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ЕКСПЛУАТАЦІЯ ТА РЕМОНТ ЗАСОБІВ ТРАНСПОРТУ

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DETERMINATION OF BRAKING OPTIMAL MODE OF CONTROLLED CUT OF DESIGN GROUP

Purpose. The application of automation systems of breaking up process on the gravity hump is the efficiency improvement of their operation, absolute provision of trains breaking up safety demands, as well as improvement of hump staff working conditions. One of the main tasks of the indicated systems is the assurance of cuts reliable separation at all elements of their rolling route to the classification track. This task is a sophisticated optimization problem and has not received a final decision. Therefore, the task of determining the cuts braking mode is quite relevant. The purpose of this research is to find the optimal braking mode of control cut of design group. **Methodology.** In order to achieve the purpose is offered to use the direct search methods in the work, namely the Box complex method. This method does not require smoothness of the objective function, takes into account its limitations and does not require calculation of the function derivatives, and uses only its value. **Findings.** Using the Box method was developed iterative procedure for determining the control cut optimal braking mode of design group. The procedure maximizes the smallest controlled time interval in the group. To evaluate the effectiveness of designed procedure the series of simulation experiments of determining the control cut braking mode of design group was performed. The results confirmed the efficiency of the developed optimization procedure. **Originality.** The author formalized the task of optimizing control cut braking mode of design group, taking into account the cuts separation of design group at all elements (switches, retarders) during cuts rolling to the classification track. The problem of determining the optimal control cut braking mode of design group was solved. The developed braking mode ensures cuts reliable separation of the group not only at the switches but at the retarders of brake position. **Practical value.** The developed procedure can be successfully used to determine the optimal braking modes of cuts in automation systems of trains breaking up on the gravity humps.

Keywords: marshalling yard; gravity hump; braking mode; cut; Box method

Introduction

The control of trains breaking up on gravity humps is quite complex mathematical and technical problem, which is characterized by a high degree of responsiveness, the insufficiency or the absence of accurate information about the controlled object, the impossibility of formalizing all random factors and processes.

The main direction of the gravity humps efficiency improvement is automation of trains breaking up process [19]. One of the most important and difficult tasks of trains breaking up process control in automatic mode is to determine the braking modes (BM) of trains cut, which provide the best conditions of separation on separating elements (switches and retarders) and the fulfillment requirements of target regulation of rolling speed of cuts [16-18]. A number of scientific papers were devoted to solve the optimization task; however, as

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a rule, design basic group is considered as a group of three cuts with controlled medium cut. In work [7] the objective function of optimization problem of controlled cut breaking mode of the design group in the following form

$$\min\{\delta t_{12},\ \delta t_{23}\} \to \max\ , \qquad (1)$$

where δt_{12}, δt_{23} – intervals on switches, respectively, in the first and second cut pairs of design group.

To solve the problem of optimization for criterion (1) in the work [5] the author proposed to use gradient methods. However, the use of gradient methods for solving the problem (1) requires its transformation into smooth function, which greatly complicates the optimization process. In the work [2] was proposed more universal method to optimize braking modes not only for the design group of cuts, but the train as a whole. But, first of all, this method is quite complicated and unmanageable, and secondly, does not always provide the required accuracy solution, because the objective function in this problem is not smooth. To address these shortcomings in work [4] solving the optimization problem of train cut BM was made with using iterative method. This method allows determining before the trains breaking up such cuts BM at which intervals on the switches in all cut pairs, including non-adjacent, take the maximum value [3].

However, the typical shortcomings of methods [2-5, 7] are optimization problem solving of cuts BM in the determined formulation. Completed researches [11] showed that the influence of random factors and inaccurate information complicate the definition of rational cuts BM at train breaking up. In this regard, in [9, 10] optimization of cuts interval speed control is proposed to do on the base of the criterion of the minimal risk of undivided cuts on switches. This approach allows solving the optimization problem of cuts BM at stochastic rolling conditions, which gives an opportunity to take into account the influence of random factors in the process of trains breaking up on the hump. The problem definition of cut BM in the proposed [9, 10] criterion is solved in [8]; with the resulting profiles ensure minimum value windows on the sorting tracks and minimal risk of undivided cut on the switches at a given level safety sorting process.

