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TECHNOSPHERE SAFETY

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Study of Death and Injury Risks Dynamics of the Federal Fire-Fighting Service Personnel Using Time Series Smoothing

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Introduction. Studies of risks dynamics of death and injury of the Federal Fire-Fighting Service personnel in the performance of official duties for a long period (from 2006 to 2021) have shown that difficulties often arise due to the heterogeneity of data, their significant fluctuations in different periods of time and the influence of random factors.

Problem Statement. In this paper, to study the risks of death and injury of personnel of the Federal Fire-Fighting Service of the State Fire Service in the performance of official duties, time series smoothing methods (the moving average method and the exponential smoothing method) were used, which made it possible to eliminate abnormal observations and reduce the influence of random factors.

Theoretical Part. To identify trends in the risks of death and injury of personnel of the Federal Fire-Fighting Service of the State Fire Service in the performance of official duties, the method of time series smoothing was used. The methods of moving average and exponential smoothing are considered. The distribution of the risks of injury and death of the personnel of the Federal Fire-Fighting Service of the State Fire Service in the performance of official duties for the period 2006-2021 is shown, the average annual levels of injury and death risks for this period are determined, the dynamics of the ratio of the number of cases of injury and death in these years is considered.

Conclusions. The number of registered cases of injuries has decreased due to the improvement of the occupational safety management system. During the period from 2006 to 2021, there was a reduction in the risk of injury to personnel by 4 times. The ratio of the number of injured and dead has significantly decreased (by more than three times) - from 31.5 to 9.4. In addition, as a result of occupational safety management system improvement, the number of injuries with severe and moderate damage has decreased due to their transition to the category of injuries with light damage.

Keywords*:* time series, moving average, exponential smoothing, injuries, death, Federal Fire-Fighting Service.

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Introduction. When studying various indicators characterizing the activities of fire units, difficulties often arise due to the heterogeneity of data, their significant fluctuations in different time periods [1]. The distribution of indicators on the time scale can be considered as a time series [2]. The most important task in the study of time series is to identify and statistically assess the main trend in the development of the process under study and deviations from it.

When studying time series, a systematic and random component is distinguished. The systematic component is the result of the influence of constantly acting factors. An example of a systematic component of a time series is a trend, which can be characterized as a smoothly changing component describing the net influence of long-term factors, i.e. a long-term trend of a feature change.

The random component reflects the influence of random factors and can be considered as random noise or error affecting the time series irregularly.

One of the most common methods of studying time series is smoothing [3], which consists in replacing the actual values with calculated ones, which are characterized by less variability. Smoothing is used in cases where the trend is not sufficiently clear. For a smoothed time series, the trend usually manifests itself more clearly. Smoothing of time series is also used to eliminate anomalous observations.

Among the most common methods of time series smoothing, the moving average method and the exponential smoothing method can be distinguished.

The moving average method [4] consists in replacing the actual values of a time series with the average values for a group of data for a certain period, and each subsequent group is formed by shifting by one unit of time. In the presented study, a year is used as a unit of time.

To calculate the moving average, the formula is used:

$$\widetilde{w}_i = \frac{1}{3}(w_{i-2} + w_{i-1} + w_i)\,, \tag{1}$$

where w_i — the initial value of the time series in the i-th year. The disadvantage of this method is the exclusion of the first two values of the time series from the smoothing procedure.

The exponential smoothing method doesn't have such a disadvantage [5], in which the weighted values of the series in previous years are used in the smoothing procedure, and the weight decreases as we move away from the year for which the smoothed value is determined. To calculate the smoothed value by exponential smoothing, the formula is used:

$$\widetilde{w}_i = \begin{cases} w_i, & i = 1 \\ \widetilde{w}_{i-1} + \alpha(w_i - \widetilde{w}_{i-1}), & i > 1 \end{cases}, \tag{2}$$

where α — the smoothing coefficient. In the presented study, it is chosen to be equal to 0.5.

Problem Statement. The aim of the research was to study the impact of improving the occupational health management system (OHMS) on reducing the risks of death and injury of the personnel of the Federal Fire-Fighting Service of the State Fire Service (FFS SFS) in the course of duty. In this work, using the methods of time series smoothing, the risks of death and injury of personnel in the line of duty were studied. Death and injury rates of the personnel of the FFS SFS for 2006-2021 are taken from the statistical data bank on morbidity, injury, disability and death of personnel of the units of the Ministry of Emergency Situations of Russia in the performance of official duties [6].

Theoretical Part. The risk of death is determined by the following formula:

$$R_{\text{гиб}} = \frac{N_{\text{гиб}}}{N_{\text{л.с.}}}, \tag{3}$$

where $N_{\text{гиб}}$ — the number of personnel killed in the line of duty for the year, people, $N_{\text{л.с.}}$ — the average annual number of personnel, people.

The risk of injury is determined by the formula:

$$R_{трав} = \frac{N_{трав}}{N_{л.с.}}, \quad (4)$$

where $N_{трав}$ — the number of personnel injured in the line of duty for the year, people.

Figure 1 shows the distribution of the risk of injury to the personnel of the FFS SFS in the performance of official duties from 2006 to 2021.

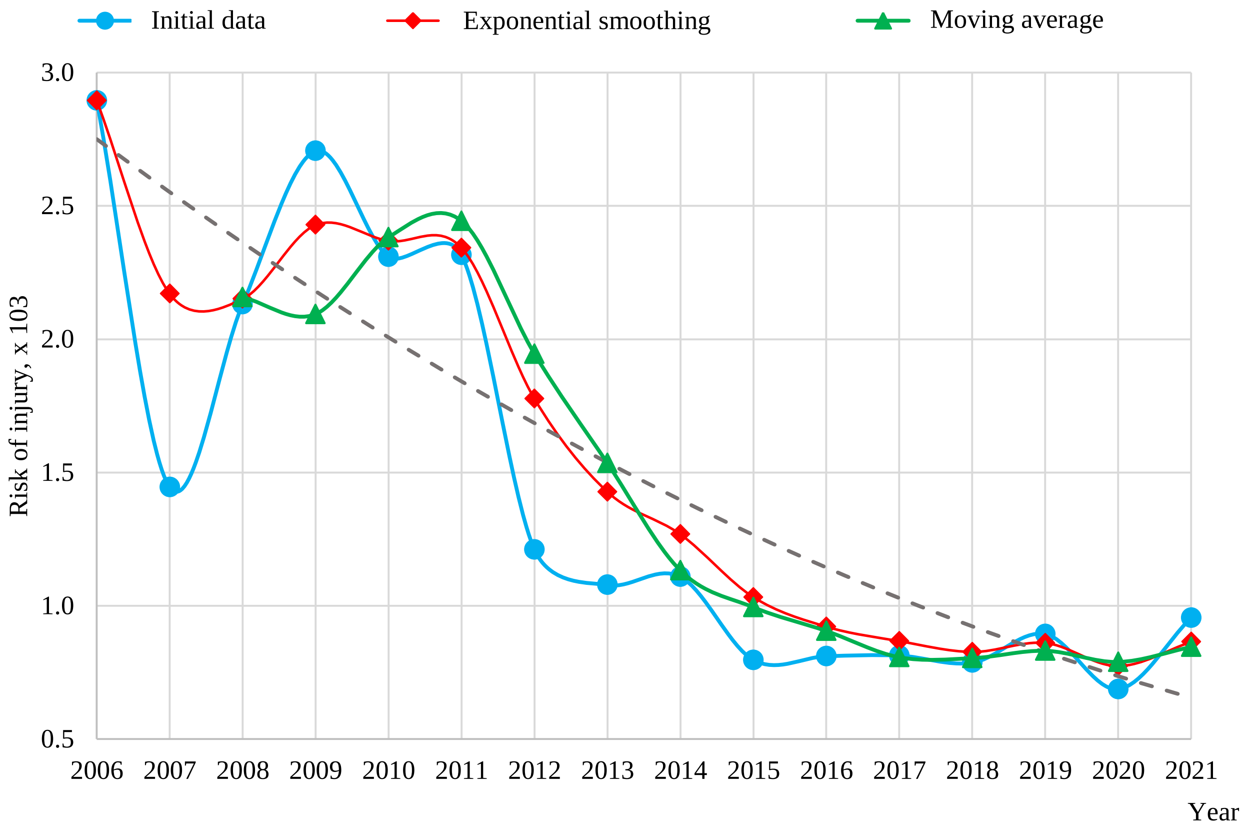

Fig. 1. The risk of injury to the FFS SFS personnel in the performance of official duties from 2006 to 2021.
Dashed curve — least squares approximation

The average annual risk of injury is 1.43×10^{-3}. From 2006 to 2011, the risk of injury to the FFS SFS personnel varied significantly from year to year. The average annual risk of injury during this period was 2.30×10^{-3}. From 2011 to 2015, there was a sharp decrease in the level of injuries. In subsequent years, the risk of injury remained approximately at the same level — on average 0.82×10^{-3}.

Smoothing of the injury risk distribution was performed using the moving average method (shown in green in Fig. 1). As it can be seen from the figure, the smoothed distribution at certain points is quite different from the original distribution (for example, in 2009, 2012 and 2013). The distribution obtained by exponential smoothing (shown in red in the figure) reproduces more accurately the original distribution. Therefore, this particular smoothing method was used further.

The smoothed distribution is approximated by the least squares method [7] using a polynomial function of the 2nd order. The risk of injury is described by the function:

$$R_{трав} = (0.0042x^2 - 0.211x + 2.962\,) \times 10^{-3}, \quad (5)$$

where x — the ordinal number of the year ($x = 1$ corresponds to 2006), the coefficient of determination $R^2 = 0.86$. As follows from dependence (5), from 2006 to 2021 there was a 4.2-fold reduction in the risk of injury – from 2.75×10^{-3} to 0.66×10^{-3}.

Figure 2 provides the distribution of the risk of death of the FFS SFS personnel in the line of duty from 2006 to 2021.

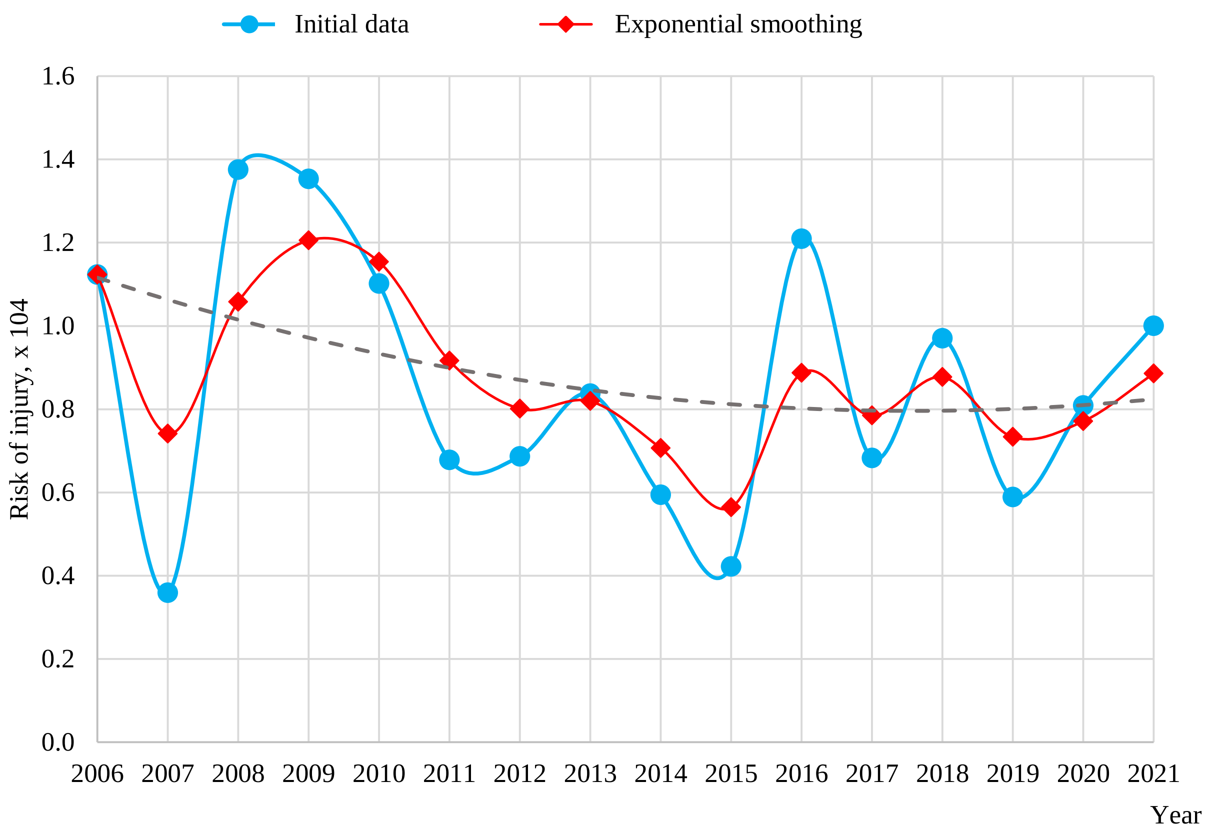

Fig. 2. The risk of death of the FFS SFS personnel in the line of duty
from 2006 to 2021. Dashed curve — least squares approximation

The average annual risk of death is 0.86×10^{-4}. The risk of death was highest in 2008 and 2009, when its value reached 1.38×10^{-4}. Then there was a reduction in the risk of death to 0.42×10^{-4} in 2015. In subsequent years, the risk of death increased and reached values from 0.6×10^{-4} to 1.2×10^{-4}.

As it can be seen from Figure 2, the distribution of the risk of death has a significant random component, which leads to significant fluctuations in its magnitude in different years. To reduce the influence of random factors and highlight the prevailing trend, exponential smoothing was performed (shown in Fig. 2 in red). The smoothed distribution is described by a 2nd-order polynomial function obtained by least squares approximation:

$$R_{\text{гиб}} = (0.0024x^2 - 0.046x + 1.015) \times 10^{-4}. \quad (6)$$

The coefficient of determination $R^2 = 0.34$. In accordance with dependence (6), over the period from 2006 to 2021, the risk of death decreased by 24% from 1.12×10^{-4} to 0.82×10^{-4}.

In international and domestic practice for the study of occupational injuries, the concept of "pyramid of accidents" is used, when for 1 case of injuries with severe damage there are about 10 cases of injuries with average damage and 100 cases of injuries with light damage [8, 9]. The analysis of injuries of the FFS SFS personnel in the performance of official duties showed [10] that on average, for 1 case of injuries with light damage, there are 8 cases of injuries with medium damage and 10 cases of injuries with severe damage. This ratio can be explained by the fact that the victims mostly go on sick leave after receiving moderate and severe injuries. Therefore, light injuries are practically not registered.

In this regard, the ratio of the number of cases of injury and death of the FFS SFS personnel in the line of duty is of interest:

$$D = \frac{N_{трав}}{N_{гиб}}. \quad (7)$$

Figure 3 shows the dynamics of this ratio from 2006 to 2021. The red color shows the distribution obtained as a result of exponential smoothing. The smoothed distribution is approximated by a 2nd-order polynomial function:

$$D = 0.038x^2 - 1.89x + 27.57 \quad (8)$$

The coefficient of deter mination $R^2 = 0.85$.

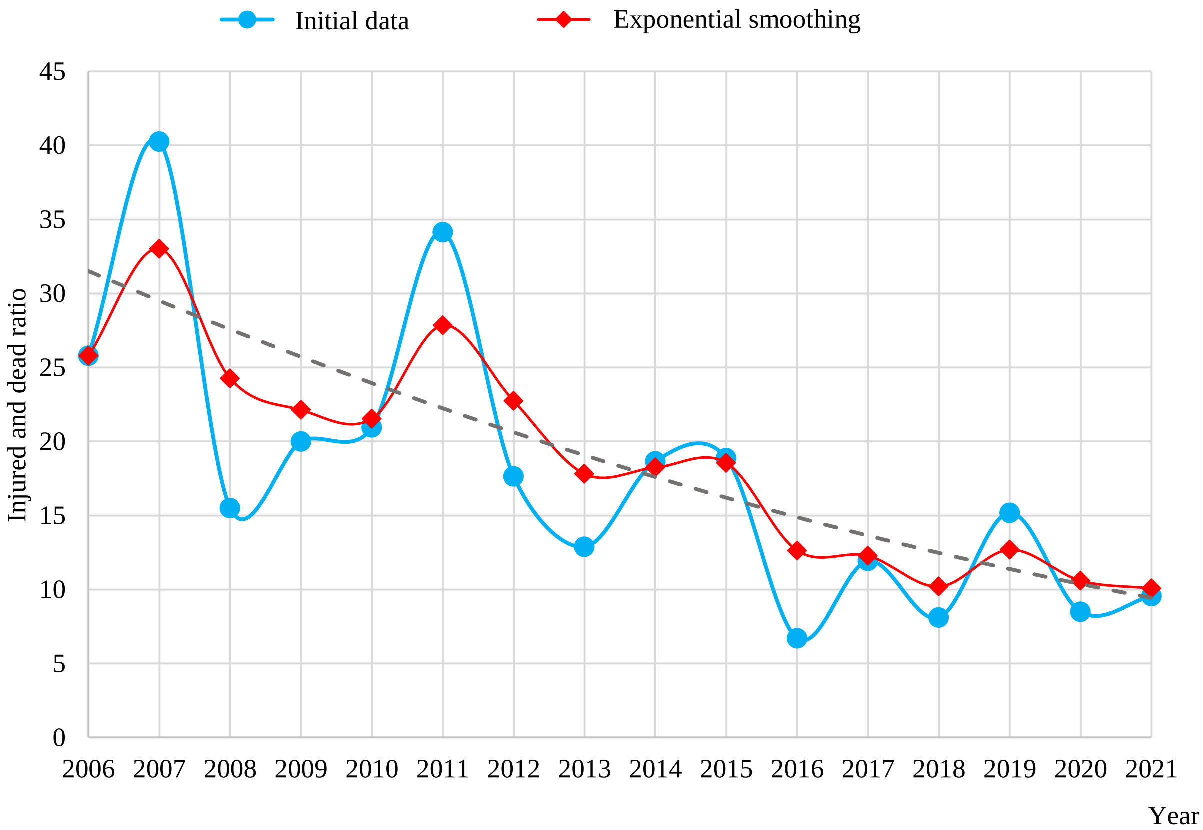

Fig. 3. Ratio of injured and dead FFS SFS personnel in the line of duty from 2006 to 2021. Dashed curve — least squares approximation

Over the period from 2006 to 2021, the ratio of injured and dead decreased by 3.3 times — from 31.5 to 9.4. Such a decrease can be explained by the fact that as a result of the improvement of the occupational safety management system, namely, the adoption of regulatory legal acts, including Order of the Ministry of Labor and Social Protection of the Russian Federation of 13.12.2014 No. 1100N "On approval of the Rules on Occupational Safety in the Units of the Federal Fire Service of the State Fire Service"[1], the number of injuries with severe and average damage (injuries with minor damage without temporary loss of working capacity are not always recorded), as a result of which the number of reported cases of injuries has decreased.

[1] The document became invalid due to the entry into force of Order of the Ministry of Labor and Social Protection of the Russian Federation No. 881n of 11.12.2020 "On Approval of the Rules on Labor Protection in Fire Protection Units"; the use of personal and collective protection of workers (Article 3 of Federal Law No. 426-FZ of 28.12.2013 "On Special Assessment of Working Conditions").

Conclusions. Over the period from 2006 to 2021, the ratio of injured and dead decreased by 3.3 times — from 31.5 to 9.4. This decrease can be explained by the fact that as a result of improving the occupational safety management system, the risk of injury with severe and moderate damage to health has decreased. It is possible that this risk has decreased not to zero damage, but to the level of injury with light damage.

Thus, the study of the risks of death and injury of the FFS SFS personnel in the line of duty for the period from 2006 to 2021 has been carried out. To identify trends in the observed dependencies, the exponential smoothing method was used. In 2006–2021, the average risk of injury to the FFS SFS personnel in the line of duty was 1.43×10-3. During the period under review, the risk of injury decreased by more than four times. The risk of death of the FFS SFS personnel in the line of duty is characterized by significant fluctuations from year to year; the average value of the risk of death for the period under review was 0.86 × 10-4. The ratio of the number of injured and dead personnel of the FFS SFS in the line of duty decreased by more than three times, which can be explained by a decrease in the number of medium and severe injuries as a result of improving the occupational safety management system.

For further optimization of the occupational health management system, it is necessary to:

– implement constant monitoring by labor protection officials that personnel in the line of duty follow the instructions on labor protection;

– organize occupational safety classes among the personnel in the system of service training;

– regular monitor the state of injuries and deaths of personnel in the line of duty.

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Claimed contributorship:

V. A. Mashtakov — analysis of the research results, revision of the text, correction of the conclusions; A. A. Kondashov — formulation of the main idea and concept of the study, development of the purpose and objectives of the study, calculations, analysis and interpretation of data, participation in writing the text of the manuscript, formulation of conclusions; E. V. Bobrinev — academic advising, review of publications on the topic of the article, participation in the collection and processing of material, analysis of research results, participation in writing the text of the manuscript; T. A. Shavyrina — participation in writing the text of the manuscript, editing the text, making the final version of the article; E. Y. Udavtsova — development of research design, preparation of literature, participation in the collection and processing of material, participation in writing the text of the manuscript.

TECHNOSPHERE SAFETY

Original article
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Improvement of Employees' Working Conditions When Processing Vegetables in Open Ground by the Designing Device for Lifting and Lowering Containers in the Storage

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Introduction. Vegetable production is one of the branches of plant cultivation that is distinguished by the specifics of conducting technological processes, characterized by the structural variety of cultivation facilities and special working conditions. Injuries of employees are the serious problem in the workplace now. The body of a worker is exposed to a complex of unfavorable production factors: mineral fertilizers, pesticides and products of their metabolism: heating microclimate, high humidity, significant physical exertion. If agrotechnical techniques are followed, they cannot be a source of deterioration of health. Violation of sanitary and hygienic regulations and technological schemes for growing crops increases the risk of health problems and affects the ability to work.
Problem Statement. The task for the study is to develop a simplified design to lower vegetables into storage, improve working conditions and safety of workers.
Theoretical Part. Occupational safety improvement in agriculture is necessary, first of all, from the point of the preservation and purpose of the system as a mechanism for protecting the interests of workers, guaranteeing the preservation of their life, health, working capacity in the process of professional activity, as well as for the purpose of agricultural production efficiency. There is an urgent problem of safety when laying vegetables in containers. The main type of injury to workers is occurred during work for eliminating technical and technological failures.
Conclusions. As a result of the research, market analysis and evaluation of the competitiveness of the development under consideration, the main distinguishing features of the proposed device from the existing ones are determined. This design can be recommended for further integration into the existing enterprise system, as well as for use in any agricultural enterprises.

Keywords: working conditions, labor safety, technology, vegetable storehouse, containers, lift, trolley, ramp, overturning.

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Introduction. The development strategy of the Russian Federation is aimed at the development of the agro-industrial complex, which provides for a steady increase in agricultural production and entails an increase in labor productivity, acceleration of scientific and technological progress. As a result, the role of the human factor increases under certain working conditions associated with the production and sale of agricultural products [1, 2].

