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IMPROVEMENT OF THE EFFECTIVENESS OF THE PROCESS OF SEPARATION OF COMPOSITION ON THE SORTING HUMPS

The purpose of the study is dedicated to improving the quality of sorting process using the developed method to determine rational regimes of the train breaking up. These modes provide maximum of reliability division of the wagon cuts at switches, as well as the possibility of implementing a safe speed collision of wagons in marshalling tracks. **Methodology.** Investigations of the separations of the cut of the train at switches were carried out using simulation modeling. For research, we used the model for the running cut from sorting hump, which allows us to realize the set exit speeds from the brake positions when adjusting the braking zone of the cut. **Findings.** A quantitative assessment of the indicators of the sorting process was carried out using the developed method for optimizing the braking modes of the cuts to control the process of decomposition of trains on one of the sorting hump of Ukraine. The performed analysis of the results showed sufficient efficiency of the developed method, which can be recommended for calculating the exit speeds of cuts from brake positions in automation systems of the sorting process. The braking modes obtained as a result of optimization can provide a sufficiently high quality of interval regulation, as well as the possibility of realizing a safe approach speed of cuts to vagons on the sorting paths of automated humps. **The scientific novelty** of the work is to prove the effectiveness of the considered method of optimizing the composition breaking mode. **Practical value** of the thesis as well as developed models and methods can be used to create an automated process control system for breaking up of the stocks on sorting humps, as well as to assess the quality of the construction of projected sorting humps. Automation of humps will help to improve the economic performance of stations, reduce the cost of processing cars, save energy for braking cuts and shunting, improve working conditions and safety of workers of the sorting hump.

Keywords: braking modes; cut; sorting hump; optimization; automated system

Introduction

Automation of the process of disbanding trains is one of the main ways to improve the efficiency of the operation of sorting humps, improving the quality of the process of disbanding the compositions and effective using of technical facilities. Creating a modern automated control system for the sorting process would improve the productivity of sorting humps, reduce downtime of wagons at sorting stations, and due to this way speed up the process delivery of goods, reduce the turnover of wagons and their fleet. In addition, the automation of the humps will further improve the economic performance of the stations, reduce the cost of processing cars, saving of energy resources for braking cars and shunting work, improve the conditions and safety of humps workers.

An element of creating an integrated automation system is the introduction of the microprocessor system of automatic speed control (ASC). The ASC system is designed for calculating and then setting in real time the cut speed values at the exit from the brake positions, ensuring that the conditions for separating the cut routes for separating switches (interval control) and the safe connection of carriages on sorting paths (aiming control).

As the analysis of existing systems showed automation of the disbanding process compositions on the sorting humps, the automatic regulation of cut the rolling speed is a rather complicated task [1-4]. It's necessary to determine the optimal braking modes (BM) of the composition cut and ensure their implementation with sufficient accuracy in the process of realization [5-7] to ensure reliable separation of the sliding cut on the switches and the safe speed of their collision with the cars on the tracks.

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Research of the rolling cut process with different parameters under the conditions of the random factors action [8] showed that their influence significantly complicates the determination of BM of cut during the dissolution of the compositions. Random errors in measuring the parameters of cuts, used to determine the optimal BM, as well as errors in their implementation can significantly increase the likelihood of separation of cut on the switches. In this regard, it is necessary to search for such BM, at which the calculated intervals on the separating elements between all detachments of the composition reach a maximum. This will preserve the minimum interval between cuts, necessary for their successful separation in the event of an adverse combination of influencing factors occurring and thereby reducing the likelihood of nonseparation during the dissolution of the compositions on the sorting humps.

Main part

Mathematical models of rolling cut is carried out with a uniform distribution of the energy height which the cut braking, redeemable throughout the range of the brake position, not entirely consistent with the actual braking process.

An improved mathematical model for rolling off from the sorting humps was proposed in [9], which allows you to control the choice of a zone of brake release. The cut is braked by the rated power of the moderator at the selected degree of braking. In the model, the braking mode of each cut rolling down the hump is represented by the vector **U**=(U', U'') of the speeds of its release from the brake positions of the discharge part of the sorting hump and the vector S_{sb} =(S'_{sb} , S''_{sb}) the points of the beginning of braking at the corresponding brake positions (BP).

