Development of an Algorithm for Determining the Movement of Products Between Racks Based on Data from Their Radio Frequency Tags

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Abstract. At present, in connection with the need to move to new intellectual digital production technologies and implement international quality standards, it is necessary to introduce new science-based approaches to controlling the movement of products and small-scale mechanization of warehouses. This is due to the fact that the warehouses of large industrial organizations, at the current level of hardware and software, can not fully comply with domestic and foreign quality standards in the field of product tracking, regulated by GOST and ISO. The article is devoted to the development of an algorithm for determining the movement of products between racks based on data from their radio frequency tags to automate the control of the movement of products in industrial enterprises. The main methods of development of such systems based on technical vision and radio frequency identification are considered. The main normative documents and interstate standards regulating the described processes are given. The review of modern publications and automation systems for the control of the movement of products of domestic and foreign manufacturers is conducted. The developed algorithm operates radio-frequency labels of racks and products. Data processing is performed using statistical methods of analysis. The results of experimental research at Vyksa Steel Works are presented.

Keywords: positioning, radio frequency identification, racks.

1 Introduction

One of the most important elements of the quality management system of industrial production, which largely determines the efficiency of its operation, is the identification mechanism, which makes it possible to ensure traceability of products throughout the technological production cycle. Traceability in production helps to ensure compliance with the requirements of government and international quality standards, to perform a fast and purposeful tracking of the entire technological cycle of manufacturing products, which, in turn, minimizes financial consequences. Especially relevant is the question of tracking products at the enterprise, if the production cycle consists of many stages, implemented in large production areas. The organization of the mechanism for tracking products is possible by automating the control of the movement of industrial products [1,2].

Automation of traffic control is currently predominantly made using two technologies: technical vision and radio frequency identification (RFID). The use of technical vision approaches is complicated by the need for graphic marking of proper quality, which is difficult to realize in real production conditions and requires significant financial and human resources. The use of radio frequency identification is less demanding in the process of marking products. Traffic control, based on radio frequency identification methods, is an advanced information technology for the construction of warehouse accounting systems [3,4].

2 Subject Overview

When solving problems of controlling the movement of products during its stochastic movement by various transport devices, either methods of digital image processing coming from video sensors or methods of radio frequency identification are often used. The use of methods of digital image processing provides great opportunities for implementing various ways of identifying symbolic markings printed on the surface of manufactured products. In most cases, developers of such solutions prefer modern controlled cameras, which are equipped with rotary devices, optical zoom and automatic focus adjustment, to obtain a variety of images and analysis of disparate features. To develop such solutions it is necessary to have a high level of expertise in the field of digital image processing, and the algorithms themselves are very narrow-based. During the implementation of the project, it is proposed to develop methods and algorithms for the detection, localization and recognition of symbolic markings, which make it possible to reliably identify industrial products on a variety of images using a wide variety of disparate features. Analysis and selection of signs of symbolic markings should be carried out in accordance with existing international and interstate standards [5-11]:

1. GOST R ISO / IEC 15459-3-2007 "Automatic identification. Identifiers are unique international. Part 3. General rules for unique identifiers »
2. GOST R ISO / IEC 15459-4-2007 "Automatic identification. Identifiers are unique international. Part 4. Unique Identifiers of Single Items for Supply Chain Management »
3. GOST 27465-87 "Information processing systems. Symbols. Classification, name and designation »
4. GOST R 51294.2-99 "Automatic identification. Encoding is a dashed. Description of the format of the requirements for symbolism »
5. GOST 30832-2002 "Automatic identification. Encoding is a dashed. Linear symbols of the bar code. Testing requirements for print quality »
6. GOST ISO 15394-2013 "Packing. Linear bar code symbols and two-dimensional symbols on labels for shipping, transportation and acceptance. General requirements"
7. GOST ISO / IEC 15459-1-2008 "Automatic identification. Identifiers are unique international. Part 1. Unique identifiers of transported units»