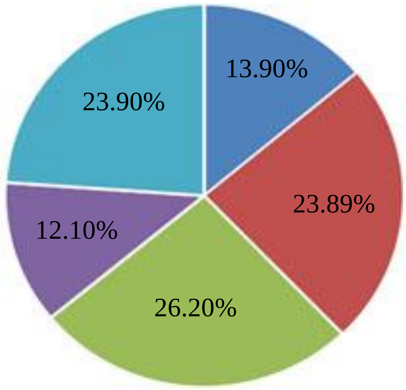
During the years of reforms, about half of the fixed assets of the agro-industrial complex were lost; a large amount of machinery and equipment became obsolete and became unusable [3]. It is no coincidence that every third injury with temporary disability and every fourth with a fatal outcome that occurred in the national economy of the country fall on the agro-industrial complex (AIC) of Russia [4]. It is also important that, with a general decline in production volumes, injuries and morbidity in the industry have not significantly decreased. Over the past ten years, the number of fatalities in rural construction has amounted to about 9% of the number of victims in all branches of agriculture, crop production — 23.2%, repair and maintenance of machinery — 18.1%, animal husbandry — 16.2% and food production — 9.9% [5–8].

Improving labor protection in agriculture is one of the priority areas. First of all, it is necessary to improve labor safety at the level of the agricultural industry development system, move away from outdated equipment, modernize human labor, replacing manual labor with mechanical labor, introduce the principles of digitalization, and calculate risks and possible negative developments.

The problem of ensuring the safety of workers when using agricultural machinery remains relevant today, as the sources of injury in 74% of cases with a fatal outcome are machines and mechanisms.

As a result of experimental studies during potato harvesting in various farms from 2010 to 2020, the most dangerous and harmful production factors affecting workers were identified.

The main type of injury to workers is work to eliminate technical and technological failures, which accounts for about 27% of the total operating time. According to source [8], a diagram was compiled reflecting the troubleshooting time (Fig. 1):



- Time of inspection of the movable objects of machines during the direct execution of the technological process
- Troubleshooting time due to clogging of the movable objects of the combine
- Time for technical troubleshooting
- Time for adjustment work
- Time to eliminate clogging of movable objects, as well as to regulate work and maintenance during downtime for organizational reasons

Fig. 1. Main causes of injuries to workers

The process of laying vegetables in storage remains dangerous from the point of view of safety and labor protection (Fig. 2). The technology has remained unchanged since the 90s. First, the potatoes are poured into a hopper, from where they are transported and moved, then at the end of the work they are put into containers.

Fig. 2. The process of laying potatoes in storage

After that, with the help of loaders, containers with potatoes are delivered to the storage and put up in columns. The disadvantage of this technology is that not all storages have the possibility of access of loaders. Part of the storages of large agricultural concerns is buried in the ground by 1–1.5 meters and ramps are specially equipped for arrival. However, it is impossible to move along the ramps due to the danger of car overturning together with the container [9, 10].

Problem Statement. The objective of the study is to propose a developed, simplified design for lowering vegetables into storage, which will improve the working conditions and safety of workers.

Theoretical Part. The rationale for the development of a device for lifting and lowering containers into storage during the processing of open-ground vegetables was the study of regulatory requirements for the organization of this type of work on the territories of agricultural complexes. After conducting a critical analysis of the existing solutions to this problem, a number of shortcomings were identified.

Lifts can be installed both outside the building and inside in a temporal and permanent way. A variety of options for lifting cargo, different high-altitude tasks, working conditions gave rise to differences in the design features of lifts: various cargo open and closed platforms, swing doors or roller shutters, only one control panel or one on each floor, various types of safety and locks, the type of lift drive, etc. The design of the lift depends on the load rate, installation location and application. This type of lifts is capable of lifting cargo to a height of up to 50 m. The cargo lift is installed outside or inside the building.

For the installation of the lift, it is possible to use the existing lift shafts of the building. Each lift model has an upper and lower drive arrangement. The main technical characteristics of the cargo lift are its load capacity from 50 to 6300 kg, lifting height from 7500 mm to 36 meters.

The SC 100 construction lift with a single cab is characterized by ease of maintenance and operation. The cabin is equipped with a speed limiter to stop the equipment when the lowering speed reaches 12 m/sec. The lift is equipped with an overload protection system that turns off the power when the permissible load capacity is exceeded. This equipment is able to significantly increase the level of production safety due to the stability and evenness of work [11].

The main components of the construction lift with two cabins SC 200/200 are cabins, operator's cabin, transmission mechanism, speed limiter, roller guide frame, connectors, lower cabin, mast, electrical system, safety system.

The container lift with manual mechanical (winch) drive "BAMBULA 252-16-4" with a steel frame is designed for lifting and moving baskets/containers. The considered devices do not allow to be used when lowering and lifting loads on the territory of the vegetable storage. The most suitable in this case are inclined lifts.

The advantages of inclined lifting platforms:

– available in three different options;

– the installation of the lift does not require any construction work and does not spoil the design of the premises;

– has remote control, active and passive safety devices, retractable safety barriers, which reduce the occupied space when the equipment is not in use.

The developed inclined lift consists of a rectangular cross-section mast located at a certain angle to the ground (Fig. 3). A cargo platform (cab) moves along one of the sides of the mast under the action of an electric drive, which can be installed at the top, bottom or side of the mast (Fig. 4). The lift is mounted on a load-bearing base, which is flat or in the form of a pit. The control is carried out using push-button control posts from any stop. On request, it is possible to supply a lift with fences for each floor.

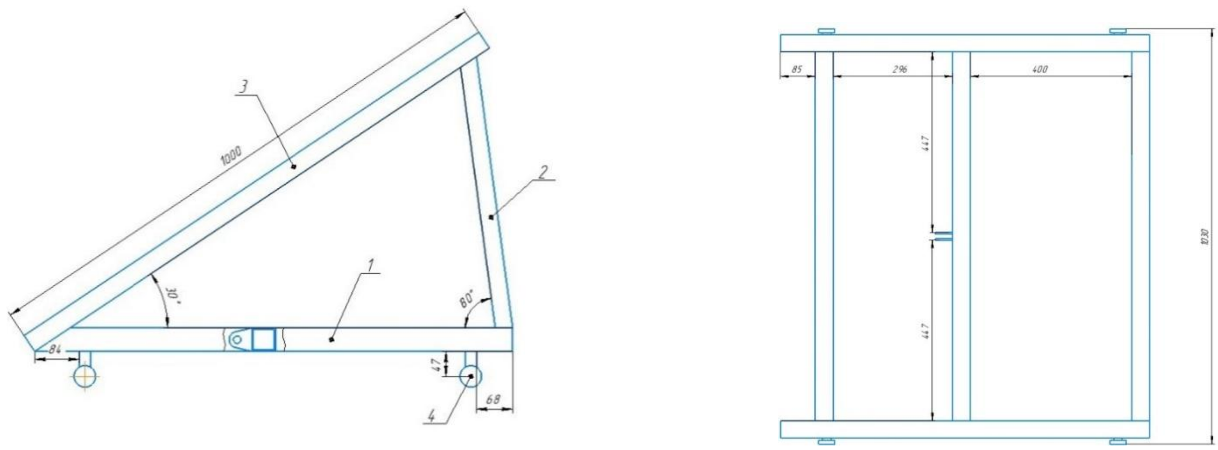


Fig. 3. General view of the inclined lift under development

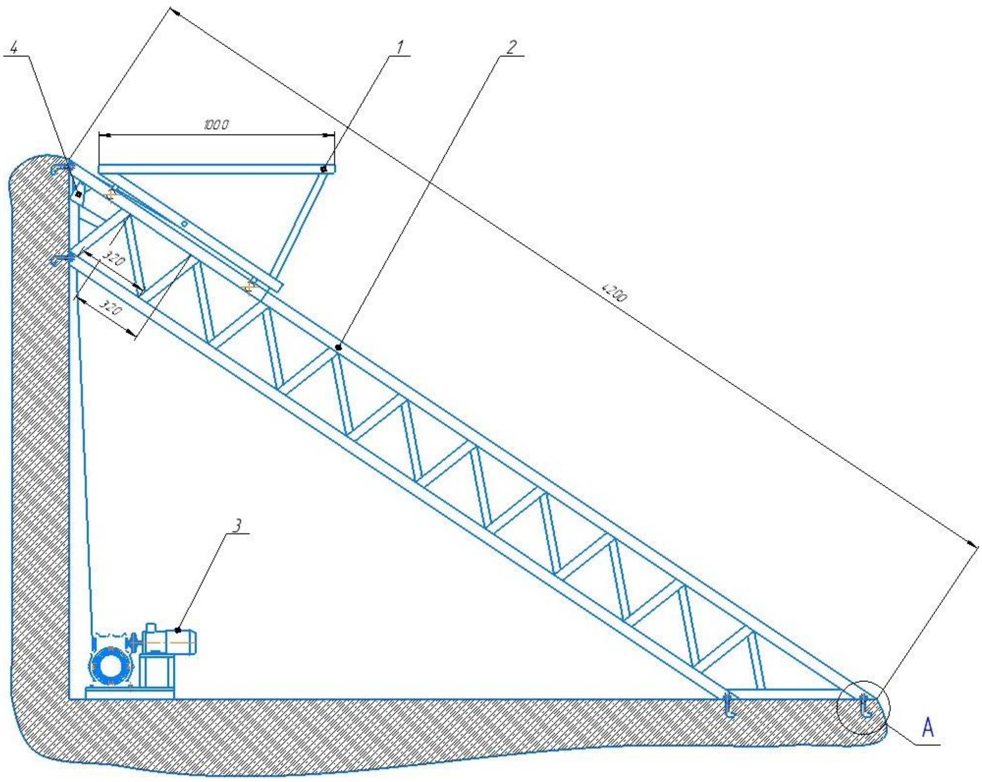


Fig. 4. General view of the inclined lift under development:
1 — trolley, 2 — lift, 3 — engine

The control is carried out using a push-button station (PBS), which is located on or near the mast. Sending and calling of the cargo cage is carried out with the help of the PBS from any floor to any floor. The control units are equipped with a light indication that allows you to determine the location of the cage (Fig. 5).

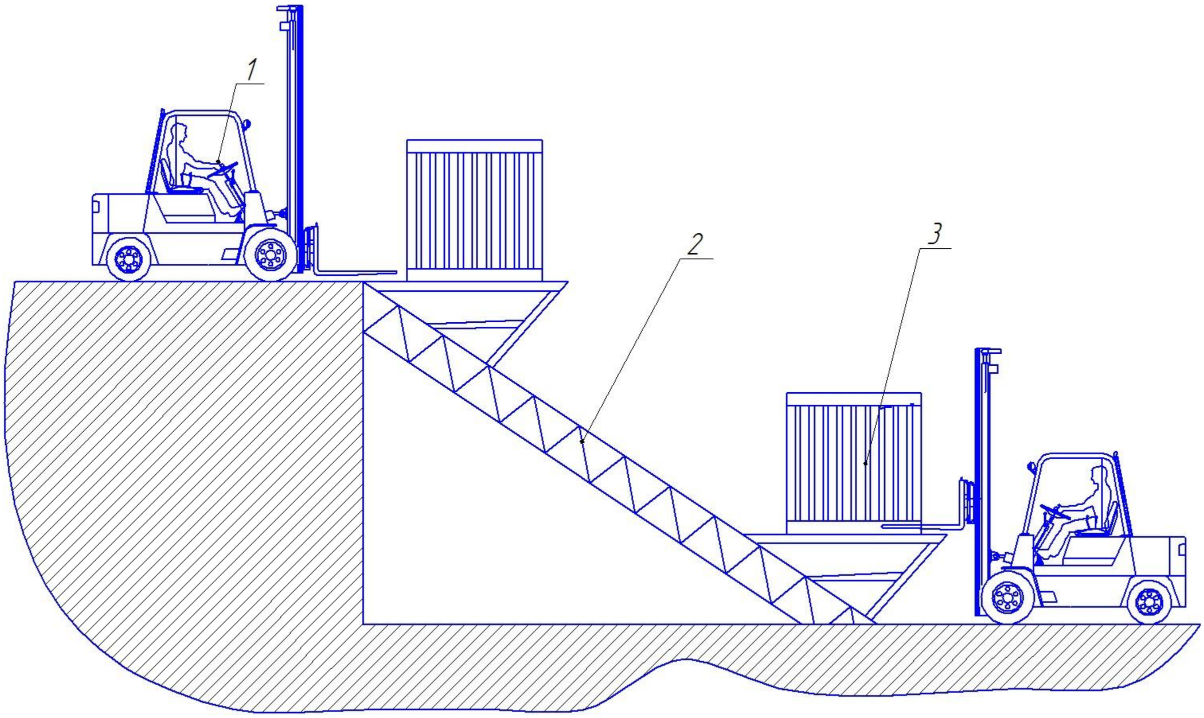


Fig. 5. General view of work using an inclined lift for containers:
1 — loader, 2 — lift, 3 — container

When designing an inclined lift, constructive calculations were carried out, the method of calculating inclined lifts was used; its performance, load capacity, required power, speed of movement of the lifting platform and permissible angles of inclination of the mast were determined. The introduction of the design will solve the problem of improving working conditions; reduce the number of injuries and accidents.

Conclusions. An inclined lift for containers has been developed and recommended for implementation, which makes it possible to perform these works more safely and efficiently, taking into account the specifics of the industry and work. This development can be recommended for use in any agricultural enterprise with similar types of work.

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Improvement of Interaction Mechanism between Oil Refining Enterprises and Contractors

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Introduction. Major projects in the oil refining industry require the involvement of contractors. Cooperation with qualified and responsible contractors can be considered as a competitive advantage, allowing timely delivery of objects with the proper level of quality and safety.

Significant injury rates in contracting organizations operating at oil refining facilities attract attention. This leads to an interest in safety of working conditions in the industry. One of the approaches to solving the problem is to use the occupational health and safety management system in the interactions of the customer and the contractor.

Problem Statement. The objective of this study is to improve the mechanism of rating contractors from the point of view of occupational and industrial safety.

Theoretical Part. The paper uses the official statistical reports on injuries and the data on injuries of employees of contracting organizations at an oil refinery of a large Russian company. A mechanism for rating contractors in this area has been developed. It includes three sections with their own criteria and weight coefficients. The automatically generated and periodically updated rating is proposed to be placed in open access on the website of the Federal Service for Labor and Employment.

Conclusions. The use of the proposed rating will allow customers working in the field of oil refining to reasonably judge the risks generated by the industrial safety system of potential contractors.

Keywords: contractors, oil refining industry, accidents, rating, criteria, information card, interaction between the customer and the contractor.

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Introduction. Companies of the oil refining industry attract contractors during the construction of facilities [1]. In most cases, the customer wants to minimize the expenses. At the same time, many contractors intend to win the tender at all costs. One of the tools is the reduction of the economically sound contract price, dumping. This not only affects the quality and timing of work, but also causes violations, including in the field of industrial safety (IS) and occupational safety (OS) [2]. Thus, inappropriate cost reduction is one of the causes of injuries. Dumping in tenders for the performance of work at hazardous production facilities (HPF)[1], including at oil refineries, creates special risks.

Figure 1 shows data on injuries over the past ten years in the field of petroleum products production[2].

[1] Nguen O. Kak obespechit' bezopasnost' podryadnykh organizatsii [How to ensure the safety of contractors]. Available from: https://journal.ecostandard.ru/ot/opinion/kak-obespechit-bezopasnost-podryadnykh-organizatsiy/ (accessed 14.01.2022). (In Russ)

[2] Rosstat. Information about victims in production according to OKVED code 19.2 — Production of petroleum products in 2010-2020. Working conditions, industrial injuries (by certain types of economic activity). Available from: https://rosstat.gov.ru/working_conditions (accessed 14.01.2022). (In Russ)

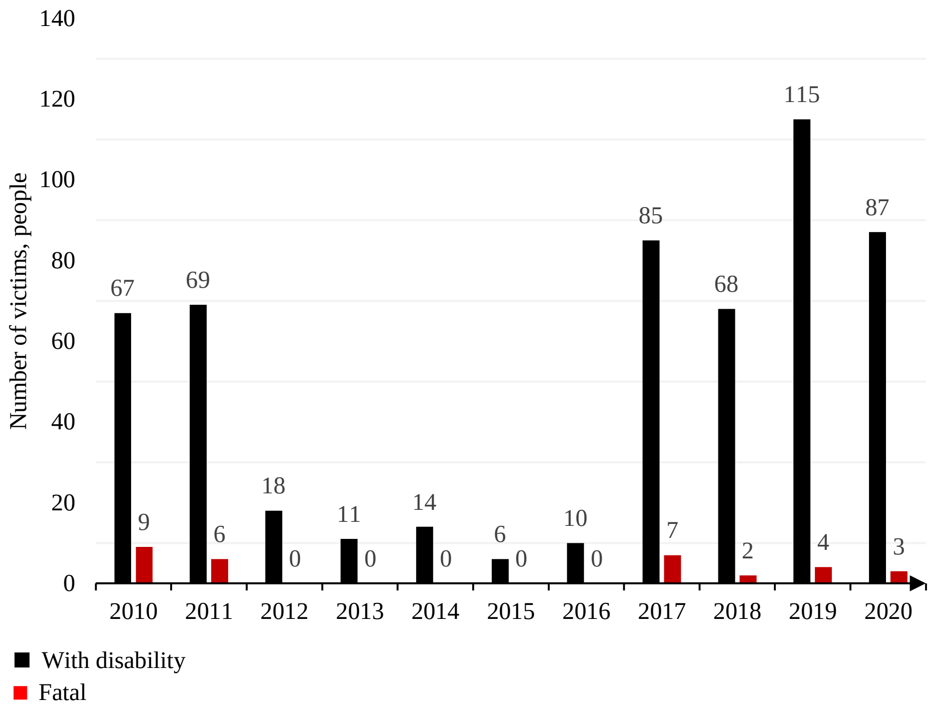

Fig.1. The number of victims in the field of petroleum products production (Russia, 2010-2020).

Figure 2 shows data on injuries of employees of contracting organizations at an oil refinery of a large Russian company in 2019-2021. This indicates problems in the field of safety and occupational safety management.

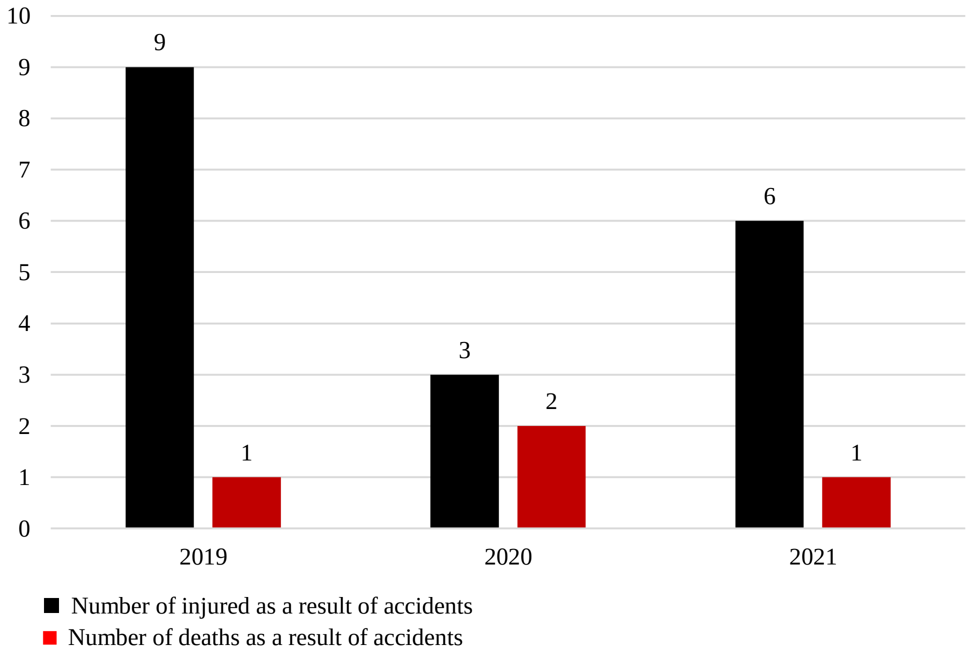

Fig. 2. Injuries and related mortality in contractor organizations of the Russian oil refinery (2019-2021)

Problem Statement. The main task is to improve the mechanism of interaction of oil refining industry enterprises with contractors based on an objective assessment of the contractor's activities in the field of IS and OS.

Theoretical Part. In most cases, contractors engaged in the HPF of the oil refining industry perform four types of work:

– basic (installation, repair, reconstruction, etc.),

– preparatory and commissioning,

– logistics,

– transportation (including personnel transportation) [3].

The main reasons for safety regulations violation:

– failure to take measures to ensure safety of work on the customer's territory;

– use of faulty tools, devices, technical devices, mechanisms and other technical means;

– low qualification of the contractor's personnel;

– staff turnover among the contractor's staff;

– insignificant production experience of the contracting organization[3];

– lack of motivation of the staff to observe safety regulations [4].

The interaction of the customer with the contractor takes place in several stages:

1) preparation of technical specifications,

2) evaluation of contractors' applications,

3) contractor selection,

4) interaction with the contractor,

5) analysis of the work [5].

Let us take a look at the examples of erroneous behavior of the customer at different stages.

1. When preparing the terms of reference, the requirements in the field of IS and OS are described in general terms, which does not reflect in detail the specifics of the work.

2. Evaluating applications, the customer cannot reliably find out how potential contractors comply with the requirements of IS and OS.

3. The winner of the tender in most cases becomes the participant who offers the minimum price [6]. As practice shows, customers do not consider it a weighty criterion to ensure a high level of compliance with the requirements of IS and OS.

4. Certificates of admission and transfer of the object are drawn up with the contractor. In the part of IS and OS, only data on penalties imposed by state organizations are checked. Counterparties do not discuss and, accordingly, do not carry out preventive measures to ensure safety.

5. At the end of the contract, the customer does not analyze the work and, when announcing a new tender, makes the same mistakes.

The situation can be significantly improved if, at the 2nd stage (evaluation of applications), the level of provision by the applicant for IS and OS is taken into account.

As a solution, a rating mechanism is proposed that objectively reflects the situation with IS and OS that has developed in the company participating in the tender [7, 8].

For the corresponding rating of organizations, an assessment is provided in three sections:

1) risk category,

2) local regulatory documents,

3) statistics on IS and OS.

Rating should be carried out on the platform of the Federal Service for Labor and Employment (Rostrud). To participate in the rating, the contractor will have to send an application to Rostrud with a package of required documents. According to section 1, Rostrud assigns points in accordance with the risk category calculated on the basis of a risk-oriented approach[4]. For section 2, documents are analyzed and verified using the developed algorithm. In this case, points are awarded as follows: "present" — 1 point, "absent" — 0. The algorithm receives part of the data from the portals of state authorities.

For section 3, Rostrud analyzes the statistics of data from various departments. The points are summed up; the rating is published on the Rostrud website and is regularly updated. For greater clarity, you can use three colors that will indicate a high, medium and low level of IS and OS provision. The high reliability index of the contractor corresponds to 42-50 points, average — 32-41, low — 0-31 (Table 1).

[3] Simonova N. I., Vikhrov S. V., Ivanov V. V. Povyshenie bezopasnosti rabotnikov podryadnykh organizatsii na osnove upravleniya professional'nymi riskami [Improving the safety of employees of contracting organizations based on occupational risk management]. Klinskii institut okhrany i uslovii truda. Available from: https://www.kiout.ru/info/publish/29114 (accessed 14.01.2022). (In Russ.)