The given analysis of scientific papers showed that optimization of cuts BM is done in case of their reliable separation only on the switches; thus cuts separating on the retarder of hump are not included, or considered as restriction [12], which does not maximize the quality of regulation interval on all separating elements of humps. Moreover, given in [12] method of searching these restrictions is quite complex and requires for its implementation the use of simulation and regression analysis, which in turn complicates the application of the technique in automation trains breaking up systems on the hump.

The authors in work [6] noted that the optimization of the braking cut of the design group should be considered not only at intervals separating switches and in the first retarder of the first (FBP) and second (SBP) brake position. This approach in solving the optimization problem of BM will improve the quality of interval regulation at all separating elements of hump and, therefore, the safety of the trains breaking up process.

Purpose

The aim of this work is to solve the optimization problem of the design group braking cut based on the intervals between switches and retarders of brake positions.

Methodology

The braking mode $\mathbf{U}(U', U'')$ of design group controlled cut is characterized by its set speed out of the FBP and SBP respectively U' and U''.

The task of optimizing braking mode $\mathbf{U}$ of controlled cut of the group is to find such a mode, which ensures reliable separation of all group cuts both at the switches, and at the retarders of FBP and SBP. At this regard, the best for controlled cut is the braking mode $\mathbf{U}$, in which the smallest of intervals in the group reaches its maximum:

$$f = \min\{\delta t_{12}(\mathbf{U}),\ \delta t_{23}(\mathbf{U}),\ \delta t_{12}^{VGP}(\mathbf{U})$$

$$\delta t_{12}^{SGP}(\mathbf{U}),\ \delta t_{23}^{VGP}(\mathbf{U}),\ \delta t_{23}^{SGP}(\mathbf{U})\} \to \max,$$

$$\text{At } \mathbf{U} \in \Omega \qquad (2)$$

where $\delta t^{\text{VGP}}, \delta t^{\text{SGP}}$ – the interval between adjacent cut on the first retarder of FBP and SBP respectively; Ω – the domain of permissible speeds (DPS) of cuts coming out of FBP and SBP.

It should be noted that the number of variables

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in (2) depends not only on cut routes of the group, but also the relative position of switches and brake positions scheme at the gravity hump.

In [6] is found that for hump necks with 4 beams of classification tracks exists 9 characteristic destination track combinations and accordingly, separating switches to groups of 3 cuts, which differ in the number and placement of separating elements on FBP and SBP and respectively, the number of intervals of objective function (2).

Thus, according to [6], the number of intervals in the group can vary from 2 to 6, due to the lack of separation cut on FBP and (or) on the SBP under certain combinations of routes of their movement. Moreover, at the same time, conditions may vary and adjustment intervals between cuts – interval can be unregulated, can depend only on the braking on FBP or breaking on both positions – FBP and SBP. These features greatly complicate solving the optimization problem of controlled cut braking mode of the design group.

The objective function (2) is an undifferentiated, plain and nonlinear function, while its derivatives have discontinuities at the points where $\delta t_i = \delta t_j,\ i \neq j$. Taking into account these characteristics to solve the optimization problem (2) should be used methods of direct search (zero-order) as they do not require smoothness and derivatives calculation of the objective function, and use only its value. In this paper, to solve the problem (2) was used the complex Box method [15]. The minimum function search is performed with the help of dots set moving to the direction of its minimizing within the restriction region. As the indicated method minimizes the objective function, therefore, the sign of the objective function f was changed to $-f$.

The complex Box method provides a sequential selection of k random points, which form the set. The number of such points is $k = 2n$, where n – the dimension of the problem. As braking mode of cut is presented with speeds U' and U'', the dimension of the problem is $n = 2$. In general, the optimization procedure of the separate cut braking mode using the Box method can be represented in the form of an iterative scheme, which is shown on Figure 1.

