that taking into account the mass of rotating parts practically does not affect the acceleration of the carriage along the slope of the slide. The acceleration formulas and the resulting forces acting on the car are presented in the generally accepted notation and in the usual sense, followed by the calculated data. Keywords: Railway, station, sorting hill, carriage, acceleration of carriage movement, reduced mass, inertia of rotating parts.

1 Introduction

As is known [1-10], public discussions about the correctness of the existing theoretical provisions of the design and technological calculations of the projected sections of the sorting slide have been actively discussed on the pages of the periodical press [11-16].

It is noted in [6] that the authors of the article [4], having mathematically unsubstantiated the correctness of the universal formula (4), stubbornly defend their opinion that it can be used for calculations on any sections [15] with a slope of sorting slides. At the same time, in formula (4) [4], the acceleration of free fall $g'$, taking into account the inertia of the rotating masses, is also taken into account in the sections of the braking positions (see subtracted $2g'h_m$ in formula (4)). In addition, the impact of accounting and/or not taking into account the inertia of rotating masses on the acceleration of the movement of the car along the profile of the sorting slide has not yet been assessed.

In the article, based on the classical provisions of mechanics (the Dalembert principle) for an imperfect connection [17, 18], an analytical proof will be given that the linear acceleration of the car with its equidistant movement along the descent part of the sorting slide $a_i = a_{Ci}$ depends on the force $F_{si}$, under the influence of which the car rolls down the slope of the slide, resistance forces of all kinds $|F_{el}|$, as well as from the reduced mass of the carriage with the load $M_{red}$, taking into account the moment of inertia of the rotating parts.

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At the same time, it will be proved that taking into account the mass of rotating parts practically does not affect the acceleration of the carriage along the slope of the slide.

2 The purpose of this article

To prove and explain to the authors of the article [2, 4] that in the design and technological calculations of the projected sections of the slide, the most important kinematic parameter of the movement of the car is the calculation of its acceleration, the value of which directly depends on the rest of the movement parameters (time, speed and path of passage of the studied sections).

3 Problem statement

It is required to give the results of calculations of acceleration with equidistant movement of the car on a specific section of the slide (for example, on the second high-speed section HS2), taking into account and without taking into account the mass of rotating parts, and to prove that in this case the relative error is THE PURPOSE OF THIS ARTICLE

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Problem statement. It is required to give the results of calculations of acceleration with equidistant movement of the car on a specific section of the slide (for example, on the second high-speed section SK2), taking into account and without taking into account the mass of rotating parts, and to prove that in this case the relative error is \( \delta a_{\text{sw}} = 4.18 \approx 4.2\% \), which is less than the accuracy of engineering calculations (\( \approx 5\% \)), which is less than the accuracy of engineering calculations (\( \approx 5\% \)).

4 Research method

As in [6], the solution of the engineering problem of the carriage movement along the slope of the sorting slide is given on the basis of the application of the basic law of dynamics for non-ideal connections (the Dalembert principle) [17, 18].

5 Mathematical description solution of the problem

Mathematically, the movement of the car on the high-speed sections of the sorting slide will be described according to the Dalembert principle [17, 18] in projections on the descent part of the sorting slide.

Similarly [6], the analytical formula for finding the acceleration of the carriage \( a_{Ci} = a_i \) along the descent part of the sorting slide has the form:

\[
a_{Ci} = \frac{|\Delta F_{xi}|}{M_{\text{red}}} 10^3, \tag{1}
\]

Where

- \( i \) – the numbers of sections along the entire length of the sorting slide path profile (\( i = 1, \ldots 9 \));
- \( |a_{Ci}| = |a_i| \) – acceleration of the center of mass of the \( C_c \) car to be found [19], mps\(^2\);
\( M_{\text{red}} \) is the reduced and/or imaginary mass of a car with a load, taking into account the moment of inertia of the rotating parts (wheel pairs) \( J_D \) on all sections of the slide descent (see formula (5.39b) on page 411 in [20]), kg:

\[
M_{\text{red}} = M_1 + 6m_{\text{wh}},
\]  