As the analysis has shown, in real conditions, the given output speed of the detachment U can be implemented using many modes that differ in the coordinate of the point of the start of braking S_{sb}. In this case, the length of the braking zone L_{b} is uniquely determined by the coordinate S_{sb} and the given speed U.

The analysis performed in [10] showed that each of the output speeds U', U'' may have several restrictions of a different nature; all possible values of the vector **U**=(U', U'') belong to the region of permissible speeds (RPS) of the output from the upper (UBP) and middle (UMP) brake positions.

The constraints that form the RPS are determined by four groups of factors:

– braking power retarder brake positions;

– permissible speed of rolling of cut on the downhill part of the sorting hump;

– requirements of aiming speed control cut;

– the possibility of implementing a given speed of cut out of the brake position.

The research results showed that the configuration, dimensions and positions of the RPS significantly depend on the design of the hump, as well as on the cut parameters and rolling conditions [7]. Therefore, the methodology was formalized and the algorithm for constructing the RPS taking into account the above parameters was developed. The method is based on the use of simulation modeling of rolling out of an unhooking from a hill; it also makes it possible to identify and exclude inactive restrictions on the speed of cut from the BP before starting the optimization problem.

The choice of braking modes is determined both by the parameters of the rolling-off cut of the train, and by the sequence of numbers of switchs of their separation. Thus, in almost all systems of automation of the sorting process [11], the choice of modes for separation the trains and rolling them out takes into account the coordinates of the separation switchs, which, in turn, are determined by the rolling routes of the adjacent cut trains.

Meanwhile, in [12] the possibility of surges on beam switches between non-adjacent cuts of the composition (cut separated in the composition by one or several other cut) and, consequently, the need to take into account such situations between these cut was noted.

The analysis of cut divisions on switches using the probabilistic approach, performed in [13], allowed us to obtain an analytical expression (1) to determine the probability of separating an arbitrary pair of composition cut on some switch σ. In order for this separation to take place, it is necessary that the i and ($i+k$) cut pass the switch σ in different directions; at the same time, all cuts from ($i+1$) to ($i+k-1$) should not proceed through this switch. Then the specified probability can be defined as

$$P_{i,i+k}(\sigma) = \frac{2m_{\text{l}}(\sigma)\cdot m_{\text{r}}(\sigma)\cdot(M - m_{\text{l}}(\sigma) - m_{\text{r}}(\sigma))^{k-1}}{M(M-1)^{k}} \quad (1)$$

It was shown that the conditions of separation of non-adjacent cut not less affect the quality of the management of dissolution than the normally controlled conditions of separation of adjacent cut of the composition.

For the convenience of analyzing the divisions of routes of a particular composition, they were represented by an upper triangular matrix [14], the rows and columns of which were assigned to the number of ways to assign its release sequence. The elements of the matrix σ_{ij}, $i < j$ are the numbers of the switch positions, which separate the routes of the cut i and j; following, respectively, on the way W_i, W_j.

A method was developed to determine the actual number of cut separations in specific compositions. The method provides for the definition of all elements of the matrix of numbers of switches for a particular sorting hump and composition using the Boolean functions:

$$\sigma_{ij} = \varphi(\zeta_i, \zeta_j),$$

ζ_i, ζ_j – codes of destination paths of the i and j cuts.

The code of each sorting path ζ is formed in such a way that it is possible to determine the position of the switches in the route to this path. The specified code in binary form consists of N digits by the number of switch positions on the sorting hump.

The proposed method allows you to determine the elements of a triangular matrix for each specific composition, disbanded on the sorting hump with any design of the switch mouth. The analysis of the matrix allows you to set the total number of divisions of cut composition, as well as their distribution among individual switch positions.

The results of statistical processing of sorting sheets on one of the large sorting stations in Ukraine showed that the total number of separations is on average 1,71 times higher than the number of separations of adjacent pairs of cuts. The number of separations in the composition is linearly dependent on the number of cut (fig.1); the correlation coefficient between the number of cut and the number of divisions is 0.96.