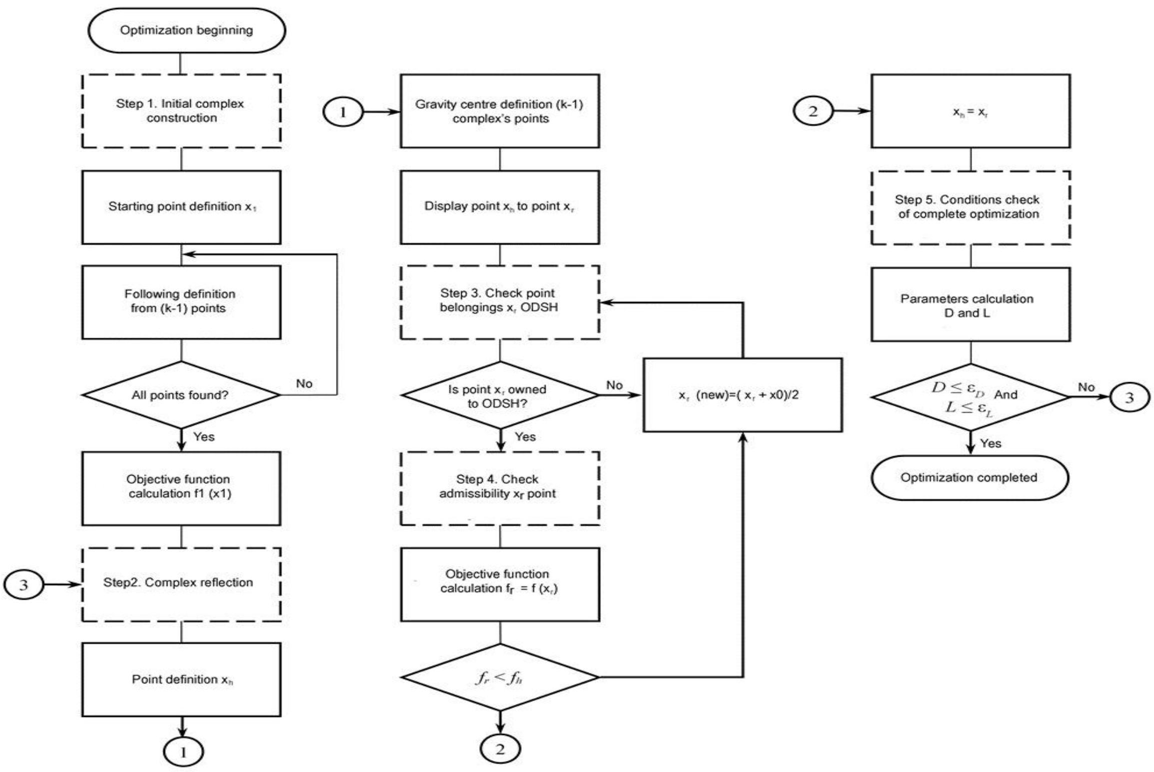

Fig. 1. Optimization procedure of controlled cut braking mode using Box method

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Step 1. In the first step of the optimization procedure it is necessary to obtain the set with k points. In turn each point of the set $\mathbf{x}_i$ is characterized by the following parameters $U_i^{'}, U_i^{''}$, the value of which is defined by the formulas

$$U_i^{'} = U_{i,\min}^{'} + r_i(U_{i,\max}^{'} - U_{i,\min}^{'}) ,$$

$$U_i^{''} = f(U_i^{'}) = U_{i,\min}^{''} + r_i(U_{i,\max}^{''} - U_{i,\min}^{''}),$$

where i – point number of the set, i =1, 2,…, k ; r_i – random numbers, uniformly distributed in the interval [0;1]; $U_{i,\min}^{'('')}, U_{i,\max}^{'('')}$ – the minimum and maximum coming out speed of cut from FBP (SBP), which is determined by its DPS (see Fig. 2).

It is essential to note that all points of initial set are acceptable, as determined within DPS. In each of the k set points is determined by the value of objective function $f_i(\mathbf{x}_i)$.

