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GRAPHIC RESULTS OF DETERMINATION OF CAR MOVEMENT ON THE SORTING SLOPE OF THE SLIDE WITH A FAIR WIND

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Annotation
In the article, the results of tabular data of previously performed studies of the movement of a wagon along the descent part of the marshalling yard - from its top to the calculated point under the influence of a tailwind of small magnitude are presented in a convenient for plotting graphical dependencies. For the first time, graphical dependences of the acceleration, travel time and rolling speed of the car on the length of the descent part of the hill have been constructed.

Keywords: railway, station, hump, wagon, tailwind, presentation of research results in graphical form, analysis of research results

Introduction
This article is a continuation of a series of publications on the dynamics of rolling a wagon along the downhill section of a marshalling yard under the influence of a small tailwind force projection in a simplified formulation of the problem [1–21]. It is known [19] that the descent part of the sorting hump, starting from its top (SH) and ending up to the design point (RT), consists of nine sections without taking into account the zone of installation of the braking shoes of the marshalling yard. These sections are commonly called: the first and second high-

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speed sections (SK1 and SK2), the first braking position (1TP), the intermediate section (PR), the second braking position (2TP), the switch zone (SZ), the first section of the marshalling track (SP1), park mechanized braking position (3TP), the second section of the marshalling track (SP2), the zone for installing the brake shoes of the marshalling yard (ZTB). Each of the sections of the marshalling hump are interconnected by a breakpoint in the hump profile [15]. These sections have different conditions for the movement of the car. For this reason, the power relations that take place in the "car-track" system on each of the sections of the hump are different [1 - 16]. On each section of the marshalling yard, the car rolls down with linear accelerations ak of different magnitudes (k are the numbers of the sections of the humps) and, accordingly, the travel time tk and the rolling speed of the car vek(tk) are different in them, which are determined according to the basic law of dynamics with a nonideal communication [20] in the MathCAD environment [21]. Note that the applied problem of studying the movement of a car from one section of the hump to another is solved, assuming that the speed of rolling the car at the end of one section vek is equal to the initial speed for another section in the form v0k (k is the number of the section under study) [14–16].

However, so far, the results of studies of the movement of a car along the descent part of the marshalling yard under the influence of a projection of a tailwind force of small magnitude are not presented in the form of graphical dependencies of linear acceleration ak(lj), movement time tk(lj) and rolling speed of the car vek(lj) along the length of the descent part lj (j is the length of each section of the slide corresponding to the number of the section under study k). The results of such studies are of scientific and practical interest to researchers and design engineers of the marshalling yard, and therefore are relevant in the railway transport industry.

PURPOSE OF THIS ARTICLE

Using tabular data [16], build graphical dependences of linear acceleration, travel time and rolling speed of the car along the length of the descent part of the marshalling yard and perform a general analysis of the research results.

PROBLEM FORMULATION

It is required to present tabular data in [16] in a form convenient for constructing graphical dependences of linear acceleration ak(lj), travel time tk(lj) and rolling speed of the car vek(lj) along the length of the hump lj (j is the length of each section slide corresponding to the number of the studied section k) under the influence of the projection of the tailwind force of small magnitude on the end side of the car Frвx, taking into account the resistance force of any kind (from the environment, arrows, curve and snow and hoarfrost) Fc..

PRESENTATION OF RESEARCH RESULTS IN GRAPHIC VIEW AND THEIR ANALYSIS

To present tabular data [16] in graphical form, the length of each section lj and the time of passage of the car tk in these sections should be presented taking into account the length lj-1 and the time of movement of the car tk-1 of the previous section of the hump.

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Below we explain the values of acceleration a1, travel time t1 and rolling speed of the car v1, obtained for each section of the hump downhill section and given in Table. 1 for the case of exposure to the projection of a tailwind of small value Fгвх, taking into account the resistance force of any kind of medium (medium, arrows, curves, snow and hoarfrost) Fc..

1. The first high-speed section (SK1) of the slide with a length lsk1 = 39.95 m. The slope of the slide ψ01 = 0.05 rad. (50 ppm). On SC1, the acceleration of the car a1 = 0.519 m/s2, the time it takes the car to pass this section t1 = 9.558 s, and its rolling speed v1 = 6.659 m/s or 23.97 km/h. For comparison, when exposed to the projection of a headwind, these data are as follows: a1 = 0.445 m/s2, travel time t1 = 10.113 s, and rolling speed of the car v1 = 6.2 m/s or 22.3 km/h [15]. As can be seen, under the influence of the tailwind projection on the car, the acceleration is greater (a1п > a1в, where the index 1п means a tailwind, and 1в is a headwind), the travel time is shorter (t1п < t1в), and the rolling speed is greater (v1п > v1в). Similar results can be observed in other parts of the hill, so in the future we will omit such comparisons.

