Progress Annals: Journal of Progressive Research
Volume 1, Issue 8, December, 2023
ISSN (E): 2810-6466
Website: https://academiaone.org/index.php/8

MATHEMATICAL MODELLING OF THE ROLLING SPEED

Shukhrat Saidivaliev[1], Diyora Juraeva[1], Xushnudbek Farkhodov[1], Ulugbek Gafforov[1]
[1]Tashkent State Transport University, 1 Temiryulchilar Str., Tashkent 100069, Uzbekistan

Abstract. The article shows the consideration of the rolling friction moments (pure rolling) of the wheels on the rail threads and in the bearings of the front axlebox units. and rear bogies of the car with their subsequent replacement by conditional sliding friction. It is noted that if the active force in the form of a projection of the force of gravity and the aerodynamic drag force on the direction of rolling of the car (or release), acting on the car, is greater than the limiting friction force, then simultaneously with rolling, the wheels may also slip on the rail threads. An analytical formula was obtained for finding the difference between the driving forces and all resistance forces when rolling wheels with sliding, which, based on the theorem on the change in the momentum of a material point, made it possible to create a mathematical model for finding the speed of a single car (or cut) on the first profile section of the hump. An analysis of the results of solving the problem of determining the rolling speed of a car has been carried out. It is noted that the theorem on the change in the momentum of a material point for solving the problem of finding the time of rolling down a hill is applicable only when the final speed of the car is known, otherwise solving the problem in such a formulation will be meaningless.

1 Formulation of the problem

An analysis of literary sources [1 – 5] shows that the recommended formulas for determining the time of rolling a car (or trailer) from a hill do not take into account the movement of the car along the profile of the hill when the wheels roll with sliding, except that such movement is indirectly taken into account by the concept of basic resistivity w_o, which was found empirically. Without explaining the reasons for the occurrence of various types of resistance that appear when a car rolls down a hill, it is noted that "the determining factors are: the main resistivity w_o, specific resistance from air and wind w_{aw}, resistivity from snow and frost w_{sn}; additional – episodic resistance forces from impacts on turnouts w w_s, when moving in curves w_c and braking on retarders w_b" All of the indicated types of dimensionless specific resistances (i.e., resistances related to the gravity force of the car) are found using empirical formulas.
In addition, it should be taken into account that the results of solving the problem of determining the time of movement of a car when rolling down a hill, which were obtained in [4, 12], can only be used to determine the time of stopping (or braking) of the car t_1, taking into account that at this moment the final speed of the car $v_{fin} = 0$.
In [5, 16], computational models of rolling a car from a hump were built and an attempt was made to find the time of its rolling, taking, following [1, 2], the speed of rolling according to the formula that is used to find the speed of a freely falling body from a given height, which is erroneous.
Thus, until now, researchers have completely overlooked the construction of a mathematical model of a car rolling down a hill in strict accordance with the classical principles of theoretical mechanics, which makes it possible to find the speed of a car rolling down a hill.
In this regard, finding the speed when sliding along the profile of a slide is still an urgent task in railway transport and transport science.

Progress Annals: Journal of Progressive Research
Volume 1, Issue 8, December, 2023
ISSN (E): 2810-6466
Website: https://academiaone.org/index.php/8

2 Problem formulation

It is required to create a mathematical model of the speed of rolling a car (or trailer) down a hill with a headwind and/or tailwind, taking into account the driving forces and resistance forces in the first profile section (from the top of the hill to the beginning of the first braking position).

3 Solution methods

Let's use classical concepts and provisions of theoretical mechanics, for example, such as bonds, bond reactions, the principle of liberation from bonds, Coulomb's law, the moment of rolling friction, Newton's second (fundamental) law, the theorem on the change in the momentum of a material point [6].

