



About Designing the Height of the First Profile of the Marshalling Hump

Khabibulla Turanov, Andrej Gordienko, Shuxrat Saidivaliev and
Shukhrat Djabborov

EasyChair preprints are intended for rapid
dissemination of research results and are
integrated with the rest of EasyChair.

January 18, 2020

¹ Tashkent state technical University named Islam Karimov, Tashkent, 2, Uzbekistan, University Str, 10000, Tashkent. Uzbekistan

² Ural State University of Railway Transport, 66, Kolmogorova st., 620034, Yekaterinburg, Russia

³ Tashkent Railway Engineering Institute, 1, Temirylchilar 1- tor kycha, 100167, Tashkent, Uzbekistan

⁴ Tashkent Railway Engineering Institute, 1, Temirylchilar 1- tor kycha, 100167, Tashkent, Uzbekistan

* Corresponding author: khturanov@yandex.ru

ABOUT DESIGNING THE HEIGHT OF THE FIRST PROFILE OF THE MARSHALLING HUMP

Abstract. The Height of the high-speed section of the sorting slide. Design of high-speed section of the marshalling hump. To prove mathematically the absence of theoretical basis of the formula by which the height of the first profile section of the marshalling hump is calculated in current method of calculation of marshalling humps. The paper uses the theorem on the change of kinetic energy for a non-free material point in the final form, known from theoretical mechanics. The results of the research revealed that the formulas by which the height of the first profile section of the marshalling hump is calculated contradict the theorem on the change of kinetic energy for a non-free material point in the final form. The results of the research can be used in the processing of the normative-technical document on the design of hump devices on railways and making adjustments to the dynamics of rolling the car in textbooks for universities of railway transport. The results of the calculations proved the incorrectness of the derivation of the formula for calculating the height of the first profile section of the marshalling hump in the normative-technical document "Rules and standards for the design of sorting devices on the railways with gauge 1 520 mm".

Key words: railway, station, marshalling hump, wagon, the height of the first high-speed section, the results of calculation data

Introduction

Continuing to discuss the correctness of the theoretical base of the current calculation methods of hump yards [1 – 18], we note that it is still the subject of discussion not become the theoretical assumptions of the mathematical model formula (8) in the fifth counterexample [12]. It is known that when designing a sorting slide, the height of the first profile section (from the top of the slide to the first arrow zone or the first brake position (1TP)) is calculated by the formula (see formula (8) in [12]):

$$h_1^{\max} = \frac{v_{in}^2 - v_0^2}{2g'_o} + h_{sp1} + h_{ac1}, \quad (1)$$

where v_{in} – maximum permissible speed input of uncoupling [accurately, single wagon] [v_{rm}] on wagon retarding mechanisms [12], i.e. $v_{in} = [v_{rm}]$, m/s;

v_0 – the greatest initial velocity sliding of «very good free axle (GFA)», since $G = 908$ kN accept 1.7 to 2.5 m/s), m/s;

g'_o – acceleration of gravity taking into account the inertia of the rotating masses GFA, m/s^2 ;

h_{sp1} и h_{ac1} – losses of specific energy at overcoming of the basic specific resistance to movement and resistance from arrows and curves within advance section l_1 , e.m.h (*the energy meter of height*).

It should taken into account [12] that the profile height h_1 of advance hump section (i.e. from the top of the hump (TH) to the point in the middle 1BP) can be determined from the input condition of the calculated free axle (wagon) he second retarder of the first braking position (1BP) the first wheel pair of the calculation free axle, «good axle (GA)» under favorable conditions of rolling with the maximum allowable for the adopted type of retarder entry speed $v_{in} = 7$ m/s.

In the first term of the formula (1) the rate of entry v_{in} can be determined by the formula (see formula (3) in [12]) only taking into account the initial velocity $v_{beg} = v_{in} = v_0$, derived for a *perfect connection*):

$$v_{in} = \sqrt{2 \cdot g'_o \cdot h_{ac} + v_o^2}, \quad (2)$$

where $v_o = v_{od}$ – rating speed of detaching, e.g., $v_{od} = 1.4$ m/s for hump of large-capacity.