(2)

Taking into account that in it
\( M_1 = 80.94 \times 10^3 \) – the weight of the wagon with cargo, taking into account non-rotating parts (i.e. bogies, wagon body), kg;
\( m_{\text{wh}} = 1.937 \times 10^3 \) – weight of one wheelset, kg;
\( |\Delta F_i| \) – the resultant force under the influence of which the car rolls down the descent part of the sorting slide, similar to the formula (7) in [6]), kN:

\[
|\Delta F_{xi}| = F_{xi} - |F_{ri}|
\]  

(3)

Taking into account that in it,
\( F_{xi} \) – the projection of the gravity of the loaded car \( G \) on the direction of movement of the car, taking into account and/or without taking into account the projection of the force of the tailwind \( F_{wx} \), under the influence of which the car moves along the slope of the descent part of the slide, kN:

\[
F_{xi} = G \sin \psi_i + F_{wx} \cos \psi_i.
\]  

(4)

Note that the value \( F_{wx} \), can be neglected due to its smallness: \( F_{wx} \ll G \) (for example, \( 3.2 \ll 908 \) kN);
\( \psi_i \) – the slope angle of the descent part of the slide, rad.;
\( |F_{ri}| \) – in general, the resistance force of any kind.

Here, the resistance force of any kind is \( |F_{ri}| \) taking into account and/or without taking into account the projection of the headwind force of a small magnitude \( F_{wx} \), which can be taken as a fraction of the gravity of the wagon with the load \( G \), i.e. \( |F_{ri}| = f(G) \), which does not contradict the force ratios of the hill calculations (see page 180 in [11], p. 141 in [12]), includes the following forces:

- sliding friction, taking into account the rolling friction forces in the bearings of axle assemblies, as a force from the main (running) resistance \( F_{mi} = F_{mi} \);
- the resistances that appear during the transition of curves (and/or resistance from curves), which depend on the sum of the angles of rotation in the curves, including the switch angles in the section under consideration, and the speed of the car, \( F_{curi} \);
- resistances arising from switches (from wheel impacts on wits, crosses and counter rails) \( F_{sw} \);
- resistance from air and wind \( F_{ra} \);
- resistance to overcome additional resistance from snow and frost within the switch zone of the bundles and on the sorting tracks of the \( F_{sa} \).

Based on this, the resistance force of any kind \( |F_{ri}| \), taking into account the impact of the projection of the tailwind force \( F_{wx} \), should be determined by the formula

\[
|F_{ri}| = (F_{mi} + F_{curi} + F_{sw} + F_{ra} + F_{sa}).
\]  

(5)

For the descent part of the slide, except for the sections of the braking positions, the following condition must always be met in formula (1):

\[
F_{xi} > |F_{ri}|
\]  

(6)
It follows from formula (1) that, if the condition $|\Delta F_i| > 0$ and/or, according to (6), $F_{ri} > |F_{ri}|$, corresponding to the consideration of the effect of the projection of the force of a tailwind of a small magnitude $F_{wx}$, the movement of the car along the descent part of the slide at the speed of the car entrance to the investigated section of the slide $v_{ni} > 0$ it will be uniformly accelerated, and if this condition is not met, it will be uniformly slowed down, which may correspond if the impact of the projection of the headwind force of a small magnitude $F_{wx}$, is taken into account.

