Proceedings of 27th International Scientific Conference. Transport Means 2023.

Determination of the optimal cars exit speeds from the retarders on sorting humps

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Abstract

Sorting humps are the main technical means providing the breaking- and making-up of freight trains on marshalling yards. Automation of sorting process by implementing microprocessor control systems is the main direction of increasing hump yard capacity, enhancement of safety in trains breaking-up, improvement of working conditions on hump yards. The purpose of the research is determination of the optimal cars exit speeds from the retarders on sorting humps. Its solution is significantly complicated because of the uncertainty of cars rolling resistance coefficient, wind velocity and direction, retarder control errors. The research is performed using the methods of the simulation modelling, mathematical statistics and direct optimization methods. The originality of the work is related to the solution of the problem of choosing cars exit speeds from the retarders in a stochastic formulation. The practical value of the work lies in the fact that the proposed method allows improving the quality of sorting process as a whole by improving the software of microprocessor control systems for automatic humping, rather than by increasing their technical facilities, which as a result will reduce the cost of their construction and operation.

KEY WORDS: *railways, marshalling yards, sorting hump, car retarder*

1. Introduction

Sorting humps are the main technical means that ensure the breaking- and making-up of freight trains at railway stations. Mainly, the development of sorting humps took place in the middle and end of the 20th century and was connected with the need to increase the processing capacity of the stations. In the current conditions, research in the field of sorting humps remains relevant, however, the tasks of ensuring the safety and economy of the process of trains breaking-up on them come to the fore. Today, the main direction of increasing the processing capacity of sorting humps, increasing the level of safety and improving working conditions on them is the management automation of the breaking-up of trains and implementation of microprocessor-based systems. Modern management systems of breaking-up the trains include complex hardware and software for collecting information and evaluating the running characteristics of the cuts and the ambient conditions. They are also quite sensitive to the quality of maintaining the technical condition of brake retarders and track lay-out. An alternative approach is the development of algorithms that provide effective decision-making on the management of train breaking-up even in the absence of accurate information about the characteristics of the cuts and their rolling conditions. The research presented in this work is aimed at implementing this approach.

2. Literature review and purpose of the study

Breaking- and making-up the trains and shunting compositions is one of the main shunting operations in railway transport. Sorting humps have been used since the end of the 19th century to intensify the breaking-up of trains. Modern sorting humps are equipped with brake retarders for the control mechanization of the rolling speed of cars and microprocessor-based systems for complex control of trains breaking-up [1]. Initially, the mechanization and automation of sorting humps was carried out mainly with the aim of increasing their processing capacity. However, today more and more attention is being paid to the issues of safety and economy of the train breaking-up process [2, 3]. The main method used for the study of the cuts' rolling processes is the simulation of the car rolling. In particular, the simulation of the car rolling is widely used when designing the sorting humps [4-7]. A characteristic feature of the cut rolling models used to solve the sorting humps design problems is that the cuts parameters, parameters of their rolling routes, and ambient conditions are assumed to be known. Herewith, the problem of choosing the braking modes of cuts is solved in a deterministic formulation. This approach to solving the problem of choosing the braking modes of cuts in calculation groups is implemented in [8]. However, application of the deterministic approach in automated control systems for trains breaking-up is associated with a number of problems. First of all, the running characteristics of the cars are measured with an error even after the start of rolling. Second, ambient parameters are also determined with error and may change during rolling. Third, under operating conditions, the real parameters of the rolling routes may change and differ significantly from the design ones [9]. And, finally, brake retarders implement specified braking modes with errors [10]. As a result, the process of cuts rolling is subject to the influence of significant random factors, and such indicators of train breaking-up as the number of cars that ran on the sorting tracks not as intended, the number of cases of exceeding the set speed of the cut approach to the cars on the sorting tracks, the degree of filling the sorting tracks with cars are probabilistic in nature [11]. The purpose of this work is to solve the problem of choosing the optimal speeds of cuts exit from brake retarders in a stochastic setting.