Note that if formula (2) is correct, then in formula (1) the first term will be found by formula (3) in [15] only taking into account the initial velocity $v_{beg} = v_{in} = v_0$, derived for a *perfect connection*.

It should be noted that in [12] to determine the required height of hump h_{hump} the kinetic sum is found E_0 and potential E_p wagon energies (see formulas (4) and (5) in [16]), kJ

$$E_0 = M \frac{v_0^2}{2} \rho \text{ и } E_p = gMh_{\text{hump}} \quad (3)$$

given the fact that they M – mass of the wagon, t; v_0 – initial speed, m/s; ρ – coefficient that takes into account the correction for the rotation of wheel pairs; $g = 9.81$ – gravitational acceleration, m/s²; h_{hump} – required height of the hump, m.

Total energy (kinetic E_0 and potential E_p) equated to the work of the component of the gravity projection ($G\sin\psi$) of a moving wagon, which is taken to be equal to the sum of the works of the forces of resistance of every kind $A_{r,c,s}$:

$$M \frac{v_0^2}{2} \rho + gMh_{\text{hump}} = A_{r,c,s}, \quad (4)$$

where

$$A_{r,c,s} = A_r + A_c + A_s \quad (5)$$

given what they indicate: A_r – the work of the forces of resistance in the movement of the wagon at a distance between the top of the hump (TH) and a control point (100 m further from TH), kJ; A_c – the work of the resistance forces during the passage of the curve section of the track, kJ; A_s – work of resistance forces at impact of wheels of wheel pairs of the wagon about switches, kJ.

Work of resistance forces A_r (see formula (1) в [16]), kJ:

$$A_r = gM \frac{r_m \cdot l}{1000}, \quad (6)$$

where r_m – coefficient taking into account rolling resistance of wagon wheels, N/kN; l – the distance between the vertex and the considered reference point, m.

The work of the resistance forces during the passage of the curve section of the track A_c (see formula (2) in [16]), kJ:

$$A_c = gM \frac{\sum r_c \cdot l_c}{1000} = gM \frac{c \cdot \sum \alpha_c}{1000}, \quad (7)$$

where r_c – coefficient taking into account the resistivity of the curve, N/kN; l_c – track length in curve, m; $c \cdot \sum \alpha_c$ – work of relative resistance of a curve of a site of track, N/kN; c – coefficient taking into account the specific resistance of the wagon on the curve, N/kN; $\sum \alpha_c$ – the sum of the central angles of rotation of the curve of the track section, deg.

Work of resistance forces at impact of wheels of wheel pairs of the wagon about switches A_s (see formula (3) in [16]), kJ:

$$A_s = gM \frac{20 \cdot n}{1000}, \quad (8)$$

where n – the number track switches on the studied section of the track profile.

Substituting formulas (6) – (8) in (4) obtain equality (see equality (7) in [16]):

$$M \frac{v_0^2}{2} \rho + gMh_{\text{hump}} = gM \frac{r_m \cdot l}{1000} + gM \frac{c \cdot \sum \alpha_c}{1000} + gM \frac{20 \cdot n}{1000}.$$

After elementary mathematical transformations of the last equation to obtain a formula to determine the required height of the hump slides h_{hump} (see formula (8) in [16]), m:

$$h_{\text{hump}} = \frac{r_m \cdot l}{1000} + \frac{c \cdot \sum \alpha_c}{1000} + \frac{20 \cdot n}{1000} - \frac{v_0^2}{2g'}, \quad (9)$$

where g' – acceleration of gravity taking into account the inertia of the rotating parts of the wagon, m/s².

In [16] there is a formula by which the speed of the wagon is determined v_2 from the hump crest with an initial velocity $v_1 = v_0$, m/s:

$$v_2 = \sqrt{v_1^2 + \frac{2g'(s-r)l}{1000}}, \quad (10)$$

where s – profile grade of track, ‰; r – coefficient, taking into account the resistivity of the movement of the car, N/kN. Hence it is clear that in [16, ‰ = N/kN, which is unacceptable.