In the latter formula, the force $F_{xi}$, under the influence of which the car rolls down the slope of the high-speed sections of the slide, is found by formula (4), and the resistance force of all kinds $|F_{ri}|$, according to formula (5), can be represented as:

$$|F_{ri}| = (k_{mi} + k_{cur} + k_{sw} + k_{ra} + k_{sn})G.$$  \hspace{1cm} (7)

In formula (7) it is indicated:
- $k_{mi} = 0.001$ – the coefficient of rolling friction with sliding of hardened steel on hardened steel (see page 42 in [21]) and/or a coefficient that takes into account the strength of rolling resistances of sliding wheels $F_{mi}$ in fractions of $G$;
- $k_{cur,i}$ – a coefficient that takes into account the strength of the resistances during the transition of the curves $F_{cur}$ in fractions of $G$ (the value is calculated);
- $k_{sw} \approx 0.00025$ – a coefficient that takes into account the strength of the resistances from the switches $F_{sw}$ in fractions of $G$;
- $k_{ra} \approx 0.0005$ – a coefficient that takes into account the strength of resistances from the air and wind $F_{ra}$ in fractions of $G$;
- $k_{sn} \approx 0.00025$ is a coefficient that takes into account the force of $F_{sn}$ in fractions of $G$;
- $k_{w,x} \approx 0.004$ is a coefficient that takes into account the force of $F_{wx}$ in fractions of $G$.

Thus, by the formula (1), it is mathematically proved that the linear acceleration of the car with its equidistant movement along the descent part of the sorting slide $a_i$, similar to the expression (8) in [6], depends on the force $F_{xi}$, under the influence of which the car rolls down the slope of the slide, resistance forces of all kinds $|F_{ri}|$, and also from the reduced mass of the carriage with the load $M_{red}$, taking into account the moment of inertia of the rotating parts $J_D$, i.e.

$$a_i = f(F_{xi}, F_{ri}, M_{red}).$$ \hspace{1cm} (8)

As can be seen, the acceleration of the movement of the car along the descent part of the slide $a_i$, determined according to the Dalembert principle, in particular, depends on the reduced mass of the $M_{red}$ of the car with the load, taking into account the moment of inertia of the rotating parts $J_D$.

Note that the speed ($v_{spi} = v_i$) and the path ($l_{spi} = l_i = x_i$) of the carriage movement on the high-speed sections of the track profile at which $v_{xi,sp} \neq 0$, is determined by the formula of speed and path of elementary physics (see formulas (18) and (19) in [19]):

$$v_i = v_{li} + |a_i|t_i;$$ \hspace{1cm} (9)

$$l_i = x_i = v_{li}t_i + \frac{1}{2}|a_i|t_i^2,$$ \hspace{1cm} (10)

Where
- $v_{li}$ – the initial speed and/or the speed of the entrance of the car to the investigated section of the slide profile from the previous section, i.e. the value taken from the results of calculations of the previous sections of the slide;
\(a_i\) – the acceleration of the carriage (the value calculated by the formula (1)).

Jointly solving the last two formulas, it is possible to find the speed \(v_i\) and the time \(t_i\) of the carriage movement on the high-speed sections of the track profile (see formulas (20), (21) in [19]):

\[v_i = \sqrt{v_{i0}^2 + 2|a_i|l_i};\] (11)

\[t_i = \frac{1}{|a_i|}(-v_{i0} + \sqrt{v_{i0}^2 + 2|a_i|l_i}).\] (12)

We will make a special reservation that the applicability of the formula of elementary physics for determining the speed \(v_{s\text{spi}}\) and the path \(l_{s\text{spi}}\) of the movement of the car on the high-speed sections of the track profile is justified on the basis of solving the differential equation of acceleration of the movement of the car, derived on the basis of the Dalembert principle (see formulas (16) and (19) in [19]).

Summarizing the results of studies of the dynamics of the car at equidistant acceleration when moving along the descent part of the sorting slide, it can be concluded that the derivation of formula (1) is correct, the theoretical basis of which is the classical D’Alembert principle of theoretical mechanics [17, 18].

