БЕЗОПАСНОСТЬ ТЕХНОГЕННЫХ И ПРИРОДНЫХ СИСТЕМ

№4 2022

SAFETY OF TECHNOGENIC AND NATURAL SYSTEMS

n.4 2022

ISSN 2541-9129

DOI 10.23947/2541-9129

Сетевой электронный теоретический и научно - практический журнал

Network Electronic Journal

https://btps.elpub.ru

Safety of Technogenic and Natural Systems

No. 4, 2022

Online electronic journal

Published since 2017

Quarterly
(February, May, August, November)
September 2022 – November 2022

ISSN 2541-9129
DOI: 10.23947/2541-9129

Founder and publisher* ─ *Federal State Budgetary Educational Institution of Higher Education Don State Technical University (DSTU)

Included in the list of peer-reviewed scientific editions where the basic research results of doctoral, candidate's theses should be published (State Commission for Academic Degrees and Titles List).

The journal publishes scientific articles in the following areas:

1. Machine Building
2. Chemical Technologies, Materials Sciences, Metallurgy
3. Technosphere Safety.

The journal is indexed and archived in the Russian Science Citation Index (RSCI), CyberLeninka, ROAD, GoogleScholar.

he journal is a member, Association of Science Editors and Publishers (ASEP) and CrossRef.

Certificate of mass media registration ЭЛ № ФС 77 – 66531 of 21.07.2016 is issued by the Federal Service for Supervision of Communications, Information Technology, and Mass Media

The issue is prepared by:
Inna V. Boyko, Daliya S. Bogatyreva (English version)

Founder's, Publisher's and Printery Address:
Gagarin Sq. 1, Rostov-on-Don, 344003, Russia. Phone: +7 (863) 2-738-372
E-mail: spu-10.2.3@donstu.ru https://btps.elpub.ru/

CONTENTS

IN MEMORY OF THE SCIENTIST

On September 14, 2022, a well-known scientist, Doctor of Engineering Science, Professor of the Operation of Transport Systems and Logistics Department of Don State Technical University, reserve colonel, member of the Editorial Board of the Safety of Technogenic and Natural Systems journal, Viktor Vladimirovich Deryushev died suddenly.

V. V. Deryushev was born on November 4, 1952 in Kemerovo. After graduating from high school in 1969, he was enrolled in the Mozhaiskiy Engineering Military Academy, from which he graduated in 1974 (diploma with honors and a gold medal). After serving as a laboratory engineer of a military unit in 1978, he entered the Rostov Higher Command Engineering School named after Chief Marshal of Artillery M. I. Nedelin. Viktor Vladimirovich began teaching in 1981. In 1982 he defended his thesis for the degree of Candidate of Engineering Science. In 1986 to continue his scientific activities, he took the position of senior researcher at the research laboratory. In 1990, by the decision of the Higher Attestation Commission, he was awarded the academic title of senior researcher in the specialty "Dynamics, strength of machines, instruments and equipment", in 1992 — the military rank of colonel. In 1993, V. V. Deryushev was appointed to the post of the head of the Department of Transport and Technological Equipment of Missile Systems, which he headed for 16 years until 2009. In 2000, he was awarded the degree of Doctor of Engineering Science, in 2001 — the academic title of professor.

After the end of his service and the disbandment of the Rostov Military Institute of Missile Troops, he was elected by competition as the head of the Auto Repair Department of the Rostov Technological Institute of Service and Tourism (branch) of the South Russian State University of Economics and Service. Since 2013 he headed the Department of Technical Operation and Service of Machinery and Technological Equipment at the Rostov State University of Civil Engineering. Since 2017, he worked as a professor at the Operation of Transport Systems and Logistics Department of Don State Technical University.

Viktor Vladimirovich made a significant contribution to the solution to the problem of ensuring the durability of the power shell elements of the aircraft structure from the thermomechanical effects of damaging factors of new types of weapons. He developed and justified criteria for structural failure based on thermal stress concentration and short-wave dynamic instability, and means of protection against them. The scientist was one of the authors of a new optimization method based on the unified maximum principle in relation to the problems of synthesis of optimal controls and identification of parameters of dynamic systems, as well as multi-criteria optimization of objects in conditions of uncertainty and risk.

V. V. Deryushev published 200 scientific, educational and methodical works, received 24 copyright certificates and patents for inventions, wrote and published a textbook "Launchers and command posts of missile systems", 11 textbooks, 2 monographs.

In 2003, Viktor Vladimirovich received a grant from the Ministry of Education of the Russian Federation for fundamental research in the field of engineering sciences for the research (Method of optimal parametric damping of vehicle vibrations). Over the years, the scientist led research work in the framework of government programs on assignments: Scientific-Production Organization "Astrofizika", Scientific-Production Organization "Energiya", Central Research Institute of Mechanical Engineering, Scientific-Production Organization of Mechanical Engineering, Central Research Institute of Special Engineering, "Yuzhnoye" Design Bureau, "Raduga" Design Bureau, Department of Housing and Utilities and Energy of Rostov-on-Don on the conformity assessment of the supplied road and municipal equipment.

In 2002-2017, V. V. Deryushev was a member, chairman of the state attestation commissions at Perm Military Institute of the National Guard of the Russian Federation, South Russian State University of Economics and Service, Rostov State Transport University.

V. V. Deryushev has 12 government awards (medals of the Ministry of Defense of the USSR and the Russian Federation), Commemorative badges and diplomas of the Commander-in-Chief of the Strategic Missile Forces.

Viktor Vladimirovich Deryushev was an open and approachable person, distinguished by exceptional diligence, generously shared his knowledge and experience with everyone — colleagues, students. He enjoyed a high reputation among both teachers and students.

The memory of Viktor Vladimirovich Deryushev will remain in the hearts of colleagues in joint work. He will always be an example of boundless devotion to his profession.

TECHNOSPHERE SAFETY

Original article
UDC 331.45
https://doi.org/10.23947/2541-9129-2022-4-6-11

Stochastic Factor Analysis of Occupational Injuries at Railway Transport Enterprises

Yuliya V. Dementyeva ✉, **Svyatoslav D. Tatarintsev**
Samara State Transport University (Samara, Russian Federation)
✉ yulia_dementyeva@bk.ru

Abstract
Introduction. Railway enterprises are characterized by an increased labor risk, the professional activity of personnel is associated with the risk of injury. Occupational safety measures are regularly carried out in the industry. At the same time, accidents are known to occur in Russian Railways JSC (Russian Railways). Risk reduction requires a theoretical study of the problem, as well as the study of applied solutions, which determines the relevance and significance of the proposed study. The purpose of the work is to determine the resulting indicators on which the dynamics of industrial injuries in Russian Railways depends.
Materials and Methods. To identify the causes of injury to railway transport workers of the Russian Railways holding, the authors analyzed statistics for 2007–2021. We systematized and ranked 17 types of accidents, which are associated with accidents resulting in injuries. Using the Pareto chart, they were differentiated as resultant and non-resultant. We identified 7 resultants. We performed a stochastic analysis and established the relationship of each factor with the total number of accidents. The correlation coefficients were calculated.
Results. Preliminary calculations were presented in the form of a table to obtain the coefficient of stochastic dependence of industrial injuries on the number of injured employees of Russian Railways in road accidents. The value of the stochastic relations coefficient was calculated and adjusted. The average error was determined — the difference between the general injury rate and the injuries in road accidents. The results of these calculations were compared with the data of the Student's t-distribution quantile table for confidence probability. Similarly, the degree of stochastic relationships for the other resulting types of incidents was calculated and summarized in a table. The result was visualized in a diagram.
Discussion and Conclusion. The results of the conducted surveys allow us to assert that the dynamics of industrial injuries in Russian Railways JSC is determined mainly by incidents in road accidents. It is necessary to investigate their causes and develop measures aimed at improving occupational safety.

Keywords: occupational safety, road traffic injuries, stochastic analysis, railway transport.

For citation. Dementyeva Yu. V., Tatarintsev S. D. Stochastic Factor Analysis of Occupational Injuries at Railway Transport Enterprises. Safety of Technogenic and Natural Systems, 2022, no. 4, pp. 6−11. https://doi.org/10.23947/2541-9129-2022-4-6-11

Introduction. Legislative acts of the Russian Federation and documented standards of Russian Railways JSC give a systematic idea of measures to protect labor, ensure the safety of life and health of employees [1,2]

Russian Railways JSC owns the railway infrastructure of the Russian Federation and is one of the largest employers. The railway industry is a high-risk occupational hazard zone. The professional activity of railway workers is associated with the risk of injury. In this regard, the tasks of the Russian Railways JSC management are:

– occupational safety provision;

– prevention of occupational injuries;

– minimization of occupational risks.

The problem of occupational safety was studied by O. P. Petrova, S. V. Yanchiy, J. Bell, and others [1–3].

In 2007–2021, 5029 accidents with injuries and deaths were recorded at railway transport enterprises.

Injury to employees results in high economic costs for the employer. The dynamics of occupational injuries should be analyzed, and then the impact of each resulting factor should be considered pointwise.

The company is constantly working in these areas, but accidents still occur at railway enterprises, which confirm the relevance of the study of the problem [4].

The work objective is to determine the resulting indicators that affect the dynamics of occupational injuries in Russian Railways JSC.

To achieve this objective, it is necessary to identify the share of the impact of various types of accidents on the dynamics of industrial injuries of Russian Railways JSC in 2007-2021 using stochastic factor analysis.

Materials and Methods. First of all, it is necessary to rank the incidents that most affect the dynamics of occupational injuries. To do this, we use the Pareto chart. It allows us to determine 20% of the most significant indicators that provide 80% of changes in the dynamics of occupational injuries[3].

Based on the statistical data of industrial injuries of Russian Railways JSC in 2007-2021, we will form a Pareto chart (Fig. 1). On the left axis of the ordinates we note the total number of injury cases, on the right — an interval scale of 0–100 %. On the abscissa axis we note the indicators of accidents. Let us construct a cumulative curve. To do this, we will plot the points of accumulated amounts on the graph field, which on the right axis of the ordinates will be equal to the quantitative value of the accumulated cumulative percentage for each type of incident. Let us connect them.

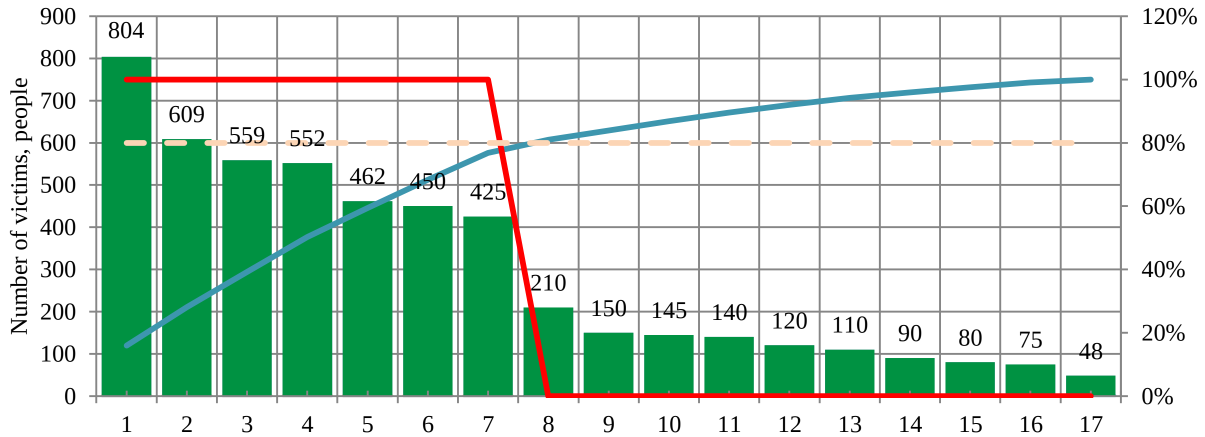


Fig. 1. Pareto chart — distribution of accidents by types of incidents: 1 — traffic accidents; 2 — falling on the surface; 3 — falling from a height; 4 — electric shock; 5 — impact of cargo movement; 6 — impact, crushing; 7 — hitting, impact, clamping by rolling stock; 8 — fall, collapse of materials, cargo, structures; 9 — exposure to harmful chemicals; 10 — impact, clamping, unrelated to rolling stock; 11 — prick, cut; 12 — impact of objects flying off from the impact; 13 — contact of a foreign body with eyes; 14 — accident, crash on railway transport; 15 — falling at sudden braking of rolling stock; 16 — illegal actions of other persons; 17 — exposure to extreme temperatures

[1] The Labor Code of the Russian Federation. Article 210. The main directions of state policy in the field of labor protection. State Duma, Federation Council, Available from: http://www.consultant.ru/document/cons_doc_LAW_34683/ed198846c41aa4fc2123f3abe0fe692a5587c5ed/ (accessed 12.08.2022). (In Russ.).

[2] Organization standard. STO RZD 15.001-2020 "Occupational safety management system in Russian Railways JSC. General provisions". Russian Railways JSC. Moscow: Russian Railways JSC, 2020. p. 46 (In Russ.).

[3] Organization standard. STO RZD 1.05.515.2-2009 "Methods and tools for improvements. Pareto Analysis". Russian Railways JSC. Moscow: Russian Railways JSC, 2009. p. 18. (In Russ.).

To divide the factors into resultant and non-resultant, we construct a horizontal line from the axis of the cumulative line to the intersection with the Pareto curve. From the place of this intersection, we draw a segment to the abscissa axis. The factors to the left of the segment are resultant, and to the right — non-resultant.

The diagram shows that in 2007–2021 the resultant types of accidents in Russian Railways were:

– traffic accidents (804 people);

– falling on the surface (609 people);

– falling from a height (559 people);

– electric shock (552 people);

– impact of transported goods (462 people);

– impact, pressure (450 people);

– accidents, hit, clamping by rolling stock (425 people).

Let us determine the accidents that most affect the statistical indicators of industrial injuries in Russian Railways. To do this, we will perform a stochastic analysis of the totality of the resultants. Let us establish the presence (absence) and significance of the corresponding correlation relationships [5, 6]. The correlation coefficient determines the interdependence of changes in the values of factors (from –1 to +1).

Let us find out the degree of interrelation of each *i*-th factor in different types of accidents from the total number of accidents. Let us calculate the correlation coefficients [7–9].

Let us establish how the dynamics of industrial injuries in Russian Railways depends on road accidents (the largest number of victims, Fig. 1).

Let us calculate the correlation coefficient r_{xy} , which determines the stochastic relationship between the variables x (the number of injured workers in *i*-th types of accidents) and *y* (the total number of injured workers in accidents at work):

$$r_{xy} = \frac{\sum(x_i - \bar{x}) \times (y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \times \sum(y_i - \bar{y})^2}}, \quad (1)$$

where x_i — the values taken by the variable$x$; y_i — the values taken by the variable y.

Results. Let us present the preliminary calculations in the form of a table to obtain the coefficient of stochastic dependence of industrial injuries on the number of injured employees of Russian Railways in road accidents in 2007–2021.

Table 1

Calculated data for obtaining the stochastic relations coefficient

Year	x	y	$x_i - \bar{x}$	$y_i - \bar{y}$	$(x_i - \bar{x})^2$	$(y_i - \bar{y})^2$	$(x_i - \bar{x}) \times (y_i - \bar{y})$
2007	63	573	22.40	237.43	501.76	56373.31	5318.45
2008	52	650	11.40	314.70	129.96	99038.20	3587.62
2009	52	650	11.40	314.70	129.96	99038.20	3587.62
2010	67	583	26.40	247.31	696.96	61163.25	6529.04
2011	41	410	0.40	74.70	0.16	5580.59	29.88
2012	59	369	18.40	33.45	338.56	1119.13	615.54
2013	37	336	–3.60	1.07	12.96	1.14	–3.84
2014	44	275	3.40	–60.30	11.56	3635.68	–205.01
2015	33	220	–7.60	–115.30	57.76	13293.32	876.25
2016	40	223	-0.60	–112.30	0.36	12610.54	67.38
2017	23	182	–17.60	–153.30	309.76	23499.86	2698.02
2018	34	168	–6.60	–167.30	43.56	27988.17	1104.16
2019	23	152	–17.60	–183.30	309.76	33597.66	3226.02
2020	20	119	–20.60	–216.30	424.36	46784.24	4455.71
2021	21	120	–19.60	–215.30	384.16	46352.64	4219.81

Correlation coefficient between the variables under consideration is $r_{xy} = 0.86$. To determine its significance, we will make an adjustment modulo:

$$|\bar{r}| = \sqrt{1 - (1 - r^2)\frac{n-1}{n-2}}; \quad (2)$$

where $|\bar{r}|$ — the adjusted value of the stochastic relations coefficient; r — the calculated value of the stochastic relations coefficient calculated by formula (1).

According to the results of calculations we get $|\bar{r}|$ = 0,89.

Next, we will perform the calculation with the obtained correlation coefficient r_{xy}. Let us determine its average error m_r (the difference between general injuries and injuries in road accidents)

$$m_r = \sqrt{\frac{1-r^2}{n-2}}. \quad (3)$$

Substituting the calculated values into formula (3), we get $m_r = 0.14$.

To assess the significance of r_{xy} we determine the statistical value of $t_{\text{ст}}$ by formula:

$$t_{\text{ст}} = \frac{|\bar{r}|}{m_r}. \quad (4)$$

Substituting the calculated values into formula (4), we get $t_{\text{ст}} = 6.21$.

The results of the study are comparable with the data of the Student's t-distribution quantile table for a confidence probability $1 - a = 0.99$, depending on the number of degrees of freedom $v = n - 2, \alpha_1 = 0.05$ and $\alpha_2 = 0.01$.

For $t_{\text{ст}} \leq t_{\alpha=0,05}$ the null hypothesis is determined, where $r = 0$. This indicates that the connection is not essential. When $t_{\text{ст}} > t_{\alpha=0,01}$ the null hypothesis is not accepted and the connection between the phenomena is considered established [7–9].

In this case 6.21 > − 6.29, that is $t_{\text{ст}} > t_{\alpha=0,01}$. The null hypothesis is rejected, and the connection between the phenomena is considered established.