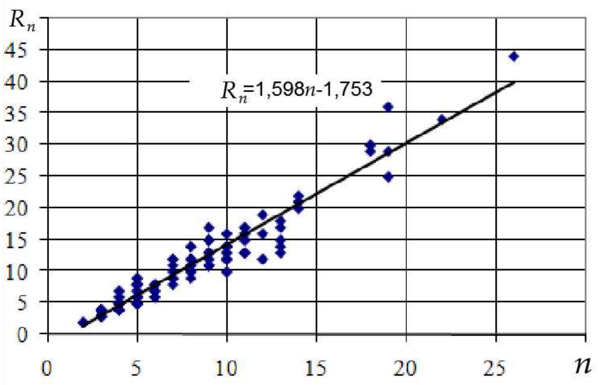

Fig. 1. Correlation dependence between the number of divisions R_n and the number of cuts n in the composition for Odessa-Sortuvalna station

Thus, the data obtained allow us to conclude that a sufficiently large number of cuts compounds have multiple separations with non-adjacent cuts and therefore they need to be taken into account when solving a wide range of practical tasks aimed at improving the efficiency of the sorting process on the humps, including and when optimizing the mode of dissolution of the compositions.

In [15], a method was developed to optimize the mode of dissolving of the composition, which takes into account the conditions of separation between non-adjacent cuts of the composition.

The task of optimizing the mode of dissolving trains to improve the quality of interval speed control is to maximize the intervals on the switches between all pairs of cut units. Therefore, as an optimization criterion, it is advisable to use the vector of intervals between the cuts of the composition, constructed taking into account the multiple divisions of each of them:

$$\boldsymbol{\delta t} = (\delta t_1, \delta t_2, \ldots, \delta t_c) \rightarrow \max \qquad (2)$$

c – is the total number of cut separations in the composition, in composition including non-adjacent.

As the analysis showed, the δt_i intervals in (2) are not independent. A change in the mode of inhibition of an cut leads to a change in the values of the set of intervals δt_i of the vector $\boldsymbol{\delta t}$. In this case, those intervals with which the controlled detachment has a separation on the switches, incl. and secondary.

In this regard, it is obvious that it is necessary to control all the specified intervals in the process of solving the optimization problem. To this end, when choosing the braking mode of the i cut, it was proposed to consider the tuple of all cut members of the train, which are separated from this cut (fig. 2). In this tuple, in addition to the controlled i cut and adjacent cut with numbers p_1=(i–1) and q_1=(i+1) it is necessary to include all other cut units that have a separation with the i cut. These are cuts with numbers $p_2 \ldots, p_N$, located in the composition up to the controlled one ($p< \ldots < p_2 < p_1 = i$-1) and also cut numbers $q_2, \ldots, q_N$, located after it ($q_1 = i$+1 $< q_1 < q_2 < \ldots < q_N$); N - is the number of switch positions on the hump.

The number of cuts in a tuple depends on the combination of their purpose in the composition and on the design of the hump neck; the maximum number of cuts having a separation with a controlled one and located before and after it is 2N. The tuple composition of the i cut can be unambiguously determined according to the matrix of numbers of dividing switches of the composition cut.