The development of new methods and algorithms for the detection, localization and recognition of symbolic markings is aimed at improving the two main technical and operational indicators: - reduction in the speed of the processing of incoming multi-image images on a set of dissimilar features; - increasing the reliability of the results obtained during the analysis of different digital images. The requirements for performance and reliability indicators are determined experimentally. However, the use of symbolic markings is complicated by the fact that the execution of the hardware, its location and the quality of the installation do not always allow us to cover the entire area of potential identification of the product identifier, which in turn has a negative impact on the reliability of the results obtained. Also, the symbolic markings applied to the surface of the monitored products may be damaged during transport, which leads to the impossibility of identifying the current product, which also has a negative effect on the reliability of the results obtained. The use of radio frequency identification, at present, is a very popular and effective approach to identification, because Allows to bypass a number of restrictions imposed by digital image processing. For implementation of radio frequency solutions, both manual and stationary readers can be used with the option of installing remote antennas. To develop such solutions, it is necessary to have a high level of expertise in the field of radio frequency identification and to take into account limitations on the use of this equipment. During the implementation of the project, it is proposed to develop methods and algorithms for the statistical analysis of data of radio frequency identifiers to determine the position relative to storage locations and identifiers of captured items. Identification is proposed to be made by standard means of radio frequency readers, when positioning - using statistical data. The determination of the movement of products is planned to be controlled by analyzing the space-time information on the state of the transporting device. The analysis and choice of the signs of radio frequency identifiers and space-time characteristics should be carried out in accordance with existing international and interstate standards [12-18]:

1. GOST R 54621-2011 "Information technology. Radio frequency identification for the management of objects. Recommendations for use. Part 1. Labels and packaging with RFID tags according to ISO / IEC 18000-6 (type C) »
2. GOST R ISO / IEC 19762-3-2011 "Information technology. Automatic identification and data collection technologies (AISD). Harmonized dictionary. Part 3. Radio Frequency Identification (RFID) »
3. GOST R ISO / IEC 18000-6-2013 "Information technology. Identification of radio frequency for the management of objects. Part 6. Radio interface parameters for the frequency range 860 - 960 MHz. General requirements"
4. GOST R ISO / IEC 18000-7-2012 "Information technology. Identification of radio frequency for the management of objects. Part 7. Active radio interface parameters for communication at 433 MHz »
5. GOST R ISO / IEC 15459-3-2007 "Automatic identification. Identifiers are unique international. Part 3. General rules for unique identifiers »
6. GOST R ISO / IEC 15459-4-2007 "Automatic identification. Identifiers are unique international. Part 4. Unique Identifiers of Single Items for Supply Chain Management»

7. GOST R ISO / IEC 15963-2011 "Information technology. Radio frequency identification for the management of objects. Unique identification of radio frequency tags»

The development of new methods and algorithms to determine the position and identifier of radio frequency marking is aimed at improving the two main technical and operational indicators: - reducing the speed of processing incoming RF data for positioning the product relative to storage locations; - increasing the reliability of the results obtained during the statistical analysis of radio frequency identifiers. With all the advantages of radio frequency identification, there are a number of limitations that can adversely affect the result of the automatic identification system. One such limitation is the directivity of the signal of radio frequency identifiers fixed on the products. The presence of this parameter rigidly sets the requirements for the composition, location and installation of equipment for identification. Another limitation is that radio frequency identifiers poorly pass radio waves through obstacles, and especially through metal. Failure to comply with the rules for the operation of radio frequency equipment can have a negative impact on the reliability of the results obtained.

A great contribution to the development of radio frequency identification technology and product movement control systems in various spheres of life was made by Bondarevsky A.S., Zolotov R.V., Do Zuy Nyat, Kamozin D.U., Manish B., Shahram M., Ke-Sheng Wang , Worapot Jakkhupan, Somjit Arch-int, Yuefeng Li, Mahir Oner, Alp Ustundag, Aysenur Budak and many others [5-10].

Application of these knowledge-intensive technologies makes it possible to automate the processes of controlling the product movement at industrial plants, ultimately, to increase the efficiency and reliability of transportation control and warehouse inventory control of manufactured products.

However, they are not without flaws. The use of existing software and hardware solutions is more aimed at organizing automated warehouse inventory control and less suitable for automating product movement control, in the absence of universal methods and algorithms. In support of this, at a number of industrial enterprises, developers of RFID systems attempted to organize traceability of products by automatic movement control based on radio frequency identification. As a result, it became clear that automatic control of the product movement is possible only in certain areas of the production process. Such areas are conveyor lines and transport tunnels, where the transportation of products is carried out along the permanently installed radio frequency identification equipment (RFID tunnels). In other production and warehouse areas, automatic control over the movement of products is impossible. This is due to the lack of universal methods and algorithms for product identification in the process of its transportation along unmapped routes.