Similarly, we calculate the degree of stochastic relationships for the other resulting types of incidents and summarize them in Table 2.

Table 2

Calculation results of stochastic relationships of the resultant types of incidents

No.	Incident	r_{xy}	$\lvert\bar{r}\rvert$	m_r	$t_{\text{ст}}$
1	Road transport	0.86	0.89	0.14	6.21
2	Falling on the surface of one level	0.62	0.64	0.22	2.92
3	Falling from a height	0.65	0.68	0.20	3.25
4	Electrical accident	0.39	0.41	0.26	1.59
5	Impact of transported goods	0.53	0.55	0.23	2.36
6	Impact, pressure	0.43	0.45	0.24	1.81
7	Impact, clamping by rolling stock	0.51	0.52	0.24	2.19

Figure 2 provides the calculated values of the significance of stochastic relations (coefficients and their statistical values).

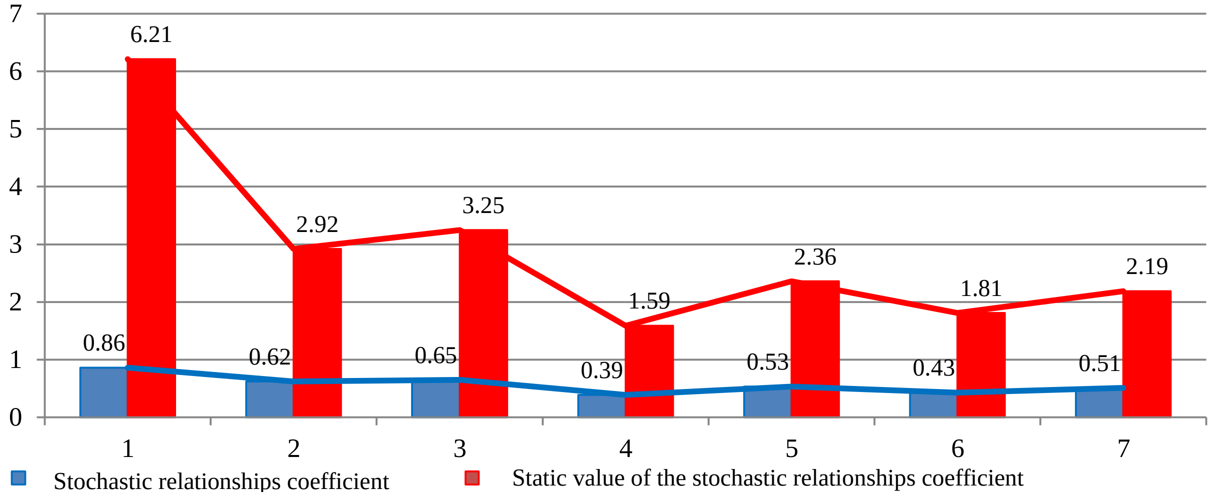


Fig. 2. Significance of stochastic relations: 1 — traffic accidents; 2 — falling on the surface of one level; 3 — falling from a height; 4 — electrical accident; 5 — impact of transported goods; 6 — impact, pressure; 7 — impact, clamping by rolling stock

The calculations have shown that all the studied resultant types of accidents are stochastically interrelated with the dynamics of industrial injuries of Russian Railways JSC in 2007-2021. The factor of injury in road accidents has the greatest weight.

Discussion and Conclusion. All things considered, the dynamics of industrial injuries in Russian Railways JSC is determined mainly by road traffic incidents. It is necessary to investigate their causes, which will make it possible to develop preventive measures aimed at improving occupational safety in the industry.

References

1. Petrov O. P. Proizvodstvennyi travmatizm na predpriyatiyakh energetiki. Young Scientist. 2020;16(306):158–160 (In Russ.).

2. Yanchii S. V., Degtyarev N. D. Analiz prichin proizvodstvennogo travmatizma v organizatsii na osnove primeneniya statisticheskogo metoda Young Scientist. 2017;4(138):95–100. (In Russ.).

3. Bell J., Holroyd J. Review of human reliability assessment methods. Buxton: HSE Books, 2009. 78 p.

4. Khamidullina E. A., Tarasova M. N. Statistics-based occupational traumatism risk management in railway industry. Technosphere Safety. XXI Century. 2016;1(1):8. (In Russ.).

5. Emelyanov, V. Yu. Metody modelirovaniya stokhasticheskikh sistem upravleniya. Saint-Petersburg: Baltic State Technical University "Voenmeh", 2004. 152 p. (In Russ.).

6. Jendoubi T., Strimmer K. A. Whitening approach to probabilistic canonical correlation analysis for omics data integration. BMC Bioinformatics 2019;20:15. https://doi.org/10.1186/s12859-018-2572-9

7. Dementyeva Yu. V. Correlation analysis of quantitative factor characteristic influence on statistic indicators of workplace injuries (using the Kuibyshev railway track facilities as an example). Vestnik Ural'skogo gosudarstvennogo universiteta putei soobshcheniya. 2016;3(31):139–147. (In Russ.).

8. Dement'eva, Yu. V. Correlation analysis of «accident type» factor on industrial injuries statistic index. Izvestiya Transsiba. 2016;2(26):127–133. (In Russ.).

9. Chernov E. D. Matematiko-statisticheskie metody issledovaniya prichin proizvodstvennogo travmatizma. N. Novgorod: NIIZhT, 1979. p. 38 (In Russ.).

Received 21.08.2022.

Revised 27.09.2022.

Accepted 27.09.2022.

About the Authors:

Dementyeva, Yuliya V., Associate professor, Department of Biomedical Safety in Transport, Samara State Transport University (2 B, Svoboda St., Samara, RF, 443066), Cand. Sci. (Eng.), ORCID, yulia_dementyeva@bk.ru

Tatarintsev, Svyatoslav D., Postgraduate student, Department of Biomedical Safety in Transport, Samara State Transport University (2 B, Svoboda St., Samara, RF, 443066), ORCID, sv2030@yandex.ru

Claimed contributorship.

Yu. V. Dementyeva — academic advising, analysis of the research results, revision of the text, correction of the conclusions. S. D. Tatarintsev — construction of the concept, collection of analytical material, calculations, preparation of the text, formulation of the conclusions.

Conflict of interest statement

The authors do not have any conflict of interest.

Author have read and approved the final manuscript.

TECHNOSPHERE SAFETY

Original article
UDC 331.45
https://doi.org/10.23947/2541-9129-2022-4-12-21

Gaming Computer Technologies in Safety Training at the Agro-Industrial Complex Enterprises

Valentina Yu. Kontareva[1] ✉, **Vladimir V. Belik**[2]

[1] Don State Agrarian University (Persianovsky, Russian Federation)

[2] Rostov State Technical University (Rostov-on-Don, Russian Federation)

✉ valia_k@bk.ru

Abstract

Introduction. The topic under consideration is updated by official domestic statistics, according to which more than a third of employees work in harmful and dangerous conditions. During the production process, people get injured and maimed, lose their ability to work. Dozens of fatal incidents are recorded at workplaces every year. The purpose of the study is to show the advantages and prospects of the introduction of gaming computer technologies in the training of workers in labor protection in the agro-industrial complex (AIC).

Materials and Methods. The scientific literature devoted to the educational possibilities of digital gaming solutions is considered. In relation to the topic of this study, the potential of a number of computer games, virtual, augmented and mixed reality technologies is evaluated. The well-known and commercially available gaming software is considered in relation to the topics and objectives of occupational safety training. The strengths and weaknesses of this approach are noted.

Results. The paper shows how to prepare for the introduction of gaming computer technologies into the occupational safety training system. In particular, it is necessary to identify and systematize the causes of accidents and injuries at work, to focus on industry (in this case, the most typical for agriculture). Special attention should be paid to organizational risks, because if they are neglected, personnel will work in initially dangerous conditions and high-quality training may be useless. The approaches to the organization of training, conducting classes, checking and consolidating knowledge are considered. Digital gaming products that have proven themselves in occupational safety training in various industries, including the agro-industrial complex, are presented. Variants of such training are considered. The use of digital gaming technology tools for the qualitative development of safety techniques, the formation of safe behavior skills and motivation to prevent injuries is justified.

Discussion and Conclusion. The results of the work allow us to assert that gaming computer technologies can be successfully used for teaching occupational health and safety in agriculture. This approach has serious advantages in terms of organization, visibility, cost-effectiveness and safety. Certain disadvantages of the method are likely to hinder the widespread implementation of such solutions in occupational safety training at agricultural enterprises for some time. However, in the medium term, it is possible to predict the solution of the identified problems due to the development of the digital games market, virtual technologies and the development of domestic analogues

Keywords*:* gaming computer technologies, virtual reality, augmented reality, mixed reality, safety training, accident causes, agro-industrial complex.

For citation. Kontareva V. Yu., Belik V. V. Gaming Computer Technologies in Safety Training at the Agro-Industrial Complex Enterprises. Safety of Technogenic and Natural Systems, 2022, no. 4, pp. 12−21. https://doi.org/10.23947/2541-9129-2022-4-12-21

Introduction. Since September 1, 2022, training and testing of knowledge in the field of occupational safety are more clearly systematized and regulated. Participation is mandatory not only for performers, but also for management, employers, and individual entrepreneurs. Training should provide knowledge, skills and abilities that allow developing competencies to ensure occupational safety, preserve life and health. Among the mandatory activities are:

– briefings;

– on-the-job internships;

– first aid practicing;

– mastering the skills of using personal protective equipment (PPE);

– occupational safety training[1,2].

According to data for 2017–2020, an average of 33.5 % of workers are employed in harmful and hazardous working conditions in Russia, and 18.4 % are engaged in heavy work[3]. During this time, 8313 people suffered from disability (an average of 2078 people per year), 530 incidents were with a fatal outcome (an average of 133 cases per year). A sufficiently high level of injury can be caused by multitasking in the implementation of technological processes, a wide range of work, a variety of equipment, tools and machines, seasonality, climatic and weather conditions, irresponsiveness to the introduction of innovations in occupational safety, etc.[4]

The work objective is to study the possibility of occupational safety and health training in the agro-industrial complex using adapted gaming computer technologies.

Materials and Methods. Domestic and foreign scientific and applied works are considered, which describe the educational capabilities of digital gaming solutions. In relation to the topic of this study, the potential of some computer games, as well as virtual, augmented and mixed reality technologies is comprehensively assessed. The products are especially noted that allow you in the learning process to:

– interact with objects on the screen;

– simulate the situation using virtual glasses or a helmet;

– recreate an environment close to the real one;

– combine physical and digital objects.

The well-known and available gaming software on the market is considered in relation to industrial hazard factors, topics and goals of occupational safety training.

[1] Labor Code of the Russian Federation. State Duma. Federation Council. Consultant Plus. Available from: http://www.consultant.ru/document/cons_doc_LAW_34683/ (accessed 03.09.2022). (In Russ.).

[2] On the procedure for occupational safety training and verification of knowledge of occupational safety requirements. Decree of the Government of the Russian Federation No. 2464 of 12.24.2021. Consultant Plus. Available from: http://www.consultant.ru/document/cons_doc_LAW_405174/ (accessed 03.09.2022). (In Russ.).

[3] Working conditions. The proportion of employees of organizations engaged in harmful and (or) hazardous working conditions, by type of economic activity (since 2017). Federal State Statistics Service. Available from: https://rosstat.gov.ru/working_conditions (accessed 03.09.2022). (In Russ.).

[4] Kontareva V. Yu. Injury analysis and organization activities industrial safety in the agricultural sector. Sovershenstvovanie tekhnologii proizvodstva, pererabotki i ekspertizy kachestva pishchevoi produktsii: mat. of All-Russ (national) scientific-practical conf. 2019, p. 79–86. Central Scientific Agricultural Library. Available from: http://www.cnshb.ru/jour/j_as.asp?id=147227 (accessed 22.10.2022). (In Russ.).

Results. When organizing training and testing of knowledge on occupational safety at the enterprises of the agro-industrial complex (AIC), it is necessary to identify and systematize general and specific, industry-specific causes of accidents and injuries. According to statistics, the main ones are:

– the impact of moving, flying, rotating objects, parts of operated machines on workers;

– falls;

– collapses and landslides;

– fires (exposure to smoke, fire, flame);

– the impact of electric current (Fig. 1).

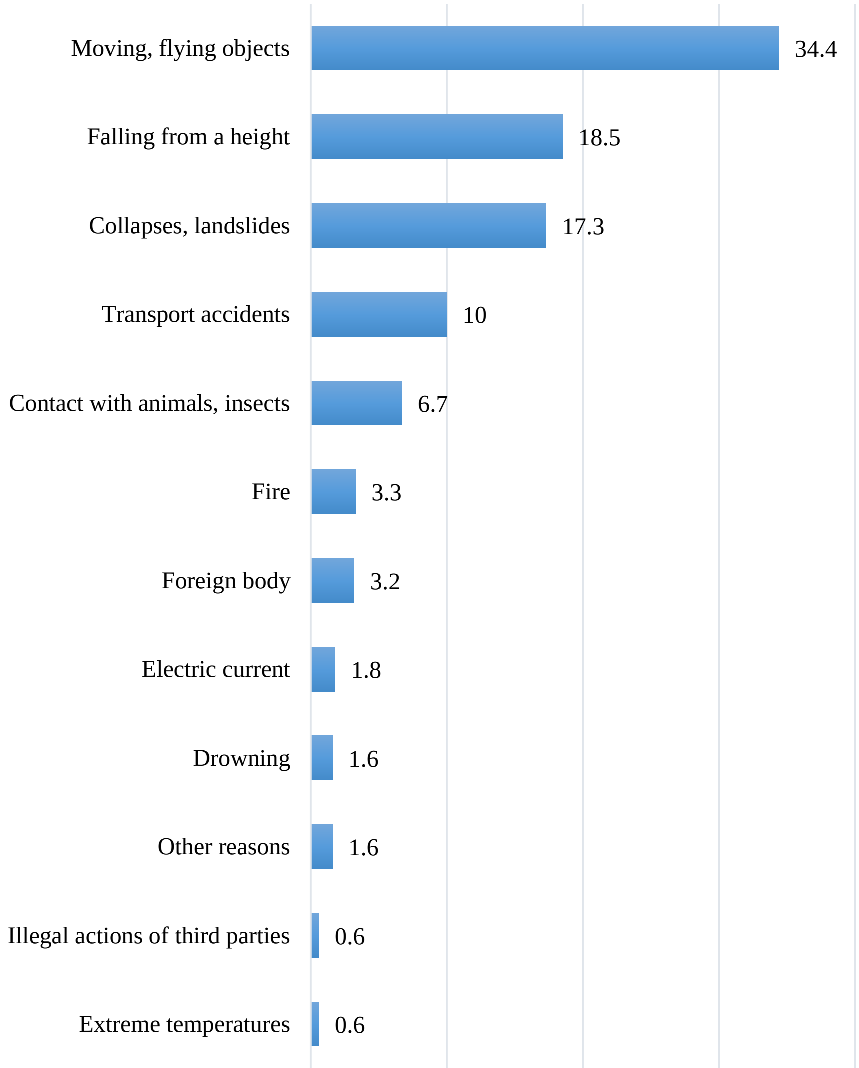


Fig. 1. Main causes of accidents in agriculture, %

It is important to identify the causes of accidents of an organizational nature (Fig. 2):

– unsatisfactory organization of work;

– ignoring training and testing of knowledge on occupational safety;

– lack of instruction;

– violation of labor regulations and discipline;

– unsatisfactory maintenance of workplaces, etc.

Significant causes of injuries in agriculture:

– non-compliance with safety requirements, including during the operation of mechanisms and equipment;

– violations of labor regulations and labor discipline by employees;

– absence or non-use of personal protective equipment, etc. [1–3].

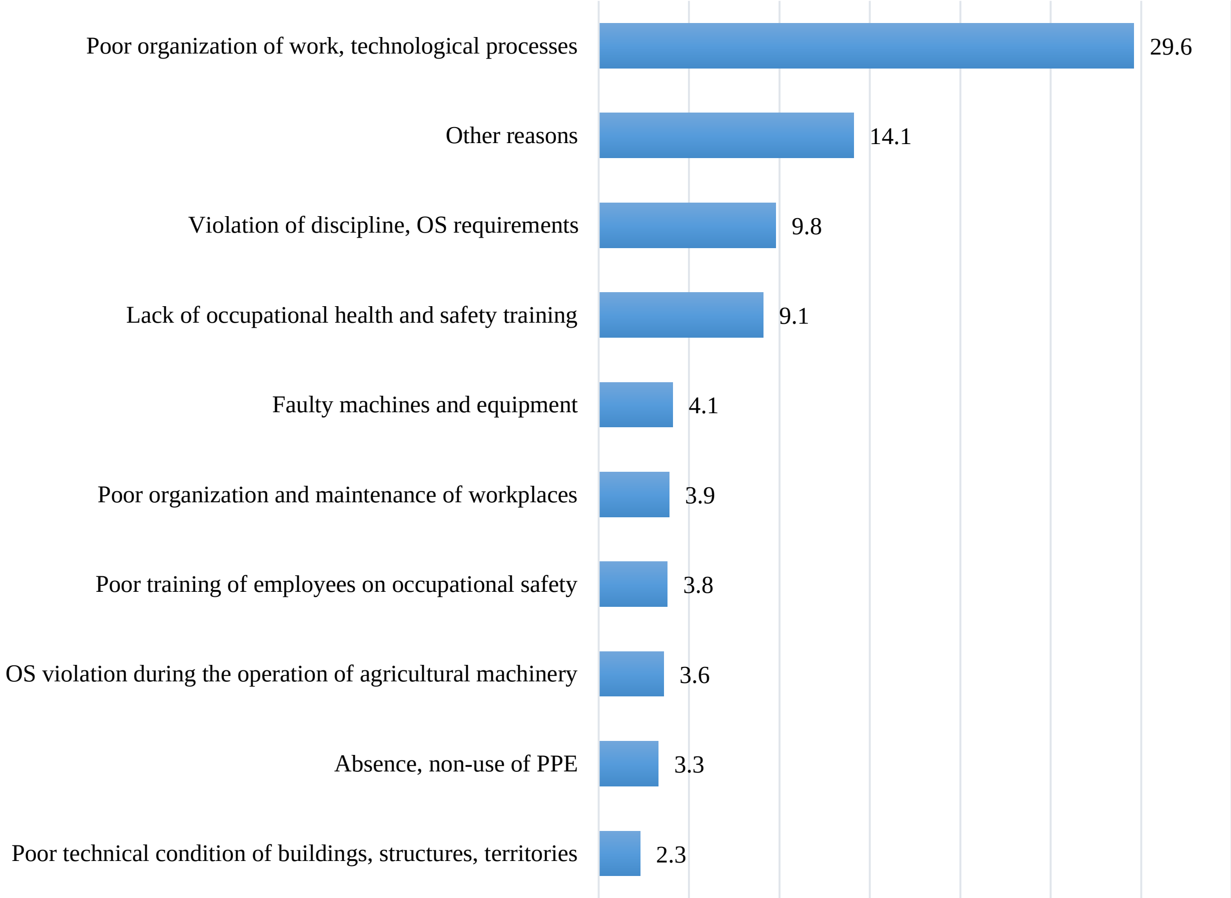


Fig. 2. Main organizational causes of accidents in agriculture, %

According to the authors of works [4, 5], high-quality training and testing of knowledge on occupational safety form safe behavior skills among employees, which contributes to injuries prevention. Passive types of training include traditional classroom and distance forms. Active ones include internships, drilling of operations on simulators and (or) training workplaces, mannequins. Theory is learned in passive learning, as a rule, to a minimum extent, if it is not supported by practical skills development[5]. Active training consolidates skills and competences, but it is more difficult to organize it because of the cost. This approach requires more time, human, material and financial resources. Such expenses are not always advisable.