Thus, we emphasize that the D’Alembert principle, being an important tool of mechanics in the study of the dynamics of motion of solids and elastic systems, has the following advantages (see page 308 in [20]):

- firstly, it allows you to use the usual static equilibrium equations (see formula (4.45) in [20]);
- secondly, it makes it possible to immediately obtain equations resolved with respect to the higher derivatives (see formula (4.46) in [20]), and therefore does not require calculations for their allocation;
- thirdly, it allows the possibility to directly find the acceleration of a point in the absolute motion of the \(a_{\text{abs}}\) with known active and reactive forces, or coupling reactions (friction forces, or braking forces), if the acceleration of \(a_{\text{abs}}\) is known and causing its active forces (see condition (6)).

6 Results of the calculated data

Calculation example 1. For example, we study the second high-speed section (HS2), located after the dividing switch (S) of the sorting slide. The initial data are as follows: \(G = 908\) – the gravity of the car with the load, kN; \(v_{2\text{sw}} = 7,285\) – the initial speed and/or the speed of the entrance of the car to the section HS2 after the switch (S), mps; \(\psi_{2\text{sw}} = 0.018\) – the slope angle of the descent part of the slide, rad.; \(l_{2\text{sw}} = 18.633\) – the length of the descent parts of the slide, m; \(F_{x2\text{sw}} = 19.535\) – projection of the gravity of the car \(G\) on the \(Cx\) axis, taking into account the projection of the tailwind force of a small magnitude \(F_{wX} (F_{wX} \approx 3,2\text{ kN})\) on the section of the slide HS2; \(F_{o2\text{sw}} = k_{o2\text{sw}}G = 0.0001\times908 \approx 0.908\) – force from the main resistance to the movement of the car, kN; \(F_{ra} = k_{ra}G = 0.0005\times908 = 0.454\) – resistance force from air and wind, kN; \(F_{s2\text{sw}} = k_{s2\text{sw}}G = 2,5\times10^{-4}\times908 = 0.227\) – resistance force from snow and frost, kN; \(F_{sw} = k_{sw}G = 2,5\times10^{-4}\times908 = 0.227\) – resistance force when passing through the dividing switch, kN; \(F_{cur2\text{sw}} = k_{cur2\text{sw}}G = 5,317\times10^{-5}\times908 = 0.048\) – resistance force when passing curves (and/or resistance from curves), kN.

Calculation results [22]. 1) In the general case, the resistance force of any kind on the slope section HS2 of the slide, calculated by the formula (7), kN:

\[|F_{2\text{sw}}| = F_{o2\text{sw}} + F_{rw} + F_{s2\text{sw}} + F_{sw} + F_{cur2\text{sw}} = (0,908 + 0,454 + 0,227 + 0,227 + 0,048) = 1,864.\]
2) The reduced mass of the carriage with the \( M_{\text{red}} \) load taking into account the moment of inertia of the rotating parts \( J_C \), calculated by the formula (2), kg:
\[
M_{\text{red}} = M_1 + 6 \cdot m_{\text{wh}} = 80,94 \cdot 10^3 + 6 \cdot 1,937 \cdot 10^3 = 9,2562 \cdot 10^4.
\]
3) The resultant force, under the influence of which the car rolls down the descent part of the sorting slide \( \Delta F_7 \), calculated by the formula (3), kN:
\[
|\Delta F_{2sw}| = |F_{2sw} + |F_{r2sw}| = 4,645 - 1,864 = 17,67.
\]
4) Acceleration of the center of mass of the \( C \) car (see Fig. 2 in [19]), calculated by the formula (1), mps\(^2\):
\[
a_{2sw} = |\Delta F_{2sw}| \cdot 10^3 / M_{\text{red}} = |17,67| \cdot 10^3 / (9,256 \cdot 10^4) = 0,191.
\]
We calculate the acceleration at the equidistant movement of the car on the section \( HS_2 \) according to the formula (1), substituting the value of \( M_{\text{cur}} \) instead of \( M_{\text{cur}} \) (where \( M_{\text{cur}} = 8,869 \cdot 10^4 \) is the mass of the car excluding rotating parts, kg), mps\(^2\):
\[
|\Delta F_{2sw}| \cdot 10^3 / M_{\text{red}} = |17,67| \cdot 10^3 / (8,869 \cdot 10^4) = 0,199.
\]
5) We present the results of the calculation according to the formulas of elementary physics (9) – (12), the possibility of using which is analytically proved in [19] (see formulas (16), (18) – (20)).
Let's calculate the time of movement of the car according to the formula (12) at the initial speed and/or the speed of entry of the car to the section \( HS_2 \) of the slide, \( v_{i2sw} = 7.285 \) m/s, and the acceleration of movement \( a_{2sw} = 0.191 \) mps\(^2\), calculated according to the formula (1): \( t_{2sw} = 2.477 \) s.
Calculate the speed of the car using the formula (9,180) and/or, which is the same according to (11), at the initial speed and/or the speed of the entrance of the car to the section of the hill \( HS_2 \) \( v_{i2sw} = 7.285 \) m/s, \( a_{2sw} = 0.191 \) mps\(^2\) and \( t_{2sw} = 2.477 \) s: \( v_{2sw} = 7,758 \) mps with and/or \( v_T \approx 27.9 \) kmph.
To control the correctness of the accepted formulas (9) – (12) from elementary physics, we calculate the path of the car according to the formula (10) at the speed of the car's entrance to the section of the hill \( HS_2 \) \( v_{i2sw} = 7.285 \) mps, \( a_{2sw} = 0.191 \) mps\(^2\) and \( t_{2sw} = 2.477 \) s:
\[
l_{2sw} = v_{i2sw} t_{2sw} + \frac{(a_{2sw} t_{2sw})^2}{2} = 7,285\cdot7,285 + (0,191\cdot7,285)^2/2 = 18,633 \text{ m}.
\]
7 Representation of formulas (1) and (3) in the generally accepted notation and in the usual sense

Let us present formulas (1) and (3), according to [4, 11-16], in the generally accepted notation and in the usual understanding (see the penultimate paragraph of the last column on page 36 in [4]).
In accordance with the initial data of the calculation example 1, we note that the force \( F_{xi} \), under the influence of which the car moves along the descent part of the slide, taking into account the projection of the tailwind force of a small magnitude \( F_{wx} \), can be represented as a fraction of the gravity of the car with a load \( G \) in the form:
\[
F_{xi} = i_{x0i} G,
\]
Where
\( i_{x0i} = i_{xi} + k_{wx} \) – a dimensionless value that conditionally characterizes the designation of the slope of the descent part of the slide in fractions of \( G \) when taking into account the impact of the projection of the force of a tailwind of small magnitude \( F_{wx} \), and when not taken into account: \( k_{wx} = 0 \), i.e. \( k_{wx} = f(G) \).

Similarly to the force \( F_{di} \), the force of all resistances \( |F_{di}| \) and, therefore, in the general case, the resistance force of any kind (sliding friction force taking into account the rolling friction forces in the bearings of axle assemblies, as the main resistance \( F_{mi} = F_{mi} \), from the curves \( F_{car} \), from the switches \( F_{sw} \), from the air and wind \( F_{ra} \), from snow and frost \( F_{sn} \) taking into account and/or without taking into account the projection of the force of a passing and/or headwind of a small magnitude \( F_{wx} \), which can be taken as a fraction of the gravity of the wagon with the load \( G \), i.e. \( |F_{di}| = f(G) \), kN.