3. Solution methodology

In this study, sorting humps with master retarders position and group retarders position, equipped with beam retarders and tangent retarders position are considered. Such design of the hump is the most common at marshalling yards. The train, which is being broke-up on the hump, consists of c cuts, which follow on the track of the sorting yard according to their destinations. In the process of the train humping, the tasks of targeted and interval speed regulation of the cuts rolling are solved. The task of targeted regulation of the cuts rolling speed is to ensure the permissible approach speed of the cuts to the cars located on the tracks of the sorting yard. The task of the interval speed regulation of the cuts rolling is to provide the intervals between cuts, which are sufficient for the switching of separating elements (points and retarders). The process of train humping is controlled. Control at the j-th step can be represented by the exit speeds of the cut $v_{j,1}$, $v_{j,2}$, $v_{j,3}$ accordingly, from the first, second and third retarder positions. The value $\mathbf{v}_j=\{v_{j,1}, v_{j,2}, v_{j,3}\}$ will be called the braking mode in the future. The exit speed of cut from the tangent retarders position $v_{j,3}$ is dependent on the exit speeds from master retarders position $v_{j,1}$, and group retarders position $v_{j,2}$. Therefore, for sorting humps with three retarder positions, for each separate cut in the coordinates $v_{j,1}$ and $v_{j,2}$, a region of permissible braking modes Ω_j can be selected, within which the requirements for targeted regulation of the rolling speed are provided.

The value of the interval on the separating element in the j-th calculation group of two cuts is determined by the expression

$$\delta t_j(\mathbf{v}_j, \mathbf{v}_{j+1}) = d_j + t_{j+1}(\mathbf{v}_{j+1}) - \tau_j(\mathbf{v}_j),\ j = \overline{1, c-1} \quad (1)$$

where d_j – the initial interval at the top of the hump in the j-th pair between the j-th and j+1 cuts, s;

$t_{j+1}(\mathbf{v}_{j+1})$ – time spent on rolling j+1 cut from the train detachment moment till the moment of occupation of the isolated section of the separating element with the j-th cut, s;

$\tau_j(\mathbf{v}_j)$ – time spent on rolling the j-th tap from the train detachment moment till the release moment of the isolated section of the separating element with the j+1-th cut.

Intervals between the train cuts are dependent on each other, while increasing the interval between some cuts leads to a decrease in the intervals between others and vice versa. A change in the state of the separating element (switching point, braking or releasing the retarder) in the j-th pair of cuts is possible if the time interval between the cuts exceeds the minimum permissible separation time $t_{sep,j}$.

It should be noted that the largest intervals between cuts can be achieved only at the border of the region of permissible braking modes Ω_j, which will be called the region of effective braking modes of cut Ψ_j. At the same time, one parameter u_j is sufficient to specify the braking mode $\mathbf{v}_j$ in the region Ψ_j.

The task of controlling the rolling speed of train cuts is solved in two stages. At the first stage, prior to the start of breaking-up, the train analysis is performed, the cars that are prohibited from humping without a locomotive are determined, the braking modes of the cuts are pre-set and the pauses in the breaking-up are planned. At the second stage, the task of controlling the speed of cuts rolling in real time is solved. The first task is under consideration in this study.

Humping control of the entire train with c cuts can be represented by a set of step-by-step controls:

$$\mathbf{u}_{\overline{1,c}}=\{u_1, u_2, \ldots, u_c\}. \quad (2)$$

Different modes of braking correspond to different indicators of the train breaking-up. In this regard, finding the best management of train humping is an optimization problem. Traditionally, the problem of choosing the braking modes of cuts is solved in a deterministic setting, when the values of random variables are replaced by their mathematical expectations. With this approach, the Wald criterion is used as an optimality criterion

$$V(\mathbf{u}_{\overline{1,c}}) = \min\{\delta t_j(u_j, u_{j+1})\} \to \max,\ j = \overline{1, c-1} \quad (3)$$

It should be noted that with the same value of the mathematical expectation of the separation interval, the conditions of the separation of cuts on the points and retarders may differ significantly due to the different dispersion of the separation interval value. For example, Fig. 1 presents the distribution density graphs of the random values of the separation intervals in the first and second pairs of the calculation group of three single-car cuts. At the same time, the separation element in the first pair is the fifth point along the rolling route, and in the second pair – the third. In both pairs of cuts, the mathematical expectation of the interval between them on the points is 4.4 s.

