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OPTIMIZATION OF THE SORTING HILL PROFILE TO SPEED UP ROLLING OF CARS OF VARIOUS CATEGORIES WITH THE HIGHEST SPEED

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Abstract:

The purpose of this work is to consider the possibility of using the fastest descent curve in relation to determining the optimal profile of the sorting hill to accelerate the rolling of cars of various categories with the highest speed.

Keywords: sorting station, sorting hill, uncoupling, longitudinal profile, mathematical model, modeling, energy.

Introduction. The sorting hill is the most important component of the sorting station, which sets and ensures the rhythm of the entire technological process of disbanding-the formation of trains. Disbandment of trains is one of the most important technological processes of marshalling yards, which requires significant energy costs.

One limiting factor in increasing the processing capacity of the slides is the significant number of unplanned detachments in the sorting fleet, which leads to the distraction of the slide locomotives, as well as the termination of the dissolution of trains during the deposition. Improving the efficiency of marshalling yards is possible only through a comprehensive approach to the automation of slides and the modernization of the slide infrastructure, as well as the revision of the technology for disbanding cars.

The longitudinal profile of the sorting hill has a significant impact on the quality of the sorting process [1-5]. Together with the established braking modes, the profile parameters determine the dynamics of rolling cars, affect the amount of intervals

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between detachments, the speed of their collision, as well as the degree of filling of sorting tracks [18].

In this regard, optimization of the parameters of the longitudinal profile of the slide, in order to minimize operating costs, is a very important task that must be solved when designing sorting slides [18].

The purpose of this work is to consider the possibility of using the curve of the fastest descent in relation to determining the optimal profile of the sorting hill to ensure the rolling of cars of various categories with the highest speed.

Case study. The General principle of operation of the sorting slide is based on the gravitational descent of chains and wagons with interval and targeted braking at the braking positions that provide the necessary processing capacity of the slide. When designing a sorting hill, five main conditions must be met:

- Traffic safety;
- The necessary bandwidth of the station;
- Complexity of the project (taking into account the requirements of the STC, labor and environmental protection, special conditions, etc.);
- Cost-effective solution;
- Possibility of further development of station devices.

This article is devoted to the problem of choosing the optimal parameters of the sorting hill, which has been covered in a significant number of works [1-16].Mathematical models of carriage movement in high-speed sections of the sorting hill under the influence of a small tailwind, described in [10] in a simplified statement of tasks. In [11], calculations of the acceleration of the car were investigated and the time and speed of the car on the second high-speed section of the hill were determined before and after the switch when exposed to a tailwind. In [13], examples of calculating the movement time and speed of the car using analytical formulas are given [12]. When solving the problem of moving a car from a sorting hill, as in [12, 13, 14], the classical position of theoretical mechanics is used – the main principle of Dalembert in coordinate form [15]. In [16], the effect of the inertia of the rotating masses of the car on the kinematic parameters of the movement of uncoupling on the hump and the steepness of the slope of the longitudinal profile the drain side hump on the high-speed properties of the estimated runners, applied modeling of uncoupling rolling with hump, is based on the analytical solution of the differential equations of motion unhook at the drain side slides. The height of the sorting slide is calculated from the condition that the calculated bad runner under adverse conditions (sub-zero temperature and headwind, mass close to the empty car) passed from the top of the hill on the most difficult path to the settlement point [1-5]. Consequently, all other runners with less resistance will continue further into the Park.

In the calculation of the longitudinal profile the drain side humps [8], it is proposed to consider the probability distribution of the underlying delegate private rolling unhooked with a hump [9].