2. The second high-speed section (SK2) of the slide with a length lsk2 = 33.63 m (in Table 1: 73.59 m). Hill slope ψ02 = 0.03 rad. (30 ppm). Here, the movement of the car is considered in two stages: before and after the turnout switch (arrows).

2.1. The entry speed of the car (initial speed) on SC2 with length l2 = 15.0 m up to the switch is equal to the speed v02 = 6.659 m/s. On this section of the hill, the acceleration of the car is a2 = 0.323 m/s2, the time of movement is t2 = 2.142 s, and the speed of the exit of the car from this section is v20 = 7.351 m/s or 26.46 km/h.

2.2. The entry speed of the car (initial speed) on SC2 with length l2 = 18.633 m after the switch is equal to v022 = 7.35 m/s. In this case, the acceleration of the car is a20 = 0.2 m/s2, and the car passes this section in the time t20 = 2.453 s with the speed of the exit of the car from this section v22 = 7.84 m/s or 28.2 km/h.

3. The first braking position (1TP) of a slide with a length of l1tp = 29.0 m). Hill slope ψ03 = 0.014 rad. (14 ppm). Similarly [15], it was assumed that the car passes this section of the hill in three stages: considering the case when the car first 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 this retarder. In the practice of car braking on the 1TP section of the slide, it is possible that the car retarder is turned on immediately when the first wheelset of the front bogie of the car enters. In this case, section 1TP of the slide the car passes in two stages.

3.1. The car entry speed (initial speed) to the wheelbase section (CB) of the first braking position (1TP) of the hump (up to the car retarder) with a length of l3 = 8.3 m is equal to v03 = 7.84 m/s. On this section of the hill, the acceleration of the car is a3 = 0.166 m/s2, and the car passes this section in the time t3 = 1.047 s with the speed of the exit of the car from this section v3 = 8.014 m/s or 28.88 km/h.

3.2. The entry speed of the car (initial speed) to the section 1TП of the hump (3T) with the length l3т = 10.227 m (the braking distance of the car) is equal to v03т = 8.01 m/s. On this section of the hill, during the braking time t3t = 1.6 s, the car moves uniformly (acceleration a3t = –2.027) m/s2 and the sliding speed v3t = 4.77 m/s or 17.17 km/h.

3.3. Car entry speed (initial speed) for the remaining length of the section 1TP of the hump (OT) l3to = 10.472 m (l3to = lt3 - (l3 + l3t) = 29 - (8.3 + 10.227) = 10.472 m, where lt3 = 29 m - the entire length of the 1TP section of the slide) is equal to v03to = 4.77 m/s. On this section of the slide with a length of l3to = 10.472 m (in Table 1: 102.59 m), during the time t3to = 2.117 s, the car moves uniformly accelerated at a3to = 0.166 m/s2, the speed of its exit from this section is v3to = 5.122 m/s or 18.44 km/h.

4. Intermediate section (IR) of the slide, length lpr = 41.27 m (in Table 1: 143.86 m). Hill slope ψ04 = 0.011 rad. (11 ppm). Here, the movement of the car is also considered in two stages [15]: before and after the turnout.

4.1. The entry speed of the car (initial speed) to the intermediate section (IR) of the hump l4 = 20.001 m before the turnout switch is equal to v04 = 5.122 m/s. On the PR section of the slide, during the time t4 = 3.721 s, the car moves with an acceleration a4 = 0.136 m/s2, the speed of its exit from this section is v4 = 5.569 m/s or 20.3 km/h.

4.2. The entry speed of the car (initial speed) to the PR section with a length of l40 = 21.271 m after the switch is equal to v042 = 5.569 m/s. In this case, the acceleration of the car is a40 = 0.13 m/s2, and the car passes this section in the time t40 = 3.626 s with the speed of the exit of the car from this section v42 = 6.1 m/s or 22.0 km/h.