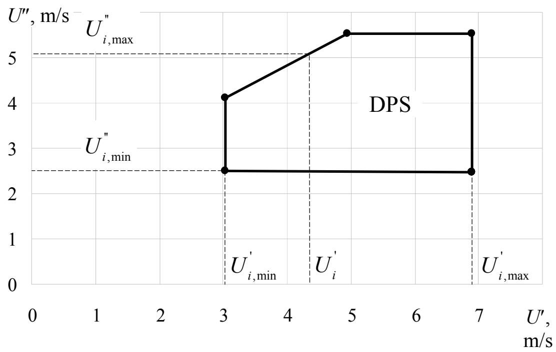

Fig. 2. Determining of $U_i^{'}, U_i^{''}$ in DPS of controlled cut

Step 2. Selected point $\mathbf{x}_h$ with the largest value of the function $f(\mathbf{x})$, that is

$$f_h = f(\mathbf{x}_h) = \max\{f_1, f_2, ..., f_k\} ,$$

and it is eliminated.

The new set point $\mathbf{x}_r$ is determined by the point reflection $\mathbf{x}_h$ through the center of gravity $\mathbf{x}_0$ the other $k-1$ points

$$\mathbf{x}_r = (1+\alpha)\mathbf{x}_0 - \alpha\mathbf{x}_h ,$$

where α – the empirical reflection coefficient (according to [14] accepted α =1,3).

In turn, the gravity center of $k-1$ set points is determined by the formula

$$\mathbf{x}_0 = \frac{1}{k-1}\left(\sum_{i=1}^{k}\mathbf{x}_i - \mathbf{x}_h\right).$$

Step 3. In this step the point $\mathbf{x}_r$ is checked to the identity to the domain of cuts exit permissible speed from FBP and SBP. To perform this verification the computational geometry method [13] is used, which is based on the position checking of the $\mathbf{x}_r$ in respect of each DPS sides.

If the point $\mathbf{x}_r$ does not belong DPS, it is moved on the half of the distance between $\mathbf{x}_r$ and $\mathbf{x}_0$, that is

$$\mathbf{x}_r(\text{new}) = \frac{(\mathbf{x}_r + \mathbf{x}_0)}{2} \qquad (3)$$

After this re-check of the $\mathbf{x}_r$ identity to DPS is done; this step is performed until reception of acceptable point $\mathbf{x}_r$.

Step 4. In this step, the check of the point $\mathbf{x}_r$ validity is performed. The value of the function $f_r = f(\mathbf{x}_r)$ is calculated and compared with f_h . If $f_r < f_h$ (the improvement of the objective function), the point $\mathbf{x}_r$ replaces point $\mathbf{x}_h$ and go to step 5.

In case if $f_r > f_h$, that is “worse” than the largest value, which was obtained earlier, the point $\mathbf{x}_r$ is shifted to the center $\mathbf{x}_0$ on the half of the distance between them by the formula (3), and the calculation process returns to step 3. The above procedure is performed until the condition $f_r < f_h$ is met.

Step 5. This step involves checking the conditions of optimization completion. For this purpose the dispersion D calculation is performed for k values of the objective function and the distance L between the points of the set $\mathbf{x}_i$ and their gravity center $\mathbf{x}_0$:

$$D = \frac{1}{k}\sum_{i=1}^{k}\left(f(\mathbf{x}_i) - \overline{f}\right)^2 ,$$

$$L = \sum_{i=1}^{k}\left(\mathbf{x}_i - \mathbf{x}_0\right)^2 .$$

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The optimization process is completed if $D \leq \varepsilon_D$ і $L \leq \varepsilon_L$ ($\varepsilon_D, \varepsilon_L$ – permissible error solution), otherwise, proceed to step 2 and repeat the optimization process.

Findings

To check the developed optimization procedure effectiveness of the braking mode of design group cut was performed series of experiments. In particular, the optimization task of braking mode of the medium cut of design group (hard-rolling cut (HRC_1)-easy-rolling cut (ERC_2)-hard-rolling cut (HRC_3)) at various combinations of rolling routes was solved; while, for comparison, the optimization was performed using two methods.