4 Problem conditions and accepted premises

Let's consider the general case when a car rolls forward from a hump at a given initial speed v0 (usually 4–5 kmph or 1.1…1.38 mps, and the permissible speed reaches 7 mps). When a single car (or cut) is rolled down a hill, the car will experience the influence of mainly external forces in the form of gravity forces of the car with or without cargo – $\overline{G}$ and aerodynamic air resistance forces – $\bar{F}_a$ where $\bar{F}_a \in \bar{F}'_{ax}, \bar{F}'_{ay}$). We believe that all the assumptions adopted in [5], remain valid, for example, the cargo in the car is placed symmetrically relative to the longitudinal and transverse axes of symmetry so that the wheel pairs are loaded evenly due to the gravity of the cargo [7, 8]. We especially note that the force of aerodynamic air resistance $\bar{F}_{ra}$ belongs to the class of reactive force, depends on the relative speed $\bar{v}_{ra}$ and acts on a car moving in, for example, a medium such as air. The aerodynamic drag force is the result of taking into account the discarded medium (air). Like the other reaction, force $\bar{F}_{ra}$ interferes with movement, in this case relative to the speed of the air flow (headwind) $\bar{v}_{ra}$.At the same time, strength $\bar{F}_{ra}$ can be classified as an active force, since, having begun to act on an object, it can set it in motion if the direction of the air speed (tail wind) coincides with the direction of the speed of the car [5].

Note that the driving forces include projections of gravity G_x and, in the case of a tailwind, aerodynamic drag forces on the direction of movement of the car F_{rax}, and among all possible types of resistance forces are aerodynamic drag forces F_{rax}, in the case of a headwind, and all random (or episodic) resistance [5].

5 Solution

For the wheels of the wheelset of a car rolling down a hill, due to the fact that the condition is always met $\bar{F} \geq \bar{F}_{fr}$ i.e. $F > (f_{wh}/r_{wh})F_z$ (Where F and F_z – the sum of the projection of all active forces onto the vertical, kN; r_{wh} – wheel radius). Here's the attitude f_{wh}/r_{wh} for most materials the coefficient of sliding friction is significantly lower f, which between the contacting surfaces of the wheels of freight cars and rail threads is taken to be 0.25 [9].
From here it is clear that rolling friction, if necessary, can be replaced by conditional sliding friction during pure rolling [6, 18]

$$F_{fr.wh} = \frac{n_{wh} f_{wh}}{r_{wh}} F_z, \tag{1}$$

Where n_{wh} – number of wheels in carts, pcs. ($n_{wh} = 8$); f_{wh} – rolling friction coefficient, m, since this coefficient is equivalent to the arm of the rolling friction pair (wheel on rail $f_{wh} = 5\times10^{-6}$, hardened steel $f_{wh} = 1\times10^{-6}$), r_{wh} – wheel radius equal to 0.475 m for a freight car;

Progress Annals: Journal of Progressive Research
Volume 1, Issue 8, December, 2023
ISSN (E): 2810-6466
Website: https://academiaone.org/index.php/8

F_z – the sum of the projection of all active forces onto the vertical axis per each axle box unit, kN:

$$F_z = G\cos\psi_0 + F'_{ax}\sin\psi_0; \quad (2)$$

or

$$F_{\text{fr.c}} = \frac{n_{wh} f_{wh}}{r_{wh}}(G\cos\psi_0 + F'_{ax}\sin\psi_0). \quad (3)$$

The mechanical system is also subject to *internal forces* in the form of rolling friction moments M_{frbA} ($M_{\text{frb}A} \in \{M_{\text{frb}A1}, M_{\text{frb}A2}, M_{\text{frb}A'1}, M_{\text{frb}A'2}\}$) and M_{frbB} ($M_{\text{frb}B} \in \{M_{\text{frb}B1}, M_{\text{frb}B2}, M_{\text{frb}B'1}, M_{\text{frb}B'2}\}$) in the bearings of the front axlebox units A and back B carriage bogies, and $M_{\text{frb}} = M_{\text{frbA}} + M_{\text{frbB}}$.

At the points of contact with the rolling elements of the inner diameter of the inner ring of the bearing, internal forces appear N_{rb} – normal reaction of the bearing and at the same point the same magnitude, but oppositely directed reaction acts on the rolling elements from the inner ring of the bearing N_{o}. Here,

$$N = \sum_{i=1}^{2}(N_{Ai} + N_{A'i} + N_{Bi} + N_{B'i}) \quad (2, a)$$

(i– number of wheels on one trolley axle);

$$\bar{F}_{\text{fr}} = \bar{F}_{\text{fr}.A} + \bar{F}_{\text{fr}.A'} + \bar{F}_{\text{fr}.B} + \bar{F}_{\text{fr}.B'}. \quad (3)$$