5. The second braking position (2TP) of the slide with the length l2tp = 31.0 m. The slope of the slide ψ05 = 0.010 rad. (10 ppm). Similarly to section 1TP, section 2TP 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 along the remaining length of the retarder.

5.1. The entry speed of the car (initial speed) to the wheelbase section (KB) of the 2TP hump (up to the car retarder) with a length of l5 = 10.401 m is equal to v05 = 6.1 m/s. On this section of the hill, the car acceleration is a5 = 0.127 m/s2, the travel time is t5 = 1.675 s. and the speed of the exit of the car from this section v5 = 6.315 m/s or 22.73 km/h.

5.2. The entry speed of the car (initial speed) to the section 2TP of the hump (ZT) with a length of l5t = 7.458 m (the deceleration path of the car) is equal to v05t = 6.315 m/s. On this section of the hill, during the braking time t5t = 1.6 s, the car moves uniformly with acceleration a5t = –2.067 m/s2 and sliding speed v5t = 3.01 m/s or 10.8 km/h.

5.3. The entry speed of the car (initial speed) to the remaining length of the section 2TP (OT) l5to = 13.142 m (l5to = 31 - (10.401 + 7.458) = 13.142 m, where lt5 = 31 m is the entire length of the section 2TP of the slide) is equal to v05to = 3, 01 m/s. On this section of the slide with a length of l5to = 13.142 m, during the time t5to = 4.027 s, the car moves uniformly accelerated with an acceleration a5to = 0.127 m/s2, the speed of its exit from this section is v5to = 3.518 m/s or 12.7 km/h.

6. Switch zone (SZ) with a length lsz = 86.69 m. Slope of the hill ψ06 = 0.002 rad. (2 ppm). Here we consider the movement of the car in four stages: before and after the first turnout (turnout), after the second turnout and after the third turnout.

6.1. The entry speed of the car (initial speed) to the NW section of length l6 = 16.0 m to the first switch is equal to v06 = 3.518 m/s. On this section of the hill, the movement of the car, in contrast to [14], is uniformly accelerated at a6 = 0.048 m/s2, the time of movement is t6 = 4.414 s, and the speed of the exit of the car from this section is v60 = 3.731 m/s or 13.4 km/h.

6.2. The entry speed of the car (initial speed) to the NW section after the first turnout of length l6c1 = 25.69 m is equal to v06c1 = 3.731 m/s. At the same time, the movement of the car is

uniformly accelerated with an acceleration a6c1 = 0.041 m/s2 and the car passes this section in the time t6c1 = 6.641 s with the speed of the exit of the car from this section v6c1 = 4.0 m/s or 14.4 km/h.
6.3. The entry speed of the car (initial speed) to the NW section after the second turnout of length l6c2 = 21.0 m is equal to v06c2 = 4.0 m/s. In this case, the car moves uniformly accelerated with an acceleration a6c2 = 0.041 m/s2, and the car passes this section in the time t6c2 = 5.11 s with the speed of the car leaving this section v6c2 = 4.214 m/s or 15.2 km/h.
6.4. The entry speed of the car (initial speed) to the NW section after the third arrow of length l6c3 = 24.0 m is equal to v06c3 = 4.214 m/s. At the same time, the movement of the car is uniformly accelerated with an acceleration a6c3 = 0.041 m/s2, and the car passes this section in the time t6c3 = 5.545 s with an exit speed v6c3 = 4.442 m/s or 16.0 km/h.
7. The first section of the sorting track (SP1) with a length lsp1 = 59.18 m. The slope of the hill ψ07 = 0.0016 rad. (1.6 ppm). The entry speed of the car (initial speed) to this section is v07 = 4.442 m/s. In this case, the movement of the car, uniformly accelerated with an acceleration a7 = 0.044 m/s2, and this section of the car passes with a speed v7 = 4.49 m/s or 18.0 km/h in the time t7 = 12.549.
8. Park mechanized braking position (3TP) slide length l3tp = 14.5 m. The slope of the slide ψ08 = 0.0015 rad. (1.5 ppm). Unlike sections 1TP and 2TP, section 3TP the car passes in two stages: first, the car passes part of the length of the wheelbase, then it is braked by the car retarder.
8.1. The entry speed of the car (initial speed) to the wheelbase section (KB) of the 3TP hump (up to the car retarder) with a length of l8 = 6.25 m is equal to v05 = 4.9 m/s. On this section of the hill, the acceleration of the car is a8 = 0.041 m/s2, the time of movement is t8 = 1.246 s, and the speed of the exit of the car from this section is v8 = 5.04 m/s or 18.15 km/h.
8.2. The entry speed of the car (initial speed) to the section 3TП of the hump (3T) with the length l8т = 3.965 m (the braking distance of the car) is equal to v08т = 5.04 m/s. On this section of the hill, during the braking time t8t = 1.0 s, the car moves uniformly with acceleration a8t = –2.15 m/s2 and sliding speed v8t = 2.89 m/s or 10.4 km/h.
9. The second section of the sorting track (SP2) with a length of l9 = 51.285 m. The slope of the hill ψ09 = 0.0006 rad. (0.6 ppm). The speed of the car entering this section is v09 = 2.89 m/s. The car passes this section of the hill in the time t9 = 16.182 s. In this case, the acceleration and speed of the car are a9 = 0.034 m/s2 and v9 = 3.448 m/s or 12.4 km/h. As can be seen, the collision speed of a wagon “with a group of standing wagons” is more than 2 times (12.4 km/h) higher than the permissible one (5 km/h) [19]. From this it is clear that in the marshalling yard there is a kind of “hard” collision of a wagon “with a group of standing wagons”, which is unacceptable. It is for this reason that brake shoes are used in practice in the marshalling yard.
10. Installation area for marshalling yard brake shoes (ZTB). If the brake shoe is installed at a distance of 5 m from the design point (RT), then the car moves uniformly with acceleration a9b = -1.817 m/s2 and after t9 = 1.88 s the car stops v9b = 0, not reaching the RT, which is extremely undesirable, since in this case it is necessary to perform additional shunting work to eliminate the "windows". If the brake shoe is installed at a distance of 3.0 m from the design point (RT), then the car moves uniformly with the same acceleration a9b = -1.817 m/s2 and