In [16] the energy heights between the switch and the considered point of the slide profile are presented in the form, m:

$$\frac{v_{in}^2}{2g'} + \frac{s \cdot l}{1000} = \frac{r_m \cdot l}{1000} + \frac{c \cdot \sum \alpha}{1000}.$$

Hence the speed of the wagon is determined v_{in} between the switch and the considered point of the slide profile (see formula (15) in [16]), m/s:

$$v_{in} = \sqrt{\frac{2g'}{1000}[(s-r)l_t + c \cdot \sum \alpha]}, \quad (11)$$

where l_t – the length of the path between the switch and the considered point, m.

It is well known [6, 19] that for a system with ideal connections and/or for a conservative system, the total energy ($E_0 + E_p$) remains constant (see p. 293 in [19]):

$$M \frac{v_0^2}{2} \rho + gMh_{hump} = \text{const},$$

i.e., the kinetic energy of the car E_0 with mass M , breaking up from the top of the hump with the initial speed v_0 , can be converted into potential energy E_p of wagon, which is waiting for its break thrust on the top of the hump, located at a height of h_{hump} , and vice versa.

Mechanical system "wagon – track rail" described in the solution of engineering problems in [16], is a proprietary system, i.e. a system with non-ideal constraints, where part of the kinetic energy acquired by the wagon after the breaking up of the hump crest, lost in overcoming the work of the forces of resistance of any kind (friction forces; forces of resistance that appears when the passage curves plots the path; the forces of resistance that occur when hitting the blades of switches; the drag force from the aerial environment and of wind, of snow and frost).

In this regard, the hypothesis adopted in [16] that the total energy is spent on overcoming the work of the forces of any resistance (see mathematical expression (4)), contradicts the theorem on the change of kinetic energy for a non-free material point in the final form [6, 19], where the work of the resistance force must have a negative sign:

$$\Delta E = -A_{r,c,s}.$$

Hence the required height of the hump h_{hump} can be defined as, m:

$$h_{hump} = -\frac{1}{gM} A_{r,c,s} - \frac{v_0^2}{2g'}. \quad (12)$$

As can be seen, the obtained formula is not comparable with formula (9), since the result is pseudoscientific. Thus, analyzing the results of [16], we note that they contradict the theorem on the change of kinetic energy for a nonfree material point in the final form. From here it becomes obvious the relevance of discussion of theoretical provisions on the choice of height of the first profile site (from the top of the hump to the first switching area or the first brake position (1BP)) of the marshalling hump.

Object:

- mathematically prove the absence of a theoretical basis for the formula by which to calculate the height of the first profile section of the marshalling hump;
- the results of the calculations to justify and / or refute the correctness of the derivation of the formula for calculating the height of the first profile section (from the top of the hump to the braking zone of the first brake position) of hump;
- to justify the erroneous use in the normative-technical document of the formula $h_0 = v_0^2 / 2g'$ to determine the energy height of the hump taking into account the inertia of the rotating parts, applicable only for the ideal connection (see pp. 286, 287 in [19]).

Research methods

The research methods are based on the use of the theorem on the kinetic energy change for a non-free material point in the final form [6, 19].

The main findings of the study

To determine the height of the first section of the profile hump h_1 , applying the theorem on the change of kinetic energy for a free material point (which means that no restrictions are imposed on its movements) in a finite form [6, 19] we obtain:

$$\frac{G}{2g'_o} v_{in}^2 - \frac{G}{2g'_o} v_0^2 = A_G, \quad (13)$$

where A_G – the work of gravity G , as a potential force that maintains a constant direction (vertical down) and modulus:

$$A_G = Gh_1 \quad (14)$$

given the fact that it h_1 – vertical movement of the body from gravity G , otherwise, according to formula (1), part of the height of the first profile section (from the top of the hill to the first arrow zone or the first brake position), m.

Further, substituting (14) into (13), after elementary calculations we obtain:

$$h_1 = \frac{v_{in}^2 - v_0^2}{2g'_o}. \quad (15)$$

Hence, it is clear that the last formula is derived correctly, however, considering the connection (profile section of the hump) ideal (smooth and/or frictionless).

It is obvious that by formula (15) it is permissible to calculate the part of the height of the first profile section of the hump h_1 , assuming that this section is an ideal (smooth and/or frictionless) connection. However, in reality, the profile of this section of the slide corresponds to a non-ideal (non-smooth and/or friction) connection (i.e. track rail).