The rolling friction moment in the bearings of the axle units of the front and rear bogies of the car

$$M_{\text{frb}} = n_{\text{b}} f_{\text{r0}} N_{\text{b}}, \quad (4)$$

where n_{b}= 8 – quantity of axle box unit in bogies, pcs.; f_{r0} – coefficient of friction of rolling elements on bearing rings (usually taken ~$1\cdot10^{-6}$), m; N_{b} – normal reaction per one rolling bearing, or force acting on the most loaded rolling element and determined by the formula, kN [10]:

$$N_b = \frac{kF_z}{n_b n_{\text{re}}} \quad (4, a)$$

taking into account the fact that n_{re} – total number of rolling elements taking the load in each bearing, pcs.; k – a constant coefficient taken depending on the row and type of rolling bearings (for single row bearings k= 4, for roller bearings with n_{b} = 10…20 average value $k \approx 4$. Taking into account the influence of the gap in rolling bearings, for the calculation we take k= 4.6).

Similarly to (1), rolling friction can be replaced by conditional sliding friction during pure rolling of rolling elements in bearings [6]

$$F_{fr.\text{r}} = \frac{n_b f_{r0}}{r_b} N_b, \quad (4, b)$$

where n_{b} – number of bearings in axle boxes of bogies, pcs. (n_{b}= 16); r_{b} – outer radius of the inner ring of the rolling bearing, m,

Let us rewrite the last formula taking into account (2) and (3, a):

$$F_{\text{fr.r0}} = \frac{n_b f_{r0}}{r_b}\frac{k}{n_b n_{\text{re}}}(G\cos\psi_0 + F'_{ax}\sin\psi_0). \quad (5)$$

Progress Annals: Journal of Progressive Research
Volume 1, Issue 8, December, 2023
ISSN (E): 2810-6466
Website: https://academiaone.org/index.php/8

By combining (3) and (5), the rolling friction of the wheels can be replaced by conditional sliding friction during pure rolling of the wheels and rolling elements in the bearings of the axlebox units:

$$F_{\text{fr}}^{wh} = F_{\text{fr.r}} + F_{\text{fr.r0}},$$

or

$$F_{\text{fr}}^{wh} = \left(\frac{n_{wh} f_{wh}}{r_{wh}} + \frac{n_b f_{r0}}{r_b}\frac{k}{n_b n_{\text{re}}}\right)(G\cos\psi_0 + F'_{ax}\sin\psi_0),$$

or

$$F_{\text{fr}}^{wh} = f_0(G\cos\psi_0 + F'_{ax}\sin\psi_0). \quad (6)$$

where f_0 – some conditional (or reduced) coefficient of sliding friction:

$$f_0 = \frac{n_{wh} f_{wh}}{r_{wh}} + \frac{n_b f_{r0}}{r_b}\frac{k}{n_b n_{\text{re}}}. \quad (6, a)$$

We especially note that if the active force $\bar{F}$, acting on the car, is greater than the maximum frictional force $F_{\max} = F_{\text{trac}}^{\max} = f_{\text{trac}} N$ (where N – normal component of the reaction of rail threads), i.e. $\bar{F} \geq \bar{F}_{\max}$, then simultaneously with rolling, *sliding* is also possible. At the same time, the attitude $\frac{f_{wh}}{r_{wh}}$ will be greater than the sliding friction coefficient f, i.e. $f < \frac{f_{wh}}{r_{wh}}$. This case is possible when the car is exposed to the projection of aerodynamic drag force F'_{rax} with tailwind and strength F'_{ray} (which tends to press the ridges of the outer wheels of the bogie wheel pairs against the thrust rail), when the active force is equal to $F = G\sin\psi + F_{rax}$ and the condition is met $\bar{F} \geq \bar{F}_{\max}$.
The sliding friction forces of the wheels on the rail threads counteract the rolling of the car down the hill in the form $F_{\text{fr}A}$ ($F_{\text{тр}A} \in \{F_{\text{fr}A1}, F_{\text{fr}A2}, F_{\text{fr}A'1}, F_{\text{fr}A'2}\}$) и $F_{\text{fr}B}$ ($F_{\text{fr}B} \in \{F_{\text{fr}B1}, F_{\text{fr}B2}, F_{\text{fr}B'1}, F_{\text{fr}B'2}\}$).
Friction forces according to Coulomb's law consists of two terms that take into account friction forces from normal pressure and wind pressure from the side of the car:

$$F_{\text{fr}}^{\text{sl}} = F_{\text{fr}AB} + F_{\text{fr}A'B'}, \quad (7)$$

where $F_{\text{frAB}} = F_{\text{fr}A} + F_{\text{fr}B}$ – sliding friction forces of wheels along rail threads from the influence of the normal component $\bar{N}$ ($\bar{N} \in \{\bar{N}_A, \bar{N}_B\}$) communication reactions: $F_{\text{fr}AB} = f_{\text{sl}} N$ taking into account the fact that f_{sl} – coefficient of sliding friction of the wheel on the rail (usually "metal on metal" – f_{sl} = 0.15...0.25);
$F_{\text{fr}A'B'} = F_{\text{fr}A'0} + F_{\text{fr}B'0}$ – the sliding friction force of the wheel flanges along the thrust rail from the influence of the projection of the aerodynamic drag force from the side of the car $F'_{r\text{By}}$: F'_{ray}: $F_{\text{fr}A'B'} = f_{\text{sl0}} F'_{ray}$ taking into account the fact that f_{sl0}– coefficient of sliding friction of the wheel flanges on the rail (usually taken f_{sl0}= 0.25 [9, 17], and in the case of using comb lubricators (or lubricators) the value f_{sl0} significantly less) (in the particular case $f_{\text{sl}} = f_{\text{sl0}}$).
Let us consider the case of a flat system of forces when the trailer rolls down a hill along a straight track profile, taking into account that the resulting aerodynamic drag force is directed at a certain angle to the direction of the car rolling down the hill, i.e. $\bar{F}_{ra} \in \bar{F}'_{rax}, \bar{F}'_{ray}$ [5, 15].
Introducing the concepts of "shearing" and "holding" forces, taking into account all the active and reactive forces that were found in [5, 7, 11, 13], we obtain:
- in a headwind

$$F_{\text{sh.x}} = G_x = G\sin\psi_0;$$

Progress Annals: Journal of Progressive Research
Volume 1, Issue 8, December, 2023
ISSN (E): 2810-6466
Website: https://academiaone.org/index.php/8

- with a fair wind

$$F_{\text{sh.x}} = G\,sin\,\psi_0 + F'_{rax}\,cos\,\psi_0;$$

- in a headwind

$$F_{\text{h.x}} = F_\tau + F'_{rax}\,cos\,\psi_0;$$

- with a fair wind

$$F_{\text{h.x}} = F_\tau.$$

The carriage will roll down the hill only if the following conditions are met:

$$F_{\text{sh.x}} \geq F_{\text{h.x}}, \tag{8}$$

or

$$\Delta F_{\text{x}} = F_{\text{sh.x}} - F_{\text{h.x}} \geq 0, \tag{9}$$

where ΔF_x – the driving force that forces the car to roll down the hill.
Having written down the equilibrium conditions for a plane system of forces, we obtain:

$$F_{\text{sh.x}} - F_{\text{h.x}} = 0,$$

or

$$G_x \mp F'_{rax}\,cos\,\psi_0 - F_\tau = 0, \tag{10}$$

where the "minus" sign corresponds to a headwind, the "plus" sign to a tailwind;
F_τ – the sum of all resistance forces when wheels roll and slide:

$$F_\tau = (f_0 + f_{\text{sl}})N + f_{\text{sl0}}F'_{ray}. \tag{11}$$

Substituting (11) and (2) or (2, a) into (10), we will have:

$$G\,sin\,\psi_0 \pm F'_{rax}\,cos\,\psi_0 - (f_0 + f_{\text{sl}})(G\,cos\,\psi_0 + F'_{rax}\,sin\,\psi_0) - f_{\text{sl0}}F'_{ray} = 0,$$

or, after elementary mathematical calculations,

$$G(sin\,\psi_0 - (f_0 + f_{\text{sl}})\,cos\,\psi_0) + F'_{rax}(\pm\,cos\,\psi_0 - (f_0 + f_{\text{sl}})\,sin\,\psi_0) - \\ -f_{\text{sl0}}F'_{ray} = 0.$$

Transforming the last expression, we get:

$$\begin{bmatrix} G\left(\text{tg}\psi_0 - (f_0 + f_{\text{sl}})\right) + F'_{rax}\left(\pm 1 - (f_0 + f_{\text{sl}})\text{tg}\psi_0\right) - \\ -f_{\text{sl0}}F'_{ray} \end{bmatrix} cos\,\psi_0 = 0.$$