The main disadvantages of both approaches are:

– they do not give a complete picture of real hazardous production situations;

– they do not provide a sufficient level of training for workers with low literacy;

– they do not allow you to hold the attention of the audience for a long time [5].

In connection with the above, it seems promising to use digital game forms for training and testing knowledge in the field of occupational safety and health [6].

[5] Anikina O. M. Geimifikatsiya proizvodstvenno-tekhnicheskogo obucheniya. Nauchnye issledovaniya i innovatsii: proc. of V internat. scientific-practical conf. Saratov, 2021. p. 306–311 (In Russ.).

Gaming computer technologies are successfully used as educational resources in medicine, mining, agriculture, sports, construction, defense, safety, labor protection, etc. [5] (Table 1).

Table 1

Basic gaming computer technologies

Technology	Brief description	Example
Computer game	Game participants interact with objects on the screen	BUT-Safety Digital game on safety, labor protection. Objective — to test and consolidate knowledge
Virtual reality (VR)	Experience is simulated using virtual glasses or a helmet. Immersion in a 3D environment close to a real one	HSE VR simulator Working out actions on industrial and environmental safety, occupational safety and civil protection
Augmented reality (AR) and mixed reality (MR)	Recreated situation combines physical and virtual objects modeled by computer technology. A smartphone or tablet is enough to use AR	ARgument.Safety The service to reduce injuries and emergencies instructs on the use of equipment, warns about possible dangers, forms a culture of occupational safety

The data in Table 1 make it possible to judge the educational potential of gaming technologies. They allow you to work out the reaction to:

– hazardous and harmful production factors;

– fire threat and fire;

– energy accidents;

– failures in the operation of machinery and equipment.

In addition, digital solutions are used to clarify:

– legal and theoretical principles of occupational safety;

– fundamentals of safe behavior in the workplace;

– rules of first aid to victims.

So you can teach how to use personal protective equipment, conduct an instruction and test your knowledge. Technologies should be correlated with the topics and objectives of training (Table 2).

Table 2

Use of gaming computer technologies depending on the topic and objective of training

Hazard factor	Topic of training	Training objective	Technology
Chemical, physical, biological	Hazardous and harmful production factors, their impact on the employee, protection from them	Identification of sources of danger	Augmented virtual environment (System for Augmented Virtuality Environment Safety — SAVES) [7]
		Hazard awareness and safety training	Virtual learning environment using experimental Kolb's learning theory [8]
Risk of falling		Identification of hazard sources	SAVES
		Identification of unsafe conditions and multiple choice solution	AR application on the Microsoft HoloLens platform
		Emergency response	Harry's Hard Choices Game [9]
Fire hazard	Fire safety		
Operation of agricultural machinery and equipment	Safety in the operation of agricultural machinery and equipment	Improving operational skills and awareness of the machinery and equipment safety	Modeling in a computer-aided design system

Hazard factor	Topic of training	Training objective	Technology
		Hazard identification, risk assessment, control of the operation of machinery and equipment	Safety training program of the University of Waterloo [10]
			Trouble Tower Game [11]
		Solution to situational problems during the operation of machinery and equipment	"Serious game" [12]
Non-compliance with safety requirements or erroneous actions	Safe working methods, fundamentals of safety and labor protection	Training in safe working methods and labor protection, search for safe options	Personalized learning support system in the game [13]
		Study of ergonomics, safety, documents, procedures, equipment, workplaces, technological processes	Manufacturing Training System (MTS) Augmented Reality and Gamification System [14]
			"Digital Ergonomics" and "Serious Game" [12]
Electricity	Electrical safety	Risk analysis, learning the basics of electrical safety	Electrical safety training game[6]
		Hazards, risk assessment, establishment of control measures	University of Waterloo Safety Program [10]
Non-use, improper use of personal protective equipment	Personal protective equipment (purpose, application)	Application of personal protective equipment	Virtual learning environment using the experimental Kolb's learning theory [8]

Let us consider the options for such training. For example, an adaptive personalized in-game learning support system [12] focuses on the rules for maintaining health and safety in the workplace. The player practices the skills of occupational health and safety. Before the start of the test, he/she fills in a short profile so that the system takes into account his/her level of training in advance.

"Digital Ergonomics" and "Serious Game" [14] give a general and detailed idea of occupational safety. In the first case, "Digital Ergonomics" is better suited. It is designed to spread safety culture among the staff. "Serious Game" teaches specific safety procedures and allows you to test skills.

Virtual learning environment using the experimental Kolb's learning theory [10] provides the practice of:

– hazard identification;

– risk assessments;

– control;

– finding out the current effectiveness.

The use of gaming computer technologies in the study of the subjects under consideration does not contradict legislative norms. As an example, let us consider the occupational safety briefings: introductory, primary (at the workplace), repeated, unplanned, targeted. According to the current laws and regulations, their forms and methods are determined by the employer, which means that he/she can use one or another digital solution. Checking the knowledge about labor protection, the employer is also guided by local regulations.

The organizer independently selects technical means and visual aids for training on more complex topics: practicing skills in providing first aid to victims and the use of personal protective equipment.

Thus, it is permissible to use computer games, virtual, augmented and mixed reality technologies to study a number of topics on occupational safety.

[6] Shilov A. V, Shampanov S. O, Yamshchikov S. A. Obuchayushchaya komp'yuternaya igra po elektrobezopasnosti. Electronic Library of the Belarusian-Russian University. Available from: http://e.biblio.bru.by/bitstream/handle/1212121212/12542/343-344.pdf?sequence=1&isAllowed=y (accessed 22.10.2022). (In Russ.).

Table 3 presents possible options for the participation of different categories of employees in occupational safety training using gaming computer technologies.

Table 3

Participation of various categories of employees in the study of industrial safety standards with the help of gaming computer technologies

Technology	Type of training	Topic of training	Category of employees
AR, MR	Introductory briefing	Hazard sources. Actions in an emergency	Newly hired employees
	Occupational safety briefing at the workplace	Hazard sources established by a special assessment of working conditions and occupational risks. Working conditions, harmful, hazardous factors	All employees, except those exempt from briefing by order of the employer
	Verification of knowledge of labor protection requirements	Labor protection	Workers who have been instructed and trained in labor protection
VR	Internship at the workplace	Working out practical skills of safe performance of work	Employees who have successfully passed instruction and training on labor protection
	First aid training	First aid for loss of consciousness, respiratory arrest, bleeding, injuries, etc.	Those, who are authorized to instruct and provide first aid. Workers who manage machines and mechanisms. Others (by the decision of the employer)
	Training on the use of PPE	Personal protective equipment	Employees using PPE, the use of which requires practical skills

Discussion and Conclusion. The considered gaming computer technologies can be adapted for teaching occupational health and safety in agriculture. This approach can increase the success of solving such educational tasks as: instructing, illustrating theoretical material, consolidating and verifying knowledge, working out skills.

Let us list the advantages of the introduction of digital gaming technologies in the occupational safety training:

1) greater flexibility in choosing the time of classes;

2) high-quality interactive simulation of real experience [6, 15];

3) focusing the player's attention on specific tasks: what to do, what to avoid [5];

4) low costs (in comparison with the development of skills when using real machines in a real production situation) [16];

5) complete error safety in the gaming environment;

6) the possibility to conduct part of the training remotely [17].

The disadvantages that limit the spread of gamification as a popular learning technology should also be noted:

1) lack of interaction with real working materials [18];

2) psychosomatic reactions of players (dizziness, headache, eye fatigue) [19];

3) unavailability at some enterprises (especially in agriculture) of high-speed Internet, as well as 3D, VR, AR, MR technologies [20].

It is worth noting that with the development of digital technologies, it will be possible to overcome the shortcomings noted above. Solutions will become more accessible, the range of games will significantly expand, and the realism of simulations will increase. In addition, domestic analogues can be developed for various industries and activities.

References

1. Galyanov I. V., Studennikova N. S. Types and causes of severe accidents in agriculture and the main directions for their prevention. National Interests: Priorities and Security. 2015;27:47–60. (In Russ.).

2. Alekseenko A. S., Tsaits M. V. Usloviya truda i bezopasnost' raboty operatorov mobil'nykh sel'skokhozyaistvennykh mashin v APK Respubliki Belarus'. Bulletin of the Belarusian State Agricultural Academy. 2019;2:280–285. (In Russ.).

3. Studennikova N. S. Overview of traumatism in crop production in Russia and foreign countries. National Interests: Priorities and Security. 2018;14(3):541–557. (In Russ.).

4. Leiter M. P., Day A. L., Harvie P., Shaughnessy K. Personal and organizational knowledge transfer: Implications for worklife engagement. Human Relations. 2007;60:259–283. https://doi.org/10.1177/0018726706076025

5. Vigoroso L., Caffaro F., Micheletti Cremasco M., Cavallo E.Innovating Occupational Safety Training: A Scoping Review on Digital Games and Possible Applications in Agriculture. International Journal of Environmental Research and Public Health. 2021;8(4):1868. https://doi.org/10.3390/ijerph18041868

6. Mohd N. I., Ali K. N., Bandi S., Ismail F. Exploring gamification approach in hazard identification training for Malaysian construction industry. International Journal of Built Environment and Sustainability. 2019;6:51–57. https://doi.org/10.11113/ijbes.v6.n1.333

7. Albert A., Hallowell M. R., Kleiner B. et al. Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality. Journal of Construction Engineering and Management. 2014;140:1–11. 10.1061/(ASCE)CO.1943-7862.0000860

8. Dholakiya N. D., Ferjencik M., Schofield D., Kubík J. Virtual learning for safety, why not a smartphone? Process Safety Progress. 2018;38(1). https://doi.org/10.1002/prs.12005

9. Brown L. D., Poulton M. M. Improving safety training through gamification: An analysis of gaming attributes and design prototypes. Advances in Intelligent Systems and Computing. 2019;780:392–403. https://doi.org/10.1007/978-3-319-94223-0_37

10. Catton J., Shaikhi R., Fowler M., Fraser R. Designing and developing an effective safety program for a student project team. Safety. 2018;4:21. https://doi.org/10.3390/safety4020021

11. Greuter S., Tepe S. Engaging students in OH&S hazard identification through a game. In: Proceedings of the Digital Games Research Association Conference, 2013, Atlanta, Georgia. Available from: https://www.researchgate.net/publication/259044058_Engaging_students_in_OHS_hazard_identification_through_a_game (accessed: 03.09.2022).

12. Lanzotti A., Vanacore A., Tarallo A. et al. Interactive tools for safety 4.0: Virtual ergonomics and serious games in real working contexts. Ergonomics. 2020;63:324–333. https://doi.org/10.1080/00140139.2019.1683603

13. Chodan C., Mirza-Babaei P., Sankaranarayanan K. Safety does not happen by accident, can gaming help improve occupational health and safety in organizations? Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management. 2017;10287:321–332. 10.1007/978-3-319-58466-9_29

14. Gilotta S., Spada S., Ghibaudo L., Isoardi M. A technology corner for operator training in manufacturing tasks. In: Proceedings of the 20th Congress of the International Ergonomics Association. 2019. P. 935–943. 10.1007/978-3-319-96071-5_96

15. Williams-Bell F. M., Kapralos B., Hogue A. et al. Using Serious Games and Virtual Simulation for Training in the Fire Service: A Review. Fire Technology. 2014;51:553–584. https://doi.org/10.1007/s10694-014-0398-1

16. Leba M., Ionicã A., Apostu D. Educational Software based on Gamification Techniques for Medical Students. Recent Advances in Information and Communication Technology. 2014:225–230. https://doi.org/10.13140/2.1.2901.8881

17. Amal G. K., Mclain M. L., Bijlani K. et al. A Novel Approach for Training Crane Operators. In: Proceedings of the 2016 IEEE Eighth International Conference on Technology for Education (T4E). 2016. P. 116–119. 10.1109/T4E.2016.030

18. Hafsia M., Monacelli E., Martin H. Virtual Reality Simulator for Construction workers. In: Proceedings of the Virtual Reality International Conference.Laval Virtual, 2018. P. 1–7. 10.1145/3234253.3234298

19. Liang Z., Zhou K., Gao K. Development of Virtual Reality Serious Game for Underground Rock-Related Hazards Safety Training. IEEE Access. 2019;7:118639–118649. https://doi.org/10.1109/ACCESS.2019.2934990

20. Craig C. Understanding perception and action in sport: How can virtual reality technology help? Sports Technology. 2014;6:161–169. 10.1080/19346182.2013.855224

Received 05.09.2022

Revised 30.09.2022

Accepted 30.09.2022

About the Authors:

Kontareva, Valentina Yu., Associate professor, Department of Life Safety, Mechanization and Automation of Technological Processes and Productions, Don State Agrarian University (24, Krivoshlykova str., Persianovsky, Rostov region, RF, 346493), Cand.Sci. (Eng.), ORCID, valia_k@bk.ru

Belik, Vladimir V., Student, Computer Science and Computer Engineering Faculty, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344003, RF), ORCID, superbelik@mail.ru

Claimed contributorship:

V. Yu. Kontareva — formulation of the basic concept, analysis of the research results, revision of the text, correction of the conclusions. V. V. Belik — formulation of the goals and objectives of the study, preparation of the text, formulation of the conclusions.

Conflict of interest statement

The authors do not have any conflict of interest.

All authors have read and approved the final manuscript.

TECHNOSPHERE SAFETY

Original article
UDC 630.43: 634.0.43
https://doi.org/10.23947/2541-9129-2022-4-22-29

Comparative Analysis of Environmental Risks of Wildfires in the Baikal Region

Svetlana S. Timofeeva ✉, **Vladimir V. Garmyshev**, **Aleksandra Yu. Astrakhantseva**

Irkutsk National Research Technical University (Irkutsk, Russian Federation)

✉ sstimofeeva@mail.ru

Abstract

Introduction. The article is devoted to the problems of ecological consequences of forest fires in protected areas. It is proposed to assess atmospheric air pollution during forest fires and their impact on public health by the calculated method of specific emissions and hazard coefficients. The aim of the work is to perform a comparative analysis of environmental risks for the populations of three subjects of the Russian Federation in the Baikal region, and ranking of territories by the level of atmospheric air pollution during forest fires.

Materials and Methods. The initial data were statistical information on forest fires in the Irkutsk region, the Republic of Buryatia, the Trans-Baikal Territory in the period from 2013 to 2020, procedural documents of forest fires, including schemes and types of fires, areas and coordinates of fires, protocols of inspection of the fire site, acts of official investigation and other materials.

Results. The paper analyzes forest fires in the protected Baikal natural area of the Baikal region and their environmental consequences. The emphasis is placed on establishing the average annual characteristics of forest fires (number, area, economic damage, specific emissions of combustion product into the atmosphere, risks to public health). It is proved that bulk emissions from forest fires bring additional atmospheric pollution; it is 20 % of stationary sources of emissions. The Republic of Buryatia and the Irkutsk region contribute the most to the pollution of the atmosphere of the Baikal region.

Discussion and Conclusion. The methodology proposed by the authors for ranking territories by environmental risks can be used for predictive assessment of the consequences of fires for public health. The forecast results serve to support organizational and administrative measures, including decisions to attract additional forces and equipment, and to evacuate the population. According to the results of the forecast of the consequences of fires for the health of the population, a fire-fighting plan is being developed, which determines the methods and tactics of fire extinguishing, the distribution of forces and means, the decisive direction of actions, etc. According to the greatest contribution to the deterioration of living conditions and the risk of poisoning by combustion products, the studied territories are ranked in the following order: Irkutsk region – Republic of Buryatia – Trans-Baikal Territory.

Keywords: forest fires, environmental risk, pollution, forecasting, Baikal natural area, ranking.

For citation. Timofeeva S. S., Garmyshev V. V., Astrakhantseva A. Yu. Comparative Analysis of Environmental Risks of Wildfires in the Baikal Region. Safety of Technogenic and Natural Systems, 2022, no. 4, pp. 22‒29. https://doi.org/10.23947/2541-9129-2022-4-22-29

Introduction. Forest and landscape fires are among the most terrible and dangerous natural disasters that are widespread in the modern world and in the Russian Federation. Every year, people and animals die from uncontrolled fire, forests are destroyed, the oxygen and heat balance of the Earth is disrupted, the atmosphere, soil, water resources are polluted, there is toxic poisoning by combustion products and destabilization of the habitual lifestyle of the population, as well as air, river communications, rail and automobile traffic [1, 2]. Forest fires cause significant disturbances in aerodynamics and the state of the environment. The resulting convective flows spread gaseous combustion products and aerosols over considerable distances and cause significant harm to human health, the environment, and affect weather conditions [3, 4].