In this regard, it is not clear and / or doubtful for what reason the dependence is still widely used to determine the energy heights in the design methodology of sorting slides (see the fifth cotrprimer in [1]) relation is still widely used $h = f([v_{in}], v_0, 2g')$ (where $[v_{in}]$ – the permissible input speed of the estimated free axle the retarders ITP under favorable conditions, sliding, m/s; v_0 – the greatest initial velocity sliding FA, m/s), arising from formula (1) in [6] where $a = g'i = g'h/l$ (see formula (7) in [15]), fair only for ideal connections (see p. 287 in [19]).

Discuss the second term of formula (1). Specific energy losses h_{sp1} , as the specific work of the forces of resistance to movement, is determined by the formula (14) in [12]:

$$h_{sp1} = l_1 \omega_0 10^{-3}, \quad (16)$$

where ω_0 – the calculated value of the basic resistivity of the movement, taken in [12] at calculation of height of the hill depending on weight category of cars, and at constructive and technological calculations - from type of the runner (for example, GA or GFA) and conditions of rolling (favorable or unfavorable), kgf/ts; l_1 – the length of the section of the track on which the effect of the main resistance is considered ω_0 , as an imperfect connection, m.

Analyzing the formula (16), we note that in it the product of the length of the track section l_1 (in m) on the basic resistivity to movement ω_0 (B kgf/ft), how different the meaning of physical concepts (measure of length and the measure of the imperfect communication in non-systemic units of measurement), does not fit into the basic principles of General mechanics [19], to which attention is drawn also in the twelfth counterexample in [12].

As can be seen, the formula (16) cannot be derived using the principles and/or methods of theoretical and/or engineering mechanics [6, 20], and therefore has no theoretical basis.

We also discuss the content of the third term of formula (1). Loss of specific energy when overcoming resistance from switches and curves h_{ac1} within the advance section l_1 :

$$h_{ac1} = (0.56n + 0.23 \sum \alpha_{ac}) v^2 10^{-3}, \quad (17)$$

where n – number of switches; $\sum \alpha_{ac}$ – sum of angles of rotation, deg., including arrow angles, on the route (section) of rolling [16]; v – the average speed of the wagon on the route (section) of rolling, as a normalized value, i.e. $v = [v_m]$, m/s.

In the last formula n and $\sum \alpha_{ac}$ find from the plan of a neck of marshalling tracks (see p. 141 in [13]). Analysis of the formula (17) shows that it is empirical, has no theoretical basis, and, at the same time, it is determined $h_{ac1} = f(n, \sum \alpha_{ac}, [v_m])$.

Here bewilderment and/or doubt is that only at the initial stage of calculation of parameters of a hump use $v = [v_m]$, the magnitude of which and the permissible value of the speed of the entrance of the car to the retarders $v_{in} = [v_{rm}]$, without performing any other calculations, you can find the sought speed, for example, at the end of the speed section v_{ss2} .

Generalizing the analysis of formulas (16) and (17) containing elements of non-ideal connection in the form ω_0 , n and $\sum \alpha_{ac}$, it can be argued that they have no theoretical basis, and formula (15) holds for an ideal connection. For this reason, in contrast to the erroneous opinion of the authors of the article [11] (see the first paragraph of the last column on page 36 in [14]), it is according to the formula (2) in [14], slide structural and technological calculations modeling the conditions of movement of calculated free axles with different running properties can not be performed.

Research result

Calculation example. For example, let us perform a comparative calculation of the height of the first profile section (from the top of the hump to the braking zone of the first brake position) of the hump according to the formula (1), comparing the result with the data performed by the exact formula $h = l \cdot i$ (see formula (4) in [15]) for each section. Here we take into account that the first profile section consists of the first and second high-speed sections (l_1, l_2) and the length of the wagon wheelbase (l_{in1}).

The initial data of the example are as follows: $l_1 = 39.95$, $l_2 = 15.007$, $l_{2c} = 18.633$ и $l_{in1} = 8.301$ – length of the projected sections of the hump, m; $i_1 = 50$, $i_2 = 30$, $i_{2c} = 18$ and $i_{bx1} = 14$ – slope of the studied areas, ‰; $v_{in} = 7.924$ – the maximum permissible input speed of single cars on a railway car retarders (which is less than the allowable input speed of the car retarders of the type KZ-3, KZ-5 and VSGP-5 [20]), m/s; $v_0 = 1.7$ – highest initial rolling speed " of a very good free axle (GFA)», m/s; $g'_0 = 9,635$ – acceleration of gravity taking into account the inertia of the rotating masses GFA for $G = 908$ кН, m/s².