In the first method, which was developed in this work, search of the best braking mode was performed on the base of criterion (2) and the second method proposed in [12] involves intervals maximization between cuts of the group only on the switches. The results of the optimization using two methods are given in Table. 1.

As the table shows, using the second method set breaking mode provides maximum and equal intervals on the switches, but it leads to a significant reduction some of them (comb. 7). At the same time, the first method allows to increase the intervals value not only on the switches but on retarders of FBP and SBP (comb. 2-4, 7), which, in turn, reduces the fail risk of cuts non-separation under conditions of performance error of their set braking modes [1].

Table 1

The results of optimization the braking mode of the medium cut of group HRC_1-ERC_2-HRC_3

Comb	σ_1	σ_2	Method	U', m/s	U'', m/s	δt_{12}. s	δt_{12}^{FBP}. s	δt_{12}^{SBP} .,s	δt_{23}. s	δt_{23}^{FBP} ,s	δt_{23}^{SBP} ..s
1	1	1	1	~	~	2,27	–	–	4,23	–	–
			2	~	~	2,27	–	–	4,23	–	–
2	1	2	1	6,90	3,15	2,27	–	–	8,10	6,37	–
			2	3,43	4,40	2,27	–	–	2,28	5,91	
3	1	5	1	6,90	5,19	2,27	–	–	9,35	6,37	8,68
			2	4,21	4,99	2,27	–	–	2,27	5,91	2,45
4	2	1	1	3,03	3,79	5,60	2,45	–	4,23	–	–
			2	4,60	2,50	4,23	2,45	–	4,23	–	–
5	2	2	1	4,43	2,86	4,39	2,45	–	4,39	5,91	–
			2	4,44	5,16	4,38	2,45	–	4,39	5,91	–
6	2	5	1	4,72	5,36	4,12	2,45	–	5,38	5,91	4,12
			2	4,53	5,23	4,29	2,45	–	4,30	5,91	3,55
7	5	1	1	3,03	3,79	17,67	2,45	9,77	4,23	–	–
			2	6,90	4,27	4,23	2,45	1,23	4,23	–	–
8	5	2	1	4,79	3,39	14,62	2,45	5,02	5,02	5,91	–
			2	6,90	3,46	8,08	2,45	1,23	8,10	6,37	–
9	5	5	1	4,96	5,36	4,65	2,45	4,65	5,91	5,91	4,65
			2	4,70	5,36	5,27	2,45	5,20	5,28	5,91	4,06

Note:

«~ « – unspecified breaking mode

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Originality and practical value

The scientific novelty of this work is in the procedures development of the controlled cut braking mode optimization of the design group, which ensures the best conditions of cut separation both on the switches and retarders of hump rolling down part.

Developed procedure can be used to solve the problem of process control of cut rolling on the automated gravity humps.

Conclusions

1. Formalized optimization problem of controlled cut braking mode of the design group taking into account the group cuts separation on the switches and brake position retarders. This approach allows providing reliable group cuts separation on all elements (switches, retarders) during their rolling to the classification tracks.

2. Developed the iterative optimization process of controlled cut braking mode of the group using Box method. The experiments results analysis showed that the method is quite effective and can be successfully used to solve multi-objective problem of cuts braking mode optimization of train, which is broken-up on gravity hump.