So, for example, in relation to the section of the first sorting path (SP1):

\[ F_{x7} = k_{x07}G, \]

where \( k_{x07} = 0.0051 \) is a coefficient that takes into account the fraction of the driving force of \( F_{x7} \), taking into account the projection of the tailwind force of a small magnitude \( (F_{wx} \approx 3.2 \text{ kN}) \) from \( G \) on the \( Cx \) axis, i.e. \( F_{x7} = 0.0051 \times 908 = 4.645 \text{ kN} \);

\[ F_{07} = k_{07}G, \]

where \( k_{07} = 0.0001 \) is a coefficient that takes into account the fraction of the main resistance force of \( F_{07} \) from \( G \);

\[ F_{cur} = k_{cur}G, \]

where \( k_{cur} \approx 0.00087 \) is a coefficient that takes into account the fraction of the resistance force during the transition of curves (and/or resistance from curves) \( F_{cur} \) from \( G \);

\[ F_{ra} = k_{ra}G, \]

where \( k_{ra} \approx 0.0005 \) is a coefficient that takes into account the proportion of the resistance force from the air and wind \( F_{ra} \) from \( G \).

As a result, the strength of any resistance \( |F_{di}| \) when taking into account the effects of a tailwind is determined by the formula (7), where \( k_{wx} = 0 \) – corresponds to the case of not taking into account the projection of the wind force \( F_{wx} \), since \( F_{wx} \ll G \) and / or \( 3.2 \ll 908 \).

Finally, formula (1), according to [4, 11-16], will be presented in the generally accepted notation and in the usual sense in the following form (for comparison, see the second term of formula (4) in [4]):

\[ a_i = g(i_{x0i} - |w_i|), \]

(14)

Where,

\( a_i \) – the acceleration of the center of mass of the \( C_t \) car to be found (the figure is not given here), \( \text{mps}^2 \);

\( g \) – the acceleration of gravity of the body, \( \text{mps}^2 \):

\[ g = \frac{G}{M_{red}} \times 10^3; \]

(15)

\( i_{x0i} = i_{xi} + k_{wx} \) – an abstract number and/or a dimensionless quantity represented in (13);

\( |w_i| \) – an abstract number and/or a dimensionless quantity that conditionally characterizes the designation of the specific resistance to the movement of the car along the descent part of the slide in fractions of \( G \) (i.e. \( w_i = f(G) \)), in contrast to [11, p. 180; 12, 14 – 16], where \( |w_i| \) has dimension in an off-system unit of measurement (kgfpt):

\[ |w_i| = k_{mi} + k_{cur} + k_{sw} + k_{ra} + k_{sn}. \]

(16)

It follows from formula (14) that if the condition \( i_{x0i} > |w_i| \) is met, the movement of the car along the descent part of the slide will be uniformly accelerated (which corresponds to taking into account the effects of a tailwind), and at \( i_{x0i} < |w_i| \) – uniformly slowed down, which may occur when taking into account the effects of a small headwind.
Note that formula (14) is apparently equivalent to dependence (1).

As can be seen, the acceleration of the movement of the car along the descent part of the slide \(a_i\), determined according to the Dalembert principle, in the generally accepted notation and in the usual sense depends on the acceleration of the free fall of the body, the slope and the resistivity of the movement of the car along the descent part of the slide \(i_{sw}\) and \(|w_i|\), i.e.

\[
a_i = f(g, i_{sw}, w_i),
\]

(17)

Which, apparently, is equivalent to the dependence (8).

However, for the convenience of performing the calculation, it is more convenient to represent the resulting force \(|\Delta F_i|\) (see formula (7)), under the influence of which the car rolls down the slide, in the form of:

\[
|\Delta F_i| = (k_{x0i} + |k_m| + k_{cur} + k_{sw} + k_{ra} + k_{sn})G,
\]

(18)

Where \(k_{x0i} = i_{sw} - k_{wx}\) – a conditional coefficient that takes into account the effect of the force contributing to the movement of the car along the slide profile.

As can be seen (see formula (15)), the acceleration of the movement of the car along the descent part of the slide \(a_i\), determined according to the Dalembert principle, in particular, depends on the reduced mass of the \(M_{red}\) of the car with the load, taking into account the moment of inertia of the rotating parts \(J_c\).

However, previously performed calculations proved that when taking into account the reduced mass of the \(M_{red}\) of a wagon with a load, taking into account the moment of inertia of the rotating parts \(J_c\), the relative error compared with the failure to take into account this moment of inertia (which is equivalent to calculating \(M_{red0}\)) is only 4.2%, which is less than 5%, which is negligible when performing engineering calculations.