In the case of random cut parameters and imprecise implementation of specified braking modes by the retarders, the time interval between the cuts should include an additional reserve to compensate for errors in determining the moments of release and occupation of the separating elements. The possibility of changing the state of the separating elements depending on the braking modes is probabilistic, and the very task of choosing the braking modes is stochastic. To take into account the stochastic nature of the problem, after finding the best braking modes according to criterion (3), the obtained solution is checked by simulating the train humping with random parameters when applying the braking modes determined as a result of solving the problem in a deterministic setting.

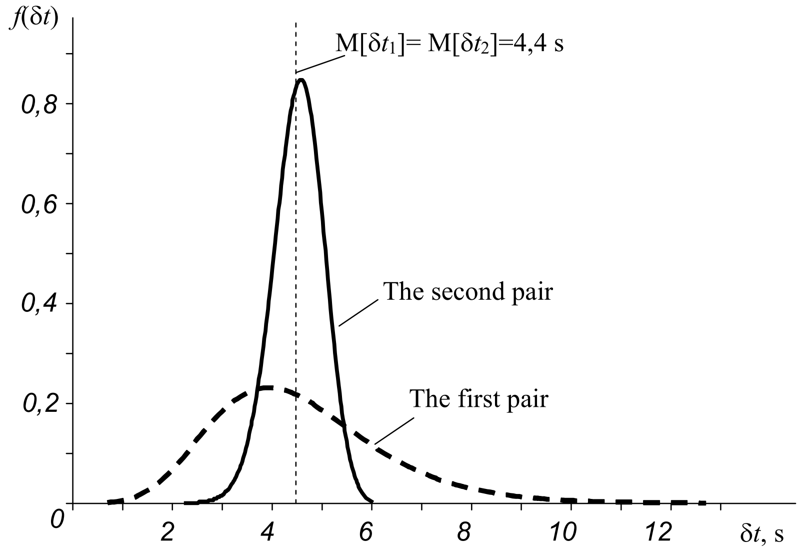

Fig. 1. Function distribution density graphs of the separation intervals in the first and second pairs of cuts

As a result of this approach to solving the problem, admissible solutions are established, but they do not ensure the minimization of the risks of non-separation of cuts.

In order to minimize the amount of work to eliminate the consequences of non-separation of cuts during the humping, it is proposed to outline the problem of choosing the braking modes of the train cuts in a stochastic setting. Taking into account that the rolling of cuts on the hump is of a mass nature, the laws and parameters of the random values distribution of the cuts characteristics and the conditions of their rolling are subject to statistical evaluation. Therefore, it is proposed to use the Bayesian criterion instead of the Wald criterion (3) as an optimality criterion

$$B = \max_{k \in b} \sum_{i=1}^{n} p_i a_{ki}, \qquad (5)$$

where p_i – the probability of the state of nature; a_{ki} – profit, when applying the k-th strategy at the i-th state of nature; n – the number of possible states of nature; b – number of possible strategies.

When forming a criterion for solving the problem of choosing the braking modes for train cuts in a stochastic setting, it is assumed that the costs for eliminating the consequences of non-separation of cuts are proportional to the number of cars that followed the track not as intended, it is also taken into account that cases of non-separation of cuts are rare events and the probability of their simultaneous occurrence is close to zero. With this in mind, it is suggested to use the criterion

$$R\left(\mathbf{u}_{\overline{1,c}}\right) = \sum_{j=1}^{c-1} p_j\left(u_j, u_{j+1}\right) m_{j+1} \rightarrow \min, \qquad (6)$$

where p_j – is the probability of non-separation of cuts in the j-th pair; m_{j+1} – the number of cars in the second cut of the j-th pair.