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ОПРЕДЕЛЕНИЕ ОПТИМАЛЬНОГО РЕЖИМА ТОРМОЖЕНИЯ УПРАВЛЯЕМОГО ОТЦЕПА РАСЧЕТНОЙ ГРУППЫ

Цель. Внедрение систем автоматизации процесса расформирования составов на сортировочных горках направлено в основном на повышение эффективности их функционирования, безусловное обеспечение требований безопасности роспуска составов, а также улучшение условий труда персонала горки. Одна из основных задач указанных систем – обеспечение надежного разделения отцепов состава на всех элементах по маршруту их скатывания на пути сортировочного парка, которая является достаточно сложной оптимизационной задачей и не получила окончательного решения. Поэтому, задача определения режимов торможения отцепов состава является достаточно актуальной. Целью данной работы является поиск оптимального режима торможения управляемого отцепа расчетной группы. **Методика.** Для достижения поставленной в работе цели предлагается использовать прямые методы поиска, а именно – комплексный метод Бокса. Данный метод не требует гладкости целевой функции, учитывает ее ограничения, а также не требует расчета производных функции, а использует только ее значение. **Результаты.** С использованием метода Бокса была разработана итерационная процедура определения оптимального режима торможения управляемого отцепа расчетной группы, которая позволяет максимизировать наименьший из управляемых интервалов в группе. Для оценки эффективности разработанной процедуры проведен ряд имитационных экспериментов по определению режима торможения управляемого отцепа расчетной группы. Полученные результаты подтвердили эффективность разработанной процедуры оптимизации. **Научная новизна.** Автором была формализована задача оптимизации режима торможения управляемого отцепа расчетной группы с учетом разделения отцепов группы на всех элементах (стрелках, замедлителях) при их скатывании на сортировочные пути. Решена задача поиска оптимального режима торможения управляемого отцепа группы, при котором обеспечивается надежное разделение отцепов группы не только на стрелочных переводах, а и на замедлителях тормозных позиций спускной части горки. **Практическая значимость.** Разработанная процедура может быть успешно использована при поиске оптимальных режимов торможения отцепов в системах автоматизации расформирования составов на сортировочных горках.

Ключевые слова: сортировочная горка; режим торможения; отцеп; комплексный метод Бокса

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ВИЗНАЧЕННЯ ОПТИМАЛЬНОГО РЕЖИМУ ГАЛЬМУВАННЯ КЕРОВАНОГО ВІДЧЕПА РОЗРАХУНКОВОЇ ГРУПИ

Мета. Впровадження систем автоматизації процесу розформування составів на сортувальних гірках спрямоване в основному на підвищення ефективності їх функціонування, безумовне забезпечення вимог безпеки розпуску составів, а також покращення умов праці персоналу гірки. Одна із основних задач вказаних систем – забезпечення надійного розділення відчепів состава на всіх елементах маршруту їх скочування на колії сортувального парку, яка є досить складною оптимізаційною задачею і не отримала остаточного вирішення. Тому задача визначення режимів гальмування відчепів состава достатньо актуальна. Метою даної роботи є пошук оптимального режиму гальмування керованого відчепа розрахункової групи. **Методика.** Для досягнення поставленої у роботі мети пропонується використовувати прямі методи пошуку, а саме – комплексний метод Бокса. Даний метод не вимагає гладкості цільової функції, враховує її обмеження, а також не потребує розрахунку похідних функції, а використовує лише її значення. **Результати.** З використанням метода Бокса було розроблено ітераційну процедуру визначення оптимального режиму гальмування керованого відчепа розрахункової групи, яка дозволяє максимізувати найменший із керованих інтервалів у групі. Для оцінки ефективності розробленої процедури проведено ряд імітаційних експериментів із визначення режиму гальмування керованого відчепа розрахункової групи. Отримані результати підтвердили ефективність розробленої процедури оптимізації. **Наукова новизна.** Автором була формалізована задача оптимізації режиму гальмування керованого відчепа розрахункової групи з урахуванням розділення відчепів групи на всіх елементах (стрілках, уповільнювачах) при їх скочуванні на колії сортувального парку. Вирішено задачу пошуку оптимального режиму гальмування керованого відчепа групи, при якому забезпечується надійне розділення відчепів групи не лише на стрілочних переводах, а й на уповільнювачах гальмових позицій спускної частини гірки. **Практична значимість.** Розроблена процедура може бути успішно використана при визначенні оптимальних режимів гальмування відчепів у системах автоматизації розформування составів на сортувальних гірках.

Ключові слова: сортувальна гірка; режим гальмування; відчеп; комплексний метод Бокса

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