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Table 1

Contractor reliability rating scheme

Place	Contractor's number	Contractor's details	Sum of points	Reliability index
1	1	–	50	**High**
2	2	–	…	
3	3	–	…	
4	4	–	…	
5	5	–	42	
6	6	–	41	**Average**
7	7	–	…	
8	8	–	…	
9	9	–	…	
10	10	–	32	
11	11	–	31	**Low**
12	12	–	…	
13	13	–	…	
14	14	–	…	
15	15	–	0	

The ranking system and evaluation criteria are described below.

1. The risk category of the contractor is determined on the basis of the Rules for Assigning its Activities and (or) Used Production Facilities to a certain risk category or a certain hazard class (category) approved by the decree of the Government of the Russian Federation[5]. The points are assigned as follows: extremely high risk — 1, high — 2, significant — 3, medium — 4, moderate and low — 5.

2. Local regulatory documents of the contractor in the field of IS and OS (for the presence of each report — 1 point, absence — 0).

2.1. The existence of a policy in the field of occupational health and safety, in the field of quality, in the field of environmental protection, in the field of energy, as well as a corporate policy of social responsibility (for the presence of each policy — 1 point, absence — 0).

2.2. Conducting an assessment of working conditions.

2.3. Operational accident reporting system.

2.4. Internal procedure for the organization and investigation of incidents.

2.5. Occupational risk assessment measures.

2.6. Provision (more than enough) of employees with means of individual and collective protection.

2.7. Periodic medical examinations of employees.

2.8. Procedure for informing employees about working conditions at their workplaces, levels of occupational risks, as well as guarantees and compensation for work in harmful and hazardous conditions (monetary incentives and health resort treatment).

2.9. Organization and conduct of additional training in the field of occupational safety.

2.10. Certificates of compliance with the requirements of international standards ISO 9000:2008, ISO 14001:2004 and GOST R ISO 45001-2020.

2.11. Positive reviews, letters of thanks, certificates, etc.

2.12. Procedure for admission to high-risk work.

2.13. Commission for checking employees' knowledge of the requirements of IS and OS.

3. Statistics on IS and OS.

[5] Rules for assigning the activities of legal entities and individual entrepreneurs and (or) production facilities used by them to a certain risk category or a certain hazard class (category).

3.1. Working time on the market (less than 5 years — 0 points, 5-8 — 1, 8-10 — 2, more than 10 — 3).

3.2. Maintaining statistics on injuries at the enterprise: more than 5 years — 3 points, 3-5 years — 2, less than 3 years — 1, no statistics — 0.

3.3. Accident statistics for the last 5 years: without accidents — 3 points, 1-2 cases — 2, 3-4 — 1, 5 or more – 0.

3.4. Data on injured and suffering from occupational diseases employees: without disability — 3 points; with disability (up to 30% of the total number of employees) — 2; with disability (up to 50% of the total number of employees) — 1; with disability (over 50% of the total number of employees) — 0.

3.5. Notices of control and supervisory authorities (Rostrud and Rostechnadzor) for the last three years: not issued — 3 points, less than 3 regulations — 2, 3-6 — 1, more than 6 - 0.

3.6. The amount of administrative fines: 0 — 3 points, up to 100 thousand rubles — 2, 100-300 thousand rubles — 1, more than 300 thousand rubles — 0.

The customer should identify dangerous and harmful production factors in advance, develop occupational risk management measures, procedures for investigating accidents with the contractor's personnel [9]. This is important, given that the contractor does not know about all the risks to the health and safety of its employees on the customer's territory.

An effective interaction between the customer and the contractor involves the creation of an information card for the IS and OS of the enterprise. The document will inform the contractor about the existing and possible hazards and prepare for the work in the appropriate production conditions. The information from such a map should be reflected in the IS and OS section of the terms of reference.

Conclusions. The creation and publication of the rating of contractors in the field of IS and OS will allow customers working in the field of oil refining to reasonably judge the system of industrial safety of potential contractors. The result should be a reduction in the risks of accidents and injuries.

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Practical Implementation of the Concept of Industrial Safety Culture on the Example of the Largest Mining Enterprises

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Introduction. Currently, there are a number of different concepts for reducing occupational injuries. One of the most important mechanisms for reducing the number of potentially dangerous events and injuries at hazardous production facilities is the formation of an industrial safety culture. However, there are currently no studies devoted to the effectiveness of the use of the occupational safety and health management system.
Problem Statement. The objective of this study is to analyze the state of industrial safety culture based on occupational injury statistics.
Theoretical Part. As the basic information, statistical reports on cases of industrial injuries provided by the Kola Mining and Metallurgical Company Joint Stock Company (JSC Kola MMC), a subsidiary of PJSC "MMC "Norilsk Nickel", were used, on the basis of which an analysis of the state of industrial safety culture was carried out.
Conclusions. The results of a detailed analysis of the effectiveness of creating a favorable environment for the formation of industrial safety culture on the example of the concern PJSC "MMC "Norilsk Nickel", which includes the largest mining enterprise in the region, Kola Mining and Metallurgical Company (JSC Kola MMC), indicate the effectiveness of the measures taken.

Keywords: industrial safety culture, potentially hazardous facility, injury rates, occupational safety.

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Introduction. In Russia, the concept of "safety culture" appeared in 1986 in the course of analyzing the causes and consequences of the accident at the Chernobyl nuclear power plant. The IAEA, following the investigation of a man-made accident at the nuclear power plant, named the lack of safety culture among personnel (hereinafter referred to as SC) as one of the main reasons. In accordance with the requirements of Federal Norms and Rules in the field of atomic energy use "General Provisions for Nuclear Power Plant Safety Assurance" (NP-001-15), approved by Order of the Federal Service for Environmental, Technological and Nuclear Supervision of December 17, 2015 No. 522, safety culture is one of the fundamental principles of safety management, which is determined by a set of "characteristics and features of the activities of organizations and the behavior of individuals" [1]. Therefore, these characteristics are of high importance and they need to be paid close attention.

Problem Statement. Currently, key safety requirements based on the concept of safety culture for domestic nuclear power plants are most fully formulated and presented in a number of regulatory documents, of which we highlight the most important ones [2]:

– IAEA Safety Requirements No. SF-1 and SSR-2/2 [3, 4];

– IAEA Safety Guides No. GS-G-3.1, NS-G-2.11 [5, 6];

– IAEA Guidelines on Operating Experience at Nuclear Power Plants [7, 8–14];

– WANO NPP Manual on operating experience at NPP GL 2003-01 [15];

– Company standards of Concern Rosenergoatom JSC Company Standard 1.1.1.04.005.0797-2012 and Company Standard 1.1.1.01.002.0646-2012 [16, 17].

A detailed practical presentation of the SC concept for nuclear power plants is given in sources [18, 19]. It should be noted that according to source [20, paragraph 5], the category of hazardous production facilities (HPF) also includes facilities where "mining, mineral processing, as well as underground operations are carried out". Nowadays, society has come to understand that safety culture goes far beyond its use only on the HPF. It is equally important that the safety culture in everyday life is applicable to each individual and to society as a whole. Vorobyov Yu. L. under the safety culture understands such a state of development of a person, a social group, a society that has a stable need to ensure a safe life and work. In addition, at this stage in society there is a need to reduce the level of hazard [21].

Thus, the SC must be formed in the conditions of a certain state of the environment, to achieve which it is necessary to form a personality. This personality must carry certain specific qualities [22]. In order to form the methodological foundations of a safety culture, it is necessary to identify objects and choose methods of influence.

These methods should allow obtaining the necessary qualities and properties [21]. The state and society are at the top stage of the formation of a safety culture. Social and state values and priorities act as the main system-forming factor of ensuring safety. The leading role in the formation of a safety culture in the relevant areas is assumed by the federal executive authorities and the Ministry of Emergency Situations of Russia [22]. The formation of a culture of life safety is usually divided into three levels: individual, corporate and public-state [22].

The individual level of SC is aimed at forming a worldview of safe activity in all spheres of human activity, recognition and acceptance of the priority of one's own safety, which is inextricably linked with the safety of other people and the environment. The individual level should also include:

– formation of patterns of safe behavior based on the development of natural qualities and acquired human abilities aimed at the possibility of effective prevention and protection from potential hazards;

– formation of the ability to create and maintain safe living conditions in everyday life and in professional activity.

The individual level certainly also affects the issues of protection and preservation of the natural environment, understanding the importance of solving environmental problems and the global nature of negative impacts associated with anthropogenic activities.

At the corporate level, the culture of life safety should be one of the highest values of the organization (company) itself. This is achieved by creating a sense of personal responsibility in matters of safety and psychological commitment to the safety of each employee. This requires control by the administration, organization of the process of hazard identification and risk assessment in the workplace, professional selection, training of personnel in each field of activity in the organization that affects the safety of all the staff members [23]. There should be an understanding in the team that the reduction of production risks, incidents and accidents consists of compliance with labor discipline and clear regulations for safe actions of each employee. Moral and material stimulation of the staff plays an important role in the SC issue.

At the public-state level, the safety culture is implemented through the formation of social consciousness and a certain system of social values (priorities) in the field of life safety aimed at ensuring sustainable development of society. This should be facilitated by: the development of the regulatory legal field; insurance mechanisms for ensuring safety; the development of science and art; public and state incentives; purposeful promotion of safety policy in professional activities, in the social sphere and in everyday life.

In matters of safety culture, propaganda, social advertising and education play an important role, which should be based on the spiritual, moral and patriotic education of a person. The main objective of the study is to evaluate the effectiveness of the occupational safety and health management system, the formation of an industrial safety culture among the employees of PJSC "MMC "Norilsk Nickel".

Theoretical Part. In the process of transforming the corporate safety culture, socially responsible organizations (companies) focus on personnel training in safe techniques and work skills and on reducing occupational injuries. Thus, the leading mining companies have long come to the need for the practical implementation of the safety culture concept in the workplace. Let us have a look at PJSC "MMC "Norilsk Nickel, where the approach to the formation of SC among employees is implemented, and where they strictly observe the rules of industrial safety, actively conduct educational work on labor protection issues and apply innovative solutions. PJSC "MMC "Norilsk Nickel has 17 corporate standards for risk minimization. One of them is the corporate standard for industrial accidents investigation.

The specifics of the ore mining sector is a high degree of mechanization, where a large number of large-sized machines and huge volumes of raw materials are simultaneously moving in the working area of mines, which can cause injuries.

Article 219 of the Labor Code of the Russian Federation states that an employee has the right to refuse to perform work in case of danger to his life and health [24]. The Department of Industrial Safety and Labor Protection of PJSC "MMC "Norilsk Nickel" not only promotes this article of the Labor Code among its staff, but also insists on its application. The practical implementation of the concept of safety culture requires understanding that ensuring safety is not only the control of production risks, but also the introduction of innovative equipment and new organizational and technical measures. For example, in order to optimize the safety of the work area and prevent possible accidents, all mechanized equipment is equipped with video recorders, parking sensors with an "anti-hit" system notifying the driver about people being in the "blind zone".

In order to monitor and record production processes online, video surveillance and electronic gadgets are installed at workplaces. Such innovative solutions make it possible to monitor the compliance with sanitary and hygienic and fire safety standards, industrial safety rules. Video monitoring makes it possible to check the compliance with various protocols and apply administrative methods to influence the situation, and as a result, increase the responsibility of the employee himself and reduce industrial injuries.

At the Zapolyarny Mine of Medvezhy Ruchey LLC, an IT project of a dispatching system has been implemented with the creation of an underground positioning system for personnel and equipment, which is based on the recognition of individual employee tags and micro-cellular communication by personal phone with it.

The SC organizational activities include working with specialists of different levels and profiles, in order to change the attitude, behavior and style of thinking of the employee, the active involvement of each employee. So, in order to conduct mass high-speed testing of the control of knowledge of SC and safety of workers before the start of each shift, a computerized complex using text questions, interactive video files and 3D-computer models was launched in a test mode at the non-state educational establishment "Norilsk Nickel" Corporate University.

In the future, this will help to improve the interaction between the employees, maintain constant contact between the administration and the employee (monitor and respond to requests, as part of feedback), thereby forming a sustainable safety culture at work. This process takes quite a long period of time and requires active involvement of management at different levels. But it is worth it, since the formed corporate SC leads to an improvement in working conditions in organizations and the achievement of high production efficiency.

The implementation of the safety culture concept should be based on an objective comprehensive and systematic approach due to properly structured and integrated processes of the management system in the field of occupational safety and health protection in the company.

We will analyze the effectiveness of the implementation of the stated SC design at the enterprises of PJSC "MMC "Norilsk Nickel", for which we will consider the change in the number of various types of industrial injuries based on data on industrial injuries published in the company's annual statistical reports. As the main analyzed indicators, we take:

– FIFR (Fatal Injury Frequency Rate) —an indicator of the frequency of fatal accidents at work. It is calculated as the number of deaths per 1 million hours worked;

– LTIFR (Lost Time Injury Frequency Rate) — the total working time lost as a result of injuries. It is calculated as the number of cases of loss of working time (LTI) attributed to the total working time worked in a division or organization (Work Hours — WH) for the reporting year and normalized by 1 million people/hour:

$$\text{LTIFR} = \frac{\text{LTI*1000000 (чел/час)}}{\text{WH}},$$

where LTI — the number of victims of accidents at work with disability for 1 working day or more, including fatal accidents;

WH — the total working time worked in the department or in the organization for the reporting year in hours;

– Total number of accidents related to production;

– Number of microtraumas;

– Number of potentially dangerous incidents (the number of recorded violations of labor protection and industrial safety standards).

As the statistical reporting in the field of occupational injuries of the All-Russian monitoring of the social and labor sphere shows, since 2000 there has been a positive trend, which does not fully reflect the real picture in the field of occupational safety for workers of industrial facilities (Table 1) [26].

Table 1

Key injury indicators for PJSC "MMC "Norilsk Nickel" for 2016-2020

Indicator	2016	2017	2018	2019	2020
FIFR (since 2013)	0.11	0.08	0.05	0.09	0.08
LTIFR (since 2013)	0.35	0.44	0.23	0.32	0.29
Total number of insured accidents	56	61	32	44	30
Number of fatal insured accidents	13	9	6	9	8
Number of microtraumas	611	719	842	873	791
Number of potentially dangerous incidents	1976	1845	2139	2074	1963

The analysis of data on occupational injuries of PJSC "MMC "Norilsk Nickel" for the period shows that the percentage of fatal accidents at PJSC "MMC "Norilsk Nickel" varies from 14.8% to 26.7% of the total number of insured accidents.

It should be noted that over the period from 2016 to 2020, there has been a sharp increase in the number of microtraumas (since March 2022, mandatory accounting according to Article 226 of the Labor Code of the Russian Federation, Chapter 36.1, Section X) and potentially dangerous incidents. The increase in the values of the indicators "Number of microtraumas" and "Number of potentially dangerous accidents" is due to the fact that a new corporate standard for the organization of the investigation of all accidents at work has been introduced in the organization [24]. In this situation, explanatory work among employees played an important role, which allowed the staff to form an understanding of the importance of timely informing the administration about potentially dangerous incidents and microtraumas. The new approach of active safety management based on the SC principles has allowed reducing the number of cases with more severe consequences.

Figure 1 shows the histograms of the production safety index for PJSC "MMC "Norilsk Nickel", where the production safety index is the ratio of the number of the identified inconsistencies to the time spent by the audit team to conduct the audit.

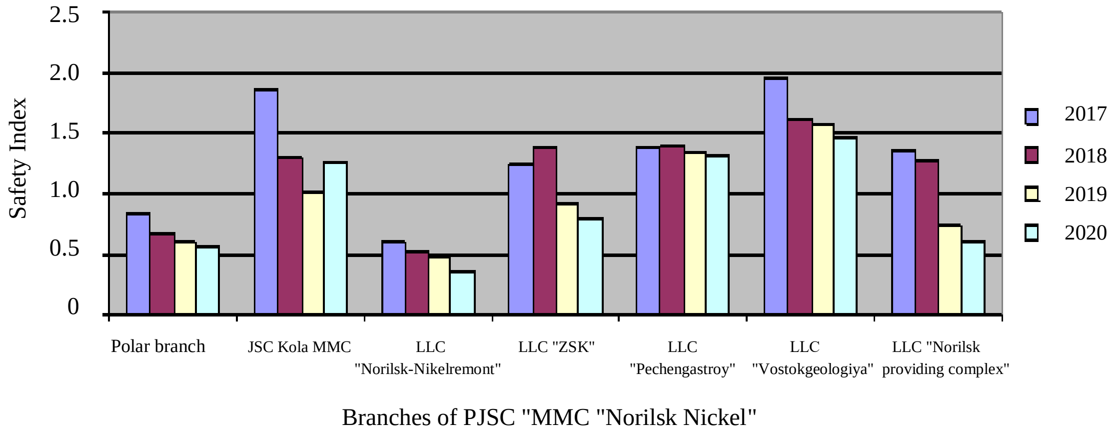

Fig. 1. Annual dynamics of the production safety index on the example of industrial enterprises of PJSC "MMC "Norilsk Nickel"

The presented data allow us to conclude that the majority of branches (the Polar branch, JSC Kola MMC, LLC "Norilsk providing complex", LLC "Vostokgeologiya", LLC "ZSK", LLC "Norilsk-Nikelremont") clearly demonstrate a clear decrease in the level of the production safety index over a four-year period of the analysis from 2017 to 2020, which allows us to talk about the effectiveness of the declared SC concept.

Due to the adoption of targeted programs to reduce production risks and the introduction of corporate standards, it became possible to revise the risk management system of an industrial enterprise itself, increase the SC level and reduce occupational injury rates in 2020. One of the goals of risk management is the compliance with modern international standards in the field of industrial safety, labor protection and the environmental protection.

At the same time, many mining enterprises of the North-Western region of the Russian Federation in the Murmansk region (JSC "Olkon", JSC "Kovdorsky GOK", etc.) still practice a compensation policy within the framework of the occupational safety management system, focused mostly on compensation for damage from accidents. Obviously, such an approach cannot eliminate the systemic causes of accidents of varying severity in the workplace and does not reduce the level of occupational injuries.

The result of the comparative analysis allows us to conclude that the goals, principles and methods of organizing a system for monitoring working conditions and the compliance with regulatory documents in the field of occupational safety in Russia do not correspond to the goals, objectives and functions of the occupational risk management system of employees. The dynamics of changes in injury rates at the micro level is not consistent with changes in the dynamics of labor safety indicators at the macro level. Consequently, it can be concluded that there is insufficient formation of a safety culture at the enterprises of the mining complex of the region. The data provided annually by the specialists of the statistical service of the EU "Eurostat" also indicate the demand for the formation of SC, which allows you to really reduce the level of occupational injuries. For example, in 2012-2017, a decrease in occupational injuries to 25–30% was found in the EU countries [26]. The purpose of the SC formation is to change the general style of behavior and the formation of a certain environment that will reduce production risks and occupational injuries. The formation of a safety culture at the HPF provides for the improvement of the organization's activities in the field of occupational safety, the development of a comprehensive system of training, analysis and control over the state of industrial safety.

When forming a SC, measures to determine the procedure for accessing information about the levels of potential production risks in the organization (company) should be the first priority. The information must be reliable, up-to-date, scientifically based, taking into account the impact of industrial risks on human health and possible damage to it, as well as collateral damage to the environment.

Conclusions. As part of the modern industrial safety strategy, the administration of PJSC "MMC "Norilsk Nickel" has created an effective occupational safety and health management system in accordance with GOST R 55271-2012 [27], focused on safety culture and occupational risk management [28]. However, it should be noted that despite the growth of the safety culture [25], the concept of "zero" fatal injuries by the end of 2020 has not been implemented. Therefore, the management of the enterprise in the field of labor protection needs to learn how to analyze the available statistical information about the causes of accidents not only at the enterprises that are part of PJSC "MMC "Norilsk Nickel", but also at other enterprises of the mining and metallurgical complex.

Despite a well-organized system of internal audit of the state of the occupational safety and industrial safety system, attention should be paid to the quality and timeliness of the reports being prepared, as well as to conduct a risk assessment at the most traumatic workplaces, while it is worth considering all causes of injuries in the context of the general level of safety culture.

When making managerial decisions, it is necessary not only to make timely adjustments to the labor protection policy, but also to determine the means and methods for preventing and eliminating the causes of occupational injuries, as well as to carry out work on the prevention of accidents and occupational diseases [29].

Thus, when making management decisions, the administration of the enterprise must demonstrate its interest in both occupational safety and industrial safety.

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TECHNOSPHERE SAFETY

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Fire Statistics as a Tool for Emergency Prevention

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Introduction. It is known that fires are one of the most large-scale emergencies. It is possible to systematize and formalize their causes only if you take into account the effective analysis of statistical data. The scientific problem lies in the lack of effective mathematical tools and techniques that allow the use of fire statistics as an emergency prevention tool. The solution of this problem is relevant for science and technology. Based on the identified problem, the purpose of this study is formulated, which consists in the analysis of fire statistics and its formalization in predicting emergencies.

Problem Statement. The objective of this study is to analyze the state and causes of fires, as well as to find a tool for their prediction.

Theoretical Part. The methodological tools for solving this problem are the use of multiple regression and correlation analysis methods that allow criticizing and formalizing the available fire statistics. It is established that an acceptable parameter characterizing the reliability and closeness of the connection of empirical data with their mathematical function in relation to the task is the correlation coefficient.

Conclusions. It is proved that an effective tool for predicting fires is the use of linear regression analysis methods. The practical significance of the results obtained for science and technology lies in the possibility of creating digital tools for predicting and preventing emergencies, which will significantly reduce resource costs for eliminating their consequences.

Keywords**:** emergencies, forecasting, forecasting models.

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Introduction. It is known that the occurrence of emergency situations is a multifactorial process that depends on a large number of components. One of the most frequently occurring categories of emergencies is fire. Fires, regardless of the object, lead to significant, and in some cases catastrophic, socio-economic and technological consequences. The work of the State Fire Service of the Ministry of Emergency Situations of Russia is aimed at preventing and minimizing such situations.

Information about fires at industrial and civil facilities is published annually in open sources [1–4]. This statistic is of a precautionary nature, since it allows us to assess the relationship between some of the factors leading to the occurrence of an emergency. Based on the analysis of sources [1–4], it was possible to identify the following factors leading to fires: violation of the rules of operation of electrical equipment and household electrical appliances, malfunction of production equipment, violation of the technological process of production, careless handling of fire, cases when children play with fire, violation of fire safety rules during electric and gas welding works, explosions, spontaneous combustion of substances and materials, malfunction and violation of the rules of operation of furnace heating, arson and other unidentified causes. However, despite the consistency of the information provided, there are no tools to formalize it and build a probabilistic forecast of the development of emergencies in the current conditions. These forecasts are necessary to indicate the significance of preventive measures with the presentation of indicative socio-cultural losses. Based on the above, we believe that the analysis of fire statistics and its formalization is a practically significant, urgent task for both industry and the civilian population.

The aim of the study is the analysis of fire statistics and its formalization in predicting emergencies.

Problem Statement. Representative statistical data on the number of fires are the values published in [1–4]. These materials are reliable and have convergence with the results published in [5–7].