Positioning of objects and people using information technology is quite a substantial task. These technologies can be used to solve social, industrial and other types of tasks. Currently, there are a large number of approaches to positioning using a large number of technologies, among them:

- Satellite navigation technologies (GPS, GLONASS);
- Local positioning technology (infrared and ultrasonic);

- Technology of technical vision;
- Radio-frequency technologies.

The use of satellite navigation technology and positioning are tightly integrated into our daily lives. They are used for navigation and transport tracking, monitoring and coordination of various kinds of events. The accuracy of positioning is 10-15 meters outdoors. Unfortunately, the application of this technology inside production facilities is almost impossible. An exception is the installation of expensive equipment for organizing GPS-positioning indoors, the unit of which can cover no more than 10 square meters, which is unacceptable for most industrial plants, whose sizes can be tens of kilometers.

Local positioning technologies are highly accurate - about 2 centimeters, but with a short range of 5-10 meters. With these attributes, they are used to achieve local accurate results and, in general, are used for flaw detection (analysis of welds, detection of chips, dents, etc.). The use of local positioning technology for small-scale mechanization is not economically effective and will lead to huge financial costs.

The use of vision technology for solving positioning problems is a relatively young concept. Currently, there are a huge number of methods and algorithms for solving localization and positioning problems, but their effectiveness depends a lot on meeting a large number of requirements, which include the quality of materials used for production of visual labels, cleanliness and lighting of premises, staff attentiveness, etc. Failure to comply with even one of the requirements can lead to a significant reduction in positioning accuracy or make it completely inoperative.

Radio-frequency technologies have found wide application in sales (organization of security in stores). Positioning based on radio frequency technologies can be divided into two categories: positioning on passive RFID tags (distance up to 5 meters) and active RFID beacons (distance up to 80 meters), but all of them are based on the principle that the moved object is marked with an RFID tag and the reading equipment is stationary. This approach allows to effectively automate production processes, where the product movement routes are strictly limited, for example, conveyor lines. However, for the positioning of chaotically moving small mechanization means, this approach will lead to a significant increase in the cost of the positioning system. Instead of a few readers they would need ten times as many.

Considering all the information stated above it is possible to draw a conclusion, that development of technology and software for the construction of positioning and control systems for small mechanization in industrial plants based on radio frequency identification methods is a substantial scientific and technical task.

The development of software and hardware for movement control systems is carried out by: PCT-Invent (Russia, Saint-Petersburg), AiTiProject (Russia, Moscow), Impinj (USA, Seattle), Motorola (USA, Morrisville), Nordic ID (Finland, Salo), FEIG (Germany, Weilburg).

Development of positioning systems based on radio frequency identification is carried out by the following scientific organizations:

- Human positioning systems, in particular patients in medical institutions: Shonan Institute of Technology (Japan, Fujisawa), Institute of Medicine (Kathmandu, Nepal), National Patient Safety Foundation (USA, Boston) and others.

- Systems for positioning moving non-metallic objects: East China Jiaotong University (China, Nanchang), Universiti Sains Malaysia (Malaysia, Nibong Tebal), University of Adelaide (Australia, Adelaide), Wellness Convergence Research Center (Korea, Daegu) and many others.

However, the tasks of developing and implementing automatic systems for tracking products in production are still unresolved. Currently, industrial enterprises still have a number of problems, the solution of which is not realized with the help of modern product movement control systems.

3 Development of an Algorithm for Determining the Movement of Products Between Racks Based on Data from Their Radio Frequency Tags

Let J be the log of product movements (the log is the result of the algorithm), $g(t_1, t_2)$ is the function that returns the set of identifiers of the moved products in the time interval (t_1, t_2) (to extract the identifier of the moved product, the time-averaged value of the signal power level is compared with the threshold value):

$$g(t_1, t_2) = \left\{ i \,\middle|\, \frac{\tau}{t_2 - t_1 + \tau} \sum_{t=t_1, t_1+\tau}^{t_2} F_i^{\langle t \rangle} > P_{product}, i \in M_{product} \right\},$$

Where $M_{product}$ is the set of product label identifiers, $P_{product}$ is the threshold value (the minimum value of the signal power level from the tag of the product being moved), $F^{\langle t \rangle}$ is the vector of signal strength levels from the product labels and racks at time t.

The power level of the signal from the label is calculated as the average value in a time τ:

$$F_i^{\langle t \rangle} = \frac{1}{N} \sum \mu = \frac{n\, \mu_{ave}}{N},$$

where N is the number of read requests during the time interval $(t, t + \tau)$, n is the number of reads of the label i, μ is the signal power level from the label i, μ_{ave} is the average value of the signal power level from the label i.