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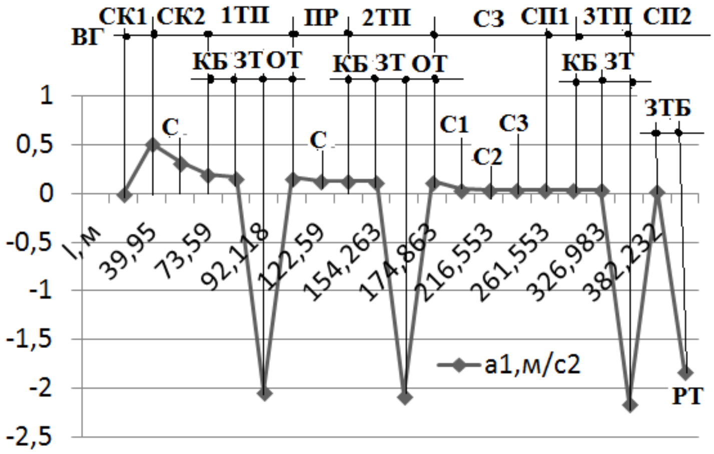
after t9b = 1.35 s its speed becomes equal to v9b = 0.993 m/s s or 3.58 km/h, which is less than the allowable (5 km/h) [19-21]. In this case, a "soft" impact "with a group of standing cars" occurs at the marshalling yard, which is acceptable.

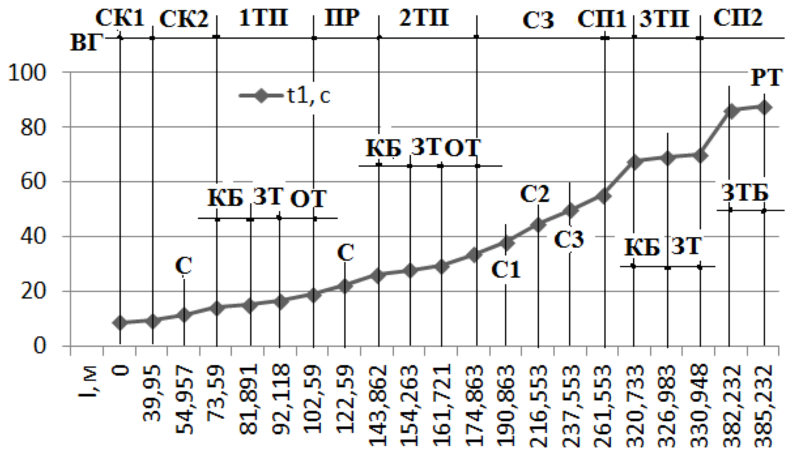
Now, using the data, we will construct a graphical dependence of the change in the acceleration of the car ak along the length lj of the lower part of the marshalling yard under the influence of a tailwind force of a small value Fгвх, taking into account the resistance force of any kind Fc. (Fig-1).