Calculation results. We calculate part of the height of the first profile section of the hump h_{1ps} , by formula (15), derived under the assumption that the profile section of the hump is an ideal (smooth and/or frictionless) bond, m:

$$h_{1ps} = \frac{v_{in}^2 - v_0^2}{2g'_0} = \frac{7.924^2 - 1.7^2}{2 \cdot 9.635} = 3.108.$$

We calculate, according to the generally accepted understanding (see page 36 in [11]), the loss of specific energy when overcoming the basic specific resistance to motion h_{sp1} within the advance section l_1 by formula (16), m:

$$h_{sp1} = l_1 \omega_0 10^{-3} = 81.891 \cdot 0.5 \cdot 10^{-3} = 0.041.$$

We calculate the loss of specific energy when overcoming the resistance of the arrows and curves h_{ac1} within the advance section l_1 by formula (17), m:

$$h_{ac1} = (0.56n + 0.23 \sum \alpha_{ac}) v^2 10^{-3} = (0.56 \cdot 1 + 0.23 \cdot 0.083) \cdot 4.5^2 10^{-3} = 0.012.$$

The height of the first profile section (from the hump apex to the braking zone of the first brake position (1BP)) of the hump is calculated by equation (1), m:

$$h_1^{max} = \frac{v_{in}^2 - v_0^2}{2g'_o} + h_{sp1} + h_{ac1} = 3.108 + 0.041 + 0.012 = 3.161.$$

Disregard values h_{sp1} and h_{ac1} obvious, since $h_{1ps} \gg (h_{sp1} + h_{ac1})$, i.e. $3.108 \gg (0.041 + 0.012) = 0.053$ m.

Perform the height calculation h_{1r} the first profile section of the hump according to the initial length data ($l_1, l_2, l_{2v}, l_{in1}$) and slope ($i_1, i_2, i_{2v}, i_{in1}$) these areas by the exact formula (4) $h_{bri} = l_{bri} i_{bri}$, in [12], e.g., $h_1 = l_1 \cdot i_1$, m:

$$h_{1br} = h_1 + h_2 + h_{2v} + h_{in1} = 1.994 + 0.45 + 0.335 + 8.301 = 2.595.$$

As can be seen, the height of the first profile section of the hump, calculated by the formula (1) and the exact formula of the form $h_{bri} = l_{bri} i_{bri}$ (see formula (4) in [15]) has relative error $\delta h = 17,9 \approx 18\%$, *not acceptable for engineering calculations*.

We assume that such results are caused by the fact that part of the height of the first profile section of the hump h_{1ps} it is calculated by the formula (1), derived under the assumption that the profile section of the hump is an ideal connection, and the loss of specific energy when overcoming the basic specific resistance to movement h_{sp1} and resistance from switches and curve line h_{sp1} within the advance section l_1 – by analytically unprovable empirical formulas for non-ideal connections (track rail).

Thus, summarizing the results of checking the correctness of the derivation of the formula (1) to calculate the height of the first profile section (from the top of the slide to the braking zone of the first brake position) slides in comparison with the results of the calculated data, it can be concluded that in the formula (1) summed values obtained for obviously different conditions. For this reason, they contain undeniable errors bearing elements of pseudoscientific material. Here we make a reservation that similar to formulas (1), (16) and (17) causes objections relating to the determination of the height of the hump.

The formula for determining the speed of the wagon at any given point in the profile of the hump [12], used only to construct the curves of the speed of free axles, and finding the specific energy corresponding to the established rate of breaking-up, can also be criticized $v_o = v_{od}$, according to Galileo's formula (3) ($v = \sqrt{2gh}$ and $h_o = v_o^2 / 2g'$ [12, 13]).