It is established that a promising tool for the formalization of statistical data is the use of multiple regression analysis methods, the essence of which can be summarized using mathematical coefficients that estimate the value of the reliability of the functional approximation of a certain data array. Based on the analysis of [8–10], it has been found that, in relation to the task, the most rational is the use of linear regression models of the form:

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ij} x_i x_j, \qquad (1)$$

where b_0, b_i, b_{ii}, b_j — coefficients characterizing the strength of the influence of free, linear, quadratic and paired interaction effects of the mathematical model; x_i x_j — factors the influence of which on the response under consideration is demonstrated by the mathematical model.

We take the correlation coefficient as the parameter that most representatively characterizes the reliability and closeness of the connection of empirical data with their mathematical function. The practical experience of assessing the reliability of statistical models using the correlation coefficient is presented in [11, 12]. Let us consider the general regularities of the algorithm for using the correlation coefficient. Let us suppose there is a sample n of the values (x_1, y_1), (x_2, y_2),…, (x_n, y_n) with their joint distribution, then the correlation coefficient is determined as:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\{\sum_{i=1}^{n}(x_i - \bar{x})^2\}^{1/2}\{\sum_{i=1}^{n}(y_i - \bar{y})^2\}^{1/2}}. \qquad (2)$$

The correlation coefficient between x and y evaluates an empirical measure of the linear relationship between them. Moreover, $n\bar{x} = \sum x_i$, $n\bar{y} = \sum y_i$. If we put multipliers *1/(n-1)* before all sums, then r_{xy} will allow us to take into account variances and covariance with their sample estimates replaced. However, in relation to the task, we will limit ourselves to the representation of the numerical values of the correlation coefficient relative to –1 and +1, where the value –1 indicates the absence of a connection, and +1 indicates its presence.

After choosing a mathematical tool for formalizing statistics, we will proceed to the analysis of empirical data necessary for the construction of probabilistic forecasts. Table 1 presents data on fires in the Russian Federation for 2015-2020, published in [1].

Table 1

Statistics of fires in the Russian Federation for 2015-2020

Year / Emergency factor	1	2	3	4	5	6	7	8	9	10	11
2015	10228	25456	338	29243	1414	618	54	305	13502	1184	9376
2016	9034	25118	300	25828	1279	552	50	287	13683	1369	8761
2017	8296	24995	318	24255	1100	549	40	273	12912	1450	8056
2018	7698	25868	351	22668	1080	531	47	298	14087	1378	8009
2019	8814	25360	327	25498	1218	563	47	291	13546	1345	8551
2020	8296	24995	318	24255	1100	549	40	273	12912	1450	8056

Note to the table: the emergency occurrence factor: 1 — violation of the rules of operation of electrical equipment and household electrical appliances; 2 — arson; 3 — malfunction of production equipment, violation of the technological process of production; 4 — careless handling of fire; 5 —children play with fire; 6 — violation of fire safety rules during electric and gas welding works; 7 — explosions; 8 — spontaneous combustion of substances and materials; 9 — malfunction and violation of the rules of operation of furnace heating; 10 — unidentified; 11 — other causes.

Theoretical Part. Figure 1 shows the distribution of the number of fires depending on the year.

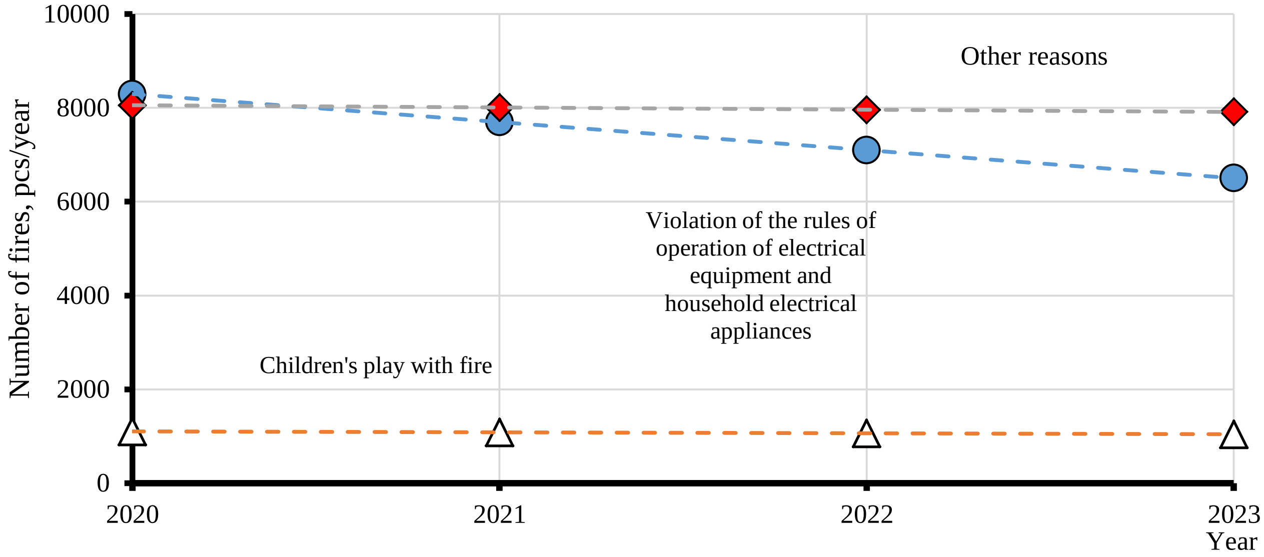

Fig. 1. Distribution of the number of fires depending on the year

The analysis of the presented statistics allowed us to establish that:

– linear model (3) characterizes with a sufficient degree of reliability the annual distribution of the number of fires from violations of the rules of operation of electrical equipment and household electrical appliances at the level of statistical significance $\alpha = 0.05$:

$$y = -598.00x + 1\,216\,256.00, \quad (3)$$

while the correlation coefficient is $r = 1.0$;

– linear model (4) characterizes with a sufficient degree of reliability the annual distribution of the number of fires from other causes at the level of statistical significance $\alpha = 0.05$:

$$y = -47x + 102\,996, \quad (4)$$

while the correlation coefficient is $r = 1.0$;

– linear model (5) characterizes with a sufficient degree of reliability the annual distribution of the number of fires caused by children's play with fire at the level of statistical significance $\alpha = 0.05$:

$$y = -20x + 41\,500, \quad (5)$$

while the correlation coefficient is $r = 1.0$;

– linear model (6) characterizes with a sufficient degree of reliability the annual distribution of the number of fires from malfunction of production equipment, violation of the technological process of production at the level of statistical significance $\alpha = 0.05$:

$$y = 33x - 66\,342, \quad (6)$$

while the correlation coefficient is $r = 1.0$;

– linear model (7) characterizes with a sufficient degree of reliability the annual distribution of the number of fires from careless handling of fire at the level of statistical significance $\alpha = 0.05$:

$$y = -1\,587.00x + 3\,229\,995{,}00, \quad (7)$$

while the correlation coefficient is r = 1.0;

– linear model (8) characterizes with a sufficient degree of reliability the annual distribution of the number of fires from violations of fire safety rules during electric and gas welding operations at the level of statistical significance $\alpha = 0.05$:

$$y = -18x + 36\,909, \quad (8)$$

while the correlation coefficient is $r = 1.0$;

– linear model (9) characterizes with a sufficient degree of reliability the annual distribution of the number of fires during explosions at the level of statistical significance $\alpha = 0.05$:

$$y = 7x - 14\,100, \quad (9)$$

while the correlation coefficient is $r = 1.0$;

– linear model (10) characterizes with a sufficient degree of reliability the annual distribution of the number of spontaneous combustion of substances and materials at the significance level $\alpha = 0.05$:

$$y = 25x - 50\,227, \quad (10)$$

while the correlation coefficient is $r = 1.0$.

– linear model (11) characterizes with a sufficient degree of reliability the annual distribution of the number of fires from malfunction and violation of the rules of operation of furnace heating at the level of statistical significance $\alpha = 0.05$:

$$y = 1\,175.00x - 2\,360\,588.00, \quad (11)$$

while the correlation coefficient is $r = 1.0$.

– linear model (12) characterizes with a sufficient degree of reliability the annual distribution of the number of unidentified fires at the level of statistical significance $\alpha = 0.05$:

$$y = -72x + 146\,890, \quad (12)$$

while the correlation coefficient is $r = 1.0$.

– linear model (13) characterizes with a sufficient degree of reliability the annual distribution of the number of fires due to arson at the significance level $\alpha = 0.05$:

$$y = 873.00x - 1\,738\,465.00, \quad (13)$$

while the correlation coefficient is $r = 1.0$.

Conclusions. From the above we can conclude:

– based on the statistics from 2015 to 2020, it was found that the largest share of fires falls on arson and careless handling of fire;

– it is proved that an effective tool for predicting fires is the use of linear regression analysis methods;

– formalization of fire statistics using linear regression models makes it possible to structure and digitalize the available data arrays in terms of the criteria presented;

– mathematical structuring of statistics from the point of view of the presented criteria allows the use of data arrays in an automated mode.

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TECHNOSPHERE SAFETY

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Situation with Fires and the Effectiveness of Fire Alarm Systems at Shipping Facilities

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Introduction. Shipping, as one of the infrastructural transport communications, is a strategic branch of the economy of the Russian Federation. The timely delivery of goods, equipment, materials and raw materials to consumers depends on the reliability of shipping facilities operation. Therefore, ensuring safety, preventing man-made and natural destructive events are urgent and priority tasks of the owners of such facilities. Among the incidents that can cause significant direct and indirect damage, the most dangerous are fires. In this regard, in order to make management decisions on fire safety, it is necessary to know the situation with fires, to understand their social and economic consequences, to be able to identify possible causes for fires both at construction infrastructure facilities (shipyards, docks, port facilities) and on watercraft. At the same time, an important component in making such decisions is the study of the effectiveness of the fire alarm as a primary element in the general technological systems of fire automation on shipping facilities.

Problem Statement. The objective of the study is to analyze the causes of fires and the operation of fire alarm systems at shipping facilities.

Theoretical Part. Based on statistical data on fires and their consequences for 2017-2021, the social (the number of dead and injured people) and economic (direct material damage) consequences of fires at shipyards, port facilities, watercraft (ships, boats, vessels) and docks are analyzed. Estimates of the effectiveness of fire alarm systems at shipping facilities are given.

Conclusions. The efficiency of fire alarm systems at all shipping facilities is on average at the level of 90%. At the same time, for sea and river vessels, this figure is about 82%, for port facilities it is almost 100%. But despite such a high level of fire alarm systems, it is not possible to avoid social and material consequences of fires. In addition, it should be noted that most fires occur at shipping facilities that are privately owned. At shipyards, port facilities and docks, fires on private property account for 71% of the total number of fires. On private sea and river vessels, the proportion of fires reaches 90%.

Keywords: shipping facilities, fire, statistical data, direct material damage, fire alarm, response efficiency.

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Introduction. The Decree of the President of the Russian Federation approved the foundations of the country's state policy in the field of fire safety [1]. New approaches to the prevention of fires, to the protection of human life and health, and the preservation of material values are formulated. One of the strategic objectives of the state policy is the task of determining fire risks at various hazardous facilities. Taking into account such assessments, measures are taken to form regulatory requirements for the fire safety system of various hazardous facilities. The latter, in particular, include shipping facilities, including buildings (structures) that are part of its infrastructure, as well as motor sea and river vehicles. An important component in fire risk assessment is to determine the effectiveness of the operation of various fire protection systems, in particular fire alarm systems (FAS). The use of efficient and effective FAS at hazardous facilities allows for the timely activation of the warning and evacuation management system, automatic fire extinguishing and smoke removal systems, as well as the transmission of information about the fire to the fire departments. The effective FAS functioning is directly related to the increase in the level of safety of people and a significant reduction in material losses in case of fire. The study of fire risks at shipping facilities makes it possible to determine the amount of fire protection requirements when concluding insurance contracts with the owners of shipping facilities, as well as the corresponding insurance rates and discounts (surcharges) on them.

In this regard, in order to assess the fire risk at shipping facilities, it is necessary to analyze the situation with fires, determine their social (the number of dead and injured people) and economic (direct material damage) consequences, as well as the causes of fires. In addition, it is also necessary to investigate the effectiveness of FAS operation, which is the primary executive element of automated fire protection control systems [2, 3]. Evaluation of the effectiveness of FAS operation at various hazardous facilities is given in publications [4, 5], they present methods and criteria for obtaining these estimates, as well as determining social and economic consequences of fires.

Problem Statement. In [5], the results of a study of the effectiveness of the FAS operation at various hazardous facilities are given. However, this study was conducted without a detailed analysis of the situation with fires at the considered hazardous facilities, as well as without comparing data on FAS operation and the consequences of fires. The features of the infrastructure of the studied hazardous facility are not determined. Based on this, it seems appropriate to assess the effectiveness of FAS functioning, taking into account the current situation with fires and their consequences. Such studies were conducted on the basis of data on shipping facilities.

Theoretical Part and Results. Statistical information of the Federal State Information System "Federal Data Bank "Fires" was used to analyze the situation with fires at shipping facilities [6]. The following objects of navigation are considered: buildings and infrastructure structures (shipyard, dock, port facility), vehicles (sea, river vessel, boat, speedboat). Data for 2017-2021 are taken for analysis. The sample was carried out for each year, and the average values of the studied indicator for a five-year period were determined.

When taking into account the social consequences of fires, the indicator (S) was studied — the number of victims (dead and injured) per one fire (person/unit). The calculation was carried out according to formula:

$$S=\frac{N_{гиб}+N_{трм}}{N_{пож}}, \tag{1}$$

where $N_{пож}$ — the number of fires during the period under consideration on the type of objects under consideration (units);

$N_{гиб}$ — the number of deaths during the period under consideration on the type of objects under consideration (people);

$N_{трм}$ — the number of injured during the period under consideration on the type of objects under consideration (people).

Accordingly, accounting for material losses from fires was carried out using the indicator (M) — direct material damage from fires per fire (million rubles/unit). The calculation of the indicator (M) was carried out according to formula:

$$M = \frac{T_{пож}}{N_{пож}}, \tag{2}$$

where $T_{пож}$ – direct material damage from fires during the period under consideration on the type of objects under consideration (million rubles).

The method, criteria and corresponding calculated dependences for evaluating the FAS effectiveness under various modes of its operation and for the consequences of fires are given in publication [4]. The proposed approach to determining the FAS effectiveness is based on statistical data.

The following results of the analysis of the situation with fires and the assessment of the FAS effectiveness at shipping facilities were obtained (Fig. 1).

As it can be seen in the figure, during the analyzed period, the largest number of fires occurred on vehicles (sea and river vessels). According to the data shown in Fig. 2, the number of victims (dead and injured) in fires per one fire (1) is distributed approximately equally among vehicles and is on average 0.153 people/unit.

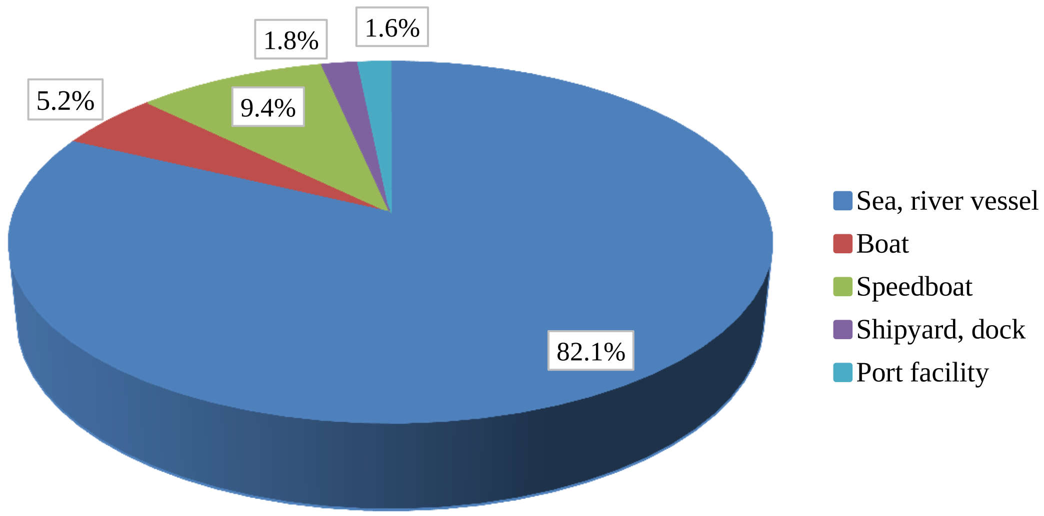

Fig. 1. Distribution of the number of fires by shipping facilities
(percentage of the total number)

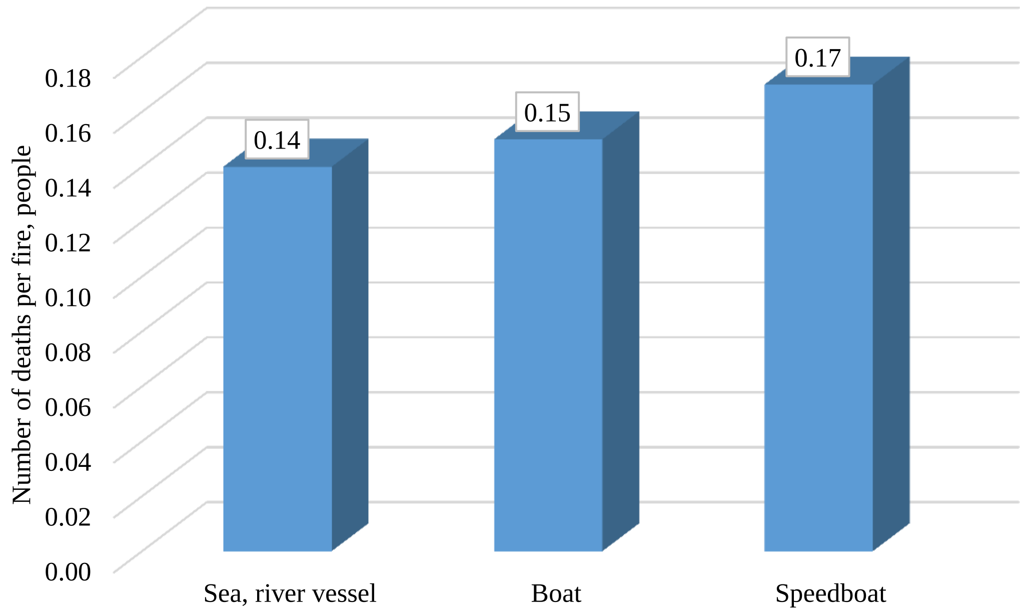

Fig. 2. Number of victims (dead and injured) per one fire on shipping vehicles, people/unit

The greatest direct material damage per one fire was registered on sea and river vessels (Fig. 3). On average, it amounts to 1,295 thousand rubles per fire. Accordingly, the least direct damage was registered on fires in port facilities — 39 thousand rubles per fire, at shipyards and docks — 9 thousand rubles per one fire.

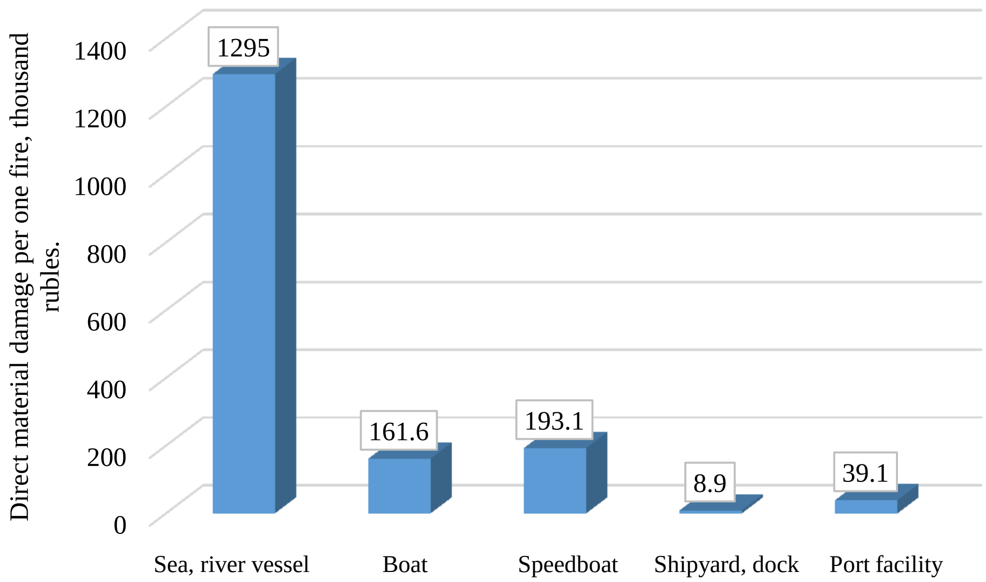

Fig. 3. Direct material damage per one fire, thousand rubles/unit

The study of the causes of fires at shipping facilities gave the following results. Figure 4 shows data on fires that occurred on sea and river vessels, their causes. Most of the fires occurred due to violations of fire safety rules during electric and gas welding and fire works (24.5%), due to careless handling of fire (19%) and violations of the rules of installation and operation (VRIO) of electrical equipment (17.9%).

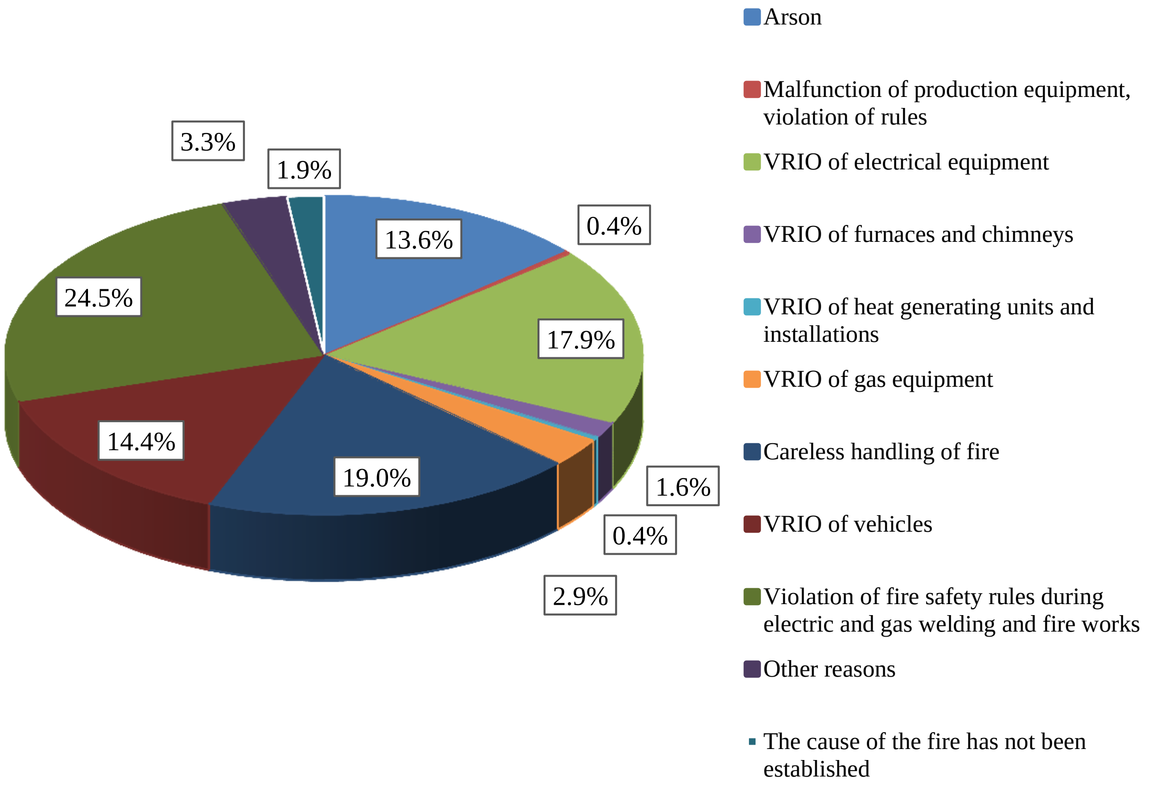

Fig. 4. Number of fires that occurred on sea and river vessels, their causes, %

As it can be seen in Fig. 5, in the fires that occurred on sea and river vessels, most people die due to careless handling of fire (41.2%), as well as for an unknown reason (29.4%). Injuries to people in fires most often occur due to violations of the operation of vehicles (29.6%) and the operation of electrical equipment (16.7%) (Fig. 6). The greatest direct damage from fires on sea and river vessels was caused due to violations of the rules of operation and installation of electrical equipment — more than 81% of the total direct damage (fig. 7).