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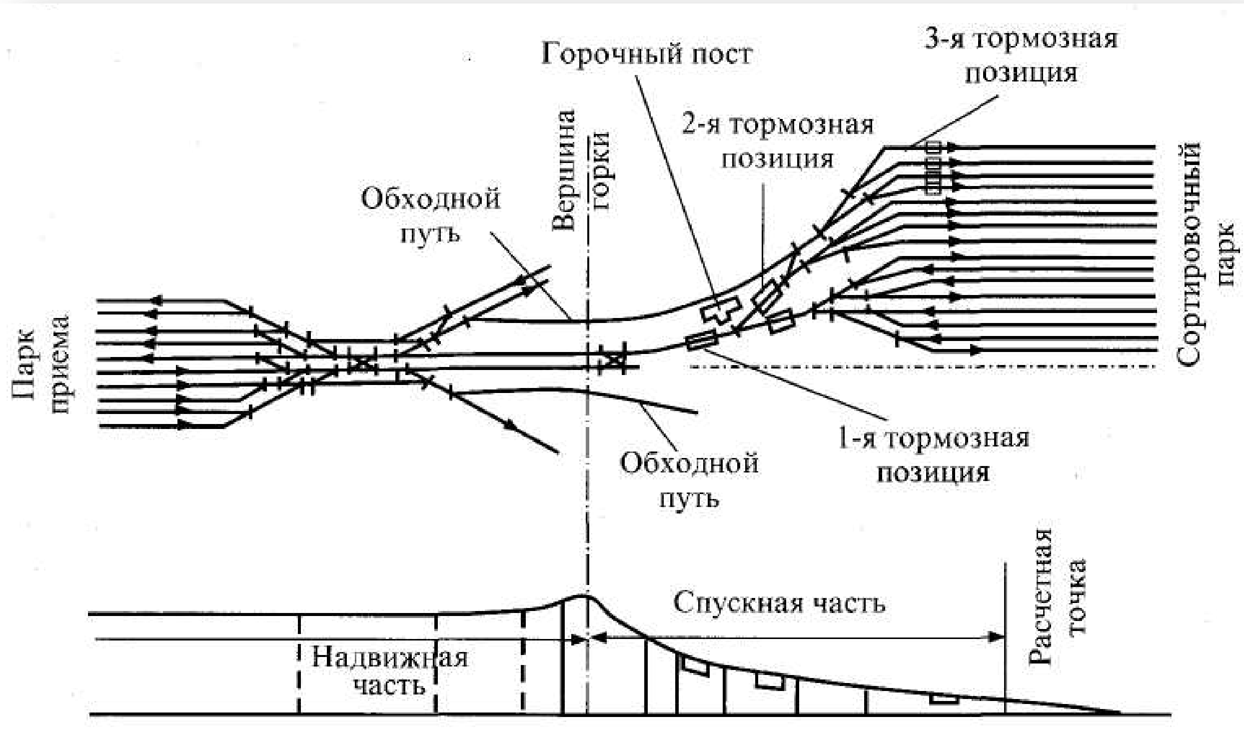
In a series of works [1-5, 10-14,16] elements of the longitudinal profile hump taken straight associated vertical curves, at the same time, in [6,7] it is shown that the longitudinal profile of the drain side hump from the top to the first brake position should correspond to brachistochrone, i.e. the fastest sliding curve by limiting output speed maximum allowable input speed of uncoupling on wagon retarders.

In order to obtain the largest intervals on the dividing elements in [17], the longitudinal profile of sorting slides is recommended to be designed in the form of a brachystochron. However, such a profile of the high-speed section of the slide provides a minimum movement time only when the detachments are free rolling [6, 7,17], without taking into account the initial speed of dissolution, dry and viscous friction resistances.

We analyze the properties of brachistochrone in relation to the profile of the hump in order to obtain the calculated dependences and recommendations necessary for the design elements of a hump on the basis of brachistochrone.

Main part. The longitudinal profile of the sorting hill can be represented as a gravitational device for the profile of the sorting hill, wagons, fences and brake devices [5].



