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Assessment of the movement of the car along the sorting slide with a tailwind in the context of environmental health

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Abstract. In the article, the results of tabular data of previously performed studies of the movement of the car along the descent part of the sorting hump – from its top to the calculated point when exposed to a tailwind of small magnitude are presented in a convenient way for constructing graphical dependencies. For the first time, graphical dependences of acceleration, travel time and rolling speed of the car on the length of the descent part of the hump are constructed.

1 Introduction

This article is a continuation of a series of publications on the dynamics of rolling a car down the descent part of the sorting hump when exposed to the projection of a small tailwind force in a simplified formulation of the problem [1 – 20]. It is known [19] that the descent part of the sorting hump, starting from its top (TH) and ending up to the design point (DP), consists of nine sections without taking into account the installation zone of the brake shoes of the sorting park. These sections are usually called: the first and second high-speed sections (HS1 and HS2), the first braking position (1BP), the intermediate section (IS), the second braking position (2BP), the switch zone (SZ), the first section of the sorting track (ST1), the park mechanized braking position (3BP), the second section sorting track (ST2), the area of installation of brake shoes of the sorting park (ZBSh). Each of the sections of the sorting hump are interconnected by a fracture point of the hump profile [15]. There are different conditions of carriage movement on these sections. For this reason, the force ratios that take place in the "wagon-way" system on each of the sections of the hump are different [1 – 16]. At each section of the sorting hump, the car rolls down with different linear accelerations a_k in magnitude (k - numbers of the sections of the hump) and, accordingly, in them the travel time t_k and the rolling speed of the car $v_{ek}(t_k)$, are different in magnitude, which are determined according to the basic law of dynamics with imperfect coupling [20] in MathCAD. Note that the applied problem of studying the movement of a car from one section of the hump to another is solved by assuming that the rolling speed of the car at the end of one section v_{ek} is equal to the initial one for another section in the form of v_{0k} (k - number of the investigated section) [14-16].

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Nevertheless, until now, the results of studies of the movement of the car along the descent part of the sorting hump when exposed to the projection of a small tailwind force are not presented in the form of graphical dependencies of linear acceleration a_k (l_j), travel time $t_k(l_j)$ and the rolling speed of the car $v_{ek}(l_j)$ along the length of the descent part l_j (j – length of each section of the hump corresponding to the number of the investigated section k). The results of such studies are scientific and practical interest to researchers and design engineers of the sorting hump, therefore they are relevant in the railway transport industry.

2 Materials and methods

Using tabular data [16], to construct graphical dependences of linear acceleration, travel time and rolling speed of the car along the length of the descent part of the sorting hump and to perform a generalizing analysis of the research results.

It is required to provide tabular data in [16] in a form convenient for constructing graphical dependencies of linear acceleration $a_k(l_j)$, travel time $t_k(l_j)$ and rolling speed of the wagon $v_{ek}(l_j)$ along the length of the descent part of the sorting hump l_j (j - length of each section of the hump corresponding to the number of the investigated section k) when exposed to projections of the force of a tailwind of small magnitude on the end side of the car $F_{r\text{вх}}$, taking into account the strength of resistances of all kinds (from the medium, arrows, curve and snow and frost) F_c

3 Presentation of research results in graphical form and their analysis

To represent tabular data [16] in graphical form, the length of each section l_j and the passage time of the t_k car in these sections should be presented taking into account the length $l_{j\text{-}1}$ and the travel time of the $t_{k\text{-}1}$ car of the previous section of the hump.

Below we will explain the values of acceleration a_1, travel time t_1 and rolling speed v_1 obtained for each section of the descent part of the sorting hump and given in Table 1 for the case of exposure to the projection of a tailwind of small magnitude $F_{r\text{вх}}$, taking into account the strength of the resistances of the medium of all kinds (medium, arrows, curves, snow and frost) $F_\text{c.}$