The constantly increasing number of fires and their size determine the relevance of the study of hazardous factors — the direct and indirect effects of the consequences of forest fires on ecosystems and human health [5, 6]. The forecast assessment of the impact of bulk emissions of combustion products of forest fires is currently not sufficiently developed. It is required to apply a systematic approach that allows taking into account the hazardous factors of fires, including the likelihood of risks to human health. Of undoubted scientific interest is the development of an integrated approach to assessing damage from forest fires, including a comparison of environmental losses at the level of specially protected areas.

The work objective is to perform a comparative analysis of environmental risks for the population of three subjects of the Russian Federation from the Baikal region, and to rank the territories by the level of atmospheric air pollution during forest fire.

Materials and Methods. The initial data were statistical information on forest fires in the Irkutsk region, the Republic of Buryatia and the Trans-Baikal Territory in the period from 2013 to 2020, procedural documents of forest fires, including schemes and types of fires, areas and coordinates of fires, protocols of inspection of the fire site, acts of official investigation and other materials.

Results. The paper analyzes forest fires in the specially protected Baikal natural territory of the Baikal region, their environmental consequences. The emphasis is placed on the establishment of the average annual characteristics of forest fires (number, area, economic damage, specific emissions of combustion products into the atmosphere, risks to public health) in the Baikal natural area, which has a special status.

As you know, the Baikal region covers the territory of the Baikal watershed and includes three subjects of the Russian Federation (Irkutsk Region, Trans-Baikal Territory and the Republic of Buryatia), as well as Mongolia. In accordance with Federal Law No. 94-FZ "On the Protection of Lake Baikal" of May 1, 1999, we distinguish the Baikal Natural Territory — the territory that includes Lake Baikal, the water protection zone adjacent to Lake Baikal, its catchment area within the territory of the Russian Federation, specially protected natural territories adjacent to Lake Baikal, as well as the territory adjacent to Lake Baikal with a width of up to 200 kilometers to the west and northwest of it. This territory is divided into three ecological zones — the central, buffer and ecological zones of atmospheric influence, for each of which the nature management regime is defined (Fig. 1).

Fig. 1. Map of the Baikal natural territory[1]

The Baikal natural area, as well as the Baikal region as a whole, is characterized by high forest cover. For example, the territory of the Irkutsk region has the highest forest cover (78 %) among the subjects of the Russian Federation. There are 21.6 hectares of forested area per capita in the Irkutsk region, which is almost 5 times more than the average in the Russian Federation and 84 times more than in Western Europe. 11.1 % of the all-Russian reserve of mature wood is concentrated on the territory of the region, and the share of the region for coniferous species is 13.4 %. The total area of land occupied by forests in the Republic of Buryatia, as of 01.01.2018, was 29,805.9 thousand hectares or 84.8 % of the total area of the republic. Almost the entire territory of Buryatia is covered with forests, most of which consists of coniferous trees (89.4 % of the total stock of forest plantations). The Trans-Baikal Territory ranks eighth in Russia in terms of the size of the felling-area resources available for forest use. Total forest reserves are estimated at 2.71 billion m^3 [7]. As of January 1, 2018, the total forest area of the Trans-Baikal Territory amounted to 34,065.8 thousand hectares. The probability of forest fires in the region is high.

The study is based on the analysis of statistical data of the Ministry of Forestry of the Irkutsk region, the Republican Forestry Agency of the Republic of Buryatia, the Chita Forest Protection Aviation Base, the Ministry of Emergency Situations for the period from 2013 to 2020 [8-10]. The authors carried out calculations using their own or involved methods [8-10]. At the first stage, the mass of substances released from forest fires was measured. The masses of substances were determined according to the method of the authors of the article, taking into account: the area of forest fires (ha), the combustion completeness coefficient, the emission coefficient, the stock of combustible material (kg/m^2). The assessment of possible adverse effects on public health — environmental risks — was assessed by hazard coefficients (HQ) and indices (HI) in accordance with the "Guidelines for assessing the risk to public health when exposed to chemicals that pollute the environment" [11].

It is established that annually on the territory of the Baikal region for the period from 2013 to 2020, an average of 3158 forest, 472 steppe and 30 peat fires occurred, as a result of which about 1,128.2 thousand hectares of natural territory were destroyed. Table 1 shows the authors' calculations based on the average values of the numbers of forest fires and their areas in the Baikal region based on information from sources [8–10].

[1] Baikal Natural Territory. Protected Baikal Region. Available from: https://baikal-1.ru/tourism/baikal-natural-territory (accessed 02.08.2022). (In Russ.).

Table 1

Average annual number and area of forest fires, taking into account their types in the Baikal region (2013–2020)

Research object	Ground fire				Crown fire				Peat fire	
	Running		Independent		Running		Independent		Independent	
	$n_п$, pcs.	$S_п$, thousand hectares	$n_п$, pcs.	$S_п$, thousand hectares	$n_п$, pcs.	$S_п$, thousand hectares	$n_п$, pcs.	$S_п$, thousand hectares	$n_п$, pcs.	$S_п$, thousand hectares
Irkutsk region	383.3	57.7	896.7	134.8	8	15.6	18	29.3	9.4	7.9
Republic of Buryatia	236	79.2	639	184.8	6	6.4	15	11.9	13.0	6.9
Trans - Baikal Territory	141	36.2	685	92.5	8	15.1	23	26.9	8.9	7.5

During the studied period, there were mainly ground fires (98 % of the total number) in the Baikal natural territory, as a result of which 80.6 % of forest territories were destroyed.

Based on the information on the species composition of forests in the studied territories, the mass of burned forest-forming species was estimated. It was established that 972.7 thousand tons of pine, 825.1 thousand tons of larch and 664.0 thousand tons of cedar were destroyed per year (based on the information from sources [8–10]) (Table 2).

Table 2

Number of burnt forest-forming species in the Baikal region (average for 2013–2020)

Types of forest-forming species	Mass of burnt forest-forming species, t year^{-1}			
	Irkutsk Region	Republic of Buryatia	Trans-Baikal Territory	Baikal region
Pine tree	490 971.7	346 253.2	135 478.6	972 703.5
Fir	78 319.6	86 325.4	35 647.6	200 292.6
Silver fir	28 052.8	35 624.4	26 895.4	90 572.6
Larch	421 899.4	254 187.5	148 967.7	825 053.9
Cedar	165 965.4	325 684.5	142 369.4	634 019.3
Birch tree	229 178.0	189 635.0	125 461.0	544 274.0
Aspen	66 316.0	52 784.0	36 889.0	155 989.0

Table 3

Average annual economic damage from the loss of wood destroyed in the Baikal region during forest fires (authors' calculations according to [8–10])

Forest-forming species	Irkutsk Region		Republic of Buryatia		Trans-Baikal Territory		Baikal region
	Price, rub. per solid m^3	Damage, million rubles	Price, rub. per solid m^3	Damage, million rubles	Price, rub. per solid m^3	Damage, million rubles	Damage, million rubles
Pine tree	19.8	15.2	18.7	10.12	17.4	3.68	29
Fir	17.3	2.42	16.3	2.51	15.2	0.97	5.9
Silver fir	17.3	0.97	16.3	1.16	15.2	0.82	2.95
Larch	19.8	10.2	18.7	5.79	17.4	3.16	19.15
Cedar	19.8	5.86	18.7	10.87	17.4	4.42	21.15
Birch tree	6.6	1.68	6.2	1.31	5.7	0.79	3.78
Aspen	1.2	0.13	1.1	0.09	1.1	0.065	0.28

It is established that the annual economic damage from the destruction of forest-forming species, calculated as the product of wood destroyed in a fire by the cost of 1 solid m^3, is: in the Irkutsk region — 36.46 million rubles, in the Republic of Buryatia — 31.85 million rubles, in the Trans-Baikal Territory — 13.91 million rubles. The total economic damage in the Baikal region is about 82.22 million rubles (Table 3).

The mass of the i-th type of toxicant released into the atmosphere during wildfires was determined by formula:

$$G_i = K_{ai}^{ЛГМ} \cdot m^{ЛГМ} \cdot K_{ai}^{Д} \cdot m^{Д} \cdot K_{ai}^{Т} \cdot m^{Т}, \quad (1)$$

where G_i — mass of the i-th type of toxic substance released into the atmosphere; $K_{ai}^{ЛГМ}$— emission coefficient of the i-th toxicant during the combustion of forest fuel, т/т; $m^{ЛГМ}$ — mass of burnt forest fuel, t; $K_{ai}^{Д}$ — emission coefficient of the i-th toxicant during the combustion of wood, t/t; $m^{Д}$ — mass of burnt wood (stand, crown), t; $K_{ai}^{Т}$ — emission coefficient of the i-th toxicant during the combustion of peat, peat soils, t/t; $m^{Т}$ — mass of burnt peat, peat soils, t.

The calculations have established that the average mass of eco-toxicants entering the atmosphere during fires in the Baikal region reaches 1,465 thousand tons, of which extremely dangerous substances — 0.2 thousand tons, highly dangerous — 4.34 thousand tons, moderately dangerous — 425.1 thousand tons, low-hazard — 517.28 thousand tons, other pollutants — 517.57 thousand tons (Table 4).

Table 4

Annual emission of combustion products by hazard classes as a result of wildfires and fires in 2013–2018 on the territory of the Baikal region

Research object	Atmospheric pollution by hazard classes of toxicants, thousand tons·year^{-1}				Other pollutants, thousand tons·year^{-1}
	Class I, extremely dangerous	Class II, highly dangerous	Class III, moderately dangerous	Class IV, low-risk	
Irkutsk region	0.08	1.97	197.95	240.70	240.04
Republic of Buryatia	0.06	1.38	143.10	171.78	165.20
Trans - Baikal Territory	0.06	0.99	84.07	104.80	112.33

The mass of uncontrolled emissions of toxic substances from forest fires depends on the season of the year (Table 5). The maximum emission of toxicants is observed in the spring (43.6%) and summer (48.4%) periods, in the autumn the emission of toxicants is insignificant (8%).

Table 5

Average annual mass of emissions of toxic combustion products into the atmosphere of the Baikal region, taking into account the time of year

Research object	Mass of emissions, thousand tons per year^{-1}			Total value, thousand tons/year
	Spring	Summer	Autumn	
Irkutsk region	297.3	329.9	54.5	681.7
Republic of Buryatia	209.9	233.1	38.5	481.5
Trans - Baikal Territory	131.9	146.3	24.1	302.3

The analysis of the population's treatment in hospitals in the region during the study period showed reliable signs of deterioration in the health of people in the smoke-filled zone. This fact is confirmed by the quantitative growth of the following indicators:

– respiratory diseases — 7.0 %;
– exacerbation of chronic bronchitis — 4.8 %;
– exacerbation of bronchial asthma — 5.9 %;
– exacerbation of cardiovascular diseases — 4.4 %;
– hospitalizations — 5.7 %;
– exacerbation of chronic diseases — 6.3 %.

The calculations have established that the average area of smoke in the Baikal region was 6.7 % (Table 6), and the specific load of the atmosphere with toxic combustion products in the Baikal region is 2.95 t/km^2·year^{-1} (Table 7). The average annual mass of emissions from wildfires is 37.84 % of the average annual mass of emissions from stationary sources of pollution.

Table 6

Average annual area of smoke on the territory of the Baikal region
as a result of wildfires in 2013–2020

Research object	Area of smoke, thousand km^2	As a percentage of the area of the region
Irkutsk region	57.6	7.5
Republic of Buryatia	27.5	7.8
Trans - Baikal Territory	20.7	4.8

Table 7

Average annual specific load on the atmosphere by toxic combustion products
in the Baikal region (2013–2018)

Research object	Area of the territory, km^2.	Amount of pollutants from stationary sources of pollution, thousand tons per year^{-1}	Specific load on the atmosphere from stationary sources of pollution, t/km^2·year^{-1}	Mass of gross emissions of toxic combustion products, t·year-^{1}	Specific load on the atmosphere with toxic combustion products, t/km2·year^{-1}
Irkutsk region	767 900	3 640.5	4.74	681 740	0.88
Republic of Buryatia	351 334	107.2	0.31	481 530	1.37
Trans - Baikal Territory	431 892	125.3	0.29	302 250	0.70
Baikal region	1 551 126	3873	5.34	1 465 520	2.95

The work assessed violations of living conditions and health risk ($R_{N\ \text{забол.}}$), according to formula:

$$R_{N\ \text{забол.}} = S_{\text{заг.}} \cdot 0.9 \cdot \Pi_{\text{нас.}}; \qquad (2)$$

where $S_{\text{заг.}}$ — the area of territory contamination, km^2; 0.9 — coefficient that takes into account the proximity of the fire to the populated area; $\Pi_{\text{нас.}}$ — population density in the region, people/km^2.

The number of potential victims who could get sick from poisoning as a result of wildfires, based on the authors' calculations, is presented in Table 8.

Table 8

Assessment of violations of living conditions and the risk to human health
in the Baikal region (average for 2013–2018)

Research object	Population density, people/km^2	Area of pollution, km^2	Number of potential victims who could get sick from poisoning with toxic combustion products as a result of wildfires, people.
Irkutsk region	3.1	53 352	148 852.1
Republic of Buryatia	2.8	26 448	66 648.9
Trans - Baikal Territory	2.5	19 559	44 007.7
Baikal region	2.8	99 359	259 508.7

Discussion and Conclusion. The methodology proposed by the authors for ranking territories by environmental risks can be used for predictive assessment of the consequences of fires for public health. The results of the forecast serve to take organizational and administrative measures, including decisions on the involvement of additional forces and equipment, on the evacuation of the population. According to the results of the forecast of the consequences of fires for the health of the population, a fire extinguishing plan is being developed, which determines the methods and tactics of fire elimination, the distribution of forces and means, the decisive direction of hostilities, etc. According to the greatest contribution to the deterioration of living conditions and the risk of poisoning by combustion products, the studied territories are ranked in the following order: Irkutsk region – Republic of Buryatia – Trans-Baikal Territory.

Thus, the authors have carried out a comparative analysis of the levels of atmospheric air pollution from forest fires in the Baikal region and found that:

– bulk emissions of toxic combustion products into the atmosphere make an additional contribution to the pollution of the atmosphere of the Baikal region. The annual emission of eco-toxicants into the atmosphere is about 20% of the mass of pollutants from stationary sources of pollution in the region;

– the Republic of Buryatia (the specific load on the atmosphere with toxic combustion products is 1.37 $t/km^2 \cdot year^{-1}$) and the Irkutsk region (the specific toxic load is 0.88 $t/km^2 \cdot year^{-1}$) make the greatest contribution to the pollution of the specially protected Baikal natural territory, the share of the Trans-Baikal Territory accounts for 0.70 $t/km^2 \cdot year^{-1}$;

– according to the deterioration of living conditions and the risk of getting poisoning by combustion products, the studied territories are ranked in the following order: Irkutsk Region – Republic of Buryatia – Trans-Baikal Territory;

– the assessment of potential risk to public health by the hazard coefficient from exposure to combustion products showed that their values range from 0.9 to 47, the maximum values were recorded in the Irkutsk region;

– based on the above studies and the assessment of the contribution of forest fires to the deterioration of the ecological situation, a comparison of the subjects of the Russian Federation of the Baikal region by gross emissions of toxic combustion products was carried out. It is established that the Irkutsk region is the most environmentally risky territory.

References

1. Yurova A. Yu., Paramonov A. V., Konovalov I. B. et al. Forecast of the intensity of thermal radiation and aerosol emission from forest fires at the Central European region. Optika Atmosfery i Okeana. 2013;26(3):203–207. (In Russ.).

2. Samsonov Yu. N., Popova S. A., Belenko O. A., Chankina O. V. Chemical composition and disperse characteristics of aerosol smoke emission from fires in boreal Siberian forests. Optika Atmosfery i Okeana. 2008;21(6):523–531. (In Russ.).

3. Timofeeva S. S., Garmyshev V. V., Zyryanov V. S. Smoke situation when burning forest combustible materials in urban and suburban areas of cities. Proceedings of Irkutsk State Technical University. 2012;3(62):50–55. (In Russ.).

4. Timofeeva S. S., Garmyshev V. V. Environmental Impacts of Forest Fires on the Territory of Irkutsk Oblast. Ecology and Industry of Russia. 2017;21(3):46–49. https://doi.org/10.18412/1816-0395-2017-3-46-49 (In Russ.).

5. Rukavishnikov V. S., Efimova N. V., Elfimova T. A. Izuchenie riska zdorov'yu pri kratkovremennoi ingalyatsionnoi ekspozitsii v usloviyakh lesnykh pozharov. Hygiene and Sanitation. 2013;92(1):50–52. (In Russ.).

6. Elfimova T. A., Efimova N. V. Approbation of the method for rapid assessment of effects of forest fires health exposed population. Modern problems of science and education. 2016;6:103. Available from: https://science-education.ru/ru/article/view?id=25634 (accessed 14.08.2022). (In Russ.).

7. Egorova A. V. Features of the Baikal natural territory. Vektor GeoNauk. 2020;3(2):58–63. https://doi.org/10.24411/2619-0761-2020-10019 (In Russ.).

8. Analysis of operational and service activities of the state fire supervision of the Irkutsk region for 2014-2020. Irkutsk: The Ministry of Emergency Situations of Russia in the Irkutsk region, 2015-2020. 20 p. (In Russ.).

9. Analysis of the situation with fires and their consequences on the territory of the Republic of Buryatia for 2014-2020. Ulan-Ude: The Ministry of Emergency Situations of Russia in the Republic of Buryatia, 2015–2020. 20 p. (In Russ.).