Pic. 1- Profile of the sorting hill

The conversion of gravity energy into kinetic energy of motion is performed on a high-speed section, which, in contrast to the straight trajectory of an inclined path, can have any specified trajectory. In this regard, the descent trajectory is of interest,

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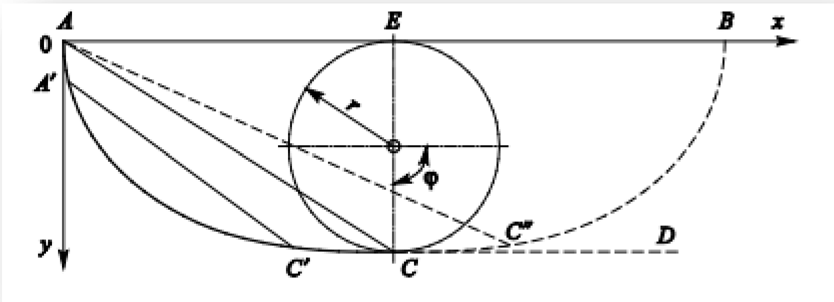
in which the acceleration section is made in the form of a curve of the fastest descent - a brachistochron, which is an inverted arc of the cycloid [19, p. 59] (DIA), which is formed when the generating circle with radius r rolls along the guide line AEB without sliding when the angle of rotation of the circle φ changes from 0 to 2π (Fig. 2). A brachystochron is any part of a cycloid-from its beginning at point A to its end at point C (C', C")[20].



Pic.2 The curve of the fastest descent.

The descent of a car under the influence of gravity along the AC curve or any part of it (for example, A'c') will always be faster than along the corresponding straight line connecting the ends of the curve, since the speed of descent on the brachystochrona is always higher than the speed of descent on the inclined straight line.

Let the coordinate system *x (t), y (t),* where the symbol t denotes the time, the points of the initial and final B positions of the body coincide, the point A is placed at the origin (Fig. 2). When a material body rolls from a resting position (point A), according to Galileo's law [20], the speed of the body at any point in the descent trajectory (when moving under the influence of gravity without friction) does not depend on the shape of the trajectory, but only on the coordinates of its initial and set points. In other words, the rolling speed v is completely determined by the current height $h = y(x)$, i.e. the kinetic energy of the body must be equal to the change in potential energy when descending from a height h:

$$\frac{mv^2}{2} = mgh \rightarrow v^2 = 2gh \rightarrow v = \sqrt{2gh}, \qquad (1)$$

Where g is the acceleration of gravity; m is the mass of the body.

From expression (1) it follows that at the end point of both trajectories, the speed of the body's motion coincide in absolute value. However, in intermediate values of x(t), the condition is always met:

$$\frac{v_{брах}}{v_{прям}} = \sqrt{\frac{h_{брах}}{h_{прям}}} > 1, \qquad (2)$$

$v_{брах}$,$v_{прям}$ and $h_{брах}$, $h_{прям}$ — the values of the speed and height of descent in the moment of time t for the brachistochrona and for the straight line, respectively.

The presence of such factors of braking of a moving body as friction and aerodynamic drag, resistance from arrows and curves will lead to the loss of some of the potential energy and, consequently, a decrease in the speed of descent.

Nevertheless, the ratio (2) will always be true under the same driving conditions, as well as if there is an initial speed of disbanding of cars. Therefore, replacing the straight-line paths of the cars ' descent with the brachistochrona in the conditions under consideration will generally increase the speed of rolling in the initial sections and allow you to gain time of descent. For sorting slides, the option of a part of the brachystochrona in the form of (as) is preferable (in Fig.2) direct inserts are provided for dampening part of the speed of cars on car decelerators.

Consider the properties of brachistochrone. To do this, we set the equation of the curve connecting point A with the line C as a function y = f (x). Then, using mathematical analysis methods, we obtain an equation for moving along the brachistochrona and the time of descent along it (without taking into account friction) [20, p. 62]:

$$ds = \sqrt{1 + \left(f'(x)\right)^2}dx, \quad (3)$$

ds— small increment of the curve.