1. The first high-speed section (HS1) of the hump with a length of l_hs1 = 39.95 m. The slope of the hump is ψ_{01} = 0.05 rad. (50 ppm). On HS1, the acceleration of the car a_1 = 0.519 mps^2, the time of passage by the car of this section t_1 = 9.558 s and the speed of its rolling v_1 = 6.659 mps or 23.97 kmph. For comparison, when exposed to a headwind projection, these data are as follows: a_1 = 0,445 mps^2, travel time t_1 = 10.113 s and rolling speed v_1 = 6.2 mps or 22.3 kmph [15]. As can be seen, when exposed to the projection of a tailwind on the car, the acceleration is greater ($a_\text{1t} > a_\text{1h}$, where the index 1t means a tailwind, and 1h means a headwind), the travel time is less ($t_\text{1t} < t_\text{1h}$), and the rolling speed is greater ($v_\text{1t} > v_\text{1h}$). Similar results can be observed on other sections of the hump, so in the future we will omit such comparisons.
2. The second high-speed section (HS2) of the hump with a length of l_hs2 = 33.63 m (in Table 1: 73.59 m). The slope of the hump is ψ_{02} = 0.03 rad. (30 ppm). Here we consider the movement of the car in two stages: before and after the switch (arrows).
   2.1. The speed of the entrance of the car (initial speed) on the HS2 length l_2 = 15.0 m to the arrow is equal to the speed v_{02} = 6.659 mps. On this section of the hump, the acceleration of the car a_2 = 0.323 mps^2, the travel time t_2 = 2.142 s and the exit speed of the car from this section v_{20}= 7.351 mps or 26.46 kmph

2.2. The speed of the car entry (initial speed) on the HS2 length l_2 = 18.633 m after the arrow is v_{022} = 7.35 mps. At the same time, the acceleration of the car a_{20} = 0.2 mps^2 and this section of the car passes during t_{20} = 2.453 s with the speed of the car leaving this section v_{22} = 7.84 mps or 28.2 kmph.

3. The first braking position (1BP) of the hump length l_{1bp} = 29.0 m). The slope of the hump is ψ_{03} = 0.014 rad. (14 ppm). Similarly, [15], it was accepted that this section of the hump car passes in three stages: considering the case when the car first passes part of the length of the wheelbase, then it is braked by a car retarder and then it rolls down the remaining length of this retarder. In practice, the braking of the car on the 1BP section of the hump, it is possible that the car retarder is turned on directly when the first wheelset of the front trolley of the car enters. In this case, the section 1TP of the roller coaster car passes in two stages.

3.1. The speed of the entrance of the car (initial speed) to the section of the wheelbase (WB) of the first braking position (1BP) of the hump (to the car moderator) with a length of l3 = 8.3 m is equal to v03 = 7.84 mps. On this section of the hump, the acceleration of the car a3 = 0.166 mps^2, and this section of the car passes in time t3 = 1.047 s with the speed of the car leaving this section v3 = 8.014 mps or 28.88 kmph.

3.2. The speed of the entrance of the car (initial speed) to the section 1BP of the hump (ZB) with a length of l3t = 10.227 m (the braking path of the car) is equal to v03t = 8.01 mps. On this section of the hump, during braking t3t = 1.6 s, the car moves equidistant (acceleration a3t = -2.027) mps^2 and sliding speed v3t = 4.77 mps or 17.17 km /h.

3.3. The speed of the entrance of the car (initial speed) for the remaining length of the 1BP section of the hump (FROM) l3from = 10.472 m (l3from = lb3 – (l3 + l3b) = 29 – (8.3 + 10.227) = 10.472 m, where lb3 = 29 m – the entire length of the section 1BP of the hump) is equal to v03from = 4.77 mps. On this section of the hump with a length of l3from = 10.472 m (in Table 1: 102.59 m) during t3from = 2.117 s, the car moves equidistant at a3 from = 0.166 mps^2, the speed of its exit from this section v_{03from}= 5.122 mps or 18.44 km /h.

4. Intermediate section (IN) of the hump length l_{in} = 41.27 m (in Table 1: 143.86 m). The slope of the hump is ψ_{04} = 0.011 rad. (11 ppm). It also considers the movement of the car in two stages [15]: before and after the switch.