10. Analysis of the situation with fires and their consequences on the territory of the Trans-Baikal Territory for 2014-2020. Chita: The Ministry of Emergency Situations of Russia in the Trans—Baikal Territory, 2015-2020. 21 p. (In Russ.).

11. Guidelines for assessing the risk to public health when exposed to chemicals that pollute the environment: P 2.1.10.1920-04. Moscow, 2004. 143 p. (In Russ.).

Received 15.08.2022.
Revised 13.09.2022.
Accepted 13.09.2022.

About the Authors:

Timofeeva, Svetlana S., Head, Department of Industrial Ecology and Life Safety, Irkutsk National Research Technical University (83, Lermontov str., Irkutsk, 664074, RF), Dr. Sci. (Eng.), Professor, ScopusID, ORCID, sstimofeeva@mail.ru

Garmyshev, Vladimir V., Associate professor, Department of Industrial Ecology and Life Safety, Irkutsk National Research Technical University (83, Lermontov str., Irkutsk, 664074, RF), Cand.Sci. (Eng.), ScopusID, ORCID, diamant1959@mail.ru

Astrakhantseva, Aleksandra Yu., Postgraduate student, Department of Industrial Ecology and Life Safety, Irkutsk National Research Technical University (83, Lermontov str., Irkutsk, 664074, RF), ORCID, aleksandraastra@yandex.ru

Claimed contributorship:

S. S. Timofeeva — formulation of the basic concept, goals and objectives of the study, calculations, preparation of the text, formulation of the conclusions. V. V. Garmyshev — analysis of the research results, revision of the text, correction of the conclusions. A. Yu. Astrakhantseva — collection and analysis of information, calculations.

Conflict of interest statement

The authors do not have any conflict of interest.

All authors have read and approved the final manuscript.

TECHNOSPHERE SAFETY

Original article
UDC 614.84
https://doi.org/10.23947/2541-9129-2022-4-30-41

Experience of Application of GOST R 59638-2021 for the Analysis of Statistics of False Alarms of the Fire Alarm System on the Example of a Multifunctional Shopping and Entertainment Complex

Dmitriy A. Siksimov ✉, **Vitaliy E. Merenyashev**
Don State Technical University, Russian Federation, Rostov-on-Don
✉ dasiksimov@list.ru

Abstract
Introduction. In 2021, new regulatory legal acts in the field of fire safety came into force. Special attention is paid to the control, classification and minimization of false alarms of fire protection systems and installations. In this regard, it makes sense to refer to the statistics of such triggers on specific objects in order to assess the sufficiency and validity of the criteria proposed in the new documents. The purpose of the work is to study the requirements for maintenance and operation of fire protection systems and installations. The objectives of this study are to study the main approaches to the regulation of false alarms of fire protection systems, analysis of the main quantitative indicators of the operation of systems of a particular object, assessment of the compliance of the protection object with new requirements.
Materials and Methods. The empirical basis of the study was the results of constant monitoring of the state of fire protection systems and installations in one of the largest shopping and entertainment complexes in the South of Russia. The reports of the fire prevention service, data from the automated workplace of the operator of the fire station, records in operational logs were used. The information is summarized in tables by types of false alarms and by chronology. Calculations were performed in MS Excel. To identify the links between different types of false positives, a correlation analysis was carried out.
Results. The connection between the number of false alarms and the intensity of work of tenants of the protection object is noted. The ratios of different types of false alarm and the significance of the triggering factors are determined. The correlation between false alarms and malfunctions of systems is revealed.
Discussion and Conclusion. The methodology developed by the authors makes it possible to monitor malfunctions of fire alarm systems on an ongoing basis. A number of problematic issues of applying the classification of false alarms of the fire alarm system in GOST R 59638-2021 have been identified. A connection has been established between the number of false alarms and the intensity of the work of the tenants of the shopping center. The conclusion is made about the compliance of the protection object with the newly introduced requirements. The identified problematic issues of the application of GOST R 59638-2021 for statistical analysis in future studies force us to develop a different classification of false alarms of fire alarm systems.

Keywords*:* fire alarm system, false alarms, shopping and entertainment complex, GOST.

For citation. Siksimov D. A., Merenyashev V. E. Experience of Application of GOST R 59638-2021 for the Analysis of Statistics of False Alarms of the Fire Alarm System on the Example of a Multifunctional Shopping and Entertainment Complex. Safety of Technogenic and Natural Systems, 2022, no. 4, pp. 30−41. https://doi.org/10.23947/2541-9129-2022-4-30-41

Introduction. Fire alarm systems (FAS) are the primary link in the functioning of fire protection systems. Its operation gives a start to actions to identify the source of fire and evacuation, informs the duty officer, turns on automatic fire extinguishing devices. Since 2021, new regulatory legal acts in the field of fire safety have been in force in Russia. Special attention is paid to the issues of control, classification and minimization of false alarms of fire protection systems and installations. In this regard, it makes sense to refer to the statistics of false alarms on specific objects. The data obtained in this way will allow us to assess the sufficiency and validity of the criteria proposed in the new regulatory documents.

The work objective is to study the requirements for maintenance and operation of fire protection systems and installations. The compliance with the standard for the number of false alarms was investigated at a specific object of protection. To achieve the goal, the following tasks have been completed:

– study of the main approaches to the rationing of false alarms of fire protection systems;

– analysis of the main quantitative indicators of the operation of fire protection systems of a particular object;

– assessment of compliance of the object of protection with the regulatory requirements in force since 2021.

It should be noted that the statistics of false alarms of fire protection systems were not the subject of scientific analysis. The reasons are listed below.

First. There is no access to this information. The relevant statistics are owned by the security services and management of economic entities.

Second. The large amount of information to be analyzed and the complexity, ambiguity of the criteria for attributing the alarm to false or justified present certain difficulties.

Third. Statistics on the alarms activation are considered secondary and insignificant. Only the information about fires and their consequences is centrally collected, systematized and published[1, 2, 3] [1]. The studies of the effectiveness and operability of fire alarm systems at various hazardous facilities have been published [2-4]. Turn-outs of fire and rescue units are recorded, but if the cause was a false alarm, then only the number of such cases are analyzed. The reasons are not considered. In addition, not every false alarm leads to the turn-out of firefighters [5].

Materials and Methods. The empirical basis of the study was the results of constant monitoring of the state of fire protection systems and installations of one of the largest shopping and entertainment complexes in the South of Russia. It is a four-storey building with a total area of 121,306 m^2. Premises and groups of premises of functional fire hazard classes: F2.1, F3.1, F3.2, F4.3, F5.1, F5.2. The facility is equipped with the following systems:

– addressable fire alarm;

– type 4 evacuation alerts and controls;

– smoke protection;

– gas, as well as sprinkler and drencher water fire extinguishing systems;

– announcement of fire notifications (FN).

The facility has implemented an algorithm C according to SP 484.1311500.2020[4]. FAS has about 12 thousand addressable devices, including about 9 thousand detectors.

Since 2019, constant monitoring has been conducted. The presented scientific work is based on data from 01.01.2019 to 30.06.2021. The information is obtained from the reports of the fire prevention service, system logs of the automated workplace of the fire station operator, operational logs. The information is summarized in tables by types of false alarms and by date [6, 7].

Since 2021, regulatory legal acts in the field of fire safety have been in force in Russia, which have fixed the need for control and corrective measures for false alarms of automatic fire protection systems and installations.

[1] Gordienko D. M. (Ed.) Pozhary i pozharnaya bezopasnost' v 2019 godu. Statisticheskii sbornik. Moscow: VNIIPO, 2020. 80 p. (In Russ.).
[2] Gordienko D. M. (Ed.) Pozhary i pozharnaya bezopasnost' v 2020 godu. Statisticheskii sbornik. Moscow: VNIIPO, 2021. 112 p. (In Russ.).
[3] Goncharenko V. S., Chechetina T. A., Sibirko V. I. et al. Pozhary i pozharnaya bezopasnost' v 2021 godu. Statisticheskii sbornik. Balashikha: FGBU VNIIPO MChS Rossii, 2022. 114 p. (In Russ.).
[4] SP 484.1311500.2020. Regulation. Fire alarm systems and automation of fire protection systems. Designing and regulations rules. Ministry of Emergency Situations of Russia. Available from: https://sudact.ru/law/prikaz-mchs-rossii-ot-31072020-n-582/sp-484.1311500.2020/ (accessed 14.03.2022). (In Russ.).

The first of them is SP 484.1311500.2020. "Regulation. Fire alarm systems and automation of fire protection systems. Designing and regulations rules". The document was approved and put into effect by the Order of the Ministry of Emergency Situations of Russia. It defines a false alarm as a fire notification generated in the absence of fire hazards[5]. FAS design should be aimed at the following tasks:

– timely detection of fire;

– reliable fire detection;

– collection, processing and presentation of information to the staff on duty;

– interaction with other fire protection systems (formation of the necessary initiating control signals) and engineering systems of the facility.

The reliability of detection in accordance with clause 6.1.3 is ensured by:

– selection of types of fire detectors;

– the choice of the algorithm for making a decision about a fire;

– protection against false alarms.

Protection against false alarms is based on the use of detectors that do not respond to factors similar, but not related to fire. To solve the problem, you should also use:

– multicriteria detectors;

– shielded cables;

– twisted pair cables;

– fiber-optic communication lines;

– algorithms for making a decision about B or C fire.

It is obvious that measures to ensure the reliability of detection correspond to the measures to protect against false alarms.

Let us consider another document —Order of the Ministry of Emergency Situations of Russia of June 7, 2021 No. 364 "On approval of the list of indicators of the risk of violation of mandatory requirements in the implementation of Federal state fire supervision" It is valid from 01.07.2021[6]. One of the indicators of the risk of violating mandatory requirements is three or more false alarms within thirty calendar days. Such a frequency of false alarm activation is the basis for unscheduled control and supervisory measures for the protected facility. The rule applies to objects where at the same time there can be 50 or more people (except residential buildings).

Finally, since September 15, 2021, the new GOST R 59638–2021 "Fire alarm systems. Guidance on the design, installation, maintenance and repair. Performance test methods" is valid[7]. It should be noted that the provisions of this GOST are not mandatory now, since it is not in the "List of documents in the field of standardization, as a result of the application on a voluntary basis of which the compliance with the requirements of Federal Law No. 123–FZ of July 22, 2008 "Technical Regulations on Fire Safety Requirements" is ensured[8]. Nevertheless, it is known that the control of false alarms of fire protection systems and installations is being tightened. Therefore, the inclusion of the GOST in question in the list is a matter of time[9]. Below are its main innovations.

First. A false alarm (fire) is defined as a notification of a fire in its absence.

Second. The classification of the causes of false alarms and their division into categories is introduced. The reasons for false alarms are described.

---

[5] SP 484.1311500.2020.

[6] Ob utverzhdenii perechnya indikatorov riska narusheniya obyazatel'nykh trebovanii pri osushchestvlenii federal'nogo gosudarstvennogo pozharnogo nadzora. Ministry of Emergency Situations of Russia. Available from: https://docs.cntd.ru/document/603896733 (accessed 14.03.2022). (In Russ.).

[7] GOST R 59638-2021. Fire alarm systems. Guidance on the design, installation, maintenance and repair. Performance test methods. Federal Agency for Technical Regulation and Metrology Available from: https://protect.gost.ru/default.aspx/document1.aspx?control=31&baseC=6&page=4&month=9&year=2021&search=&id=241176 (accessed 14.03.2022). (In Russ.).

[8] Perechen' dokumentov v oblasti standartizatsii, v rezul'tate primeneniya kotorykh na dobrovol'noi osnove obespechivaetsya soblyudenie trebovanii Federal'nogo zakona ot 22 iyulya 2008 g. No. 123-FZ "Tekhnicheskii reglament o trebovaniyakh pozharnoi bezopasnosti". Federal Agency for Technical Regulation and Metrology Available from: https://docs.cntd.ru/document/565314055 (accessed 14.03.2022). (In Russ.).

[9] Technical Regulations on Fire Safety Requirements: Federal Law No. 123-FZ. State Duma, Federation Council. Available from: https://docs.cntd.ru/document/902111644 (accessed 14.03.2022). (In Russ.).

1. Unwanted triggering. FAS was triggered as a result of exposure to factors similar to fire factors or unintentional impact on a fire manual detector.

2. Malfunction. FAS was triggered as a result of an equipment malfunction.

3. Hooliganism. FAS was triggered as a result of malicious actions.

4. Erroneous activation. FAS was triggered as a result of conscientious actions when a person activated FAS, suspecting that a fire had broken out.

5. Unknown reason.

GOST R 59638–2021 introduces an acceptable frequency of false alarms. This is an annual indicator. It takes into account one false alarm for every 500 m^2, rounded up. If the calculated value is less, the maximum allowable indicator is 12 false alarms. The frequency of false alarms in one fire alarm control zone or room should not exceed four alarms per year. If an object is provided for automatic transmission of fire notifications to a fire and rescue unit (fire notification system — FNS), then the unit may set higher requirements for the permissible number of false alarms. However, they should not exceed the following values:

– one false alarm for every 5 thousand m^2 of the object's area per year (rounded up);

– six false alarms per year per object as a whole.

At the same time, in the first year of operation of the facility, the number of false alarms may be higher. This is not considered a violation of the requirements if measures were taken to reduce the frequency of false alarms.

When compiling a statistical sample, it was taken into account that according to clause 6.5.9 of GOST R 59638-2021, the operation of a fire detector switched on according to the "And" scheme (algorithm C) may not be counted as false. However, in the daily practice of the protected facility, in our opinion, such triggers should be considered as false. This allows you to present in more detail the technical condition and performance of FAS. Accordingly, the sample included cases when the system:

– signals a fire and starts the fire automation algorithm;

– gives a "pre-alarm" signal without starting the algorithm.

Results. All actuations are classified in accordance with GOST R 59638-2021. The exception was the episodes when the alarm was turned on due to insects getting into the detector. GOST R 59638-2021 defines such cases as a malfunction. In our opinion, they should be attributed to unwanted triggers, because the optical pair of the detector reacts to dimming in the same way as in case of fire. "Erroneous activation of the "pre-alarm" signal was excluded, because such a situation is impossible: activation of a manual fire detector is in any case accompanied by a "fire" signal. Simultaneous operation of several detectors caused by a common cause for a maximum of 1.8 thous. s. was counted as one operation in accordance with GOST R 59638-2021.

Table 1 provides summary data on FAS false alarms in 2019.

Table 1

Summary data on FAS false alarms in 2019

Cause for FAS actuation according to GOST R 59638-2021	Month																							
	01		02		03		04		05		06		07		08		09		10		11		12	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
"fire" signal																								
Unwanted actuation			1	5.0															1	5.0			1	5.0
Malfunction	1	5.0					1	5.0					1	5.0										
Hooliganism																								
Erroneous																								
Unknown cause																								
"pre-alarm" signal																								
Unwanted actuation	17	5.5	2	0.6	10	3.2	10	3.2	7	2.3	8	2.6	0		18	5.8	14	4.5	10	3.2	5	1.6	11	3.5
Malfunction	8	2.6	3	1.0	2	0.6	7	2.3	0		3	1.0	3	1,0	2	0,6	0		1	0,3	0		0	
Hooliganism																								

Cause for FAS actuation according to GOST R 59638-2021	Month																							
	01		02		03		04		05		06		07		08		09		10		11		12	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Unknown cause	0		2	0.6	1	0.3	0		3	1.0	6	1.9	1	0.3	4	1.3	2	0.6	0		0		2	0.6
Total	26		8		13		18		10		17		5		24		16		12		5		14	
Including "fire" signals	1		1		0		1		0		0		1		0		0		1		0		1	
Including "pre-alarm" signals	25		7		13		17		10		17		4		24		16		11		5		13	
Total within a year	**168**																							
Including "fire"	6																							
Including "pre-alarm" signals	162																							

The proportion of actuations for one reason or another was calculated from the total number of actuations from 01.01.2019 to 30.06.2021. The total number of false alarms for all this time was 330. Of these, a "fire" signal was activated in 20 cases, and a "pre-alarm" signal — in 310 cases. The final figures were rounded to tenths. In 2019, 6 false alarms "fire" were recorded. This corresponds to the maximum value that can be set by a fire and rescue unit in the presence of FNS (this is exactly the case at the object under study). Let us mention also that the number of unwanted actuations is equal to the number of malfunctions.

Table 2 provides summary data on FAS false alarms in 2020.

Table 2

Summary data on FAS false alarms in 2020

Cause for FAS actuation according to GOST R 59638-2021	Month																							
	01		02		03		04		05		06		07		08		09		10		11		12	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
"fire" signal																								
Unwanted actuation			2	10.0					1	5.0													1	5.0
Malfunction							1	5.0							2	10.0			1	5.0				
Hooliganism																								
Erroneous activation																								
Unknown cause																								
"pre-alarm" signal																								
Unwanted actuation	8	2.6	6	1.9	9	2.9	1	0.3	1	0.3	4	1.3	4	1.3	11	3.5	4	1.3	2	0.6	4	1.3	7	2.3
Malfunction	1	0.3	1	0.3	1	0.3	1	0.3	0		0		1	0.3	0		0		0		0		1	0.3
Hooliganism																								
Unknown cause	0		1	0.3	0		1	0.3	2	0.6	5	1.6	3	1.0	0		4	1.3	4	1.3	1	0.3	1	0.3
Total	9		10		10		4		4		9		8		13		8		7		5		10	
Including "fire" signals	0		2		0		1		1		0		0		2		0		1		0		1	
Including "pre-alarm" signals	9		8		10		3		3		9		8		11		8		6		5		9	
Total within a year	**97**																							
Including "fire" signals	8																							
Including "pre-alarm" signals	89																							

In the conditions of the COVID-19 pandemic, shopping and entertainment complexes did not work. The object of protection in question was closed to visitors from 01.04.2020 to 30.06.2020. Nevertheless, false "fire" alarms were recorded more often than in 2019. There were 8 actuations in total. As noted above, this exceeds the maximum value set by the fire and rescue unit for this shopping center. The number of unwanted actuations, as in 2019, corresponded to the number of malfunctions.