Given the expression (1) and assuming that the speed of movement on a small section is constant, we get an approximate equal time dt required for passing this section:

$$dt \approx \frac{\sqrt{1+\left(f'(x)\right)^2}}{\sqrt{2gf(x)}}dx, \quad (4)$$

To use the relations (3) and (4), we find the function y = f (x).There is no such function for a cycloid. An analytical record of the inverse function x=f(y) is known, which is difficult to apply in applications. Therefore in practice we use the parametric form of connection of coordinates of the cycloid:

$$\left.\begin{matrix} x = r(\varphi - sin\varphi) \\ y = r(1 - cos\varphi) \end{matrix}\right\}, \quad (5)$$

The angle of rotation φ is a parameter of the function and changes in the range " 0...2π”for one arch of the cycloid with the radius of the producing circle r.

For the practical application of system (5), we must associate the argument x with the parameter φ by substituting x = x (φ). Having performed simple transformations taking into account system (5), instead of relations (3) and (4), we

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obtain the desired dependences. The length of the brachistochrone within the same cycloid arch is determined by the expression:

$$S = \int_x \sqrt{1 + (y'(x))^2} dx = r \int_\varphi \sqrt{(1 - cos\varphi)^2 + (sin\varphi)^2} d\varphi = \left| -4rcos\frac{\varphi}{2} \right|_{\varphi_1}^{\varphi_2}, \quad (6)$$

ϕ1 and ϕ2 are the initial and final angles of rotation of the generating circle, respectively.

To calculate the time of descent along the brachistochrone, one should determine the function f (x) in expression (4). In the coordinates y, φ, it is given by the dependence [10, p. 26]:

$$y = 2r(sin\frac{\varphi}{2})^2. \quad (7)$$

Taking into account equation (7), the descent time along the brachistochrone is determined by the expression:

$$T = r \int_\varphi \sqrt{\frac{(1-cos\varphi)^2 + (sin\varphi)^2}{4gr(sin\frac{\varphi}{2})^2}} d\varphi = \left| \sqrt{\frac{r}{g}} \varphi \right|_{\varphi_1}^{\varphi_2} \quad (8)$$

To determine the current value of the descent speed, we use the finite equality from expression (1) with the substitution of the y coordinate instead of h, determined by dependence (7):

$$v_{бpax} = \sqrt{2gv} = \sqrt{4gr(sin\frac{\varphi}{2})^2} = 2sin\frac{\varphi}{2}\sqrt{gr} \quad (9)$$

The acceleration causing the movement of the body in the gravitational descent of the brachistochrone is directed along the tangent at each of its points (Fig. 3) and

$$a_{бpax} = gsin\alpha \quad (10)$$

where α is the angle of inclination of the tangent.

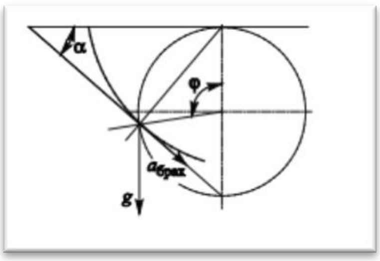

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Fig. 3. Determination of local acceleration at the brachistochrone

The angle α in relation (10) is determined by the equality:

$$\alpha = \left(\frac{\pi}{2} - \frac{\varphi}{2}\right), [10, c. 22],$$

$$a_{брах} = g sin\left(\frac{\pi}{2} - \frac{\varphi}{2}\right) = g cos\frac{\varphi}{2} \qquad (11)$$

It follows from expression (11) that for φ = 0, the tangent coincides with the direction of acceleration of gravity, i.e. angle of inclination α = 90º, which is unacceptable from the point of view of safety of descent. According to [5], the maximum slope of the high-speed section of the sorting slide should not exceed 55 ‰, and the maximum angle of inclination of an individual element of the slip section is 60 ‰. Given the rapid decrease in the local angle of inclination along the edges of the cycloid, we can take the value 60 ‰ as the initial value for the acceleration section wagon (Fig. 4).