8 Results of the calculated data

Calculation example 2. For example, we examine the intermediate section (IN) located after the dividing switch (S) of the sorting slide. The initial data are as follows: \(G = 908\) – the gravity of the car with the load, kN; \(v_{in} = 2.723\) – the initial speed and/or the speed of the entrance of the car to the IN section after the switch (S), mps; \(\psi_{ad} = 0.0011\) – the slope angle of the descent part of the slide, rad.; \(l_{ad} = 21.271\) – the length of the descent parts of the slide, m; \(F_{wx} = 13.18\) – projection of the gravity of the car \(G\) on the \(Cx\) axis, taking into account the projection of the tailwind force of a small magnitude \(F_{wx}\) \((F_{wx} \approx 3.2\) kN) on the section of the IN slide; \(F_{x0}, \psi = k_{ad}G = 0,0001-908 = 0.908\) – force from the main resistance to the movement of the car, kN; \(F_{ra} = k_{ra}G = 0,0005-908 = 0.454\) – resistance force from air and wind, kN; \(F_{sw} = k_{sw}G = 2,5\cdot10^{-4}-908 = 0.227\) – resistance force from snow and frost, kN; \(F_{sw} = k_{sw}G = 2,5\cdot10^{-4}-908 = 0.227\) – resistance force from snow and frost, kN; \(F_{cur} = k_{cur}G = 6,052\cdot10^{-4}-908 \approx 0.095\) – resistance force when passing curves (and/or resistance from curves), kN; \(|F_{rid}| = 1.911\) – in general, the force resistance of all kinds on the site of the IN hill, book.

Calculation results [22]. 1) Dimensionless value \(i_{sw0}\), conditionally characterizing the designation of the slope of the descent part of the slide, taking into account the effect of the projection of the force of the tailwind \(F_{wx}\), calculated on the basis of formula (13):

\[i_{sw0} = 0.015.\]

2) Dimensionless value \(|w_{ad}|\), conditionally characterizing the designation of the specific resistance of the movement of the car along the descent part of the slide, calculated in relation to the first sorting section slides based on the formula (16):
\[ |\mathbf{w}| = k_{\text{md}} + k_{\text{va}} + k_{\text{sm}} + k_{\text{curd}} = 0,001 + 0,0005 + 0,00025 + 0,00025 + 0,00061 = 0,0021. \]

3) The resultant force, under the influence of which the car rolls down the descent part of the sorting slide \(|\Delta F|\), calculated on the basis of the formula (3) and/or (13), kN:
\[ |\Delta F_{\text{ad}}| = F_{\text{ad}} - |F_{\text{ra}d}| = (13,18 - 1,911) = 11,268 \approx 11,3. \]

4) Acceleration of the center of mass of the \(C_c\) car (the figure is not given here), calculated by the formula (1), m/s²:
\[ a_{\text{ad}} = |\Delta F_{\text{ad}}| \cdot 10^3 / M_{\text{red}} = |11,3| \cdot 10^3 / (9,256 \cdot 10^4) = 0,122. \]

Acceleration of the center of mass of the \(C_c\) car, calculated by the formula (14), m/s²:
\[ a_{\text{ad}} = g(i_7 - |\mathbf{w}|) = 9,81 \cdot (0,015 - 0,002105) \approx 0,122, \]
which exactly matches the result calculated by formula (1).

9 Conclusions

1. It is analytically proved that the linear acceleration of the car with its equally accelerated movement along the descent part of the sorting slide depends on the force under the influence of which the car rolls down the slope of the slide, the strength of resistances of all kinds, on the reduced mass of the car with the load, taking into account the moment of inertia of the rotating parts.

2. The acceleration formulas and the resulting forces acting on the car are presented in the generally accepted notation and in the usual sense, followed by the calculated data.

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