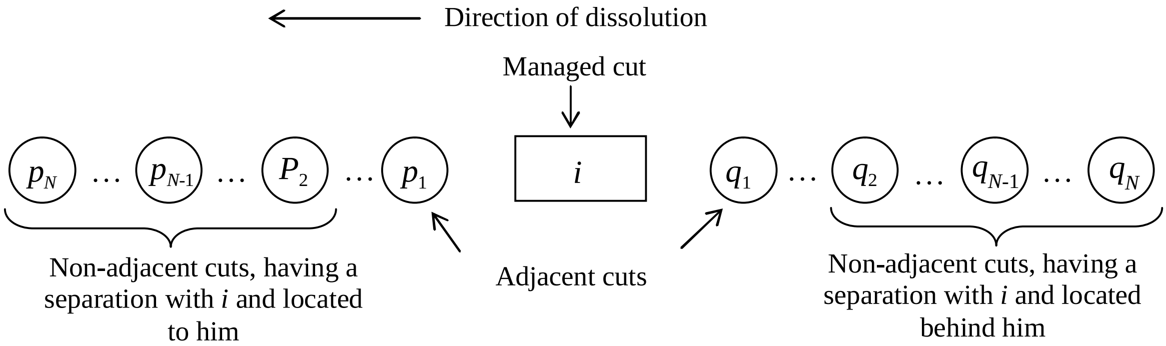

Fig. 2. Scheme of tuple managed cut

Then, the partial criterion of the optimality of the braking mode of the i cut, determined at fixed modes of all cut, which have separation with controlled, will be the absolute value of the difference of the minimum intervals with the cut, which are located in the composition before and after the i.

$$\Delta t_i(\mathbf{r}_i) = \left| \min \left\{ \delta t_{p_1}, \delta t_{p_2}, \ldots, \delta t_{p_N} \right\} - \min \left\{ \delta t_{q_1}, \delta t_{q_2}, \ldots, \delta t_{q_N} \right\} \right| \to \min$$

Using the given partial criterion for individual cut, it is possible to construct a target function to optimize the mode of dissolution of the composition:

$$\Delta \mathbf{T} = \left\{ \Delta t_2, \Delta t_3, \ldots, \Delta t_{n-1} \right\} \to \min$$

In this expression, all values Δt_i associated with appropriate cut $\overline{2, n\text{-}1}$ and ordered by their composition.

To take into account the relationship between interval and sighting regulation of the speed of cut, as well as the existing restrictions on the speed of their rolling down when selecting braking modes, their affiliation to the area of permissible speeds of their exit Ω_i from the upper BP and average BP is controlled. These areas should be determined for each detachment of the composition prior to the start of solving the optimization problem and are its restrictions.

In the process of optimization, the composition is gradually divided into groups in which the alignment of the values of adjacent intervals occurs; at the same time, the alignment of the intervals does not occur in each group separately, but at the same time throughout the whole composition (fig. 3). This result is achieved due to the use of reserves of intervals between the detachments of the composition, which are in groups with favorable conditions of separation and redistribution of these reserves between the detachments of the composition, which are in groups with unfavorable conditions of separation.

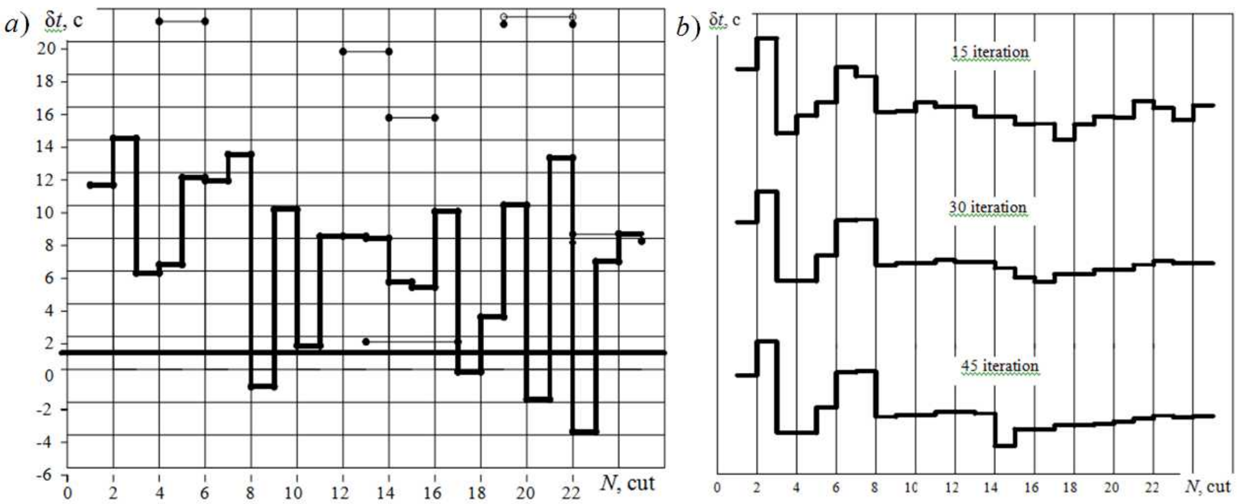

Fig. 3 Changing the size of adjacent intervals in the optimization process:
a) before optimization; *b*) after some iterations

As a result of optimization, such modes of braking of cut are established, at which the maximum possible intervals on the separating switches are provided for all unfavorable conditions of separation of the groups of cuts (fig. 4). The boundaries of the groups are cut with extreme modes of rolling: fast (F) and slow (S).