At the same time, the probability of separation of cuts in a separate j-th pair of cuts can be determined by the expression

$$p_j\left(u_j, u_{j+1}\right) = \mathrm{F}\left(\frac{d_j - t_{sep,j} + M[t_{j+1}(u_{j+1})] - M[\tau_j(u_j)]}{\sqrt{D[t_{j+1}(u_{j+1})] + D[\tau_j(u_j)]}}\right), \; j = \overline{1, c-1}, \qquad (7)$$

where F(x) – Laplace's function; $M[t_{j+1}(u_{j+1})]$, $D[t_{j+1}(u_{j+1})]$ – mathematical expectation and dispersion of the random value of the rolling time of the j+1 cut from the moment of detachment from the train till the moment of occupation of the isolated section of the separating element with the j-th cut, respectively c and c^2; $M[\tau_j(u_j)]$, $D[\tau_j(u_j)]$ – mathematical expectation and dispersion of the random value of the rolling time of the j cut from the moment of separation from the train till the moment of release of the isolated section of the separating element with the j+1-th cut, respectively c and c^2.

The values of $M[t_j(u_j)]$, $M[\tau_j(u_j)]$, $D[t_j(u_j)]$, $D[\tau_j(u_j)]$ can be obtained based on the statistical processing of the results of simulation experiments on the single cuts rolling from the sorting hump.

The restrictions of the problem are formulated as

$$\begin{cases} p_j(u_j, u_{j+1}) \le p_{pm}, j = \overleftarrow{1, c-1} \\ u_j \in \Psi_j, j = \overleftarrow{1, c} \end{cases}, \quad (8)$$

where p_{pm} – the maximum permissible probability of non-separation of cuts.

Given the properties of the problem, it can be solved by dynamic programming methods. The procedure for finding the optimal mode is performed in two stages. At the first stage (conditional optimization), for each cut the conditionally optimal braking modes u_j^* are searched, which take into account only the system state before the start of rolling of the j-th cut. Taking into account that there is no previous cut for the first one, the optimal mode for it is always a fast rolling mode with the minimum possible braking in the first retarder position and the maximum possible braking in the park retarder position. For other cuts, conditionally optimal control at the j-th step is a dependence $R\left(\mathbf{u}^*_{\overline{1,j}}\right)$.

The specified function determines the minimum value of the assessment of the braking modes with the optimal control in the previous 1..j-1steps and has a recurrent form

$$R\left(\mathbf{u}^*_{\overline{\mathbf{1,j}}}\right) = \min\left\{R\left(\mathbf{u}^*_{\overline{\mathbf{1,j-1}}}\right) + p_j(u_{j-1}, u_j) m_j\right\}. \quad (9)$$

The impossibility of obtaining conditions of restriction (8) when searching for conditionally optimal controls (9) indicates the need for an additional pause in the train humping.

At the second stage, based on the obtained conditionally optimal braking modes for each cut, unconditionally optimal braking modes of the cut of the entire train are set.

4. Research results

Table 1

Characteristics of the cars of the calculation train

j	Cut weight, t	Distance to the aiming point, m	Separation point of the cut with the following one
1	Less than 28	450	5
2	More than 72	510	5
3	Less than 28	690	4
4	Less than 28	765	2
5	28-44	720	-

The results of solving the problem in the deterministic setting are given in the Table 2.