According to (9), we give the last relation the form:

$$\Delta F_x = \begin{bmatrix} G\left(\text{tg}\psi_0 - (f_0 + f_{\text{sl}})\right) + F'_{rax}\left(\pm 1 - (f_0 + f_{\text{sl}})\text{tg}\psi_0\right) - \\ -f_{\text{sl0}}F'_{ray} \end{bmatrix} cos\,\psi_0\,. \tag{12}$$

So the strength ΔF_x is an active force, which, according to Newton's second law, when it begins to act on the uncoupling, forces the car to roll down the hill with acceleration.
Under initial conditions: $0 \le t \le t_f$ And $v_0 \le v \le v_f$ (where v_0 and v_f – given initial and acquired final speed of uncoupling), *the theorem on the change in the momentum of a material point* [6] will be written in the form:

$$Mv_f - Mv_0 = \int_0^t \Delta F_x dt = \Delta F_x (t_f - t_0),$$

or

$$Mv_f - Mv_0 = \Delta F_x (t_f - t_0), \tag{13}$$

where M – mass of the car with cargo, kg; t_f – time of passage of the car on any section of the hump, s; v_f – acquired final speed of the car (*the value being sought*), mps.
Substituting (12) into (13) and dividing the result by the mass of the cut M, and given that $G = Mg$, will have:

$$v_f - v_0 = \begin{bmatrix} g\left(\text{tg}\psi_0 - (f_0 + f_{sl})\right) + \\ + \frac{F'_{rax}}{M}\left(\pm 1 - (f_0 + f_{sl})\text{tg}\psi_0\right) - f_{sl0}\frac{F'_{ray}}{M} \end{bmatrix} \cos\psi_0 \times (t_f - t_0). \tag{14}$$

In (14) we will take into account that $\text{tg}\psi_0 = \frac{h}{l_0} = i$, where L_c and l_0 –profile length of the first profile section of the slide and its projection onto the horizontal, m; i – steepness of the first profile section of the slide, ‰.
The first profile section of the slide has a profile of *0 – 1 – 2* and on section *1 – 2* there is the 1st braking position (1BP) with coordinates *a* and *b*. It is marked: HS – height of the slide; *H* and *L* – parameters of the design height of the slide, m; h_1, h_2 and l_{01}, l_a – height and length of the corresponding sections of the slide, m; l_{ab} – length of the first braking position, m; ψ_{01} and ψ_{02} – angles of inclination of the corresponding sections of the slide, rad.

Replacing in (14) $\text{tg}\psi_0$ profile steepness i the first profile section of the slide, we get:

$$v_f - v_0 = \begin{bmatrix} g(i - (f_0 + f_{sl})) + \\ + \frac{F'_{rax}}{M}(\pm 1 - (f_0 + f_{sl})i) - f_{sl0}\frac{F'_{ray}}{M} \end{bmatrix} \cos\psi_0 \times (t_f - t_0).$$

Considering that in the last relation $t_f = t$ – is a variable quantity, and $t = 0$, we will have:

$$v_f = v_0 + \begin{bmatrix} g(i - (f_0 + f_{sl})) + \\ + \frac{F'_{rax}}{M}(\pm 1 - (f_0 + f_{sl})i) - f_{sl0}\frac{F'_{ray}}{M} \end{bmatrix} \cos\psi_0 \times t.$$

Let us rewrite the last expression in order to highlight the cases of influence of tailwind and headwind on the car:

$$v_f = v_0 + [g(i - (f_0 + f_{sl})) \pm a - a_0]\cos\psi_0 \times t, \tag{15}$$

where a and a_0 – quantities having dimensions of acceleration, mps^2:

ACADEMIA ONE
PEER REVIEWED JOURNALS
Progress Annals: Journal of Progressive Research
Volume 1, Issue 8, December, 2023
ISSN (E): 2810-6466
Website: https://academiaone.org/index.php/8

$$a = \frac{F'_{ax}}{M};\; a_0 = \frac{F'_{rax}}{M}(f_0 + f_{sl})i + f_{sl0}\frac{F'_{ray}}{M}.$$