We also introduce the intermediate variables: I_{begin} is the identifier of the initial rack (the rack from which the load is moved), I is the identifier of the current rack (the rack over which the load is at the time t), $I_{previous}$ is the identifier of the previous rack (the previous value of I), K is the number of shifts of the racks (the number of changes in the value of I starting from the initial I_{begin}), t_{first} is the time of the first change of the rack, t_{last} is the time of the last change of the rack, $t_{average\_of\_void}$ is the left boundary of the time interval during which there is no signal from the shelves.

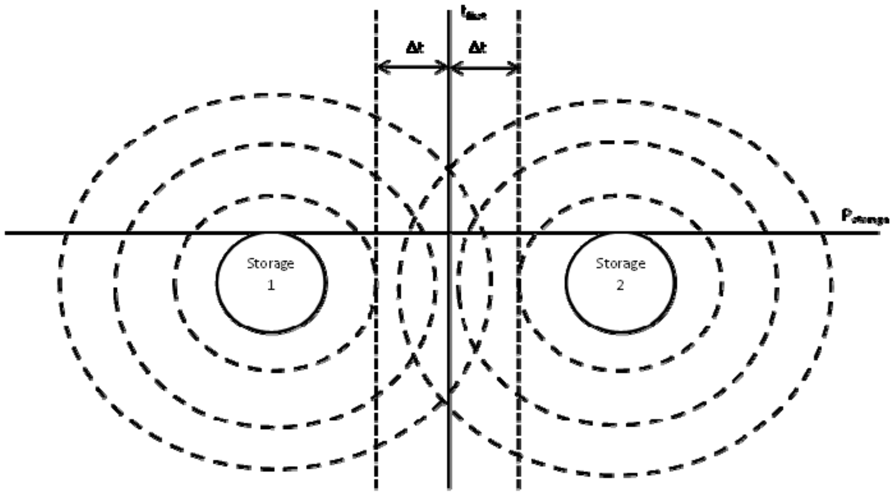

Fig. 1 Scheme of moving between racks without a void

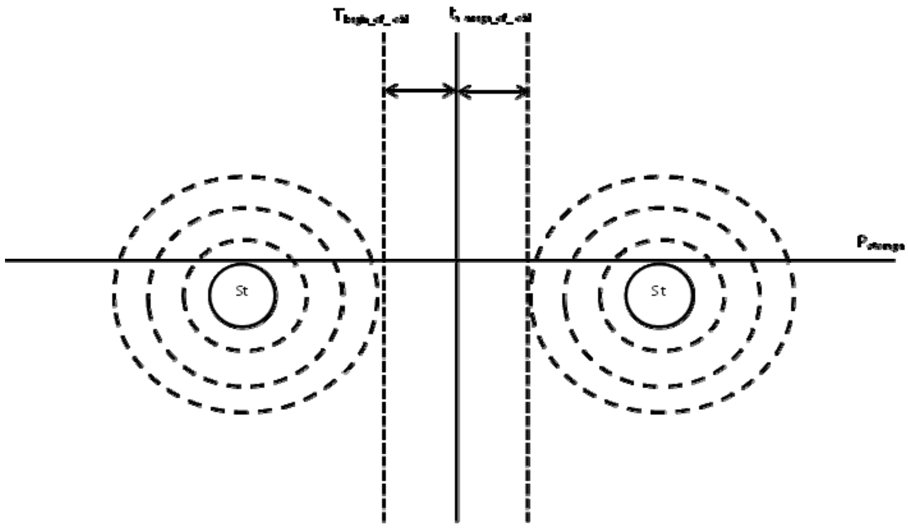

Fig. 2 Scheme of movement between the racks with a void

Algorithm steps:

1) Zeroing the values of intermediate variables (let zero mean the uncertainty of the value):

$$I_{begin} = I_{previous} = k = t_{first} = t_{last} = t_{average\_of\_void} = 0.$$

2) All the following steps (iteration) of the algorithm are performed for each time interval τ, during which a representative sampling of data from the marks is performed (each interval will be identified by its left boundary *t*).