Statistical processing of the interval values (fig. 5) obtained as a result of optimization showed that the value of the mathematical expectation of the interval between adjacent cuts is $M[\delta t_{ac}]$=6,6 s, between non-adjacent cuts is $M[\delta t_{nc}]$=42,2 s.

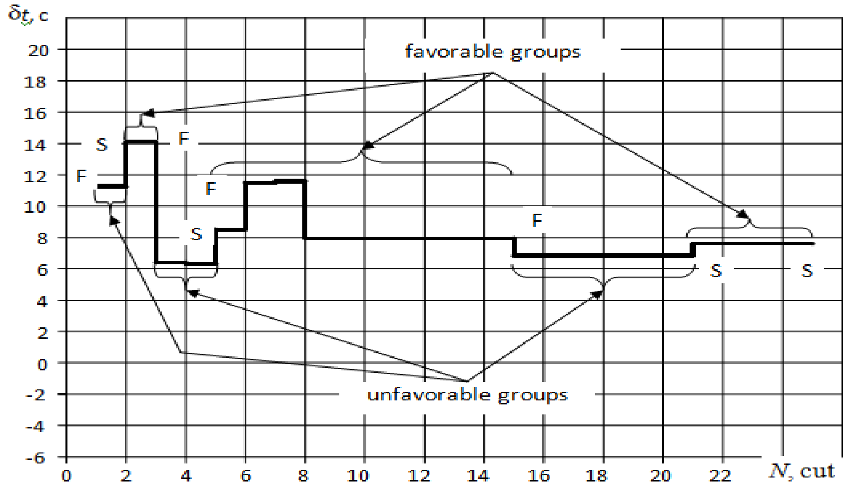

Fig. 4. Distribution of intervals between cuts after the end of optimization braking modes

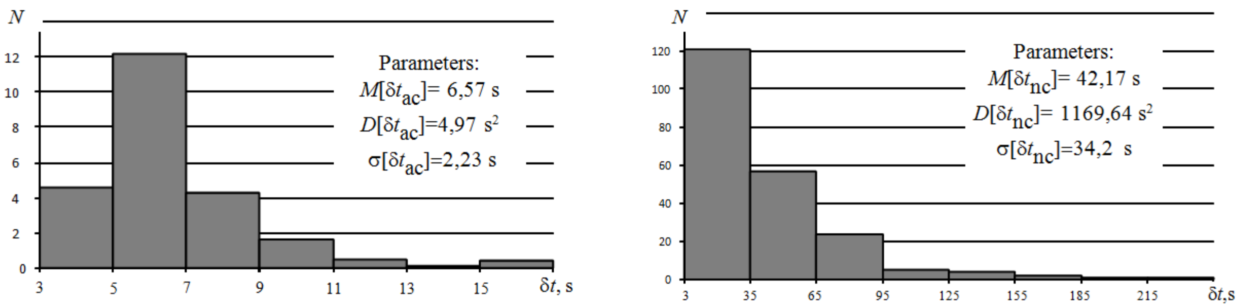

Fig. 5 Histogram of the distribution of the size of the intervals between cuts: a) adjacent; b) non-adjacent

Conclusions

The analysis of the indicators of the sorting process showed a sufficient efficiency of the method for optimizing the modes of dissolving the compositions developed in [12], which can be recommended for calculating the release rates of the cut positions in the automation systems of the sorting process.

The braking modes obtained as a result of optimization provide a sufficiently high quality of interval control, as well as the possibility of implementing a safe speed of collision of cuts on the sorting tracks of automated humps.