The analysis of fires at port facilities, shipyards and docks showed the following: most fires occurred due to violations of the rules of operation and installation of electrical equipment (35.3%) and due to careless handling of fire (23.5%) (Fig. 8).

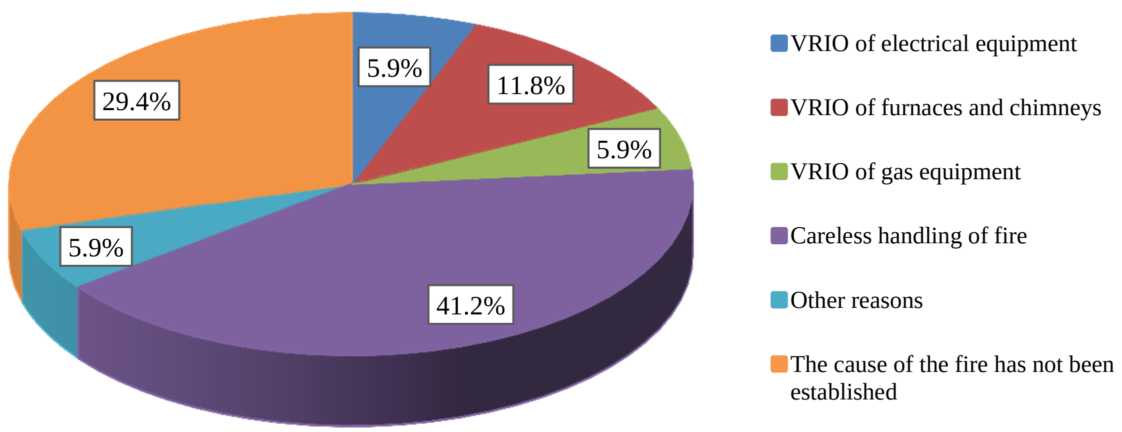

Fig. 5. Number of deaths in fires that occurred on sea and river vessels, their causes, %

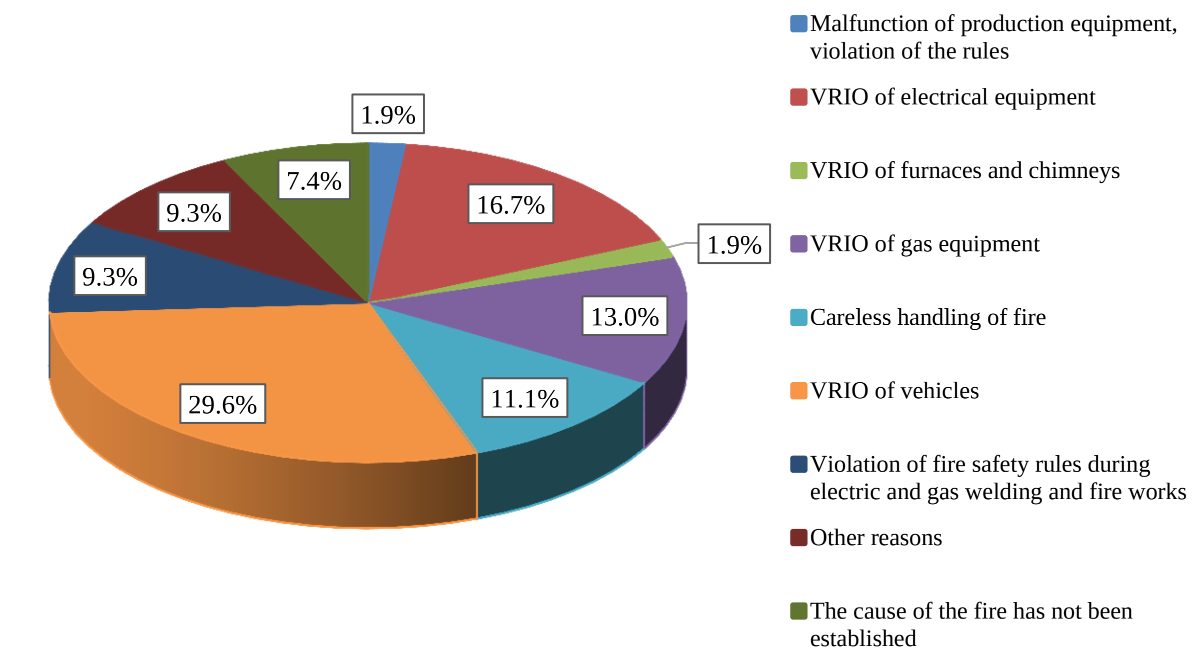

Fig. 6. Number of injured people in fires that occurred on sea and river vessels, their causes, %

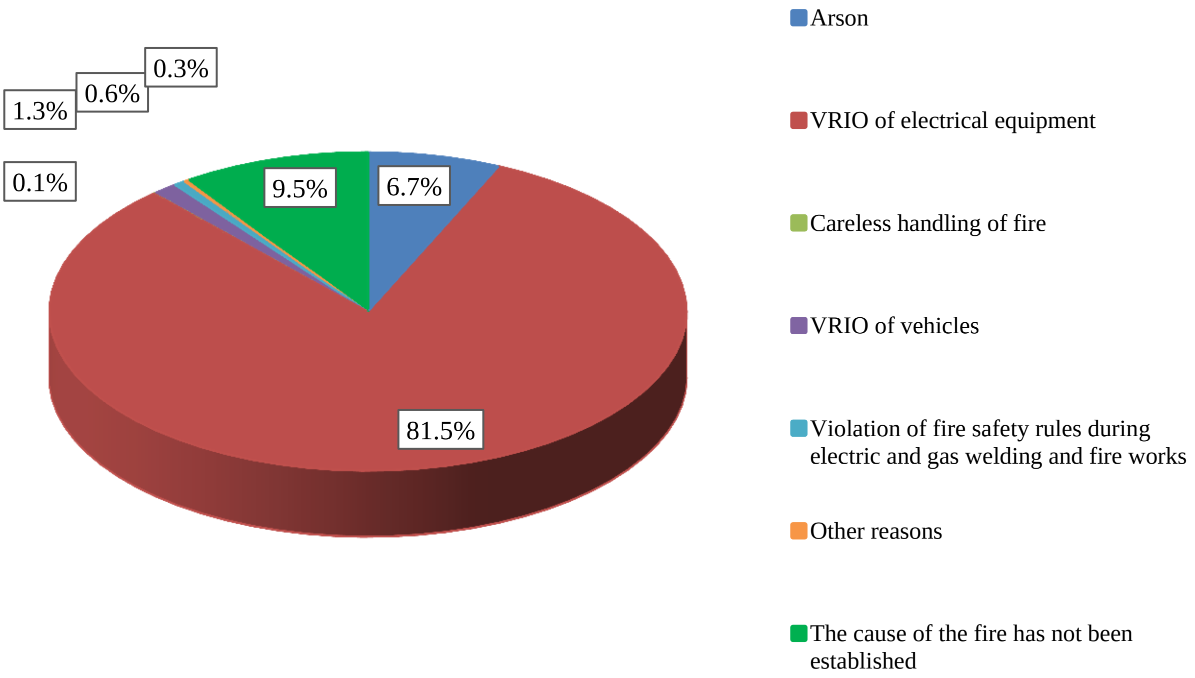

Fig. 7. Direct damage from fires that occurred on sea and river vessels, their causes, %

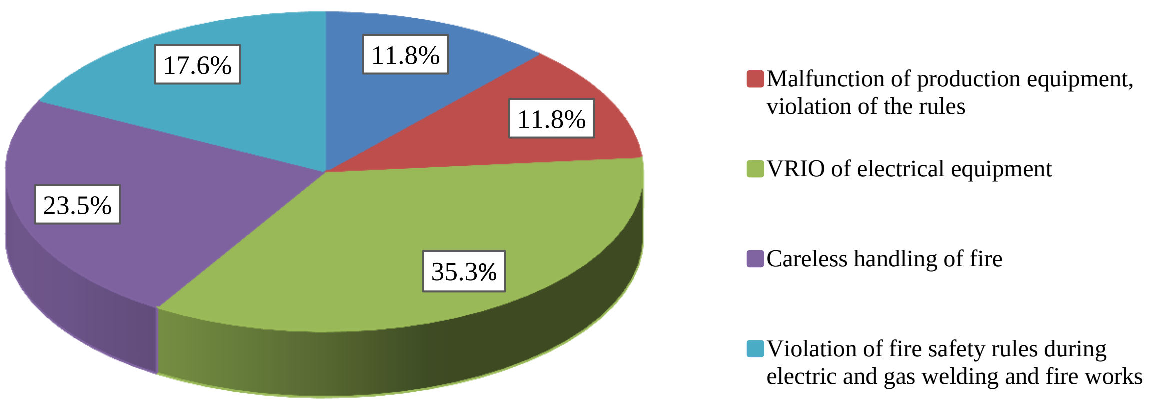

Fig. 8. Number of fires that occurred at port facilities, shipyards and docks, their causes, %

For insurance purposes, the studies of the situation with fires from the point of view of the forms of ownership of shipping facilities are of considerable interest. The interest in this kind of research is due to the fact that since 2016, a risk-oriented approach to the system of organizing inspections by supervisory authorities began to be introduced in the country, when the rigor of the implementation of control measures began to depend on the risk category of the subjects being checked, which undoubtedly affected the fulfillment of the requirements for ensuring fire safety of hazardous facilities by owners [7].

The analysis of the situation with fires and their consequences at shipping facilities by form of ownership (federal, property of a subject of the Russian Federation, municipal, private) showed the following. Figure 9 shows that most fires occur at shipping facilities that are privately owned. At port facilities, shipyards and docks, fires on private property account for 71% of the total number of fires, and on sea and river vessels the share of such fires reaches 90%.

On sea and river vessels, the biggest amount of deaths per fire is observed on objects of a different (non-private) form of ownership — 0.08 people per one fire with 0.03 people per one fire for private property objects (Fig. 10). The number of injured per one fire on private property is 0.11 people with 0.13 people per one fire at objects of other types of property.

Figure 11 shows data on the distribution of the material consequences of fires at shipping facilities, depending on the types of their property. The greatest direct damage per one fire on sea and river vessels was caused to objects of private property, while on objects of other forms of ownership this damage is 17 times less.

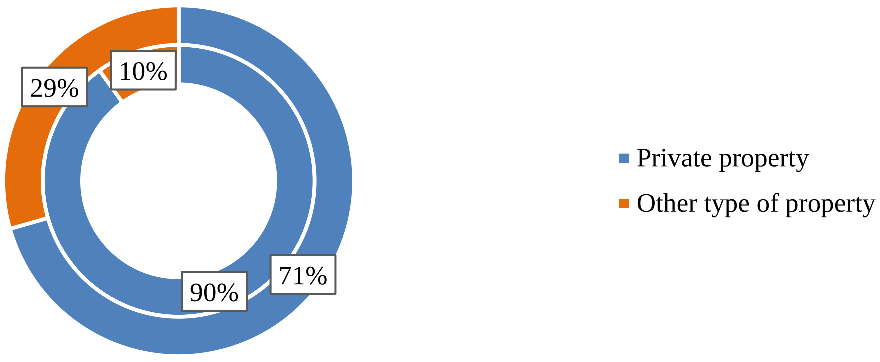

Fig. 9. Number of fires that occurred at port facilities, shipyards and docks (external diagram), on sea and river vessels (internal diagram), depending on the form of their ownership

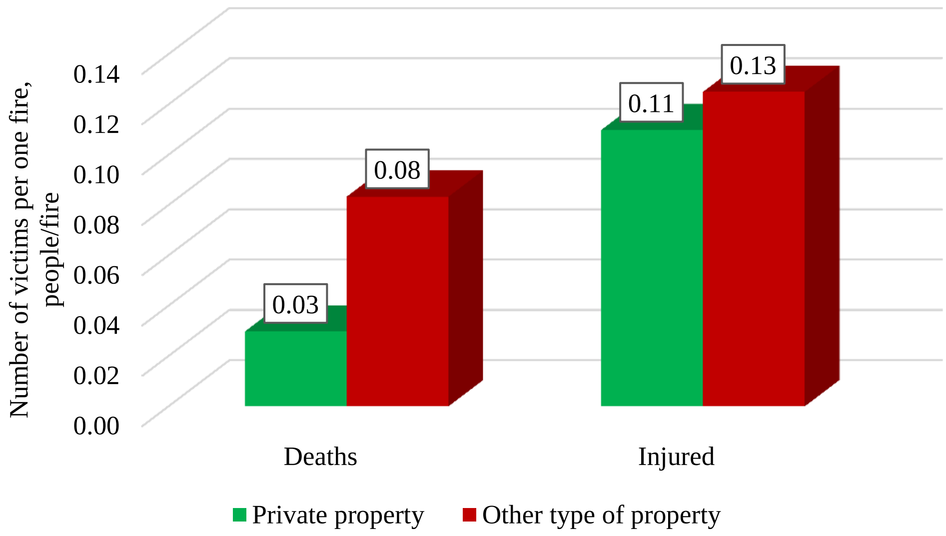

Fig. 10. Number of dead and injured people in fires that occurred on sea and river vessels, depending on the form of ownership

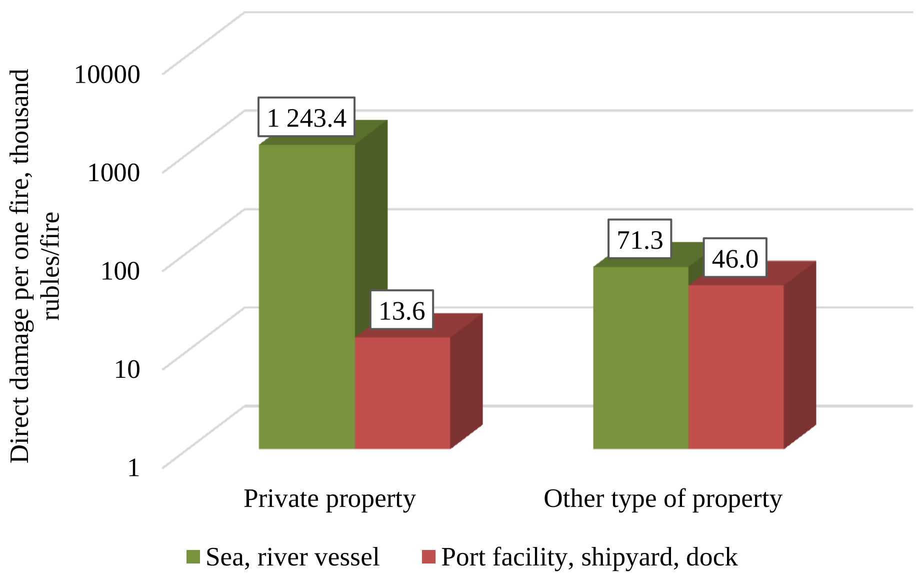

Fig. 11. Direct damage per one fire at shipping facilities, depending on their form of ownership
(logarithmic scale is used along the ordinate axis)

As noted earlier, the basis for the construction of fire protection systems are FAS — primary actuating elements, on the reliability of which the activation of other fire automation systems designed to ensure the safety of people and the performance of fire extinguishing functions depends. The results of the assessments of the effectiveness of FAS response at shipping facilities are shown in Fig. 12. As it can be seen in the diagram, the efficiency of FAS operation on sea and river vessels is 82%, at port facilities it reaches 100%.

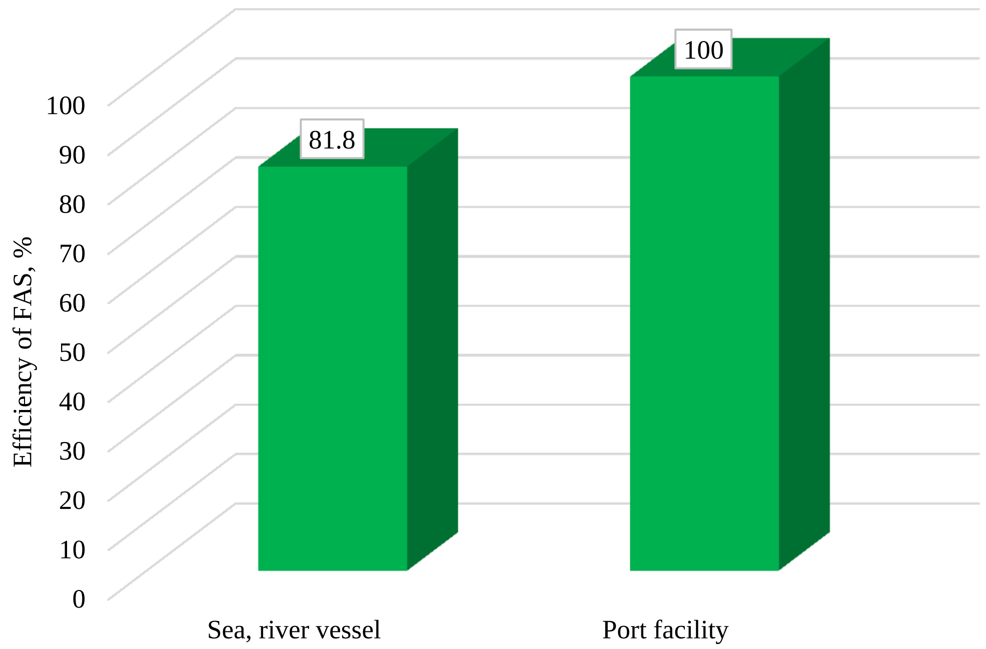

Fig. 12. Efficiency of FAS response at shipping facilities

It should be noted that with such a high level of FAS operation, according to the analysis of the consequences of fires (Fig. 3, 5-7), significant social and material losses from fires at shipping facilities are still observed, which may be due to the low efficiency of other automatic fire protection systems, such as the warning and evacuation management system, smoke ventilation, automatic firefighting system.

Conclusions. The study of statistical data on fires and their consequences at shipping facilities for 2017-2021 showed the following. During this time, fires occurred mainly on sea and river vessels. The greatest direct material damage from fires (1,295 thousand rubles per fire) was also registered on sea and river vessels.

The main causes of fires that occurred on sea and river vessels are violation of fire safety rules during electric and gas welding and fire works (24.5% of the total number of fires), careless handling of fire (19%) and violation of the rules of operation and installation of electrical equipment (17.9%). At shipyards, port facilities and docks, fires most often occurred due to violations of the rules for the installation and operation of electrical equipment (35.3%), careless handling of fire (23.5%). There is a fairly high level of arson at these shipbuilding facilities (11.8%).

The study also showed that most fires occur at shipping facilities that are privately owned. On private property in port facilities, shipyards and docks, they account for 71% of the total number of fires, and on sea and river vessels the share of such fires reaches 90%.

The effectiveness of FAS operation at shipping facilities is significant. For sea and river vessels, it is almost 82%, for port facilities — 100%. Nevertheless, with such a high level of operation of fire alarm systems, social and material consequences of fires are noted.

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A. A. Poroshin — formulation of the concept of the article, goals and objectives of the study, calculations, preparation of the text, formulation of the conclusions; V. L. Zdorov — preparation of literary sources, conducting and analyzing the calculations results; N. V. Semenenko — preparation of the text and source data for calculations; I. V. Volkov — preparation of literary sources and source data for calculations.

MACHINE BUILDING

Original article
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On the Control of Metal Strength of Structural Elements of Floating Cranes

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Introduction. The article is devoted to the issues of non-destructive testing of mechanical characteristics of metal structural elements of cranes. The reliability of cranes largely determines their safety. The main manifestations of operational failures of floating cranes are analyzed on the example of the UMK-2 crane. It is noted that 27% of failures occur due to the loss of metal strength of their structural elements. Determination of the causes of such failures is possible by conducting non-destructive testing of the mechanical characteristics of the failing structural elements metal. The paper provides the principle of one of the methods of non-destructive strength control based on the impact insertion of a conical indenter into the metal under study with the subsequent analysis of the intermediate parameters of this insertion. The results of measurements of the mechanical characteristics of the metal deformed during the operation of the boom strut of a floating crane are given. The current measured values of the mechanical characteristics of the metal obtained at various points of the strut are processed for compliance with the three-parameter Weibull law to obtain the minimum values of these characteristics. As a result of such processing, it is stated that the minimum values of yield strength, strength and elongation are lower than those claimed by the design documentation for the crane. This may be one of the reasons for the deformation of the structural element during operation.

Problem Statement. The application of the method of non-destructive testing of the metal of the boom strut is considered in order to assess the mechanical characteristics and establish possible causes of its deformation when analyzing the operational reliability of the crane.

Theoretical Part. When identifying possible causes of deformation or destruction of steel elements of crane structures, it is proposed to apply a method of non-destructive testing of mechanical characteristics based on the impact insertion of a conical indenter into the test surface. Further, it is proposed to process the obtained sample of values of the measured characteristic for compliance with the three-parameter Weibull law to estimate the shift parameter or the minimum value of this characteristic.

Conclusions. The minimum values of the tensile strength, yield strength and relative elongation of the metal of the deformed boom strut of the UMK-2 crane were obtained on the basis of the application of the method of non-destructive testing with subsequent approximation of statistical information by the Weibull distribution law. A conclusion was made about the reduced strength characteristics of the metal relative to those stated in the technical documentation, which could cause deformation of the crane boom element.

Keywords: reliability, mechanical characteristics, lifting cranes, non-destructive testing.

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Introduction. Lifting cranes are high-risk industrial objects, as a result of which particularly high requirements are imposed on their safety, largely determined by operational reliability. From the analysis of works devoted to the reliability of floating cranes [1-3], it follows that 22% of failures are caused by violation of rules of operation, 27% of failures are associated with a leak in the hydraulic system and 51% — the share of failures due to the physical and mechanical properties of the metal of structural elements, of which: 24 % — failures due to wear (rope, support rollers, bearing assemblies, elements of the rope-and-pulley system, brakes, etc.) and 27% of failures are because of the loss of metal strength (destruction of the base metal and welds, as well as excessive deformation of the elements of the boom metal structure, contact deformation of support rollers and hooks, etc.).