3) The identifier of the rack label is defined as the index of the maximum value of the signal power level (the zero identifier will denote the absence of a signal from the labels, i.e., $I = 0$):

$$I = \begin{cases} \text{match}\left(\max F^{\langle t \rangle}, F^{\langle t \rangle}\right), if \ \max F^{\langle t \rangle} > P_{rack}, \\ 0, \ else, \end{cases}$$

Where *match (·, ·)* is the function that returns the index of the given element (the first parameter) in the vector (the second parameter), P_{rack} is the signal level threshold below which it will be considered to be absent, $F^{\langle t \rangle}$ is the vector of signal power level values from labels of the racks at time *t*.

Note. $I \in M_{rack}$ (M_{rack} – is set of label identifiers for racks).

4) If the initial rack is not defined ($I_{\text{begin}} = 0$) and the signal from the marks is present ($I \neq 0$), then the initial rack is defined as the current:

$$I_{\text{begin}} = I.$$

5) If the previous rack is not defined ($I_{\text{previous}} = 0$) and the signal from the marks is present ($I \neq 0$), then the previous rack is also determined as long as the current one (the value of the identifier of the previous rack is necessary at the next iteration):

$$I_{\text{previous}} = I.$$

6) If the values of the previous rack are determined ($I_{\text{previous}} \neq 0$ и $I \neq 0$) and the identifiers of the current and previous rack are different ($I_{\text{previous}} \neq I$), This means that at a given moment of time *t*, when moving the load with the tag reader, the signal power level from the current rack marker has exceeded (at that moment the load is somewhere between the two racks), and the steps are performed 7-13.

7) If there is no signal from the labels between the racks, the instant of time for changing the racks is refined and taken as the middle of the absence interval:

$$t_{average\_of\_void} = \frac{t_{begin\_of\_void} + t}{2}.$$

8) If the change of the racking occurred for the first time (while $k = 0$), then the obtained time is taken as the time of the first event of changing the rack:

$$t_{first} = t_{average\_of\_void}.$$

9) As the time of the last event of changing the rack, time is always taken $t_{average\_of\_void}$:

$$t_{last} = t_{average\_of\_void}.$$

10) If during the movement of the load the rack has changed several times ($t_{first} < t_{last}$), but the identifiers of the labels of the transferred products have also changed, i.e. the composition of cargo changed

$$g\left(t_{first} - \Delta t, t_{first} + \Delta t\right) \neq g(t_{last} - \Delta t, t_{last}),$$

where Δt is half the time of moving the captured cargo over the racks, it means that it is necessary to create a record of the movement of the load from the initial to the previous rack (steps 11, 12 are performed).

Note. In the above formula to t_{last} not added Δt, i.e. The composition of cargo in the future has not yet been determined.

11) In the journal J information is written about that from the rack I_{begin} in rack I_{previous} there was a movement of cargo with identifiers $g\left(t_{first} - \Delta t, t_{first} + \Delta t\right)$:

$$J = J \cup \langle I_{begin}, I_{\text{previous}}, g\left(t_{first} - \Delta t, t_{first} + \Delta t\right)\rangle.$$

12) The values of the intermediate variables are overridden. Because The movement of a new cargo has already begun, then:

- the initial rack becomes the previous one

$$I_{\text{begin}} = I_{\text{previous}};$$

- the number of shifts of the rack will be equal to one

$$k = 1;$$

- the time of the first event of the change of the rack will be the time of the last change of the rack

$$t_{first} = t_{last}.$$

13) Otherwise (the condition of step 10 is not fulfilled, i.e., when the rack is changed the composition of the cargo has not changed), the current rack is taken as the previous rack, and the number of shifts of the racks is increased by one (the resulting values of these variables are used at the next iteration):

$$I_{\text{previous}} = I,$$
$$k = k + 1.$$

14) If the signal from the rack label is present ($I \neq 0$) and assuming that the signal from the rack label disappears at the next iteration, the left boundary of the time interval during which the signal from the racks is absent will be the time instant at the next iteration:

$$t_{begin\_of\_void} = t + \tau.$$

If the signal from the label of the rack is not lost for the next iteration, then the value of this time is also redefined and will be used in the subsequent iteration.

15) If the moment of the last change of the rack is determined ($t_{last} > 0$), and from that moment the time passed exceeds the threshold value T (waiting time including the time Δt and the unloading time):

$$t - t_{last} > T,$$

then steps 16 and 17 are performed.