Let us recall that in (15) the “plus” sign takes into account the tailwind, and the “minus” sign – the headwind.
Expression (15) can be presented differently, taking into account the mass of rotating parts (wheel pairs of bogies) M_0 as

$$v_f = v_0 + [g'(i - (f_0 + f_{sl})) \pm a - a_0]\cos\psi_0 \times t, \qquad (15, a)$$

Where $g' < g$, because the $M < M_0$) – fraction of free fall acceleration, mps^2.
Analysis of the results of problem solutions. Analysis of the resulting formula (15, a) shows that at any initial speed of rolling the car from the hump v_0, with a tailwind, the second term $g'(i - (f_0 + f_{sl})) + a - a_0 > 0$ or$g'(i - (f_0 + f_{sl})) + a > a_0$, and with a headwind – $g'(i - (f_0 + f_{sl})) - a - a_0 > 0$ or $g'(i - (f_0 + f_{sl})) > a + a_0$. From this it is clear that the rolling speed of the car with a tailwind is greater than with a headwind, which confirms the correctness of the obtained mathematical calculations.
From (15, a) the time can be found $t = t_f$, corresponding to the specified value of the final speed of the car v_f, at $t = 0$:

$$t = t_0 + \frac{v_f - v_0}{[g'(i - (f_0 + f_{vs})) \pm a - a_0]\cos\psi_0}. \qquad (16)$$

Let us rewrite (16) with t= 0 and cosψ0 1, as for small angles,

$$t = \frac{v_f - v_0}{g'(i - (f_0 + f_{vs})) \pm a - a_0}. \qquad (16, a)$$

If we accept $f_0 + f_{vs}$ for the main specific resistance when rolling wheels sliding along the rail – w_0, i.e. $f_0 + f_{vs} = w_0$, and when rolling a car down a hill, do not take into account the tailwind and the rolling of the wheels with sliding, then the last expression can be represented as:

$$t = \frac{v_f - v_0}{g'(i - w_0)}.$$

The last formula is similar to the formula presented in [4, 6, 8].
Comment. It is assumed that the final speed of the car v_f must be a known quantity, otherwise further solution of the problem in such a formulation will turn out to be as meaningless as it was done in [1 – 4]. In accordance with this, we note that *the theorem on the change in the momentum of a material point* for solving the problem of finding the time of rolling down a hill is applicable only when the final speed of the car is known.

Conclusions. The obtained mathematical models for finding the speed of a car rolling down a hump on a high-speed section during the formation and disbandment of rolling stock make it possible to design a high-speed section of a hump with rational profiles so that the speed at which the trailer enters the braking position does not exceed the permissible value (~ 8 mps). We especially note that the speed of a car rolling down a hill can be considered an independent problem that requires its own solution based on drawing up a differential equation of motion.