At the end of 2021, the staff of the Department of "Operation of Transport Systems and Logistics" of the Don State Technical University conducted a survey of the technical condition of the UMK-2 floating crane, which was used during the dismantling of the old and the construction of the new Voroshilov Bridge over the Don River in Rostov-on-Don, as well as on other water bodies where the work could be performed by a floating crane. When examining deformed metal structures, according to [4], it is necessary to pay attention to defects that lead to a decrease in the load-bearing capacity of the structure, namely: deviation from the straightness of the struts of truss elements, twisting of structures, misalignment of the joints of boom sections, towers, the presence of residual deflections of span beams, etc.

As a result of the survey, it was revealed that the main failures that occurred with the crane occurred on the boom, namely for the following reasons: deformation of the metal of the boom strut, cracks in the middle part of the boom root section, cracks in the welds of the boom root section, cracks in the boom hook pulley block, defects in the boom strut part that were deformed, as a result, the crane was decommissioned.

Problem Statement. The task was to investigate the cause of damage to the metal elements of the boom structure. In general, there are three possible reasons: insufficiently accurate calculation of the boom design, non-compliance of the strength characteristics of the steel grade used with the required ones, in accordance with the design documentation, and overloads during operation of the machine. The first reason is unlikely, since the UMK-2 crane was designed in the mid-70s in Soviet times and, as a rule, with a sufficient material reliability coefficient. In order to establish the second and third reasons, it was necessary to determine the strength capabilities of the applied metal of the damaged boom element. Determination of the mechanical characteristics of the metal of the operating machine is possible only by non-destructive testing.

Theoretical Part. Most methods of non-destructive testing — ultrasonic, radiation, magnetic, eddy-current, acoustic emission, etc. provide an opportunity for qualitative, rather than quantitative assessment of the condition of the object under study. Therefore, it was decided to apply the method of non-destructive testing of metal developed at the Don State Technical University to obtain quantitative values of its mechanical characteristics. The method is implemented in the "Durability" system [5–8], consisting of an electronic unit including an analog-to-digital converter L-CARDE 14-440, an impact mechanism and a laptop with a software [9].

It is based on a modified Rockwell hardness estimation method, while static indentation is replaced by dynamic indentation with impact energy of 0.16 J, and the angle at the top of the indenter is replaced from 120° to 90° for more informative measurement results. Impact indentation is carried out due to a spring mechanism in which the striker strikes the indenter holder. At the same time, the electronic unit records intermediate parameters: depth, maximum and minimum speeds, acceleration and deceleration of the indenter during its introduction into the material and transfers them into the mechanical properties of the material.

The creation of the system was preceded by long-term studies of the mechanical characteristics of a large number of steel grades of various strength classes. As a result, correlations of intermediate characteristics of the material image, standard yield strength and elongation strength and hardness were obtained.

After filling the electronic unit with these dependencies, it is enough to measure the newly studied material and the values of standard mechanical characteristics are displayed on the screen of a laptop with the developed software. The system has a total dispersion caused by the spread of properties in the metal and the measurement error. The limit values of the error of one measurement by the system are ± 4%.

Discussion. The metal of the deformed boom element was subjected to control. The surface was cleaned from paint and corrosion to pure metal, 10 to 15 measurements were made at various points of the element with a one-time registration of mechanical characteristics.

In accordance with [10, 11], the distribution of random values of mechanical characteristics obtained as a result of measurements is best described by the three-parameter Weibull law.

$$F(X) = 1 - \exp[-((X - C)/A)^B], \qquad C < X < \infty,$$

where X — the magnitude of the mechanical property; A, B, C — the scale, shape and shear parameters.

The most important parameter of this distribution is the shear parameter or the minimum value of the mechanical characteristic.

For this reason, the data obtained at different points of the element were combined into one array (Table 1) and then processed using a program for compliance with the three-parameter Weibull law.

Table 1

Array of data subject to processing

Measured current values of mechanical characteristics, ranked in ascending order of strength characteristics		
Values of yield strength $\sigma_т$, MPa	Values of tensile strength $\sigma_в$, MPa	Values of elongation δ_5, %
301	431	26
303	437	25
310	439	24
312	445	24
313	451	24
314	453	23
315	455	23
316	457	23
317	458	23
318	459	23
322	460	22
322	460	22
322	460	22
323	461	22
326	461	22
329	461	22
335	462	22
338	462	22

Measured current values of mechanical characteristics, ranked in ascending order of strength characteristics		
Values of yield strength $\sigma_т$, MPa	Values of tensile strength $\sigma_в$, MPa	Values of elongation δ_5, %
340	464	21
342	468	21
345	470	21
347	471	21
348	479	20
353	482	20
351	492	19
352	499	19

Approximation of the empirical values of yield strength $\sigma_т$, tensile strength σв and elongation δ_5 was carried out using the methods of moments and maximum likelihood with the fitting criterion ω^2 (Table 2).

Table 2

Approximation of empirical values of mechanical characteristics

Mechanical characteristics	Distribution parameter			Approximation method	Value of the fitting criterion ω^2
	Scale parameter "A"	Shape parameter "B"	Shear parameter (minimum characteristic value) "C"		
$\sigma_т$	47.29	2.89	285 (MPa)	Moments	0.49
	37.41	2.32	294 (MPa)	Maximum likelihood	0.51
σв	38.91	2.44	427 (MPa)	Moments	0.77
	43.22	2.76	423 (MPa)	Maximum likelihood	0.73
δ_5	5.45	3.17	17,3 (%)	Moments	0.51
	5.14	3.04	17,6 (%)	Maximum likelihood	0.52

According to the test results, the following was found. When assessing the yield strength, the criterion of the value ω^2 is slightly lower according to the method of moments, which corresponds to a minimum value of 285 MPa. When assessing the tensile strength, the value of the criterion ω^2 is lower according to the maximum likelihood method and this corresponds to a minimum value of 423 MPa. When assessing the relative elongation, the value of the criterion ω^2 is slightly lower according to the method of moments and this corresponds to a minimum value of 17.3%.

Let us note that in all cases the shape parameter "B" had a value exceeding 2, which also indicates the consistency of the distribution of the current measured values with the Weibull distribution.

Conclusions. The design documentation for the manufacture of the UMK-2 lifting crane specifies the material of the boom strut steel 09G2S. This steel must have mechanical characteristics values not lower than: $\sigma_т$ = 345 MPa; $\sigma_в$ = 490; δ_5 = 21%. That is, the minimum values of the mechanical characteristics of the tested material are inferior to the declared corresponding values for 09GS steel in yield strength by 17%, in tensile strength — by 14% and in elongation — by 18%, which may be one of the reasons for the plastic deformation of the boom strut.

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N. L. Vernesi — statement of the problem, development of the concept of the article; V. A. Rusakov — critical analysis of the literature, collection and processing of statistical data.

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Ballistic Resistance of Steel with the Structure of a Natural Ferrite-Martensitic Composite

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Introduction. For steel armor materials, it is important to reduce the thickness and, consequently, the metal consumption of the protective structure. The previously developed class of materials with the structure of a natural ferrite-martensite composite (NFMC) has characteristics that favor the inhibition of crack development under impact loads and has prospects as an armor material.

Problem Statement. The purpose of this work is to evaluate the possibility of using NFMC materials for armor protection devices based on the results of ballistic resistance tests under a high-power concentrated impact (a projectile flying at a hyper-high speed).

Theoretical Part. The study of ballistic resistance was carried out on samples of steel 14G2 processed according to various modes. The samples had the shape of plates and a square grid on the surface. Simulation tests of the impact of heat-strengthened dowels from a powder-actuated tool and firing of military small arms at the testing site from an SVD sniper rifle and an AK-74 assault rifle with machine loading ammunition were carried out. The results of simulation tests showed a clear advantage of steel with the NFMC structure. The comparison of the results of firing with military small arms has showed that the ballistic resistance of steel with the NFMC structure depends on the ratio of the volume fractions of ferrite and martensite, which cause different thicknesses of the ductile and strong components of the composite. The highest resistance was observed for a sample with an NFMC structure processed according to the regime: quenching 730°C and tempering 180°C.

Conclusions. Steels treated for the NFMC structure can provide effective protection for military personnel with a lower material consumption of armor protection devices, which is due to a special method of braking destruction during a high-power local impact. Thus, the practical application of the developed class of natural composite materials seems promising for obtaining an armor plate with a thinner thickness, which helps to reduce the weight of combat vehicles, increase their mobility and reduce fuel consumption.

Keywords*:* steel, composite, ferrite, martensite, fracture, crack resistance, heat treatment.

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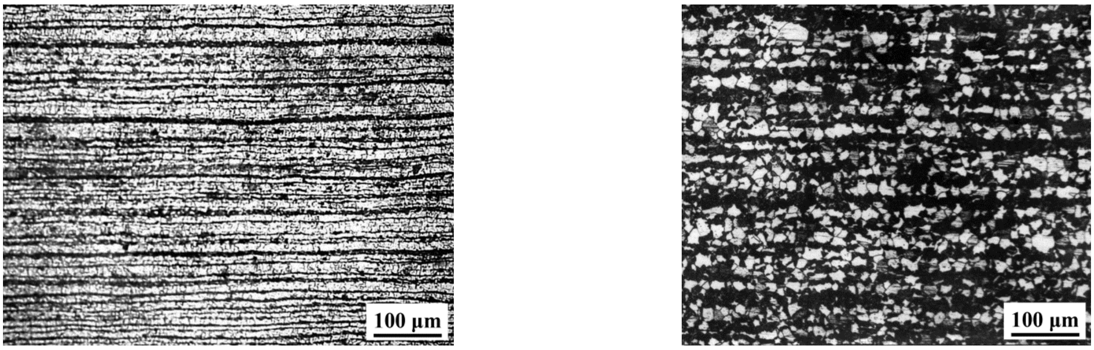
Introduction. Currently, hot-rolled steel sheet is used as a protective material for infantry fighting vehicles, amphibious assault vehicles and armored personnel carriers, which has a ferrite-perlite structure in the condition of supply. Armor made of a sheet with such a structure does not provide the necessary protection in case of high-power local collisions and is easily penetrated by a hand grenade launcher, underbarrel grenade launcher and even small arms with high destructive power — a 7.62 caliber SVD sniper rifle with an armor-piercing cartridge with a tungsten core, a new 12.7 caliber sniper rifle. An increase in the thickness of the armor plate (more than 25 mm) seriously impairs the mobility of combat vehicles on the battlefield, increases the weight and fuel consumption.

In [1, 2], the possibility of creating steel with the structure of a natural ferrite-martensitic composite (NFMC) based on the use of hypoeutectic steels with a lineage ferrite-pearlite structure is substantiated. The hardening of such steel from the intercritical temperature range (A1–A3) makes it possible to obtain a layered structure of a ferrite-martensitic composite (Fig. 1). The study of the properties of the steels under consideration under static tension and shock bending gives reason to believe that such a structure is characterized by a special mechanism of inhibition of crack development [2].



a) *b)*

Fig. 1. Structure of steel grade 14G2: *a* — lineage ferrite-pearlite;
b — after quenching from a temperature of 760 °C

Problem Statement. The aim of this work is to determine the possibility of using steels with the NFMC structure for armor protection devices (individual protection of military personnel, protection of armored personnel carriers, infantry fighting vehicles, armored assault vehicles from damage when firing small arms and grenade launchers). Based on the formulated goal, the task is to obtain data on the ballistic resistance of a steel target with an NFMC structure under a concentrated high-power impact by a projectile flying at hyper-high speed (> 800 m/s).

Research Methodology. The study of ballistic resistance was carried out on 14G2 steel samples processed according to the modes presented in Table 1. The test samples were plates with a size of 150×44×7mm. The surface of the samples was sanded, and then a grid was applied to the surface with a 3 mm pitch in two mutually perpendicular directions.

Table 1

Characteristics of 14G2 steel samples for ballistic resistance tests

Sample No.	Processing mode	Volume ratio ferrite/martensite after quenching	Hardness, HRCэ
1	delivery state	–	< 20
2	quenching 860°C + tempering 400 °C	0/100	38÷40
3	quenching 730°C + tempering 180 °C	65/35	42÷44
4	quenching 760°C + tempering 180 °C	45/55	42÷44

Preliminary simulation tests of target plates were carried out against heat-strengthened dowels (4.5 mm in diameter) using a PTs-8 powder-actuated tool (D-4 muzzle sleeves of maximum power were used).

Further, for the purpose of testing when exposed to a high-power impact (a projectile flying at hyper-high speed), a shooting with combat small arms was carried out at the training ground of one of the military units of the Ministry of Defense of the Russian Federation, stationed in the immediate vicinity of Rostov-on-Don. From the available arsenal, two types of domestic small arms with the highest destructive power were selected: a 7.62 mm SVD sniper rifle and a 5.45 mm AK-74 automatic rifle. Both types were provided with factory-loaded ammunition of two types: a light cartridge with a steel core and an armor-piercing one with a tungsten core in copper shells. The shooting was from a distance of 45 meters, allowing for targeted fire, given the lack of special measures at the training ground to prevent ricochet. The increase in the firing distance, compared with the recommended standards for bullet resistance of a distance of 10 meters, should not significantly affect it when comparing this parameter with reference data, given the high speed of bullets and the assessment of the nature of the damage for these types of weapons: SVD rifle — cartridge 7.62 mm with a bullet LPS and B-32, weight — 9.6-10.4 g, speed — 800÷840 m/s; AK-47 assault rifle — 5.45 mm with a PS and BS bullet, weight — 3.5÷3.8 g, speed — 890÷910 m/s.

Research Results and Discussion. The results of preliminary simulation tests when exposed to the powder-actuated tool dowel are illustrated in Fig. 2. It can be seen that in the state of delivery (Fig. 2 *a*), the plate is shot through to the stop of the dowel. After complete quenching and tempering at a temperature of 400 °C, the plate is shot through, but the dowel does not reach the stop (Fig. 2 *b*). A shot into a plate with an NFMC structure (sample No. 4, Table 1) leads to the destruction of the dowel without significant damage to the plate (Fig. 2 *c*).

a) *b)* *c)*

Fig. 2. Results of simulation tests of target plates made of 14G2 steel when firing a powder-actuated tool:
a — sample No. 1; *b* — sample No. 2; *c* — sample No. 4

The simulation tests carried out showed a clear advantage of steel with the NFMC structure. However, the energy of the dowel delivered to it by the powder charge of the muzzle shell is less than the energy of a concentrated impact of a projectile flying at hyper-high speed. Therefore, samples No. 3 and No. 4 with the NFMC structure (Table 1) were shot using combat small arms. A comparison of the test results showed that the ballistic resistance of steel with the NFMC structure depends on the ratio of the volume fractions of ferrite and martensite, which determine the different thickness of the viscous and durable component of the composite. Thus, sample No. 4 with a small plate thickness of viscous ferrite and low carbon content in the martensitic phase is almost always pierced through with armor-piercing bullets of 7.62 mm and 5.45 mm caliber (Fig. 3). At the same time, sample No. 3, which also has the NFMC structure, but a large thickness of the ferritic phase and the strength of the martensitic layer, is not penetrated through when fired with armor-piercing bullets. The bullet penetrates the metal by 2-3 mm and ricochets. At the same time, a small crack forms on the back side (Fig. 4).

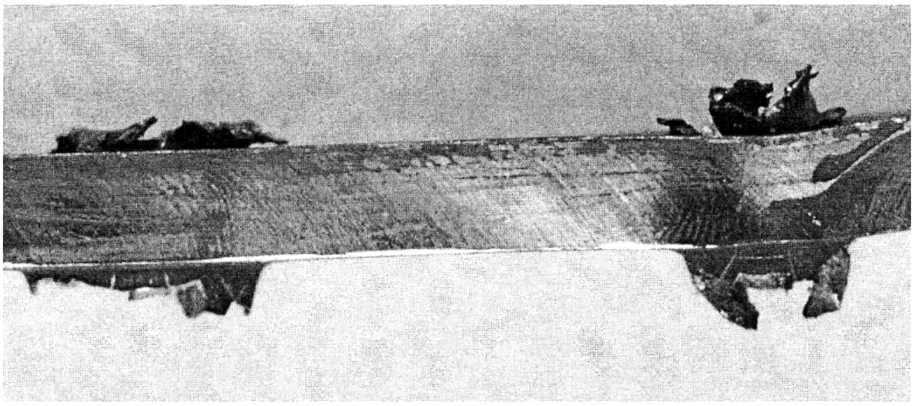
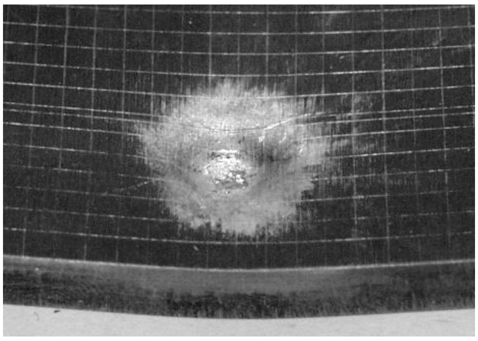
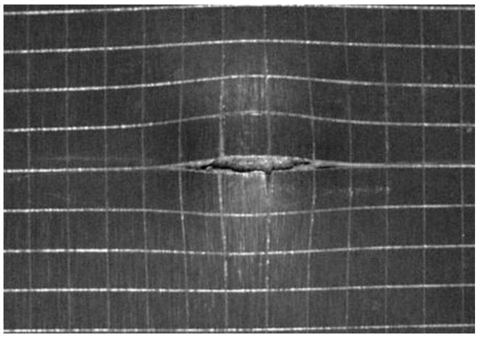


Fig. 3. Through penetration by armor-piercing bullets of 7.62 and 5.45 mm caliber. The remains of the copper shell in the holes. Processing mode: quenching at 760 °C and tempering at 180 °C



a)



b)

Fig. 4. Absence of penetration, the result of ricocheting: *a* — view from the side of the impact; *b* — view from the back side. Processing mode: quenching from 730 °C and tempering 180 °C

According to the data from the website of the Bureau of Scientific and Technical Information "Equipment for Special Services" [3], the widely used armored steel SPS-43 [4], manufactured according to TU (technical conditions) 0902-005-31041642-95 when fired from an SVD rifle with an LPS cartridge requires a two-layer sheet with a total thickness of 8.3 mm. The natural composite material created by the authors fulfills the task of bullet resistance when hit by this type of weapon with a thickness of 7 mm.

The high ballistic resistance of steel with the NFMC structure is due to a special mechanism of crack movement in steel, the structure of which is organized in the form of parallel layers of ductile, viscous ferrite and durable martensite. When a crack approaches the martensite-ferrite surface, a stratification in ferrite occurs on it (or near it) due to the presence of tensile stresses parallel to the crack plane [5-9]. In this case, part of the energy supplied from the outside is spent on the formation of the stratification surface in ferrite. The exit of the crack into the stratification leads to a change in its trajectory, a stop in its progress and relaxation of tensile stresses at its apex. To destroy the next layer of the composite (martensitic layer), a new crack must form in it, but already under conditions close to the uniaxial stress state, which will require additional energy.

In [6], the condition for the occurrence of the stratification is written as follows:

$$\sigma \geq \frac{K_D}{\varphi\sqrt{c}}, \quad (1)$$

where K_D — a certain critical value of the stress intensity coefficient; $\varphi = \frac{3+\nu}{1+\nu}$ — constant (ν — Poison's ratio); c — thickness of the breakable layer (martensite).

At the same time, it is shown that for the occurrence of stratification before the martensitic crack (before the destruction of the next breakable layer), it is necessary that $\sigma_p < \sigma < \sigma_{0,2}$ and, consequently, the condition for the occurrence of stratification inhibiting the destruction of the layered sample has the form:

$$K_D \leq \varphi\sqrt{\frac{E\sigma_{0,2}h\upsilon}{\alpha\beta}}, \quad (2)$$

where h — thickness of the plastic layer (ferrite); υ — thickness of the plastic layer (ferrite); $\alpha = \frac{1+\nu}{3-\nu}$ and $\beta = \frac{4}{3-\nu}$ — constants.

The value $K_D \sim \sqrt{\gamma_s n_s^2}$, then condition (2) will take the following form:

$$\sqrt{\gamma_s n_s^2} < \theta\sqrt{a\upsilon}\,, \qquad (3)$$

where γ_s — the ultimate shear strain in the ferrite plate; n_s — the shear hardening index; $\theta = \varphi\sqrt{\frac{E}{\alpha\beta}}$ — constant.

If the thickness of the plastic ferrite layer in a multilayer sample is sufficient to fulfill condition (3), then stratification is formed that prevents further advancement of the main crack. For steel grade 14G2 at values γ_s approximately 1000 MPa and $n_s = 0{,}43$ the stratification occurs at a ratio of $\frac{h}{c} \geq 3$. This ratio occurs when quenching steel grade 14G2 with temperatures from 730 °C to 740 °C of the intercritical interval [10, 11].

Conclusions. Thus, the results of determining the ballistic resistance of steel with the NFMC structure showed that with less material consumption, it could provide effective protection for military personnel, which is due to a special method of braking destruction during a local high-power impact. The practical application of the developed class of natural composite materials seems promising for obtaining armor plate with a smaller thickness, which helps to reduce the weight of combat vehicles, increase their mobility and reduce fuel consumption.

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Manufacturing Technology of Sliding Bearings from Ferro-Graphite Compositions

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Introduction. The development of modern technology imposes increasingly stringent requirements on materials operating under conditions of high pressures, speeds, deformations and aggressive media. The use of powder metallurgy methods in the creation of new materials makes it possible to provide a rational combination of production technology, structural and performance characteristics. Powder steels used in mechanical engineering are of great interest among the materials obtained by powder metallurgy. The article explores the possibility of manufacturing porous bearings made of iron powder for fan motors of domestic air conditioners instead of porous bearings made of bronze graphite.

Problem Statement. To ensure long-term operation of fan motors from metal powders, it is necessary to create porous bearings without alloying additives with the required mechanical properties. This requires a series of experimental work to determine the dependences of mechanical and technological properties on the sintering temperature, compacting pressure and the porosity of samples.

Theoretical Part. As a theoretical description, the use of a mold with an additional draining gap, which provides high bearing density at low compacting pressure, is analyzed. The effect of compacting pressure on the strength of sliding bearings under mechanical deformations depending on the sintering temperature is also considered.

Conclusions. It was established in the work that during the sintering of sliding bearings at a temperature of 800-1100°C, a significant charge carburization occurs due to the decomposition of zinc stearate in closed pores. As a result, a ferrite-pearlite structure is formed, due to which the bearings are well calibrated and have high wear resistance when paired with a steel shaft. Optimum sintering modes and compacting pressures were selected, which showed high reliability and durability of the products obtained from pure iron powder.

***Keywords*:** sliding bearings, sintering, carbon, alloys, strength limits, yield strength, elongation, microstructure of the surface.

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Introduction. Porous sliding bearings for fan motors of household air conditioners must withstand long-term operation (15-20 thousand hours) in the following conditions: the sliding speed is 0.5 m/s; the specific load is 2 kg/cm^2; the Permavik composition is used as a lubricant, which creates a constant oil exchange in the friction unit for the entire period of operation of the electric motor (it is filled with a special cavity of the end shield). These bearings are made of non-ferrous metal powders: sprayed bronze powder of the BRO10S brand —1.5–583.8%, electrolytic copper powder of the PMS brand — 1–36% and tin powder of the PO-1 brand with a very low packed density — 4%. In addition, 1.2% graphite powder GC-3 and 1.5% zinc stearate are added to the charge. It should be noted that these materials are quite expensive. In addition, they require precise compliance with special conditions during sintering (temperature regime, composition of the gas medium in the furnace).