Especially stipulate that the formula $h_o = v_o^2 / 2g'$ in [12, 13] to determine the energy height of the slide, taking into account the inertia of the rotating parts, it is applicable only for ideal communication (see pages 286, 287 in [19]) and in no case can it be used to determine the sliding speed of the car in the braking zones in the sections of the braking positions. Otherwise, there will be an unscientific result. Note that $h_o = v_o^2 / 2g'$ in [12, 13] derived from Galileo's formula $v = \sqrt{2gh}$ [15] to determine the rate of free fall of object. Recall that track rails can be considered as ideal bonds only under the assumption that they are absolutely solid. Unfortunately, there are no such objects in nature.

As can be seen, the formula (8) in [12] to determine the height of the first profile section (from the top of the hump to the first pointer zone or the first brake position), which is widely used in the design of hump, as one of the main criticisms of the authors [12], for some unknown reason, instead of conducting serious scientific analysis, explanations and theoretical justifications, unfortunately, remained without attention of authors [13, 14].

In this regard, summarizing the results of the critical analysis of the formula (1), it can be argued that in it, the first term is correct only for the ideal connection, and the second and third terms – for non-ideal connection, which indicates its incorrectness and, for this reason, the inadmissibility of the use in the methodology. Otherwise, the combination of terms in one formula is erroneous, where one of them corresponds to an ideal connection, and the other two correspond to a non-ideal connection.

Let us make a special reservation that the correct solution of the problem of moving the wagon down the profile of the marshalling hump from its top to the calculated point is given in [6, 20].

Application area for results

The results of the research can be used in the processing of normative and technical document on the design of marshalling devices on railways and making adjustments to the position of the dynamics of rolling the wagon down the profile of the marshalling hump in textbooks for universities of railway transport.

Conclusions

1. Analyzing the results of [16], it is revealed that the formula by which the height of the first profile section of the marshalling hump is calculated (see formula (8) in [12]) contradicts the theorem on the change of kinetic energy for a non-free material point in the final form.

2. The results of the calculations proved incorrect derivation of the formula for calculating the height of the first profile section of the hump in the normative and technical document "Rules and regulations for the design of marshalling devices on railways with gauge 1 520 mm".

3. The error of use of formula $h_0 = v_0^2 / 2g'$ in the normative-technical document is proved to determine the energy height of the slide taking into account the inertia of the rotating parts, applicable only for the ideal connection (see pp. 286, 287 in [19]).