16) In the journal J information is written about that from the rack I_{begin} to rack I there was a movement of cargo with identifiers $g(t_{last} - \Delta t, t_{last} + \Delta t)$:

$$J = J \cup \langle I_{begin}, I, g(t_{last} - \Delta t, t_{last} + \Delta t) \rangle.$$

Note. If the signal from the shelving labels is not present at the moment ($I = 0$), then to determine the freelance situation in this log record, it is also necessary to add information about the absence of this signal "the signal from the rack marks is missing".

17) The values of the intermediate variables for the next iteration again become undefined:

$$I_{begin} = I_{\text{previous}} = k = t_{first} = t_{last} = 0.$$

4 Experimental Research

During the pilot studies, a large number of different typical close to production situations were modeled (Figure 3). Among them:

– movement between two storage areas;

– movement between three or more storage areas;

– movement between storage areas with the presence of "noise" (other radio frequency tags that are not tags of storage areas)

– movement between storage areas with partial overlapping of non-metallic and metal barriers.

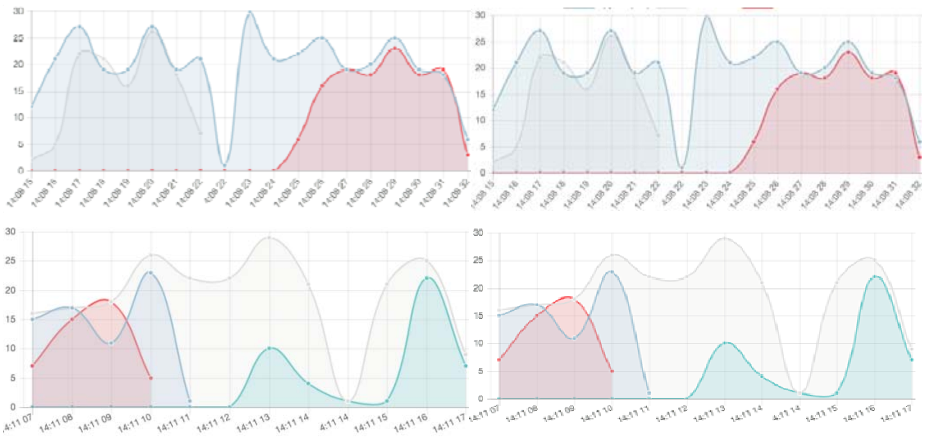

Fig. 3 The results of experimental studies

Experimental research was carried out at the industrial enterprise of JSC Vyksa Steel Works. During the research, the labeled metal products were moved between the shelves by means of small-scale mechanization, in particular a bridge crane with a load-carrying beam. The technological map of the product movement is shown in Figure 4.

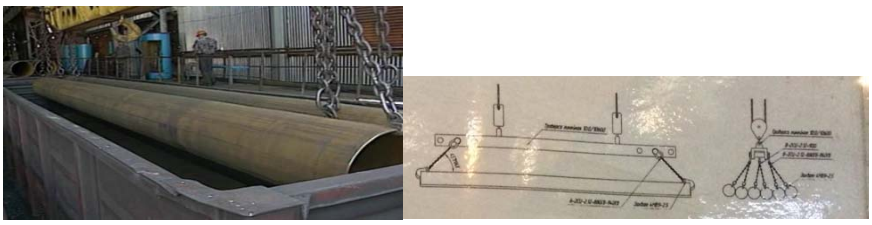

Fig. 4. A technological map for the transport of products by overhead cranes with a load-carrying cross-beam

Figure 5 shows the interpreted data on four experiments on beam movement between racks.

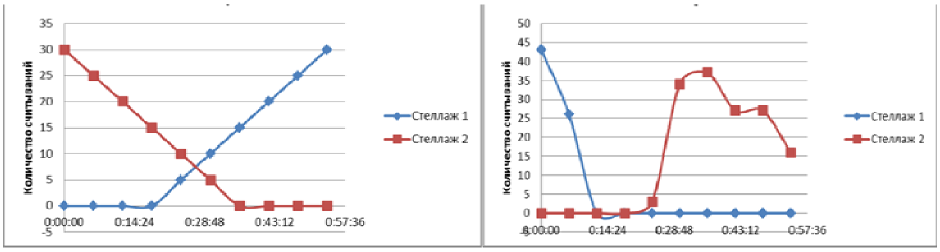

Fig. 5 - The results of experimental research at JSC Vyksa Steel Works

Experimental studies have shown the correctness of the algorithm for determining the current storage zone in laboratory and production conditions.

The work is executed at financial support of the grant of the President of the Russian Federation № MK-991.2017.9.

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