4.1. The speed of the entrance of the car (initial speed) to the intermediate section (IN) of the hump l4 = 20.001 m to the switch is equal to v04 = 5.122 mps. On the section of the roller coaster during the time t4 = 3.721 s, the car moves with an acceleration a4 = 0.136 mps2, the speed of its exit from this section v4 = 5.569 mps or 20,3 kmph.

4.2. The speed of the entrance of the car (initial speed) to the IN section with a length of l40 = 21.271 m after the switch is equal to v042 = 5.569 mps. At the same time, the acceleration of the car a40 = 0.13 mps2 and this section of the car passes during t40 = 3.626 s with the speed of the car leaving this section v_{42} = 6.1 mps or 22.0 kmph.

5. The second braking position (2BP) of the hump length l2bp = 31.0 m. The slope of the hump is ψ05 = 0.010 rad. (10 ppm). Similarly to section 1BP, section 2BP, the car also passes in three stages [15]: first, the car passes part of the length of the wheelbase, then it is braked by the car retarder and then it rolls down the remaining length of the retarder.

5.1. The speed of the entrance of the car (initial speed) to the section of the wheelbase (WB) 2BP of the hump (up to the car moderator) with a length of l5 = 10.401 m is equal to v05 = 6,1 mps. On this section of the hump, the acceleration of the car a5 = 0.127 mps2, the travel time t5 = 1.675 s. and the exit speed of the car from this section v5 = 6.315 m/ s or 22.73 kmph.

5.2. The speed of the entrance of the car (initial speed) to the section 2BP of the hump (ZB) with a length of l5b = 7.458 m (the braking path of the car) is equal to v05b =

6.315 mps. On this section of the hump, during braking t5b = 1.6 s, the car moves equidistant with acceleration a5b = -2.067 mps2 and sliding speed v5b = 3.01 mps or 10.8 kmph.

5.3. The speed of entry of the car (initial speed) for the remaining length of the section 2BP (FROM) l5from = 13,142 m (l5from = 31 – (10,401 + 7,458) = 13.142 m, where lb5 = 31 m – the entire length of the section 2BP of the hump) is equal to v05from = 3.01 mps. On this section of the hump with a length of l5from = 13.142 m during l5from = 4.027 s, the car moves equidistant with acceleration a5from = 0.127 mps2, the speed of its exit from this section v5from = 3.518 mps or 12.7 kmph.

6. The switch zone (SZ) with a length of l_{sz} = 86.69 m. The slope of the hump is ψ_{06} = 0.002 rad. (2 ppm). Here we consider the movement of the car in four stages: before and after the first switch (arrow), after the second arrow and after the third arrow.

6.1. The speed of the entrance of the car (initial speed) to the section of the NW with a length of l6 = 16.0 m to the first arrow is equal to v06 = 3.518 mps. On this section of the hump, the movement of the car, unlike [14], is equidistant at a6 = 0.048 mps2, the travel time t6 = 4.414 s and the speed of the car's exit from this section v60=3.731 mps or 13.4 kmph.

6.2. The speed of the entrance of the car (initial speed) to the section of the SZ after the first arrow with a length of l6s1 = 25.69 m is equal to v06s1 = 3.731 mps. At the same time, the movement of the car is equidistant with acceleration a6s1 = 0.041 mps2 and this section of the car passes during t6s1 = 6.641 s with the speed of the car's exit from this section v6c1 = 4.0 mps or 14.4 kmph.

6.3. 6.3. The speed of the entrance of the car (initial speed) to the section of the SZ after the second arrow with a length of l6s2 = 21.0 m is equal to v06s2 = 4.0 mps. At the same time, the car moves equidistant with acceleration a6s2 = 0.041 mps2 and this section of the car passes during t6s2 = 5.11 s with the speed of the car leaving this section v6c2 = 4.214 mps or 15.2 kmph.

6.4. The speed of the entrance of the car (initial speed) to the section of the SZ after the third arrow with a length of l_{6s3} = 24.0 m is equal to v_{06s3} = 4.214 mps. At the same time, the movement of the car is equidistant with acceleration a_{6s3} = 0.041 mps^2 and this section of the car passes during t_{6s3} = 5.545 s with an exit speed v_{6s3} = 4.442 mps or 16.0 kmph.