Table 2

The results of solving the problem of choosing the braking modes of train cuts in a deterministic setting

j	The speeds of cut exit from braking positions, m/s			δt_j, s	p_j
	$v_{j,1}$	$v_{j,2}$	$v_{j,3}$		
1	6.77	7.22	4.12	5.86	0
2	6.52	5.65	1.60	4.61	0.008
3	6.66	6.00	4.56	4.61	0
4	6.15	6.73	5.21	7.42	0
5	3.06	4.78	3.78	-	-
$R\left(\mathbf{u}_{\overline{1,c}}\right)$					0.008

According to the received solution, the mathematical expectation of the interval on the separating points during the train breaking-up will be no less than 4.61 s. At the same time, with a probability of 0.008, the second and third cuts will not be separated on the point 5, since the value of the interval between them will be smaller than t_{sep} = 1 s.

The results of solving the problem in the stochastic setting are given in the Table 3.

Table 3

The results of solving the problem of choosing the braking modes of the train's cuts in a stochastic setting

j	The speeds of cut exit from braking positions, m/s			δt_j, s	p_j
	$v_{j,1}$	$v_{j,2}$	$v_{j,3}$		
1	6.77	7.22	4.12	5.86	0
2	6.52	5.65	1.60	5.38	0
3	6.66	5.90	4.56	4.16	0
4	6.15	6.73	5.21	7.42	0
5	3.06	4.78	3.78	-	-
$R(\mathbf{u}_{\overline{1,c}})$					0

In comparison with the solution given in the Table 2, in Table 3, the speed of exit of the third cut from the second retarder position is reduced. As a result, the mathematical expectation of the interval between the third and fourth cuts on the point 4 decreased from 4.61 to 4.16 s. However, this value remains sufficient to ensure reliable separation of cuts in the third pair. At the same time, reducing the movement speed of the third cut allows increasing the mathematical expectation of the interval between it and the second cut on the point 5 from 4.61 to 5.38 s and to practically eliminate the cases of non-separation in the second pair.

The simulation results of the train breaking-up show that the transition from the problem solution in the cut braking modes selection in a deterministic setting to the problem solution in a stochastic setting allows reducing the number of unacceptable risks of non-separation of cuts by 70-77% without deterioration of the indicators of targeted regulation of the cuts speed.

In general, the originality of the work is related to the solution of the problem of choosing the speeds of cuts exit from the retarders of sorting humps in a stochastic setting. The practical value of the work is that the proposed method makes it possible to improve the quality of the car sorting process at the railway stations due to the improvement of the software of the microprocessor-based systems of breaking-up control, and not due to the improvement of their technical equipment, which will, as a result, reduce the costs for the construction and operation of sorting humps.

5. Conclusions

The theoretical research performed in the work makes it possible to draw the following conclusions.

1. The conditions of the cuts rolling from the sorting humps are subject to the influence of numerous random factors. In the case of random parameters of the cuts and imprecise implementation of specified braking modes by retarders, the time interval between cuts should include an additional reserve to compensate for the errors in determining the moments of the release and occupation of the separating elements. The size of the specified reserve depends on both the type and location of the separation element on the rolling route, and on the movement speed of adjacent cuts along the route. Taking into account that the rolling of cuts on the humps is of a mass nature, the laws and parameters of the random values distribution of the cuts characteristics and the conditions of their rolling are subject to statistical evaluation. In this regard, the problem of selecting the exit speeds of the cuts from the brake retarders can be formulated and solved in a stochastic setting.

2. The paper proposes a criterion for evaluating the braking modes efficiency of the cuts, based on the Bayes criterion. The problem of selecting the speeds of the cuts exit from the brake retarders can be solved as a problem of dynamic programming. The defined braking modes make it possible to provide the intervals between the cuts to switch the separating elements even in conditions when the actual time of the cut rolling differs from the calculated one, or to set the cuts, between which it is required to make a pause during the humping. The proposed method makes it possible to improve the quality of the car sorting process at the railway stations due to the improvement of the software of the microprocessor-based systems of humping control, and not due to the improvement of their technical equipment, which will, as a result, reduce the costs for the construction and operation of sorting humps.

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