In 2020, there were 3 false "fire" alarms, which should be considered in more detail. In February 2020, twice with an interval of 6 days, signals of a drop in water pressure in the water extinguishing system were recorded. As a result, the FAS issued a "fire" signal and launched a fire-fighting algorithm. A similar event took place in May 2020. The examination showed the good condition of the pressure detector. It follows from this that the drop in water pressure in the system corresponded to the situation of a real fire (the thermal locks of the sprinklers are triggered, the pressure in the system drops, fire pumps start working). Nevertheless, the incidents are connected with a malfunction — leakiness of the distribution water pipe of the water extinguishing section. Accordingly, the malfunction created the conditions that arise in a real fire. GOST R 59638-2021 does not contain unambiguous criteria for attributing such a trigger to unwanted actuations or malfunctions. In this sample, they were attributed to unwanted actuations, since the FAS, in fact, worked normally, responding to the conditions arising from a fire.

Table 3 provides summary data on FAS false alarms in January — June 2021.

Table 3

Summary data on FAS false alarms in January — June 2021

Cause for FAS actuation according to GOST R 59638-2021	Month											
	01		02		03		04		05		06	
	n	%	n	%	n	%	n	%	n	%	n	%
"fire" signal												
Unwanted actuation			1	5.0					1	5.0	2	10.0
Malfunction							1	5.0	1	5.0		
Hooliganism												
Erroneous activation												
Unknown cause												
"pre-alarm" signal												
Unwanted actuation	5	1.6	5	1.6	7	2.3	9	2.9	3	1.0	8	2.6
Malfunction	1	0.3	0		0		2	0.6	2	0.6	1	0.3
Hooliganism												
Unknown cause	3	1.0	6	1.9	0		2	0.6	0		5	1.6
Total	9		12		7		14		7		16	
Including "fire" signals	0		1		0		1		2		2	
Including "pre-alarm" signals	9		11		7		13		5		14	
Total within a year	**65**											
Including "fire" signals	6											
Including "pre-alarm" signals»	59											

From 01.01.2021 to 30.06.2021 there were 6 false "fire" signals. At the same time, the number of unwanted actuations exceeded the number of malfunctions. However, this does not mean anything, given that the data were recorded for six months. In 2020, in the first half of the year, the indicator of unwanted actuations also exceeded the indicator of malfunctions, but by the end of the year the difference was leveled. We note two false alarms in particular:

– the fluid pressure alarm in the water extinguishing section was triggered due to a violation of the tightness of the pipeline (classified as an unwanted actuation on the grounds mentioned before);

– "fire" signal was activated and the fire–fighting algorithm was started during the programming of the system.

From the point of view of GOST R 59638-2021, such alarms are false, but the given classification criteria require clarification and raise new questions. We should note, in particular, that the alarm system may turn on during preventive or other work on FAS equipment. GOST does not provide for such an operation. It cannot be classified as erroneous actuation, hooliganism and unknown cause. There remains a malfunction, which is also incorrect. In general, the fault criteria in GOST R 59638-2021 require clarification.

During the study, since 2019, 20 FAS false alarms with "fire" signal have been recorded at the protection facility. Of these, 11 (55%) were classified as unwanted actuations, 9 (45%) — as a malfunction. The number of false alarms per month did not exceed 2. FAS worked without false signals for no more than two months in a row. No actuations were detected due to hooliganism, erroneous actuation and for an unknown cause.

Let us consider false alarms with a "pre-alarm" signal. On average, for all analyzed periods, one false "fire" alarm accounted for 15.5 false "pre-alarms" (Table 4).

Table 4

Total number of false alarms with "fire" and "pre-alarm" signals

	n	%
"Fire"	**20**	**100.0**
Unwanted actuation	11	55.0
Malfunction	9	45.0
"Pre-alarm"	**310**	**100.0**
Unwanted actuation	210	67.7
Malfunction	41	13.2
Unknown cause	59	19.0

An unknown cause may trigger a false alarm signal (triggering of one detector switched on according to the logical scheme "And"). In the situation with the "fire" signal, such cases are not recorded.

Table 5 provides modal, median and average values for FAS triggering with the "pre-alarm" signal.

Table 5

Modal, median and average values for FAS triggering with the "pre-alarm" signal

Year 2019		**Year 2020**		**Year 2021**	
Mode		**Mode**		**Mode**	
Unwanted actuation	10.0	Unwanted actuation	4.0	Unwanted actuation	5.0
Malfunction	0.0	Malfunction	1.0	Malfunction	1.0
Unknown cause	0.0	Unknown cause	1.0	Unknown cause	0.0
Median		**Median**		**Median**	
Unwanted actuation	10.0	Unwanted actuation	4.0	Unwanted actuation	6.0
Malfunction	2.0	Malfunction	0.5	Malfunction	1.0
Unknown cause	1.5	Unknown cause	1.0	Unknown cause	2.5
Average		**Average**		**Average**	
Unwanted actuation	9.3	Unwanted actuation	5.1	Unwanted actuation	6.2
Malfunction	2.4	Malfunction	0.5	Malfunction	1.0
Unknown cause	1.75	Unknown cause	1.8	Unknown cause	2.7

Let us note that the most common cause of "pre-alarms" is unwanted actuation (210, or 67.7%). This is due to work at the facility. The examples include:

– disconnection and malfunction of the hood during cooking;

– oil and smoke emissions;

– ironing and steaming of clothes;

– fire-hazardous work;

– dust pollution of detectors during construction, installation and repair.

Obviously, the frequency of such actuations will be due to the intensity of work of tenants of a multifunctional shopping and entertainment complex. The total number of FAS malfunctions that generated the "pre-alarm" signal is 41, or 13.2 % of the total number of "pre-alarms". False alarms for unknown causes occurred 59 times (19.0 %).

Standard deviations and sample variances give the following picture. The largest spread of data relative to the average value is demonstrated by unwanted actuations ($D(x)$ = 19.9). Accordingly, the maximum standard deviation (σ = 4.5) is noted for this indicator, which is not surprising, given the high randomness of the parameter. The spread of data on false alarms due to malfunctions and unknown causes gives similar values: $D(x)$ = 3.8 and σ = 1.9; $D(x)$ = 3.7 and σ = 1.9, respectively.

The "pre-alarms" analysis gives the following results. In 2019, with intense activity of tenants, the modal value is 10 false alarms per month. The indicator corresponds to the median, i.e. the entire sample for this parameter splits into two equal parts. The most frequent value of false alarms due to malfunctions is 0, but in this case the mode does not correspond to the median and average indicators — 2 and 2.4 alarms, respectively. The situation is similar with the results of actuations for unknown causes — 0, 1.5 and 1.75, respectively.

In 2020, the highest frequency of unwanted FAS actuations is 4 per month. The indicator, as in 2019, is equal to the median. The modal value for false alarms due to malfunctions is 1 per month. The indicator is close to median and average values. Triggering for an unknown reason was recorded no more than 1 time per month, which is equal to the median indicator with an average of 1.8.

In 2021, with the growth of tenants' activity, the indicators of unwanted actuations increased. The maximum frequency reached 5 per month, which is close to the median one — 6 and the average one — 6.2. In 2021, 1 actuation due to malfunctions was recorded every month. FAS false alarms for unknown causes give a spread: 0, 2.5 and 2.7. Most likely, this is due to the fact that the sample included data for only six months.

Table 6 provides the structural averages for the entire monitoring period.

Table 6

Structural averages for "pre-alarms" for the entire monitoring period

Mode	
Unwanted actuation	4.0
Malfunction	0.0
Unknown cause	0.0
Median	
Unwanted actuation	7.0
Malfunction	1.0
Unknown cause	1.5
Average	
Unwanted actuation	7.0
Malfunction	1.4
Unknown cause	2.0

The indicators of structural averages for the entire period of the study differ significantly from the annual ones. This also proves the connection of FAS false alarms in the shopping center with the tenants' activity. In 2019, high rates were recorded with the most intense activity of tenants. The shutdown during the pandemic was accompanied by a decrease in the number of FAS false alarms.

To identify the links between different types of FAS false alarms, we conducted a correlation analysis for all monitoring periods. The following correlations were revealed in the sample under study:

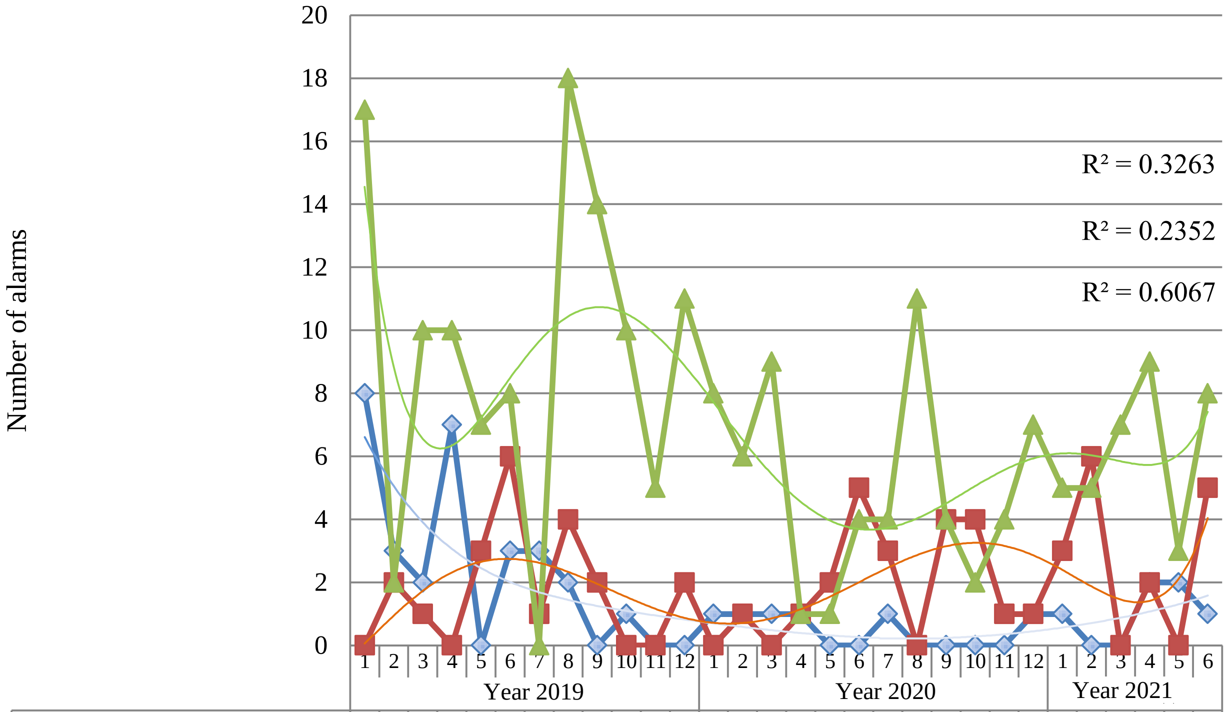
– unwanted actuation and malfunction — moderate positive correlation (Rxy = 0.35);

– unwanted actuation and unknown cause — weak negative correlation (Rxy = –0.12);

– malfunction and unknown cause — weak negative correlation (*Rxy* = –0.24).

The assessment of the significance of the identified correlations by the Student's t-criterion allows us to consider only a moderate positive relationship as significant. Apparently, it is explained by some dependence between the tenants' activity (unwanted actuations) and the intensity of construction, installation, repair and fire-hazardous work (unwanted actuations and malfunctions caused by interference with the FAS).

Figure 1 provides the dynamics of FAS false alarms for various causes.



	Year 2019												Year 2020												Year 2021					
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
Malfunction	8	3	2	7	0	3	3	2	0	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	1	0	0	2	2	1
Unknown cause	0	2	1	0	3	6	1	4	2	0	0	2	0	1	0	1	2	5	3	0	4	4	1	1	3	6	0	2	0	5
Unwanted actuation	17	2	10	10	7	8	0	18	14	10	5	11	8	6	9	1	1	4	4	11	4	2	4	7	5	5	7	9	3	8

Fig. 1. FAS false alarms

Peak values of unwanted actuations most often coincide with periods of high consumer activity. This is the time of the most intensive activity of the shopping center tenants. This situation is recorded in December, January, March, April and August. In June, the most frequent entry of insects into the detectors was noted. The dynamics are also illustrated by polynomial trend lines. The highest approximation coefficient was obtained when constructing the fault dynamics trend line (R^2 = 0.6067), the lowest is associated with actuations for an unknown cause (R^2 = 0.2352). There is a clear trend of a decrease in false alarms due to unwanted actuations and malfunctions in the first half of 2020. Then, in 2021, these indicators are growing, which, as noted above, is most likely due to the lifting of the pandemic restrictions.

The total dynamics of all false alarms for the analyzed periods is shown in Fig. 2.

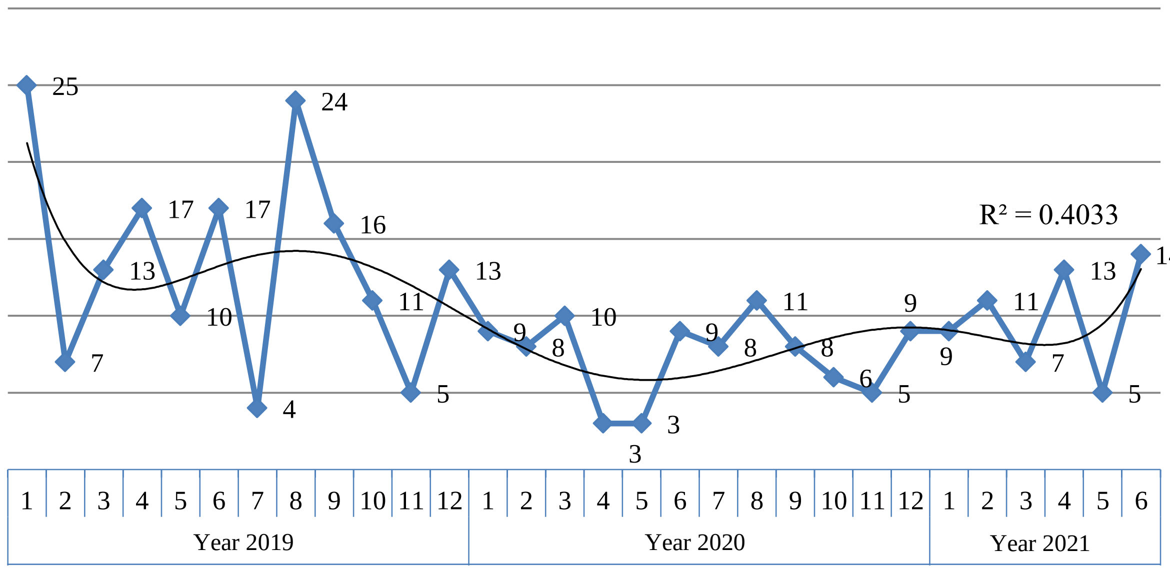


Fig. 2. Total dynamics of FAS false alarms

Let us note that the false triggering of the "pre-alarm" signal was recorded in each month. The frequency of false alarms is related to the tenants' activity. A polynomial trend line with an approximation coefficient of 0.4033 confirms the trends identified earlier when considering individual periods.

Discussion and Conclusion. The conducted research allows us to draw a conclusion regarding the applicability of GOST R 59638-2021 for the classification and analysis of statistics of FAS false alarms on a specific object.

Firstly, we note that the accepted classification is based on enlarged criteria; therefore it does not give an idea of the specific cause of actuation. More promising for future research is an analysis based on specific types of triggering (for example, violations during fire-hazardous work, non-compliance with the rules of operation of technological equipment, unauthorized interference in the system, improper operation of the system, etc.).

Secondly, there are difficulties in correlating specific actuations with GOST classification. Let us identify three main issues.

1. Attribution to malfunctions of insects entering the detector. From a technical point of view, in our opinion, this is an unwanted actuation. The detector reacts to changes in the light environment, and this is a factor similar to the effect of smoke in a fire.

2. The ambiguity of attribution to malfunction and unwanted actuation of cases when FAS is switched on normally. This happens if a faulty related fire automation system operates in conditions similar to a fire. The paper considers the situation with a pressure drop in an automatic fire extinguishing system.

3. The proposed classification excludes cases of actuation during preventive and other work related to the maintenance of the system (work on its programming is considered).

Thirdly, GOST R 59638-2021 does not contain a direct indication of the need to analyze FAS false signals when a fire detector is activated, switched on according to the logical scheme "And" (algorithm C). The wording "may not be taken into account as a false alarm" seems incorrect. The analysis of such situations (in the case of "pre–alarm") makes it possible to:

– predict the number of false alarms;

– evaluate the performance of the system;

– identify the factors of false alarms and prevent them.

A connection has been established between the number of false alarms and the intensity of the work of the shopping center tenants. In addition, the analysis allowed us:

– to determine the proportion of different types of false alarms in general statistics and the significance of factors affecting FAS false actuation;

– to identify the correlation between unwanted actuations and malfunctions.

The statistics allow us to conclude that FAS of the considered object of protection meets the requirements of GOST R 59638-2021 and Order of the Ministry of Emergency Situations of Russia of June 7, 2021 No. 364 "On approval of the list of indicators of the risk of violation of mandatory requirements in the implementation of Federal state fire supervision".

References

1. Ustin V. G., Bulygin Yu. I., Tretyakov P. P. et al. Territorial fire statistics and assessment of their causes and consequences on the example of the Rostov region. Safety of Technogenic and Natural Systems. 2020;3:21−32. https://doi.org/10.23947/2541-9129-2020-3-21-32 (In Russ.).

2. Poroshin A. A., Kondashov A. A., Sibirko V. I., Goncharenko V. S. The state of fire alarm systems at protection facilities from 2016 to 2020. Safety of Technogenic and Natural Systems. 2021;3:40–46. https://doi.org/10.23947/2541-9129-2021-3-40-46 (In Russ.).

3. Poroshin A. A., Kondashov A. A., Sibirko V. I. Efficiency Assessment of Fire Alarm Systems Actuation at the Production Facilities for the Period 2016–2020. Occupational Safety in Industry. 2021;4:32–37. https://doi.org/10.24000/0409-2961-2021-4-32-37 (In Russ.).