7. The first section of the sorting track (ST1) with a length of l_{st1} = 59.18 m. The slope of the hump is ψ_{07} = 0.0016 rad. (1,6 ppm). The speed of entry of the car (initial speed) to this section is v_{07} = 4.442 mps. At the same time, the movement of the car, equidistant with acceleration a_7 = 0.044 mps and this section of the car, passes at a speed of v_7 = 4.49 mps or 18.0 kmph during t_7 = 12.549.

8. Park mechanized braking position (3BP) humps with a length of l_{3bp} = 14.5 m. The slope of the hump is ψ_{08} = 0.0015 rad. (1,5 ppm). Unlike sections 1BP and 2BP, the 3BP section of the car passes in two stages: first, the car passes part of the length of the wheelbase, then it is braked by a car retarder.

8.1. The speed of the entrance of the car (initial speed) to the section of the wheelbase (WB) 3BP of the hump (up to the car moderator) with a length of l8 = 6.25 m is equal to v05 = 4.9 mps. On this section of the hump, the acceleration of the car a8 = 0.041 mps2, the travel time t8 = 1.246 s and the exit speed of the car from this section v8 = 5.04 mps or 18.15 kmph.

8.2. The speed of the entrance of the car (initial speed) to the section 3BP of the hump (ZB) with a length of l_{8b} = 3.965 m (the braking path of the car) is equal to v_{08b} = 5.04 mps. On this section of the hump, during braking t_{8b} = 1.0 s, the car moves equidistant with acceleration a_{8b} = -2.15 mps^2 and sliding speed v_{8b} = 2.89 mps or 10.4 kmph.

9. The second section of the sorting track (ST2) with a length of l_9 = 51.285 m. The slope of the hump is ψ_{09} = 0.0006 rad. (0,6 ppm). The speed of the entrance of the car to this section v_{09} = 2.89 mps. This section of the hump car passes in time t9 = 16.182 s. In this case, the acceleration and speed of the car are equal to a9 = 0.034 mps2 and v9 = 3.448 mps or 12.4 kmph. As can be seen, the collision speed of the car "with a group of standing cars" is more than 2 times (12,4 kmph) higher than the permissible (5 kmph) [19]. Hence it is clear that in the sorting park there is a kind of "hard" collision of the car "with a group of standing cars", which is unacceptable. It is for this reason that brake shoes are used in practice in the sorting park.
10. The area of installation of brake shoes of the sorting park (ZBSh). If the brake shoe is installed at a distance of 5 m from the design point (DP), then the car moves equidistant with acceleration a_{9sh} = -1.817 mps^2 and after t_9 = 1.88 s, the car stops v_{9sh} = 0 before reaching DP, which is extremely undesirable, since in this case it is necessary to perform additional maneuvering work to eliminate "windows". If the brake shoe is installed at a distance of 3.0 m from the design point (DP), then the car moves equidistant with the same acceleration a_{9sh} = -1.817 mps^2 and after t_{9sh} = 1.35 s its speed becomes equal to v_{9sh} = 0.993 mps or 3.58 kmph, which is less than the permissible (5 kmph) [19, 22]. At the same time, there is a "soft" impact "with a group of standing wagons" on the sorting fleet, which is acceptable.

4 Discussion

Now, using the data, we will construct a graphical dependence of the change in the acceleration of the car a_k along the length l_j of the descent part of the sorting hump when exposed to the force of a tailwind of small magnitude $F_{r\text{вх}}$, taking into account the strength of resistances of all kinds r. (fig. 1).

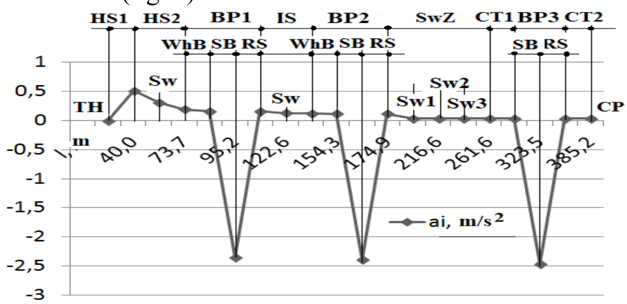

Fig. 1. Graphical changes in the acceleration of the car along the length of the descent part of the sorting hump, taking into account the strength of the resistance F_r.