Currently, many varieties of porous bearings made of ferro-graphite, ferro-copper-graphite and other materials with various properties have been developed, successfully replacing porous bearings made of bronze-graphite. But these materials are less technologically advanced, since they require much more effort when pressing and calibrating bearings, which affects the performance and durability of an expensive press tool [1–4].

The **Aim** of the work is to study the technological modes of obtaining porous bearings from iron powder without alloying additives (especially carbon), as well as the development of a mold for pressing blanks with an additional drainage gap.

Problem Statement. To ensure the continuous operation of fan motors made of metal powders, it is necessary to create porous bearings without alloying additives with the required mechanical properties. To do this, it is necessary to conduct a series of experimental works to determine the dependences of mechanical and technological properties on the sintering temperature, compacting pressure and porosity of samples.

Theoretical Part. The material for the study was selected. It was iron powder of the brand PZHRV 2.200.226 with a packed density of 2.5 g/cm^3, to which 1.5% zinc stearate was added. As it is known [5-8], the increased content of zinc stearate in the charge creates additional interconnecting pores during sintering. Mixing was carried out in a V-shaped industrial mixer for 30 minutes. Cold pressing was carried out on a mechanical press with a nominal force of 50 kN according to the principle of effective removal of air from the charge through additional drainage gaps with which the mold was equipped. Due to this, at low compacting pressures (100–200MPa), a high bearing density was achieved. The possibility of additional drainage during pressing was provided by splitting the lower punch into two parts (punch in punch) (Fig. 1).

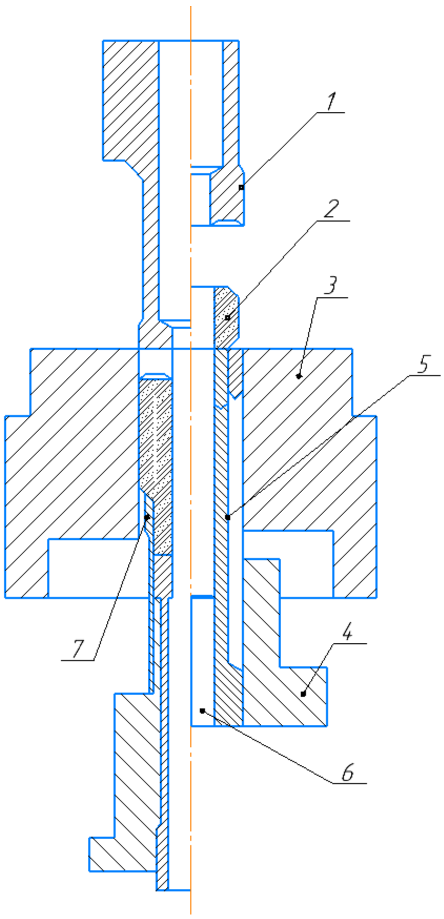


Fig. 1. Mold with additional drainage gap:1 — upper punch; 2 — porous bearing; 3 — matrix; 4 — outer lower punch; 5 — inner lower punch; 6 — rod; 7— additional drainage gap

The pressings were sintered in a continuous furnace in an endothermic gas medium (dew point temperature from +5 to +8 °C) at temperatures of 800-1100 °C for 30 minutes. Sintered bearings were calibrated with a special tool. Then the bearings were vacuum impregnated with XM-6 oil for 40 minutes at a residual pressure of 1.33 Pa.

The influence of the sintering temperature on the open porosity and oil absorption of bearings pressed at a pressure of 100-250 MPa was studied (Fig. 2). The open porosity of bearings pressed at 250 MPa decreases slightly with an increase in the sintering temperature. The difference in porosity between bearings sintered at 800 °C and 1100 °C is 1%. The porosity of bearings pressed under a pressure of 100–200MPa varies slightly with the sintering temperature. Similarly, the oil content also changes (Fig. 2b).

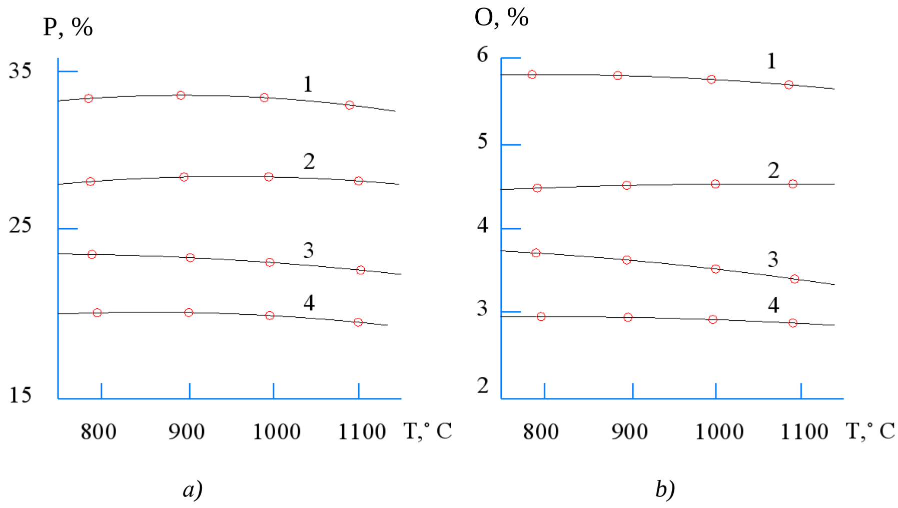
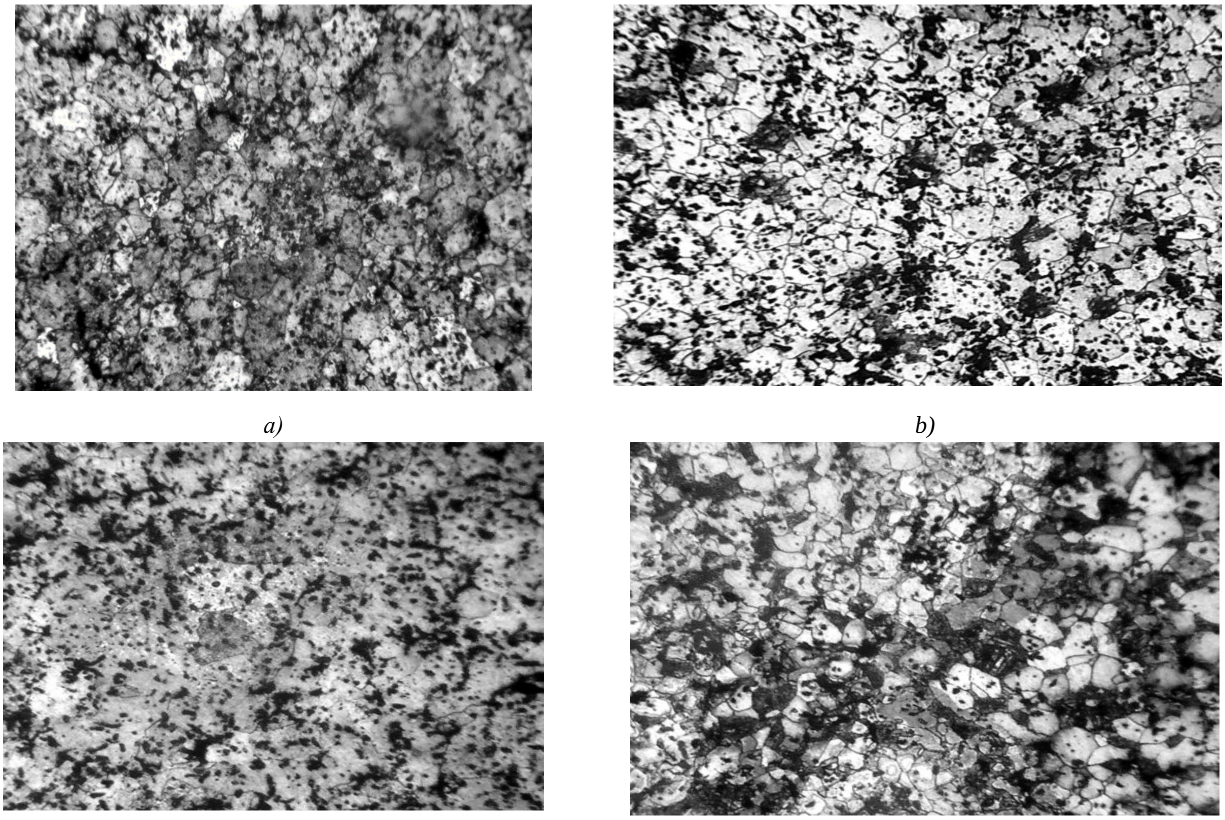


Fig. 2. The results of the study of the influence of sintering temperature on: *a* — open porosity; *b* — oil absorption: 1, 2, 3, 4 — compacting pressure 100, 150, 200 and 250 MPa

With an increase in the sintering temperature, the microstructure of bearings compressed under a pressure of 150 Pa undergoes significant changes (Fig. 3). The number of small pores is reduced, and large ones become isolated. At low sintering temperatures, zinc stearate closes in closed pores, decomposes and carburizes the sintered material. In the structure of bearings sintered at 800 °C, there is much more perlite, although carbon was not introduced into the charge (Fig. 3), but with an increase in the sintering temperature, the amount of perlite decreases at 1100 °C, it is barely noticeable along the boundaries of the pores. The appearance of perlite along the boundaries of the pores confirms the fact of carburization of the material through the pores due to the decomposition of zinc stearate and exposure to a gaseous medium. During sintering, a ferritoperlite structure is formed in all considered temperature ranges.

The calibrating possibility for bearings depends on the sintering temperature (Fig. 4 *b*) to varying degrees, depending on the compacting pressure. If for bearings pressed at a pressure of 100 MPa, with an increase in sintering temperature, a smaller calibration force is required, then for bearings pressed at 150-250 MPa, a larger one is needed. Bearing sizes change during calibration mainly due to the reduction of large pores. With an increase in the compacting pressure, the porosity of the pressings decreases, the interparticle contact of the powders increases, the number of dislocations and distortions in their structure increases. Therefore, with an increase in the sintering temperature, the material of these bearings acquires greater strength and is difficult to calibrate [9–12].



a) *b)* *c)* *d)*

Fig. 3. Microstructure of porous bearings (×400) at the following sintering temperatures: *a* — 800 °C; *b* — 900 °C; *c* — 1000 °C; *d* — 1100 °C

An increase in the sintering temperature generally leads to an increase in the strength of bearings under radial compression both after sintering and after calibration (Table 1). A sharp increase in bearing strength is observed in all cases at 900 °C. Apparently, it is at elevated temperatures that the sublimation and evaporation of zinc stearate, secondary degassing of closed pores and pore channels increases. Further, diffusion processes are activated, complete recrystallization occurs: small pores disappear, and large ones are isolated. All this contributes to increasing the strength of bearings after sintering and calibration [2, 3, 10].

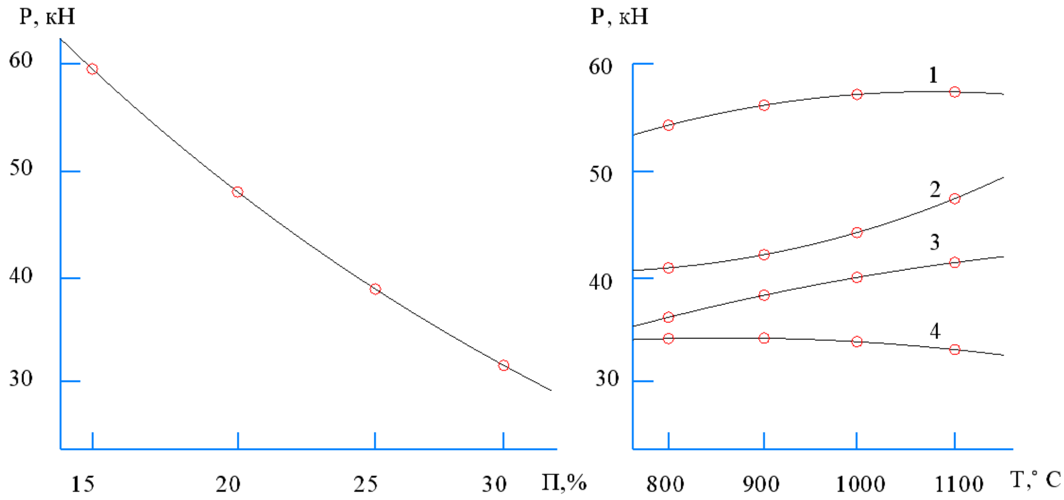
Table 1

Influence of compacting pressure and sintering temperature on the strength of bearings under radial compression

Compacting pressure P, MPa	Sintering temperature,°C	Radial compressive strength, 1×10^3 N	
		Before calibration	After calibration
1.0	800	55	62.3
	900	70	92
	1000	189	263
	1100	252	309.3
1.5	800	90	122
	900	150	178
	1000	222	288
	1100	357	417
2.0	800	221	288

Compacting pressure P, MPa	Sintering temperature,°C	Radial compressive strength, 1×10^3 N	
		Before calibration	After calibration
	900	200	250
	1000	357	457
	1100	479	547
2.5	800	160	212
	900	223	300
	1000	473	624
	1100	576	683

In accordance with the requirements of the technical specifications, bearings after sintering and calibration must have radial compression strength of at least 2.5 kN. According to Table 1, the strength of all bearings sintered at 800 °C is below this norm, regardless of the compacting pressure. Among the bearings sintered at 900 °C, those that are pressed at 200 and 250 MPa have strength of more than 2.5 kN after the calibration. Bearings pressed under a pressure of 100 MPa reach the required level of strength at a sintering temperature of 1100 °C, while other bearings — at 1000 °C.



a) *b)*

Fig. 4. Dependence of the calibration force on:
a — porosity (T = 1100 ° C, τ = 30 min); *b* — sintering temperature

With an increase in the compacting pressure in the range of 100-250 MPa, the density of both sintered and calibrated bearings increases, and the open porosity and oil absorption decreases (Fig. 5). At the same time, the nature of all curves remains unchanged.

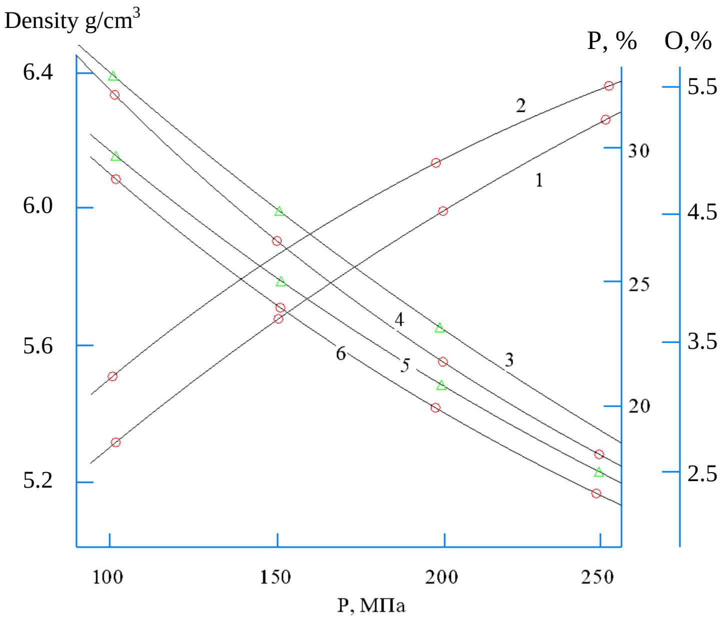


Fig. 5. Dependence of density (curves 1, 2), open porosity (curves 3, 4) and oil absorption (curves 5, 6) on compacting pressure

It should be noted that bearings pressed under a pressure of 100 MPa with high porosity and oil absorption have low strength, as a result of which they are destroyed before sintering (during installation, transportation). And bearings pressed at 250 MPa have high strength and relatively low porosity, although these parameters meet the requirements for bearings made of graphitized bronze.

Thus, the most technologically advanced bearings should be bearings pressed at a pressure of 100-150 MPa and sintered at a temperature of 1100 °C. But at all stages of their manufacture, the best properties were possessed by bearings pressed at 150 MPa and sintered at 1100 °C in an endothermic gas environment. Out of these bearings, 20 pieces of asynchronous single-phase capacitor motors of the ABT 71-115U2 type used in domestic air conditioner were assembled. Wear tests were carried out on an LG W07LC mock-up air conditioner. In accordance with the requirements of the technical specifications for this type of air conditioners, the test period was also selected — 1.5 thousand hours.

The test results have showed high reliability and durability of bearings made of pure iron powder by pressing at a pressure of 150 MPa, sintering at a temperature of 1100 °C with a calibration force of 3.8 kN and vacuum impregnation with XM-6 oil. Their wear was about the same as that of graphitized bronze bearings — about 7 microns per diameter.

Conclusions. The sintering temperature of bearings in the range of 800-1100 °C does not have a significant effect on their open porosity, oil absorption and calibrating ability.

When sintering bearings, a ferritoperlite structure is formed, which provides high wear resistance of bearings when working with a shaft made of automatic steel A-30 [13–16].

Bearings pressed under a pressure of 200 and 250 MPa and sintered at temperatures of 800-1100 °C require significant calibration effort, which dramatically reduces the durability of the press tool. Low strength of these bearings after sintering at 800-900 °C is not a factor that reduces the force of their calibration, it is inversely proportional to the porosity of the bearing.

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Technological Methods of Boriding Products from Stainless Alloys Operating in Aggressive Conditions

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Introduction. The durability and other performance characteristics of machine parts are largely determined by physical and chemical state of thin surface layers. The localization of hardening processes in these layers serves as a significant reserve for increasing the service life of parts while reducing the cost of manufacturing materials. One of the most progressive directions of strengthening technology is the application of protective coatings on the working surfaces of machine parts.

The article investigates the process of sintering compacts from steel PKh23N18 in boron carbide powder in containers with a fusible seal. It has been established that sintering in such containers provides high mechanical characteristics of sintered steel with good reproducibility of the sintering process.

Problem Statement. To improve corrosion resistance, as well as to improve wear resistance of friction surfaces of products and machine parts operating in aggressive environments, it is necessary to choose a rational technology of chemical-thermal treatment that allows increasing the mechanical and technological properties of products.

Theoretical Part. As a theoretical description, the use of various methods of stainless steel boriding is analyzed, and the dependences of changes in the mechanical and technological properties of samples on various boriding schemes and methods for obtaining samples are considered.

Conclusions. It was established in the work that the increase in strength of samples subjected to boriding sintering in an autonomous gaseous medium occurred due to the absence of oxidation and deep saturation with boron (volumetric strengthening) through the vapor-gas phase. The use of container technology makes it possible not only to simplify the technology, but also to ensure the preservation of material properties, regardless of the presence of a protective gaseous medium in the thermal shop.

Keywords: stainless steel, boriding, oxidation, sintering, mechanical properties.

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Introduction. It is known that chemical-thermal treatment is an effective way to increase physical and mechanical properties of sintered materials, as well as to give them a complex of required performance characteristics [1–4]. Boriding of sintered materials makes it possible to increase their hardness, wear resistance, as well as acid and heat resistance [3–5]. Earlier [6], the process of boriding sintering of stainless steel powders in a mixture of boron carbide with borax in a protective environment of drained hydrogen was investigated. This made it possible to create a corrosion- and wear-resistant borated friction pair designed to work in aggressive liquid media. However, for the introduction of a particular type of chemical-thermal treatment into production, it is important to preserve the reliability (stability) and simplicity of the technology during the transition from laboratory to production conditions.

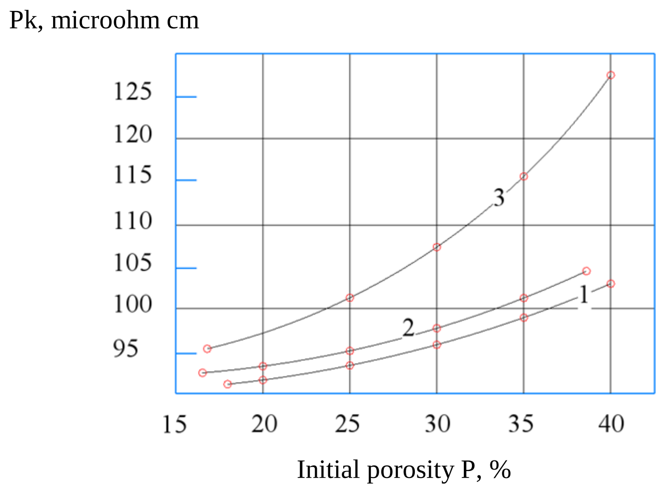
The **Aim** of the work is to study the boriding process at various temperatures, to conduct a microstructural analysis of the surface layer, as well as to study the sintering process of porous workpieces of steel PKh23N18 together with boron carbide powder in containers with a fusible seal. It is necessary to establish the dependences of the change in resistivity, mechanical properties on the density of the resulting pressings and the method of borating sintering.

Problem Statement. To create wear-resistant parts with high technological and mechanical properties, it is necessary to provide reliable chemical and thermal technology that will be introduced into production. To do this, it is necessary to conduct a series of experimental work to determine the dependencies of mechanical and technological properties on the boriding method, porosity of samples.

Theoretical Part. The technology of boriding sintering of porous blanks in a backfill from a mixture of boron carbide with borax is difficult for production conditions, since the extraction of parts from the sintered backfill (due to melting and crystallization of borax) and their cleaning from the stuck borax and boron carbide presents certain difficulties. In addition, such a backfill must be ground and mixed with a fresh mixture before reuse. Therefore, it was necessary to investigate the possibility of replacing the sintering borating backfill with a non-baking one.

It was found in [7–9] that when boriding cast steels, a dense boride layer is formed in technical boron carbide, the powder is not sintered and can be repeatedly used without any additional operations.

However, boriding sintering in boron carbide in flowing dry hydrogen with a dew point of -30 °C of porous samples made of PKh23N18 steel led to their partial detachment.



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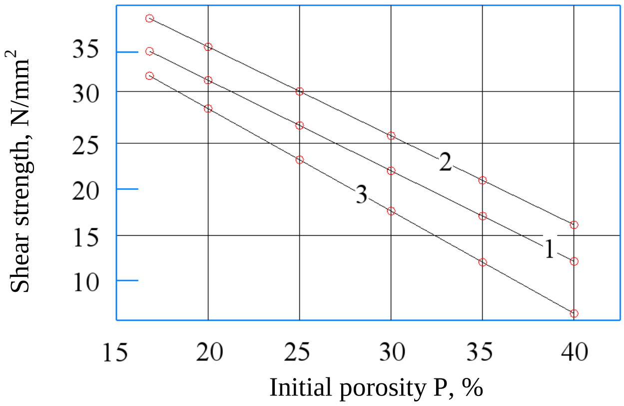

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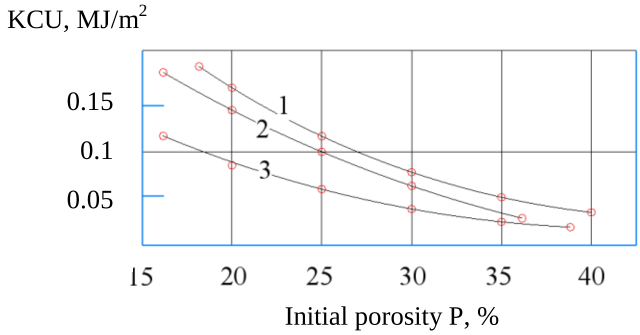

c)

Fig. 1. Dependence of changes in electrical resistivity (a), shear strength (b) and impact strength (c) of steel PKh23N18 on the initial porosity and boriding method: 1 — a sample containing borax, sintering in a hydrogen flow with a dew point of -30 °C; 2 — a tempered B4C sample, sintering in containers with a fusible seal; 3 — a tempered B4C sample, sintering in a hydrogen flow with a dew point of -30 °C

This is evidenced by the reduced strength and higher electrical resistance of samples subjected to boriding sintering in boron carbide (Fig.1 *a*, curve 3), compared with samples that underwent the same boriding sintering, but in a backfill containing borax (curve 1). Therefore, it seemed appropriate to use containers with a fusible seal for boriding sintering in boron carbide, which, as shown in [10], allow sintering stainless steel without traces of oxidation. Samples of their stainless steel PKh23N18 (5×4×40 mm in size) of different porosity were sintered in an autonomous gas medium (in a container with a fusible seal) in a backfill of boron carbide.