List Of Literature

1. Turanov X.T., Bondarenko A.N., Vlasova N.V. Krepleniya gruzov v vagonax. Yekaterinburg: UrGUPS, 2006. 286 s.

2. Faborin M.V. Momentы inersii tel. Spravochnik. Pod red. M.M. Gerneta. M: Mashinostroenie, 1977. 511 s.
3. Obmorshev A.N. Vvedenie v teoriyu kolebaniy. M: Nauka, 1965. S. 276.
4. Saidivaliev Sh.U. Determining the kinematic parameters of railcar motion in Hump yard retarder positions. AIP Conference Proceedings 2612, 060016 (2023). https://doi.org/10.1063/5.0115115
5. Shukhrat Saidivaliev, Shukhrat Djabborov, Bakhrom Abdullaev, Shakhboz Abduvakhitov and Diyora Juraeva. About the movement of the car on the high-speed sections of the sorting hill. E3S Web of Conferences 389, 05023 (2023). https://doi.org/10.1051/e3sconf/202338905023.
6. Shukhrat Saidivaliev, Samandar Sattorov, Rashida Tursunkhodjaeva and Rustam Abdul-laev. Analysis of the movement of an empty railcar on the longitudinal profile of the sorting slide. E3S Web of Conf., 376 (2023) 04036 DOI: https://doi.org/10.1051/e3sconf/202337604036
7. Shukhrat Saidivaliev, Samandar Sattorov and Diyora Juraeva. Assessment of the move-ment of the car along the sorting slide with a tailwind in the context of environmental health. E3S Web Conf., 371 (2023) 04033. DOI: https://doi.org/10.1051/e3sconf/202337104033.
8. Abdullaev, B., Gayipov, A., Rahimov, R., Djabbarov, Sh.B., Galimova, F., Khurma-tov,Y. Innovative bases of technology of autonomous transportation of perishable cargo / E3S Web of Conferences. – International Scientific Siberian Transport Forum - TransSiberia 2023. – Vol. 402. – 01013. – pp. 1–9; DOI: 10.1051/e3sconf/202340201013.
9. Khurmatov, Ya.A., Khaydarov, O.U., Abdullaev, B.A., Djabbarov, Sh.B., Inagamov, S.G. Evaluation of the efficiency of the friction tread brake of the diesel motor car / E3S Web of Conferences. – International Scientific Siberian Transport Forum - TransSiberia 2023. – Vol. 402. – 04009. – pp. 1–8; DOI: 10.1051/e3sconf/202340204009.
10. Inagamov, S., Djabbarov, S., Abdullaev, B., Ruzmetov, Ya., Inoyatov, K., Hurma-tov, Y. Study of the friction of the brake shoe of a freight car / E3S Web of Conferences. – V In-ternational Scientific Conference “Construction Mechanics, Hydraulics and Water Resources Engi-neering” (CONMECHYDRO - 2023) – Vol. 401. – 05036. – pp. 1–10; DOI: 10.1051/e3sconf/202340105036.
11. Туранов Х.Т., Илесалиев Д.И., Джаббаров Ш.Б., Саидивалиев Ш.У. Критический анализ теоретических положений движения вагона с сортировочной горки / Х.Т. Туранов, Д.И. Илесалиев, Ш.Б. Джаббаров, Ш.У. Саидивалиев // Транспорт: наука, техника, управление. 2021, № 3. С. 47 - 53. ISSN 0236-1914..
12. Djabbarov, S., Abdirakhmanov, J., Abdullaev, B., Yuldoshov, R., Ergasheva, V. Rin-in comb wheels of the wheel pair of the car when moving on a curve section of the path / E3S Web of Conferences, Ural Environmental Science Forum “Sustainable Development of Industrial Re-gion” (UESF-2023) – Vol. 389. – 05048. – pp. 1–8; DOI: 10.1051/e3sconf/202338905048.
13. Djabbarov, Sh.B., Saidivaliev, Sh.U, Abdullaev, B.A, Inagamov, S.G., Yuldashov, A.A. Vertical vibrations of a freight car as a uniaxial carriage from a wave of unevenness of the path / E3S Web of Conferences, International Scientific Conference “Fundamental and Applied Scien-tific Research in the Development of Agriculture in the Far East” (AFE-2022) – Vol. 371. – 04035. – pp. 1–9; DOI:10.1051/e3sconf/202337104035.

14. Djabbarov, S., Saidivaliev, S., Abdullayev, B., Gayipov, A., Rakhmatov, K., Sob-oleva, I. Study of the kinematic characteristics of the motion of the car from the top to the design point. E3S Web of Conferences. – International Scientific Siberian Transport Forum - TransSiberia 2023. – Vol. 402. – 04010. – pp. 1–14; DOI 10.1051/e3sconf/202340204010
15. Saidivaliev Sh.U., A new method of calculating time and speed of a carriage during its movement on the section of the first brake position of a marshaling hump when exposed headwind / Sh.U. Saidivaliev, R.Sh. Bozorov, E.S. Shermatov // STUDENT eISSN: 2658-4964. 2021, №9.
16. Rustamov, N., Kibishov, A., Genc, N., Babakhan, S., Kamal, E. Thermal Conductivity of a Vacuum Fractal Solar Collector // International Journal of Renewable Energy Research, 2023, 13(2), stranisы 612–618
17. Rustamov, N., Babakhan, S., Genc, N., Kibishov, A., Meirbekova, O. An Improved Hy-brid Wind Power Plant for Small Power Generation // International Journal of Renewable Energy Research, 2023, 13(2), stranisы 629–635
18. J.A. Shihnazarov, Comparison of technical and economic performance of wire and chain tracks used instrengthening loads in open traffic, D.Sh. Boboev, E.S. Shermatov, R.Sh. Bozorov, Cite as: AIP Conference Proceedings 2612, 060024 (2023); https://doi.org/10.1063/5.0130838.