From Fig. 1 it is clear that in the braking zones the car moves equidistant, for example, in sections 1BP, 2BP and ZBSh, where linear accelerations have negative values.
Similarly, $a_k = f(l_j)$, using the data, it is possible to construct graphical dependencies $t_k = f(l_j)$ (Fig. 2) and $v_k = f(l_j)$ (Fig. 2).

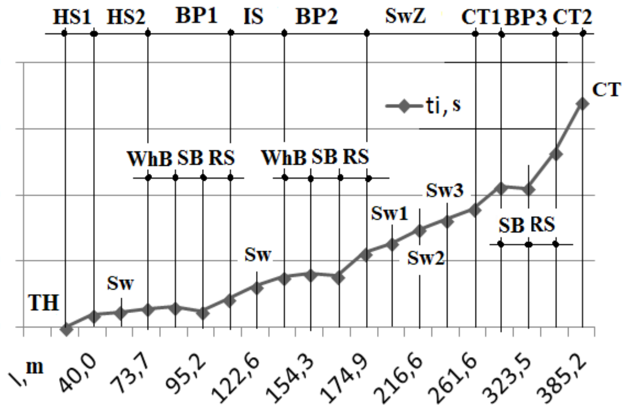

Fig. 2. Graphical changes in the time of movement of the car along the length of the descent part of the sorting hump, taking into account the strength of the resistance Fr.

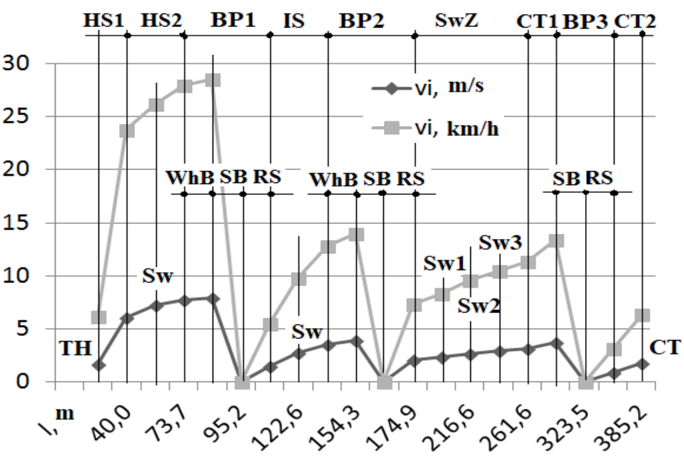

Fig. 3. Graphical changes in the rolling speed of the car along the length of the descent part of the sorting hump, taking into account the resistances of the force Fr.

The designations in Fig. 2 and 3 are the same as in Fig. 1.

From Fig. 3 it is clear that in the braking zones there are decreases in the sliding speed of the car, for example, in sections 1BP, 2BP and ZBSh, where linear accelerations have negative values (see Fig. 1).

5 Conclusions

1. Based on previously performed studies [1], for the first time, the results of calculations of linear accelerations of a wagon with its equally accelerated and/or equally slow motion on various sections of the sorting hump are presented in tabular form.
2. The analysis of the presented graphical dependences of the travel time and the rolling speed of the car on various sections of the sorting hump made it possible to note that in the case of impact on the car with a load, the projection of the force of a tailwind of small magnitude $F_{r\text{вx}}$, taking into account the strength of resistances of all kinds (medium, arrows, curves, snow and frost) F_r. the speed of collision of the car "with a group of standing wagons" more than 2 times (12.4 kmph) exceeds the permissible (5 kmph) [19-21]. Hence it is clear that in the sorting park there is a "hard" collision of the car "with a

group of standing cars", which is unacceptable. It is for this reason that brake shoes are used in practice in the sorting park. If the brake shoe is installed at a distance of 3.0 m from the design point, the car will reach "a group of standing cars" in the sorting park in 1.35 seconds at a speed of 3.58 kmph less than the permissible (5 kmph) [19-21]. At the same time, there is a "soft" impact "with a group of standing wagons" on the sorting fleet, which is acceptable.

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