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ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ ПРОЦЕССА РАСФОРМИРОВАНИЯ СОСТАВОВ НА СОРТИРОВОЧНЫХ ГОРКАХ

Целью исследования является повышение качества сортировочного процесса с помощью определения рациональных режимов расформирования составов. Указанные режимы обеспечивают наилучшие условия разделения отцепов состава на разделительных элементах, а также возможность реализации безопасной скорости соударения вагонов на сортировочных путях. **Методика.** Исследования разделений отцепов состава на стрелках выполнено с помощью имитационного моделирования. Для исследований была использована модель скатывания отцепов с горки, позволяющая реализовать заданные скорости выхода из тормозных позиций при регулировании зоны торможения отцепа. **Результаты.** Была выполнена количественная оценка показателей сортировочного процесса при использовании разработанного метода оптимизации режимов торможения отцепов для управления процессом расформирования составов на одной из сортировочных горок Украины. Выполненный анализ результатов показал достаточную эффективность разработанного метода, который может быть рекомендован для расчета скоростей выхода отцепов из тормозных позиций в системах автоматизации сортировочного процесса. Полученные в результате оптимизации режимы торможения могут обеспечить достаточно высокое качество интервального регулирования, а также возможность реализации безопасной скорости подхода отцепов к вагонам на сортировочных путях автоматизированных горок. **Научная новизна** работы заключается в доказательстве эффективности рассмотренного метода оптимизации режима расформирования составов. **Практическая значимость** работы заключается в том, что рассмотренный метод определения рациональных режимов расформирования составов может быть использован при создании автоматизированной системы управления процессом расформирования составов на сортировочных горках, а также для оценки качества конструкции проектируемых сортировочных горок. Автоматизация горок будет способствовать улучшению экономических показателей работы станций, снижению себестоимости переработки вагонов, экономии энергоресурсов на торможение вагонов и на маневровую работу, улучшению условий и безопасности труда работников горки.

Ключевые слова: режимы торможения; отцеп; сортировочная горка; метод оптимизации; автоматизированная система.

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ПРОЦЕСУ РОЗФОРМУВАННЯ СОСТАВІВ НА СОРТУВАЛЬНИХ ГІРКАХ

Метою дослідження є підвищення якості сортувального процесу за допомогою визначення раціональних режимів розформування составів. Зазначені режими забезпечують найкращі умови розділення відчепів составу на розділових елементах, а також можливість реалізації безпечної швидкості зіткнення вагонів на сортувальних коліях. **Методика**. Дослідження розділень відчепів составу на стрілках виконано за допомогою імітаційного моделювання. Для досліджень було використано модель скочування відчепів з гірки, що дозволяє реалізувати задані швидкості виходу з гальмівних позицій при регулюванні зони гальмування відчепа. **Результати**. Була виконана кількісна оцінка показників сортувального процесу при використанні розглянутого методу оптимізації режимів гальмування відчепів для управління процесом розформування составів на одній з сортувальних гірок України. Виконаний аналіз результатів показав достатню ефективність розглянутого методу, який може бути рекомендований для розрахунку швидкостей виходу відчепів з гальмівних позицій в системах автоматизації сортувального процесу. Отримані в результаті оптимізації режими гальмування можуть забезпечити достатньо високу якість інтервального регулювання, а також можливість реалізації безпечної швидкості підходу відчепів до вагонів на сортувальних коліях автоматизованих гірок. **Наукова новизна** роботи полягає в доведенні ефективності розглянутого методу оптимізації режиму розформування составів. **Практична значимість** роботи полягає в тому, що розглянутий метод визначення раціональних режимів розформування складів може бути використаний при створенні автоматизованої системи управління процесом розформування составів на сортувальних гірках, а також для оцінки якості конструкції сортувальних гірок, що проектуються. Автоматизація гірок сприятиме поліпшенню економічних показників роботи станцій, зниження собівартості переробки вагонів, економії енергоресурсів на гальмування вагонів і на маневрову роботу, поліпшенню умов і безпеки праці працівників гірки.

Ключові слова: режими гальмування; відчеп; сортувальна гірка; метод оптимізації; автоматизована система