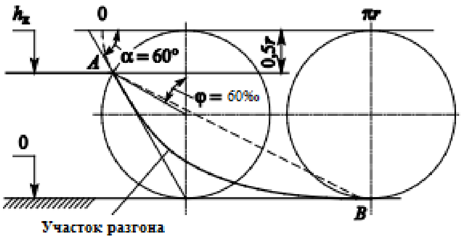

Fig. 4. Profile of the guide system of the emergency evacuation unit with a shortened brachistochrone (αnach = 60 ‰)

Here (Fig. 4), level 0 corresponds to the level of the launch complex site, and level hк - to the level of the manned carrier rocket ship. The dashed line AB shows the inclined rectilinear trough as a comparative version of the acceleration plot. The results of calculating the parameters of the acceleration plot based on the brachistochrone with an initial angle of inclination αstart = 60 ‰ and with the same initial and final coordinates A (0.181r; 0.5r) and B (πr ; 2r) (table 1). The height hk was taken equal to 3.6 m. In the calculations of the parameters of the profile of the descent of the path, the formulas of rectilinear uniformly accelerated motion were used.

Table 1

Brachistochrone with an initial angle $\alpha_{нач}$=60‰

Parameter	Brachistochrone	Straight sections of track
The radius of the circle m	30	-
Path length, m	104	100

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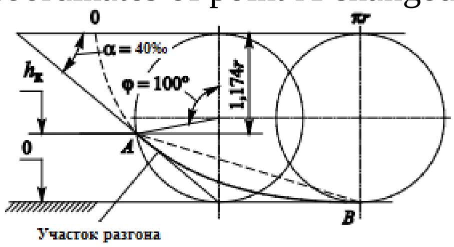
The time of descent, with	3,7	6,7
Final speed, m / s	29,7	29,7

Analysis of the results shows that the length of the descent path of the brachistochron and the straight path differ little, but the difference between the calculation results is almost twice as long as the descent time. Attention is drawn to the high value of the final descent speed. However, it should be borne in mind that this value is purely theoretical and limiting, since it does not take into account the factors of friction curves and deceleration on the decelerators. The exact calculation of the final speed of descent on the brachistochron is complicated by the nonlinear nature of changes in acceleration and friction forces during movement.

Conducting experimental studies on models will allow you to get more accurate data for the calculated parameters. Of particular interest is the influence of the initial angle of inclination of the brachistochrona on the parameters of the acceleration section. To assess this effect, calculations of the brachystochrona and rectilinear descent angle were performed at the initial angle of inclination $\alpha_{нач}$ = 40‰ at the same height $h_к$ (Fig. 5). The coordinates of point B remained the same, but the coordinates of point A changed: x_A= 0,762r, y_A=1,174r (table. 2).



Pic. 5. Profile of the guide system of the emergency evacuation unit with a shortened brachystochron ($\alpha_{нач}$ = 40‰)

table 2

Brachistochron with an initial angle of inclination $\alpha_{нач}$ = 40‰

Parameter	Brachistochrone	Straight groove
The radius of the circle m	54,5	—
Track length, m	140	137
The time of descent, with	6,1	9,2
Final speed, m / s	29,7	29,7

The calculation results showed that a decrease in the initial angle α of the slope by 1.5 times is accompanied by an increase in the length of the path and a corresponding increase in the descent time by approximately 1.5 times. In this case, the radius of the generating circle is almost doubled. The value of the final velocity has not changed, since the final velocity is determined by the height Hg.

Conclusions. A study of the properties of a brachistochrone for the construction of emergency evacuation units for the first time shows that the use of this curve in the sorting slide profile allows a significant gain in the time for the dissolution of cars compared to a straight trajectory. In addition, the brachistochron does not require a transitional section of vertical curves, which is necessary in the case of using straight sections of paths. The obtained calculated dependences can be used in the design of new and reconstruction of existing sorting slide profiles.

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