Rice. Fig. 1. Graphical changes in the acceleration of the car along the length of the descent part of the marshalling yard, taking into account the resistance force Fc.

From fig. 1, it is clear that in the braking zones the car moves uniformly slow, for example, in sections 1TP, 2TP and ZTB, where the values of linear accelerations have negative values.

Similarly, ak = f(lj), using the data, you can plot the graphic dependences tk = f(lj) (Fig. 3) and vk = f(lj) (Fig. 2).



Rice. 2. Graphical changes in the time of movement of the car along the length of the lower part of the hump, taking into account the resistance force Fc.

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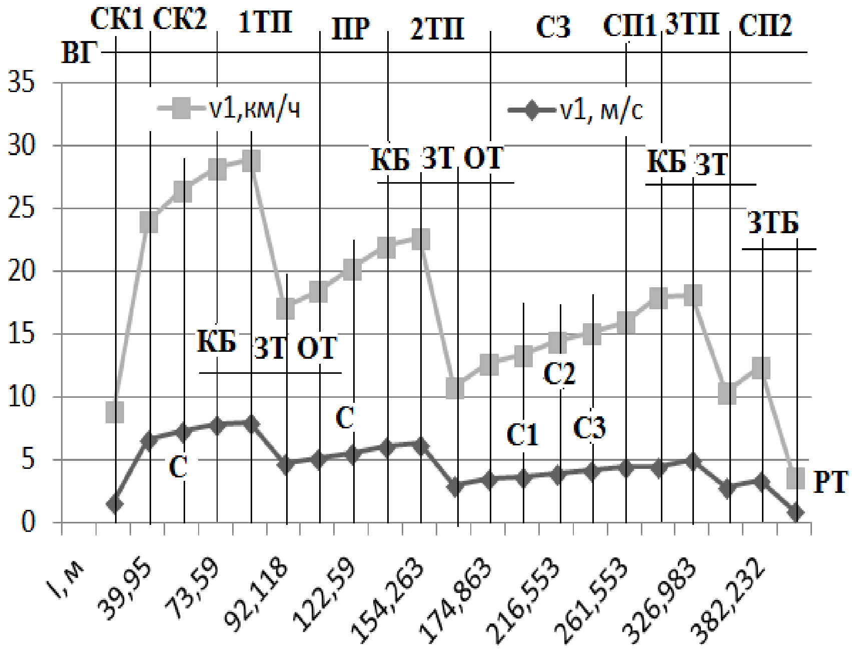

Rice. Fig. 3. Graphical changes in the rolling speed of the wagon along the length of the descent part of the marshalling yard, taking into account the resistance force Fc.

Designations in fig. 3, as in Fig. 2.

From fig. It is clear from Fig. 3 that in the zones of deceleration, the sliding speed of the car decreases, for example, in sections 1TP, 2TP and ZTB, where the values of linear accelerations have negative values (see Fig. 2).

CONCLUSIONS

1. On the basis of previously performed studies [1], for the first time in tabular form, the results of calculations of the linear accelerations of a car with its uniformly accelerated and/or uniformly slow movement in various sections of the marshalling yard are presented in tabular form.

2. The analysis of the presented graphical dependences of the time of movement and the speed of rolling the car in different sections of the marshalling yard made it possible to note that in the case of impact on the car with a load, the projection of the tailwind force of a small value Frвх, taking into account the resistance force of any kind (environment, switch, curves, snow and frost) Fc. the collision speed of a wagon "with a group of standing wagons" is more than 2 times (12.4 km/h) higher than the permissible one (5 km/h) [19-21]. From here it is clear that in the marshalling yard there is a "hard" collision of a wagon "with a group of standing wagons", which is unacceptable. It is for this reason that brake shoes are used in practice in the sorting park. If a 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 marshalling yard in 1.35 s at a speed of 3.58 km/h less than the permissible one (5 km/h) [19 -21]. In this case, a "soft" impact "with a group of standing cars" occurs at the marshalling yard, which is acceptable.

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