4. Poroshin A. A., Kondashov A. A., Sibirko V. I. Estimation of the performance of the fire alarm systems at the residential facilities for the period from 2016 to 2020. Technology of technosphere safety. 2021;1(91):19–29. https://doi.org/10.25257/TTS.2021.1.91.19-32 (In Russ.).

5. Arslanov A. M., Matyushin Yu. A., Poroshin A. A. Estimation of the volume of departures of fire and rescue units FPS GPS EMERCOM of RUSSIA with a false response of automatic fire alarm. In: Aktual'nye problemy pozharnoi bezopasnosti: mat-ly XXXIII mezhdunar. nauch.-prakt. konf. Moscow: VNIIPO, 2021. P. 249–252. (In Russ.).

6. Kirsanov A. V., Kotlubovskaya T. V., Nadvotskaya V. V. Obespechenie bespereboinoi raboty sistemy pozharnoi signalizatsii na baze kompleksa Bosch FPA-5000. Polzunovskiy vestnik. 2014;2:157–159. (In Russ.).

7. Kudryavtsev V. A. Monitoring sistemy okhranno-pozharnoi signalizatsii. Automation, Communications, Informatics. 2011;11:11–13. (In Russ.).

Received 09.06.2022.

Revised 19.07.2022.

Accepted 19.07.2022.

About the Authors:

Siksimov, Dmitriy A., Master's degree student, Department of Life Safety and Environmental Protection, Don State Technical University (1, Gagarina sq., Rostov-on-Don, RF, 344003), ORCID, dasiksimov@list.ru

Merenyashev, Vitaliy E., Associate professor, Department of Life Safety and Environmental Protection, Don State Technical University (1, Gagarina sq., Rostov-on-Don, RF, 344003), Cand. Sci. (Mil.), associate professor, ORCID, papa@xorelse.com

Claimed contributorship

D. A. Siksimov — calculations, text preparation, analysis of the research results, formulation of the conclusions. V. E. Merenyashev — formulation of the basic concept, goals and objectives of the study, revision of the text, correction of the conclusions.

Conflict of interest statement

The authors do not have any conflict of interest.

All authors have read and approved the final manuscript.

MACHINE BUILDING

Original article
UDC 621.873.2:656.081
https://doi.org/10.23947/2541-9129-2022-4-42-50

Improving the Safety of Operation of Overhead Cranes with Welded Modular Construction Based on the Analysis of Their Accidents

Anatoliy A. Korotkiy[1] ✉, **Andrey N. Pavlenko**[1], **Elvira A. Panfilova**[1], **Dmitriy N. Simonov**[2]

[1] Don State Technical University (Rostov-on-Don, Russian Federation)

[2] LLC Engineering and Consulting Center «Thought» NSTU (Novocherkassk, Russian Federation)

✉ korot@novoch.ru

Abstract

Introduction. The article presents an analysis of the destruction of welds that occurred during the operation of modular overhead cranes. Measures are proposed to prevent the occurrence of such defects in the future, reduce the likelihood of accidents and improve the safety of operation of overhead cranes with a welded modular construction. The relevance of the work is due to the fact that in the Russian Federation approximately 65 % of the lifting cranes registered with Rostechnadzor have fulfilled the standard service life.

The work objective is to improve the safety of operation of modular overhead cranes and the reliability of their welded metal structures. Achieving the objectives of the work, based on the analysis of the destruction of metal structures of overhead cranes, a diagnostic map of welded joints of metal structures of end beams with modules of travelling wheels of overhead cranes was compiled. The use of the proposed diagnostic card in a production environment will significantly improve the quality of diagnostics of welded joints.

Materials and Methods. Investigations of accidents of load-bearing metal structures of cranes by methods of technical diagnostics of destruction of welds that occurred during the operation of overhead cranes of modular design have been carried out. This made it possible to develop a number of measures to prevent accidents of overhead cranes initiated by the destruction of their welded modular structures.

Results. Based on the analysis of accidents, a diagnostic map of destructing welded joints of metal structures of end beams with modules of travelling wheels of an overhead crane has been compiled. The use of the proposed diagnostic card will increase the reliability of welded metal structures and improve the quality of diagnostics of welded joints in production conditions.

Discussion and Conclusions. As a result of the analysis of structural failures of modular overhead cranes, a number of measures are proposed to prevent the formation of such defects, the occurrence of accidents due to them, and to improve the safety of operation of overhead cranes.

Keywords: overhead lifting crane with welded modular construction, safety, accident.

For citation. Korotkiy A. A., Pavlenko A. N., Panfilova E. A., Simonov D. N. Improving the Safety of Operation of Overhead Cranes with Welded Modular Construction Based on the Analysis of Their Accidents. Safety of Technogenic and Natural Systems, 2022, no. 4, pp. 42−50. https://doi.org/10.23947/2541-9129-2022-4-42-50

Introduction. Currently, overhead cranes with welded modular construction get widespread use in the Russian Federation. They are widely used in technological processes at various manufacturing facilities, which determines the degree of mechanization of loading and unloading operations, affects the costs of products and other technical and economic indicators of production.

At the moment, in the Russian Federation, approximately 65 % of lifting cranes registered with Rostechnadzor have fulfilled their standard service life [1]. The operation of overhead cranes that have worked out their service life is often accompanied by accidents with cases of industrial injuries and significant material damage. In accordance with Federal Law No. 116[1] the category of hazardous production facilities includes facilities where cranes are used, and the Federal Norms and Rules[2], regulate the expert examination of industrial safety of cranes.

With the introduction of Technical Regulations TR CU 010/2011 "On the Safety of Machinery and Equipment"[3], TR CU 011/2011 "Elevator Safety"[4], TR CU 018/2011 "On the Safety of Wheeled Vehicles"[5] the term "lifting crane safety" can be considered as "design safety" at all stages of the life cycle: design, manufacture and operation. Design safety violation can lead to an accident of the lifting structure. The issues of ensuring the strength of crane metal structures are considered in works [2–6], and from the standpoint of crane safety as a complex technical system in work [7].

The work objective is to improve the safety of operation of modular overhead cranes and the reliability of their welded metal structures. Based on the analysis of the destruction of metal structures of overhead cranes, a diagnostic assessment checklist of welded joints of metal structures of end beams with modules of running wheels of overhead cranes has been compiled. The use of the proposed diagnostic assessment checklist in production conditions will significantly improve the quality of diagnostics of welded joints.

Materials and Methods. Analysis of the operation of overhead cranes by technical diagnostics methods [8] shows that in recent years accidents have repeatedly occurred on such cranes initiated by the destruction of their welded modular structures. Moreover, such accidents occurred on overhead cranes with a welded modular structure, which worked for less than a quarter of their service life specified by the manufacturer[6]. Let us analyze the causes of accidents of overhead cranes with welded modular construction. The analysis of structural failures of modular overhead cranes will allow us to propose a number of measures to prevent the formation of such defects, the occurrence of accidents due to them, as well as to improve safety of operation of overhead cranes.

Results. The service life of lifting machines is regulated by state standards, technical specifications and other regulatory documents. Each crane has a certain service life specified in its technical data sheet. As a rule, the service life of a crane is determined by the service life of its load-bearing metal structures.

---

[1] Federal Law No. 116-FZ of 21.07.1997 (as amended on June 11, 2021) "On Industrial Safety of Hazardous Production Facilities". Available from: http://www.consultant.ru/document/cons_doc_LAW_15234 (accessed 03.08.2022). (In Russ.).

[2] Federal Norms and Rules in the field of industrial safety "Safety rules for hazardous production facilities where lifting facilities are used". Available from: https://sudact.ru/law/prikaz-rostekhnadzora-ot-26112020-n-461-ob/federalnye-normy-i-pravila-v/ (accessed 03.08.2022). (In Russ.).

[3] TR CU 010/2011 Technical Regulation of the Customs Union "On the Safety of Machinery and Equipment". Available from: https://docs.cntd.ru/document/902307904 (accessed 10.08.2022). (In Russ.).

[4] TR CU 011/2011 Technical Regulation of the Customs Union "Elevator Safety". Available from: https://docs.cntd.ru/document/902307835 (accessed 11.08.2022). (In Russ.).

[5] TR CU 018/2011 Technical Regulation of the Customs Union "On the Safety of Wheeled Vehicles". Available from: https://sudact.ru/law/reshenie-komissii-tamozhennogo-soiuza-ot-09122011-n_19/tr-ts-0182011/ (accessed 11.08.2022). (In Russ.).

[6] GOST 33709.1-2015 Cranes. Vocabulary. Part 1. General. Available from: https://docs.cntd.ru/document/1200135709?marker=7D20K3 (accessed 13.08.2022). (In Russ.).

For example, the reliability requirements according to GOST 27584-88[7] set the parameters for indoor overhead cranes not less than the values given in Table 1

Table 1

Indicator of service life and reliability for overhead cranes

Indicator of service life and reliability for overhead cranes	Norm for mode groups			
	1K, 2K	3K	4K, 5K	6K, 7K
Service life, years, minimum	30	25	25	20
Time between failures, cycles, minimum	11000			
Established no-failure operating time, cycles, minimum	32000		40000	64000
Established time between overhauls, cycles, minimum	30000	150000	190000	230000

Thus, for a crane of the 6K, 7K mode group with 1.5 shift work per day and the number of cycles of 5 per hour, the established no-failure operating time will be 64000/300×12×5=3.5 years.

The load-bearing metal structure of the double-girder overhead crane, shown in Fig. 1, consists of two span beams, along which a cargo trolley with a lifting mechanism moves, and two end beams with a crane mounting on them.

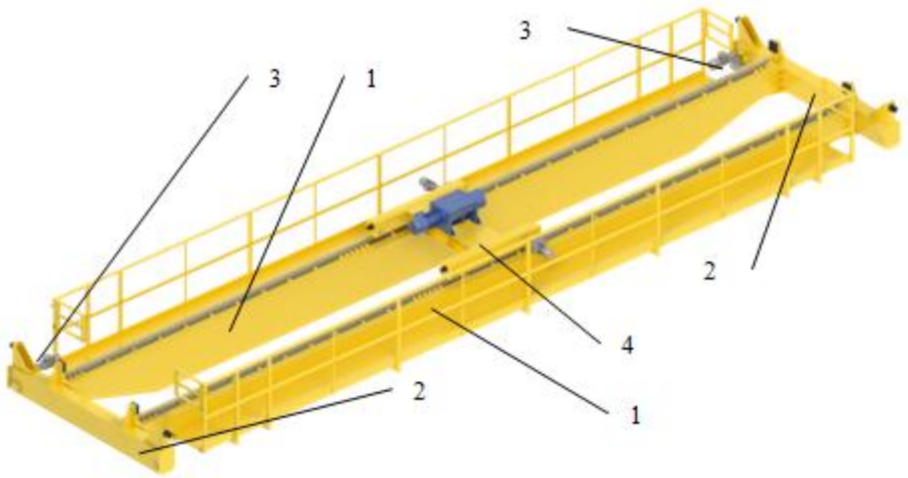


Fig. 1. General view of the metal structure of a double-girder overhead crane:
1 — span beams; 2 — end beams; 3 — crane mounting; 4 — cargo trolley

The typical metal structure of the end beam of a double-girder overhead crane, shown in Fig. 2, consists of belts (upper and lower), vertical walls and diaphragms placed inside the beam. As a rule, the vertical walls of the beams are made of a single sheet.

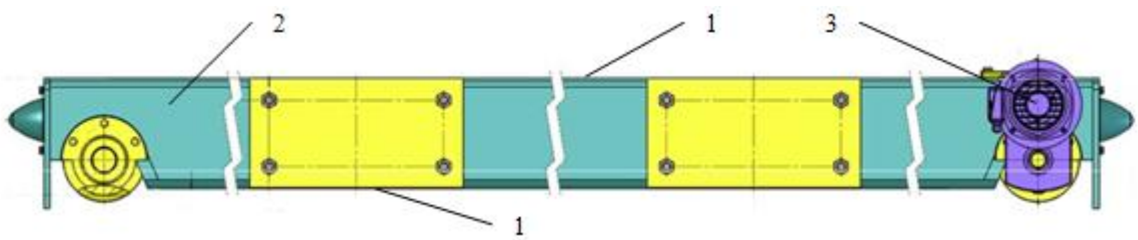


Fig. 2. General view of a typical metal structure of the end beam of a double-girder overhead crane: 1 — upper and lower belt; 2 — vertical walls; 3 — crane mounting

[7] GOST 27584-88 Electric overhead travelling cranes and gantry cranes. General specifications. Available from: https://docs.cntd.ru/document/1200004626 (accessed 19.08.2022). (In Russ.).

To install the undercarriage of a double-girder overhead crane, axle boxes with running wheels are attached to the end beams shown in Fig. 3.

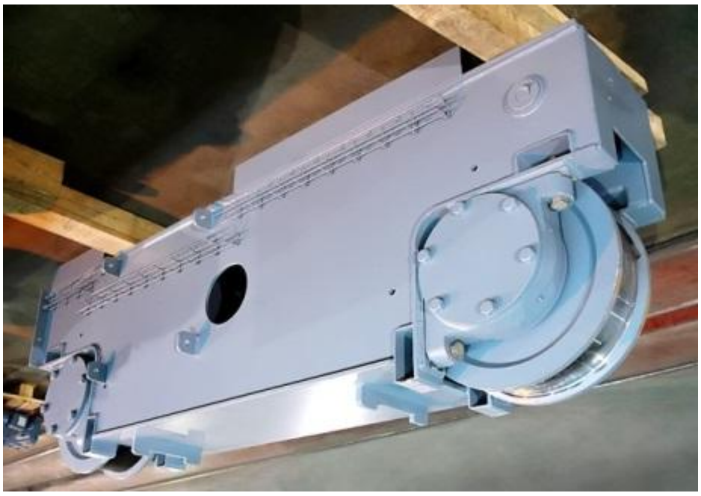


Fig. 3. Attachment of axle boxes with running wheels to the end beams of a double-girder overhead crane (photo by the authors)

Recently, modular designs of end beams with bolted (Fig. 4) or welded (Fig. 5) flange connections have become widespread.

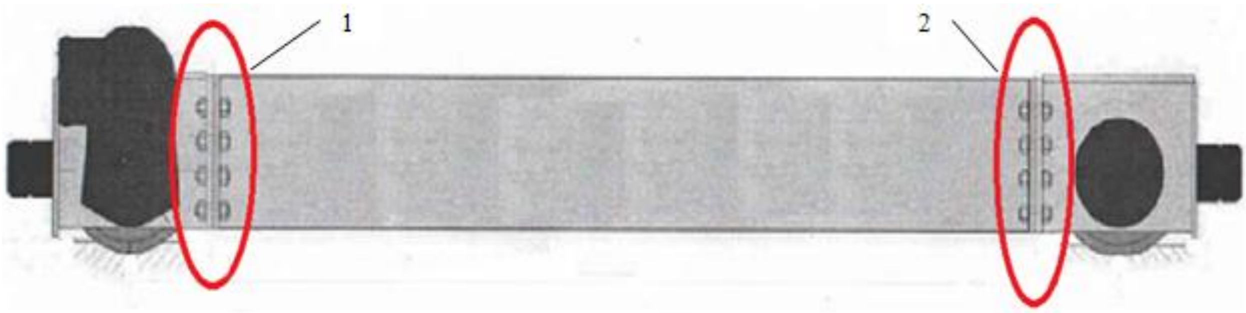


Fig. 4. Modular design of the end beam with bolted flange connection: 1 — flange connection of the drive wheel module; 2 — flange connection of the loose wheel module

Modular design makes it possible to reduce the dimensions of the end beams of the crane during its transportation to the installation site, but requires higher qualifications of specialists who install the crane in production conditions, especially modular construction with welded flange connection.

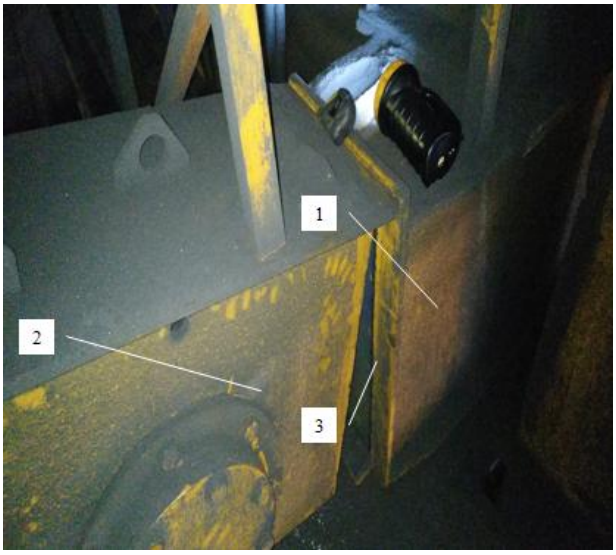
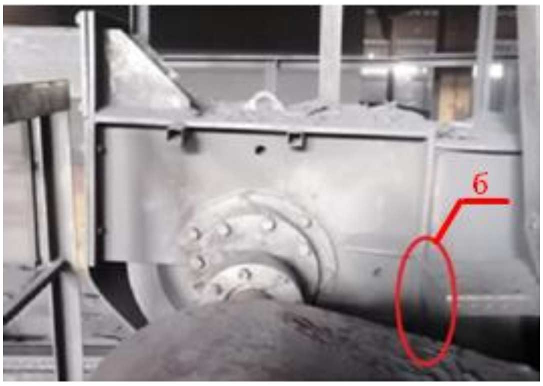


Fig. 5. Modular design of the end beam with a welded flange connection (photo by the authors): 1 — metal structure of the end beam; 2 — running wheel module; 3 — destroyed welded flange connection

The presence of a flange connection complicates the design of the end beam. In practice, there are accidents of overhead cranes caused by the destruction of the welded flange connection, shown in Fig. 6, of the undercarriage wheel module, both drive and loose, with an end beam.



a)

b)

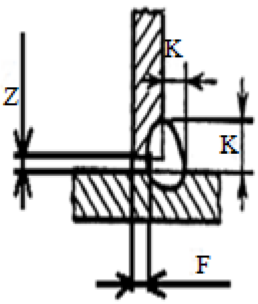
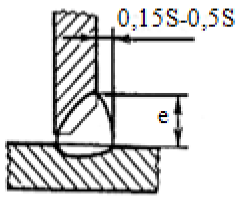
Fig. 6. Destruction of the welded joint of the drive wheel module with the end beam (photo by the authors): *a* — drive wheel module; *b* — destruction of the welded flange connection

The analysis of the causes of destruction of flange connection welds illustrated in Fig. 7, modular structures of overhead cranes allows us to prevent the appearance of such defects in the future, to increase the reliability of welded metal structures, to work out methods of diagnostics of welded joints in production conditions.