REFERENCES

1. Prokop, J. & Myojin, Sh.: Simulation of Hump Performance in Railroad Classification Yard. *Yard. Memoirs of the Faculty of Engineering, Okayama University*. 1993. Vol. 1. No. 2. P. 59-71. Available at: http://ousar.lib.okayama-u.ac.jp/file/15406/Mem_Fac_Eng_OU_27_2_59.pdf
2. Zhang C. Wei Y., Xiao G., Wang Z., Fu J.: Analysis of Hump Automation in China. *Proc. of Second Intern. Conf. on Transportation and Traffic Studies*, 2000, pp. 285-290. doi: 10.1061/40503(277)45.
3. Zářecký, S. & Grůň, J. & Žilka J.: The newest trends in marshalling yards automation. *Transport Problems*. 2008. Vol. 3. No. 4. P. 87-95. Available at: http://transportproblems.polsl.pl/pl/Archiwum/2008/zeszyt4/2008t3z4_13.pdf
4. Judge, T.: Yard Management Gets Smarter. *Railway Age*. 2007. No. 5. P. 33-34.
5. Zhang C., Li Y.: Research on Multi-objective Optimization of Vertical Section of the Hump Pushing Zone. *Proc. of Intern Conf. «Optoelectronics and Image Processing (ICOIP)»*. Haiko, 2010, vol. 2, pp. 262-265. doi: 10.1109/ICOIP.2010.274.
6. Komarov, K.L., Yashin, A.F.: *Teoreticheskaya mekhanika v zadachah zheleznodorozhnogo transporta (Theoretical mechanics in railway transport problems)*, Novosibirsk: Nauka, 2004, 296 p.
7. Volodymyr Bobrovskiy, Dmitriy Kozachenko, Andrii Dorosh, Evhen Demchenko, Tetiana Bolvanovska, Anton Kolesnik.: The research of the domain of permissible braking modes of cuts on the gravity humps. *Transport Problems. IV Symposium of Young Researchers*. 2015. – pp. 632-640.
8. Bobrovskiy V., Kozachenko D., Dorosh A., Demchenko E., Bolvanovska T., Kolesnik A.: Probabilistic Approach for the Determination of Cuts Permissible Braking Modes on the Gravity Humps. *Transport Problems*. 2016. Vol. 11, Issue 1, pp. 147-155. doi: 10.20858/tp.2016.11.1.14.
9. Kozschenko D.M., Bobrovsky V.I., Grevtsov S.V., Berezobiy M.I.. Controlling the Speed of Rolling Cuts in Conditions of Reduction of Brake Opwer of Car Retardes. *Наука та прогресс транспорту. Вісник Дніпропетровського націон. універ. залізничного транспорту*, 2016. №3 (63). – С.28-40. doi 10.15802/stp2016/74710.
10. Dmitro Kozachenko, Vladymyr Bobrovskiy, Yvgen Demchenko.: A method for optimization of time intervals between rolling cuts on sorting humps. *Journal of Modern Transportation*, Vol 26, Iss. 3, Pp. 189-199 (2018). <https://doi.org/10.1007/s40534-018-0161-2>
11. Khabibulla Turanov, Andrey Gordienko: Analytical Determination of Conditions of Wagon Rolling Down Marshalling Hump Profiles. *Open Access Library Journal*. 2, e1912. doi: <http://dx.doi.org/10.4236/oalib.1101912>. PP.1-11.
12. Turanov, Kh.T.: Nekotorye problemy teoreticheskikh predposylok dinamiki skatyvaniya vagona po uklonu sortirovochnoj gorki (Some problems of theoretical premises of dynamics of rolling of the wagon on a slope of marshalling hump). *Transport information Bulletin*, 2015, No. 3 (237), pp. 29 - 36. ISSN 2072-8115.
13. Rudanovskij, V.M., Starshov, I.P.: O popytke kritiki teoreticheskikh polozhenij dinamiki skatyvaniya vagona po uklonu sortirovochnoj gorki (About the attempt of criticism of theoretical propositions of the dynamics of the sliding of the wagon on the marshalling hump). *Transport information Bulletin*, 2016, No. 6 (252), pp. 19-28. ISSN 2072-8115.
14. Pozojkskij, Yu.O., Kobzev, V.A., Starshov, I.P., Rudanovskij, V.M.: K voprosu dvizheniya vagona po uklonu zheleznodorozhnogo puti (To the issue of the movement of the wagon on the marshalling hump of the railway track). *Transport information Bulletin*, 2018, No. 2 (272), pp. 35-38. ISSN 2072-8115.
15. Turanov, Kh.T., Gordienko, A.A.: Kriticheskij analiz teoreticheskikh polozhenij dvizheniya vagona s sortirovochnoj gorki (Critical analysis of the theoretical provisions of the movement of the wagon from the marshalling hump (Part I)). *Transport information Bulletin*, 2018, No.9 (279), pp. 23-28. ISSN 2072-8115.
16. Prokop, J & Myojin, Sh. Design of Hump Profile in Railroad Classification Yard. *Memoirs of the Faculty of Engineering. Okayama University*. 1993. Vol. 27. No. 2. P.41-58. Available at: http://ousar.lib.okayama-u.ac.jp/file/15404/Mem_Fac_Eng_OU_27_2_41.pdf.
17. Turanov, Kh., Gordienko, A.: Movement of a railway car rolling down a classification hump with a tailwind. *V zbornike: MATEC Web of Conferences* 10. 2018. P. 02027.
18. Khabibulla Turanov, Elena Timukhina and Andrey Gordienko. Mathematical Description of the Car's Movement on The Descent Part of the Hump. *TransSiberia 2019, AISC 1115*, pp. 703–716, 2020. https://doi.org/10.1007/978-3-030-37916-2_69
19. Timoshenko, S.P.: *Inzhenernaya mekhanika (Engineering mechanics)*. Moscow: Mashgiz, 1960, 507 p.
20. Kobzev, V.A.: *Technical means of marshalling humps, ensuring traffic safety. Part 1. Textbook (Tekhnicheskie sredstva sortirovochnyh gorok, obespechivayushchie bezopasnost' dvizheniya)*. Moscow: MIIT, 2009, 92 p.