The study of the depth of the boride layer, shear strength, impact strength and electrical resistance of samples subjected to boriding sintering shows (Fig. 1 *a*, curves 1-3) that these characteristics, despite the identical temperature and holding time, significantly depend on the combination of properties of the borating backfill and the protective medium.

The studies of the boriding regime were carried out at different temperatures. The samples were heated to temperatures of 1050-1150 °C in increments of 50 °C. The processing time at all temperatures was 240 seconds, the current density was 0.4−0.7 A/cm^2.

The analysis of the data obtained shows that when the samples were heated to a temperature of 1150 °C, it contributed to the formation of boride eutectic, the microhardness of which is 16 hPa (light zones) and ferritocarbide base, the microhardness of which is 5 hPa (Fig. 2). This is followed by a transitional carbonized sublayer, behind which the initial ferrite-pearlite structure of the sample is formed.

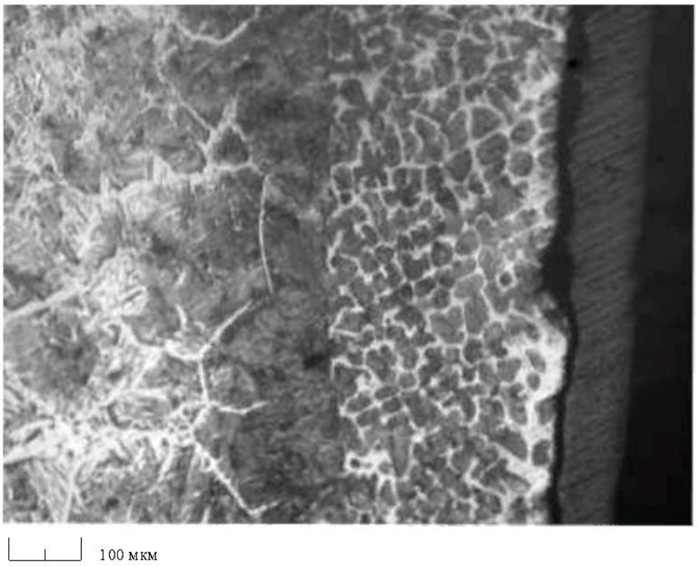

Fig. 2. Boride eutectic and the initial ferrite-perlite structure of the sample after heating to a temperature of 1050 °C

To determine the content of elements in boride eutectic and ferritocarbide-based layer, an electron microprobe analysis was performed. Figure 3 provides images of the borated layer obtained on a scanning electron microscope.

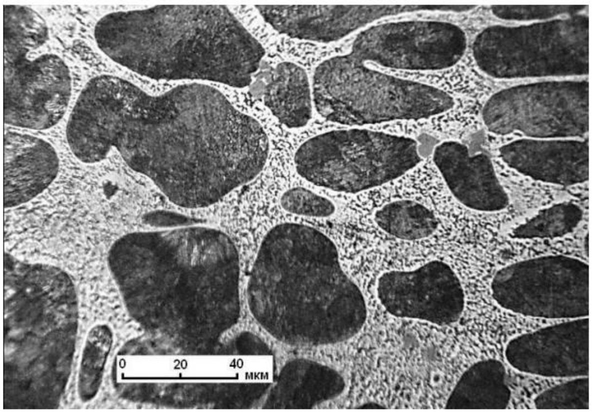

Fig. 3. Microstructure of boride eutectic after heating to a temperature of 1050 °C, obtained on a scanning electron microscope

X-ray phase analysis shows the presence of boron borides Fe_2B and cementite Fe_3C in the diffusion layer (Fig. 4). In addition, X-ray diffraction lines of boron carbide $B_{11.5}C_{2.85}$ with the ratio B:C were detected on the diffractogram, slightly different from the normal stoichiometry of B_4C carbide.

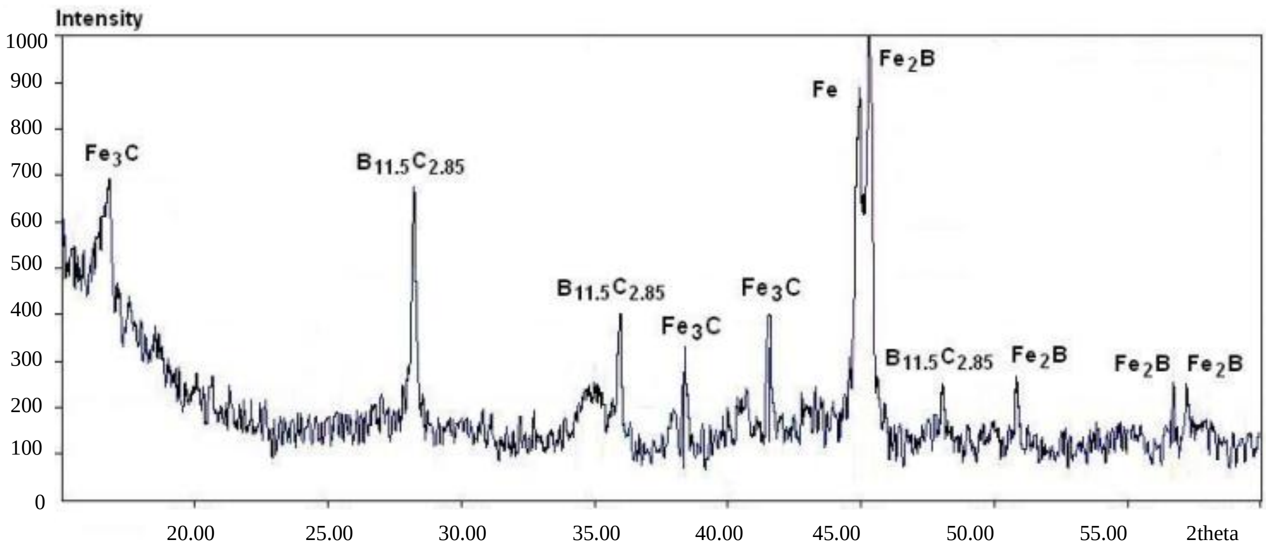

Fig. 4. X-ray diffractogram of the sample surface after boriding

The results of the experiment have showed that when the samples were heated to a temperature of 1250 °C, no boride layer was detected (Fig. 5). During the macrostructural analysis of the surface of the samples, the following defects were revealed in the form of penetration of the ends and the radial surface (the diameter change was 0.5 mm at the heating point and 0.3 mm at the ends). This is explained by the fact that under the influence of high temperature, the formed boride eutectic melts and shifts to the edge of the sample (to the end). Without a boride layer, the microhardness of the steel material was 3.5 hPa.

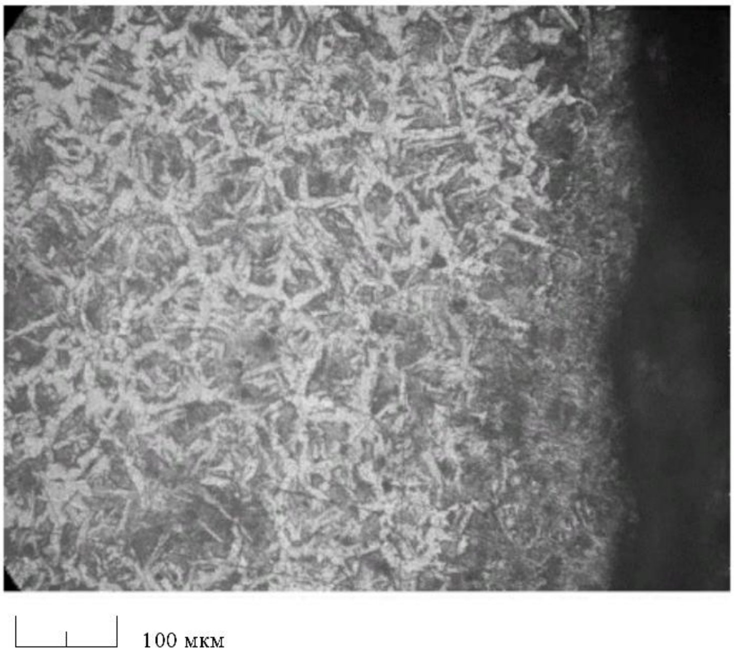

Fig. 5 Microstructure of the surface of a steel sample obtained at a temperature of 1250 °C

The experimental data analysis has showed that the formed boride layers on the material under consideration have a eutectic basis. At the same time, the samples were subjected to temperature exposure for 240 seconds. Samples heated to a temperature of 1160 °C have a high concentration of boron at the grain boundaries, as a result of which more liquid phase is formed, which contributes to the formation of a better layer. In the temperature range of 1050-1150 °C, a boride layer is obtained on the surface of the samples with places of boride eutectic along grain boundary sections of a solid solution of boron and carbon in Feα. A further increase in temperature leads to oversaturation of the surface boundaries with boron to the state of maximum eutectic concentration, melting of boride eutectic and its grain boundary slippage.

Unlike boriding sintering in flow hydrogen, sintering in a container with a fusible seal in an autonomous gas medium created by additives decomposing during heating (for example, paraffin or titanium hydride) allows you to completely protect porous stainless steel from oxidation and promotes mass transfer as a result of saturating diffusion of boron into unsealed porous material along pores and grains boundaries inside the product, and due to the sintering itself. The samples subjected to boriding sintering in a container with a fusible seal in a non-baking borating backfill have the greatest shear strength (Fig. 1, curve 2).

Conclusions. In addition to the temperature effect on the value of the interparticle melting of the surface of the material, the exposure time of the samples at the temperature conditions under consideration also has a great impact. With an increase in the temperature of the boriding process, boron oversaturation occurs to the maximum eutectic concentration and its grain boundary slippage. It is obvious that in order to obtain high-quality layers with boride eutectic sections along the grain boundary sections of the ferritocarbide matrix, constant monitoring of the process temperature and the holding time of the material at a given temperature should be carried out.

The obtained test results show that the strength increase in the samples subjected to boriding sintering in an autonomous gas medium occurred due to the absence of oxidation and deep saturation with boron (volumetric hardening) by means of the vapor-gas phase [11, 12]. The use of container (autonomous) technology for boriding sintering of porous stainless steels in a non-baking borating backfill makes it possible not only to simplify the technology, but also to ensure the preservation of material properties, regardless of the presence of a protective gas environment in the hardening shop.

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Thermal Spraying of Coatings on Aluminum Alloys of Combine Parts

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Introduction. At the present stage of technology development, special importance is given to improving the efficiency and durability of machine parts and especially parts of assemblies operating under increased loads. The problem of increasing reliability in the conditions of intensification of production, energy and resource conservation poses the task of introducing new technological processes and the use of modern materials into production. Often, the weakest element in the "material — working environment" system, which determines the operating conditions and the resource of mechanisms, is the surface of the material. Therefore, an important role in increasing its wear resistance is played by coatings that protect parts from the destructive influence of working environments.

Problem Statement. The main objective of the research is the development of technological modes for applying thermal coatings to the belt pulleys of the TORUM 750 combine harvester by Rostselmash, as well as the selection of optimal coatings to increase the durability and wear resistance of the pulley surface.

Theoretical Part. As a theoretical description, the application of various coating options is analyzed, as well as the mathematical processing of experimental data on the adhesion strength between the aluminum surface and the coating material is considered.

Conclusions. The studies carried out by the authors have shown that it is advisable to conduct thermal spraying on aluminum alloys of belt coatings on a heated substrate (preheating temperature from 210°C). In the case of spraying coatings on the rubbing surfaces of pulleys, the surfaces should be regularly cooled.

***Keywords*:** belt pulleys, wear resistance, spraying, aluminum, nickel, titanium.

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Introduction. The industry is increasingly using processes based on the connection of materials in a solid state, various types of welding, as well as new coating technologies. The process of applying coatings by gas-thermal method to aluminum material studied by the authors has much in common with those listed above.

In order to select the optimal technological parameters that provide the necessary adhesion strength, it is extremely important to know the essence of the connection mechanism of the studied metal pairs and to have a clear understanding of the relationship between the conditions of connection of dissimilar materials with the physical processes occurring in the contact zone of the surfaces of these metals. Aluminum alloys have a number of properties that distinguish them from steels and cast irons. They have a lower density and relatively high strength (2.6–2.9103 kg/m^3). The most durable alloys are used for the manufacture of products operating under loads, with changes in bending and torques. Aluminum alloys are also used in structures operating under conditions of increased wear resistance and at temperatures up to 120 C [1–3].

These characteristics of aluminum alloys contribute to their widespread use as basic structural materials, for example in the automotive, aviation, and shipbuilding industries [4]. It is known that during operation, the surfaces of the parts are subject to wear and corrosion and erosion, which is why the problem of increasing their wear resistance is so urgent at the present time. For this purpose, gas-thermal wear-resistant coatings should be used. Gas-thermal spraying of coatings on aluminum alloys, in comparison with coatings on traditional structural materials (steel, cast iron), has its own characteristics caused by a large difference in the coefficients of thermal expansion of alloys and coatings.

The **Aim** of the work is to study the technological modes of gas-thermal spraying on the belt pulleys of the TORUM 750 harvester of Rostselmash company, which is designed for harvesting all traditional grain crops: grain, legumes, oilseeds, cereals and tilled crops. It is necessary to pay great attention to the adhesion strength of coatings to the surface of the parts on which they are applied, since the adhesion strength of materials with aluminum alloys is several times lower than with the rest.

Problem Statement. To create wear-resistant parts with high technological and mechanical properties, it is necessary to apply wear-resistant coatings on the working surfaces of products. In this regard, the aim of the authors is to select such technological modes of gas-thermal spraying and recommend such a coating material that would provide better adhesion to the aluminum base.

Theoretical Part. The ability of metal coatings to increase the durability and reliability of machine parts and whole units is determined by their adhesion, sponge surface, through porosity and coating thickness. Obtaining a reliable adhesion of the coating to the base is one of the main requirements for metal coatings. Paper [5] provides information that copper and bronze alloys are among those materials that can serve as a reliable protective coating for aluminum and its alloys due to the close coefficients of linear expansion. At the same time, to ensure a strong adhesion, the temperature of the particles when interacting with the base should be about 1200 °C. This temperature was achieved using spraying with oxidation of up to 10% Cu_2O, which interacts with the aluminum base by an exothermic reaction:

$$2/3\ Al_{ж}+Cu_2O_{тв}=1/3\ Al_2O_3+2Cu_{тв.} \quad (1)$$

The proposed reaction gives seven times more heat than the process of exothermic Ni–Al reaction, which is widely used when creating a sublayer on Al.

To apply coatings to belt pulleys made of aluminum alloy AK4, powder mixtures based on nickel and titanium were used, which have high enthalpy due to exothermic reactions during plasma spraying, which significantly increases the adhesive strength (Fig. 1). Spraying was carried out using equipment from Rostselmash and on its premises (Fig. 2).

Fig. 1. Belt pulleys of the TORUM 750 combine harvester of the Rostselmash company

To ensure the adhesion of the sprayed layer with the base metal, it is recommended to carry out preliminary mechanical cleaning of surfaces with metal brushes and heating [7]. Heating of samples and parts to 210–230 °C before spraying was carried out in a two-chamber electric furnace with automatic temperature control. Heating above 230°C can change the mechanical properties of the alloy and leads to an increase in the transient contact resistance.

Fig. 2. Installation for gas-thermal surfacing of the Rostselmash company

There are recommendations to carry out thermal activation of the base to achieve chemical interaction with the coating [8]. However, preheating of the base made of aluminum alloy is associated with increased oxidation of its surface and the possibility of melting. At the same time, there are significant compressive stresses in the coating — base system caused by a sharp increase in the difference in the coefficients of linear thermal expansion of the aluminum alloy and the coating, which sometimes leads to negative results. In order to reduce residual stresses that may exceed the strength of the coating material, spraying should be performed on a cooled base.

In this paper, the authors investigated the structure and composition of oxide films on the surface of the AK4 alloy that occur when heated in air during plasma spraying, as well as the possibility of using a glow discharge at the stage of preparing the surfaces of parts for finishing coatings in order to increase the adhesion strength of the latter. It is established that the factor limiting the adhesion strength of coatings with the AK4 material is the formation of a magnesium oxide film on the surface of the latter. When processing the alloy with a glow discharge, the surface is modified due to the appearance of silicon oxides, which increases the adhesion strength of coatings by 1.3–2 times compared to traditional abrasive-jet treatment. It is noted that the "modified state" of the treated surface persists for a long time after the parts are removed from the vacuum chamber, since in all cases the coatings were sprayed 3-4 days after the surface of the pulleys was treated with a glow discharge. The technological possibilities of processing belt pulleys made of AK4 alloy with a glow discharge suggest the presence of complex vacuum equipment, and therefore the introduction of this technology into the workflow of Rostselmash had to be abandoned.

To prepare the surface of the belt pulley, it was necessary to carry out abrasive-jet treatment, requiring an optimal mode, which, creating the necessary surface roughness, would not cause deformation of the surface of the product [9–10]. The presence of metal shot residues on the surface negatively affects the adhesion strength, as well as the operational properties of the pulleys, which can cause abrasion of the V-belt. The following shot blasting mode was experimentally established (Table 1).

Table 1

Optimal shot blasting mode

Parameter	Value
Compressed air pressure, Pa	$4 \cdot 10^5$
Distance from the nozzle to the surface, m	0.1–0.18
Treatment time, s.	20–30
The incidence of the shot blast to the surface, deg.	90

The surface roughness was 15–20 microns. The deformation of the samples under this treatment mode is minimal and corresponds to an average of 40 microns.

To remove the smallest particles of shot and other impurities, the pulleys were washed in an alcohol-water mixture (in a ratio of 2:3). In order to reduce the effect of the difference in the coefficients of linear thermal expansion of the substrate and coating, as well as relaxation of residual stresses arising in them during spraying, the method of controlled cooling of pulleys was used [10–11]. To do this, during the spraying process, the heating temperature of the part was measured using a thermocouple. The sprayed part was placed in a heated (in this case up to 100-120 °C) muffel furnace. The furnace was cooled in various modes (fast cooling with a fan, cooling with an open door), the temperature regime of heating and cooling was maintained by an adjustment potentiometer RU5-01M. After each experiment, the adhesion strength of the coatings to the base was determined by the pin method. The measurement results were subjected to mathematical statistical processing. The average values (Xa), standard deviations (S) and confidence intervals of adhesion strength were calculated. Table 2 provides the results. The optimal rate of cooling temperature reduction is 5° C/min.

Table 2

Mathematical statistical processing of experimental data on adhesion strength

Coating material	Base material	Xa	S	Confidence interval
Nickel alloy PG-Yu10-N	V95	12.36	1.81	$11.50<X<13.20$
Titanium Alloy (PTS2)	D16	24.40	3.70	$22.68<X<26.16$
Stainless steel PKh18N9T	D16	11.62	1.44	$10.95<X<12.29$
Titanium Alloy (PTC2) and stainless steel PKh18N9T	D16	22.39	2.12	$21.39<X<23.38$

This technique was used during the development of gas-thermal coatings for the pulleys in question. The coatings were formed from titanium, nickel and stainless steel powders manufactured in Russia by Polema (Tula). Of the powders studied, PTS2 is the most technologically advanced by a number of indicators. The coating of this powder has a coefficient of friction with a rubber V-shaped belt of 0.16-0.18 with satisfactory wear resistance. The coating of stainless steel powders PKh18N9T has a coefficient of friction of 0.12–0.137. Their wear resistance is satisfactory. The nickel alloy showed an increased coefficient of friction of 0.21–0.23, but a more granular coating structure (Fig. 3).

Fig. 3. Belt pulleys after nickel alloy spraying

Heating the samples to 210°C reduces the temperature difference between the base material and the coating itself, which leads to an increase in the crystallization time of the sprayed particles, improves the filling and repeatability of the surface geometry of the sprayed layer, reduces the number of pores and defects on the surfaces (Fig. 4).

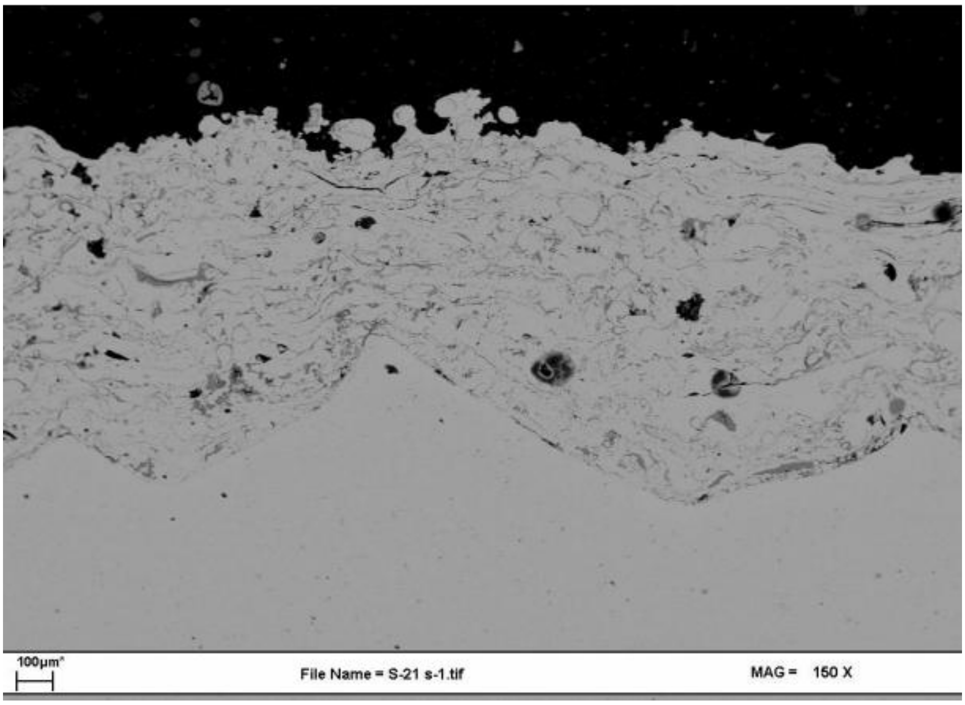

Fig. 4. The structure of the titanium coating on the aluminum surface of the pulley

Conclusions. The studies carried out by the authors have shown that it is advisable to carry out gas-thermal spraying on aluminum alloys on a heated base (preheating temperature from 210 °C). In the case of spraying coatings on the rubbing surfaces of pulleys, a regular surface cooling regime should be introduced. After the surface hardening operations, the pulleys were installed on TORUM 750 combines, which are currently undergoing field tests.

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