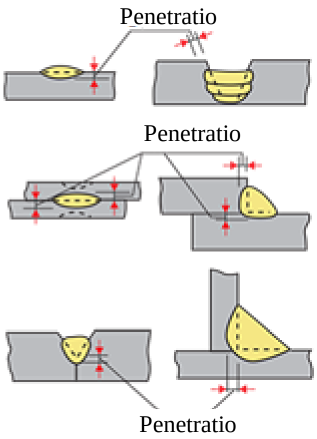
Based on the results of the survey using non–destructive testing methods [9–17], a diagnostic assessment checklist of welded joints of metal structures of end beams with modules of running wheels of an overhead crane with a lifting capacity of 10 tons was compiled, shown in Table 2.

Table 2

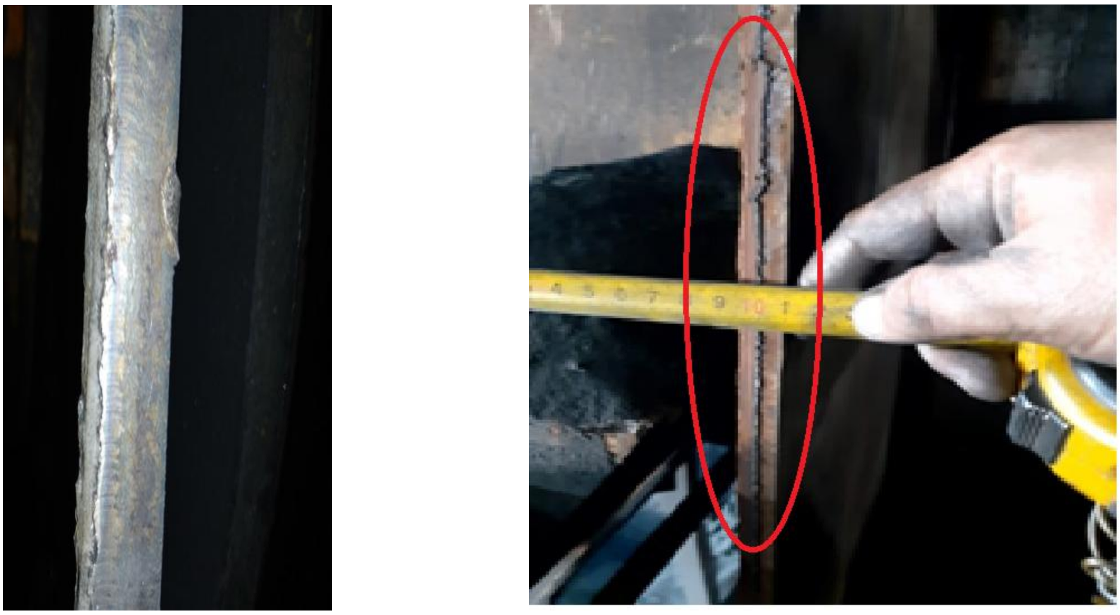
Diagnostic assessment checklist of welded joints of metal structures of end beams with modules of running wheels of an overhead crane with a lifting capacity of 10 tons

Parameter	Legend	Actual value	Recommended value
Welded joint design		T1 according to GOST 14771-76[8] – one-sided without edge preparation with constructive incomplete penetration	T6 according to GOST 14771-76 – with edge preparation 
Thickness of the metal to be welded, mm	S	10	10
Weld leg, mm, mm	K	K = 0.4s + 2 = 6	10 – 12
Gap between the metal to be welded, mm	Z	≈ 0	0 – 1.5

[8] GOST 14771-76 Gas-shielded arc welding. Welded joints. Main types, design elements and dimensions. Available from: https://docs.cntd.ru/document/1200004932 (accessed 25.08.2022). (In Russ.).

Parameter	Legend	Actual value	Recommended value
Penetration depth, mm	 H	≈ 0	1.5 – 2
Estimated height of the corner weld, mm	P	4.2	9
Estimated cross-sectional area of the weld, mm^2	F	18–20	50–70
Weld shape coefficient	$K_ф$	1.5	1.8
Calculated bearing capacity of the weld metal, kN/cm^2	$\frac{N}{\beta_f k_f l_w R_{wf} \gamma_c} \leq 1$	Estimated load-bearing capacity of 45% of the design one	Estimated load-bearing capacity of 100% of the design one

The connection unit of the undercarriage wheel module should be attributed to a heavy-loaded structure that receives loads from the crane's own weight, depends on the position of the cargo trolley in the crane span and the weight of the load lifted, receives dynamic loads from the state of the crane runway. The coefficient of shocks during the movement of the crane reaches a value of K = 1.3–1.4, and the horizontal component of the wheel pressure is R = 0.5 N, which should be taken into account when calculating the strength and durability of the structure.



a) *b)*

Fig. 7. The destroyed welded joint of the side wall of the end beam with the flange of the undercarriage wheel module (photo by the authors): *a* — penetration depth of the destroyed weld is close to zero; *b* — wall of the end beam with the destroyed weld

Discussion and Conclusion. The study presented above, in terms of improving safety of operation of modular overhead cranes and the reliability of their welded metal structures, shows that:

1. The structural safety of the modular end beam is reduced at the design stage by introducing an additional welded flange connection. The traditional design in the form of a continuous beam is more reliable in operation and has a longer service life.

2. At the manufacturing stage of the end beam, due to the unproven technological process of welding parameters, its structural safety was reduced to 45% of the required bearing capacity, which subsequently led to the complete destruction of the welded joint.

3. One-sided corner welds in the T-joints of metalwork elements should be used in structures of normal and reduced importance level according to GOST 27751-2014[9] classification. They should not be used in assemblies experiencing dynamic loads.

4. The purpose of the angle weld leg depending on the thickness according to formula K = 0.4s + 2 is acceptable for welded joints of general engineering products. For assemblies of crane metal structures that receive dynamic loads, the weld leg should be designed taking into account all possible combinations of loads.

5. The value of the weld strength coefficient φ is determined by the welding method and the weld design, which reduces its bearing capacity. For example, for a T-weld T1 with structural incomplete penetration φ = 0.65, for a welded seam T6 with full welding φ = 0.9–1.0.

6. Diagnostics of welded joints using visual and measuring control allows you to determine only surface defects, geometric parameters of the weld and their deviations. The thickness of the weld and the size of the structural incomplete penetration can be determined by ultrasonic testing using direct or inclined transducers.

References

1. Korotkiy A. A., Pavlenko A. N., Panfilova E. A., Simonov D. N. Questions of safety of load-lifting cranes structural connections. Safety of Technogenic and Natural Systems. 2022;1:41–47. https://doi.org/10.23947/2541-9129-2022-1-41-47 (In Russ.).

2. Moskvichev V. V., Makhutov N. A., Shokin Yu. I. et al. Prikladnye zadachi konstruktsionnoi prochnosti i mekhaniki razrusheniya tekhnicheskikh system. Novosibirsk: Nauka, 2021. 795 p. (In Russ.).

3. Makhutov N. A. Prochnost' i bezopasnost': fundamental'nye i prikladnye issledovaniya. Novosibirsk: Nauka, 2008. 522 p. (In Russ.).

4. Lepikhin A. M., Moskvichev V. V., Doronin S. V. Reliability, survivability and safety for complex technical systems. Computational Technologies. 2009;14(6):58–71. (In Russ.).

5. Doronin S. V., Reizmunt E. M., Rogalev A. N. Erratum to: Problems on Comparing Analytical and Numerical Estimations of Stressed-Deformed State of Structure Elements. Journal of Machinery Manufacture and Reliability. 2018;47(4):387–387. https://doi.org/10.3103/S1052618818040167

6. Doronin S. V., Reizmunt E. M., Rogalev A. N. Problems on Comparing Analytical and Numerical Estimations of Stressed-Deformed State of Structure Elements. Journal of Machinery Manufacture and Reliability. 2017;46(4):364–369. https://doi.org/10.3103/S1052618817040069

7. Kotelnikov V. S., Korotkii A. A., Pavlenko A. N., Eremin I. I. Diagnostika i risk-analiz metallicheskikh konstruktsii gruzopod"emnykh kranov. Ministry of Education and Science of the Russian Federation, South Russian State Technical University. University (Novocherkassk. polytech. institute). Novocherkassk: Educational and Production Center "Nabla" of the South Russian State Technical University (NPI), 2006. 315 p. (In Russ.).

[9] GOST 27751-2014 Reliability for constructions and foundations. General principles. Available from: https://docs.cntd.ru/document/1200115736 (accessed 03.09.2022). (In Russ.).

8. Lepikhin A. M. Nerazrushayushchii kontrol' i otsenka opasnosti defektov svarki na stadii ekspluatatsii oborudovaniya. Materials of science issues. 2007;3(51):208–213. (In Russ.).

9. Doronin S., Rogalev A. Numerical approach and expert estimations of multi-criteria optimization of precision constructions. CEUR Workshop Proceedings. 2018;2098:323–337.

10. Makhutov N. A. Bezopasnost' i riski: sistemnye issledovaniya i razrabotki. Novosibirsk: Nauka, 2017. 724 p. (In Russ.).

11. Birger I. A. Tekhnicheskaya diagnostika. 2nd ed. Moskva: URSS: LENAND, 2018. 238 p. (In Russ.).

12. Klyuev V. V., Lozovskii V. N., V Savilov. P. Klyuev V. V. (Ed.). Diagnostika detalei mashin i mekhanizmov: in 2 parts. Part 1. Moscow: Spektr, 2017. 176 p. (In Russ.).

13. Klyuev V. V. (Ed.). Nerazrushayushchii kontrol': spravochnik: in 8 volumes. V. 1: In 2 books. Book. 1: F. R. Sosnin. Vizual'nyi i izmeritel'nyi kontrol'. Kn. 2: Sosnin F. R. Radiatsionnyi kontrol'. 2nd ed., rev. Moscow: Mashinostroenie, 2008. 560 p. (In Russ.).

14. Lepikhin A. M. Risk-analiz mnogokomponentnykh sistem s mnogoochagovymi povrezhdeniyami. Tyazheloe mashinostroenie. 2009;6:23–24. (In Russ.).

15. Makhutov N. A., Albagachiev A. Yu., Alekseeva S. I. Prochnost', resurs, zhivuchest' i bezopasnost' mashin. Moscow: Book house "LIBROCOM", 2008. 574 p. (In Russ.).

16. Lepikhin A. M., Moskvichev V. V., Doronin S. V., Makhutov N. A. Probabilistic modeling of safe crack growth and estimation of the durability of structures. Fatigue & Fracture of Engineering Materials & Structures. 2000;23(5):395–401. https://doi.org/10.1046/j.1460-2695.2000.00303.x

17. Dusye V. E., Navarskii Yu. V., Zhegulskii V. P. Raschet i proektirovanie metallicheskikh konstruktsii mostovykh kranov: uchebnoe posobie. Ekaterinburg: UGTU-UPI, 2007. 133 p. (In Russ.).

Received 25.09.2022.
Revised 11.10.2022.
Accepted 11.10.2022.

About the Authors:

Korotkiy, Anatoliy A., Head, Department of Operation of Transport Systems and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344003, RF), Dr. Sci. (Eng), Professor, ORCID, korot@novoch.ru

Pavlenko, Andrey N., Associate professor, Department of Operation of Transport Systems and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344003, RF), Cand. Sci. (Eng), Associate professor, ORCID, anpavlenko@rambler.ru

Panfilova, Elvira A., Associate professor, Department of Operation of Transport Systems and Logistics, Don State Technical University (1, Gagarin sq., Rostov-on-Don, 344003, RF), Cand. Sci. (Philosoph), Associate professor, ORCID, kotorkaya_elvira@mail.ru

Simonov, Dmitriy N., Chief designer, Engineering Consulting Center "Thought" NSTU LLC (88, Troitskaya str., Novocherkassk, 346428, RF), ORCID, simonov@ikc-mysl.ru

Claimed contributorship

A. A. Korotkiy — academic advising, analysis of the research results, correction of the research results. A. N. Pavlenko — formulation of the basic concept, goals and results of the study, preparation of the text. E. A. Panfilova — revision of the text, preparation of the research results. D. N. Simonov — non-destructive testing, calculations, formulation of the research results.

Conflict of interest statement

The authors do not have any conflict of interest.

All authors have read and approved the final manuscript.

MACHINE BUILDING

Original article
UDC 621.313.12-883:629.12.037.4-83
https://doi.org/10.23947/2541-9129-2022-4-51-60

On the Prospects for the Development of Marine Propulsion Systems for Their Compliance with the Environmental Standards of the International Convention

Aleksandr N. Rak
Kamchatka State Technical University (Petropavlovsk-Kamchatsky, Russian Federation)
✉ lion15ua@rambler.ru

Abstract

Introduction. The shipping industry pays great attention to the safety of man-made and natural systems. At the same time, increased requirements are imposed not only on the quality of the fuel composition, but also on exhaust emissions. Currently, Annex VI of the MARPOL-73/78 Convention has been ratified by many of its signatories. The compliance with this document requires that engine emissions comply with the specified NO_x level limits. Until recently, such rules were mainly applied in the Baltic and North Seas, but over time, the compliance with environmental standards will affect other areas of navigation.

The work objective is to show through the study of modern technical solutions that we need an integrated approach to solve practical environmental problems, which will allow developing rational schemes of modern marine propulsion systems, taking into account their compliance with the safety requirements of technogenic and natural systems.

Materials and Methods. The methods and recommendations given in open sources and corresponding to the requirements of the International Maritime Organization (IMO) were used in the work. The experience of leading foreign firms and domestic enterprises in terms of modern design solutions that will reduce ship emissions to acceptable limits is analyzed and summarized.

Research Results. The issues related to the study of factors influencing the development of rational schemes of ship propulsion systems, taking into account their current level of development, pricing policy and the compliance with the environmental requirements, are considered. It is shown that one of the effective ways to reduce NO_x emissions is the installation of a selective catalytic reducer (SCR) on the main engine, and the use of efficient and innovative power generation technologies to reduce technogenic emissions. In the medium term, the transition to gaseous fuels is predicted, and in the long term – to hydrogen technologies.

Discussion and Conclusion. Possible technical solutions to reduce emissions of nitrogen oxides by installing selective catalytic reducers on the main marine engines are presented. It is established that one of the promising areas of development are diesel-electric propulsion systems. It is shown that in the medium term, due to stricter environmental requirements, there will be a transition to gaseous fuels, which will allow us with minor structural changes to increase the power of the existing main engines and to reduce emissions of nitrogen oxides and greenhouse gases. In the long term, the transition to hydrogen fuel cells with continuous improvement of the technological level of production, storage and development of the corresponding infrastructure can be considered as a real alternative to hydrocarbon fuels in marine transport.

Keywords: main engines, selective catalytic reducer, electric propulsion system, solid-state generator, battery system, combined system, fuel.

For citation. Rak A. N. On the Prospects for the Development of Marine Propulsion Systems for Their Compliance with the Environmental Standards of the International Convention MARPOL-73/78. Safety of Technogenic and Natural Systems, 2022, no. 4, pp. 51–60. https://doi.org/10.23947/2541-9129-2022-4-51-60

Introduction. Safety requirements of technogenic and natural systems in marine transport attract attention to exhaust emissions. Currently, Annex VI of the MARPOL-73/78 Convention [1–3] has been ratified by many of its signatories, and, consequently, all engines currently in operation must meet the required NO_x emission levels. For example, in the Baltic and North Sea regions, a reduction in port fees is used as an incentive to use low-sulfur fuels. The use of modern technologies should ensure the required permissible level of emissions and further improvement and development in order to adapt to such restrictions [1–3].

Emission limits may require the development of new technologies, but then the chosen solution will not necessarily be optimal. The systems operating on the built vessels will be used on average for at least 25 years, which corresponds to the service life of the vessel. Such methods of reducing exhaust emissions as selective catalytic reduction and water emulsification are already used on two-cycle engines of some well-known manufacturers, for example, MAN B&W.

Until recently, NO_x and SO_x were the main focus of environmental services, but now more attention is paid to exhaust gas components such as HC, particulate matter, CO and CO_2.

The work objective is to show through the study of modern technical solutions that an integrated approach is needed to solve practical environmental problems, which will allow developing rational schemes of modern ship propulsion systems to meet the safety requirements of technogenic and natural systems.

Materials and Methods. In this work, the calculated ratios given in open sources and corresponding to IMO requirements [1–3] were used. The author's research and observations on reducing the amount of greenhouse gas (GHG) emissions, taking into account the operating modes of generating plants, are given in [4]. The experience and recommendations of leading foreign firms and domestic manufacturers of marine mechanical and electromechanical equipment, their latest and promising developments in terms of layout arrangement and the development of individual elements were taken into account [5, 6].

Results. To assess the prospects for the possible development of marine propulsion systems, let us consider its generalized scheme (Fig. 1).

In general, the ship's propulsion system has a main engine (ME), diesel generators (DG) and a shaft generator/engine (SG/E). As an electric propulsion installation (EPI), rudder propellers (RP) and "Azipod" systems are used; reduction gearing (RG); solar panels (SP); batteries (B); fuel cells (Fc) (hydrogen or ammonia according to the hydrogen principle of operation); central switchboard (CS); thruster (T); frequency converter (FC) and fuel tanks (FT).

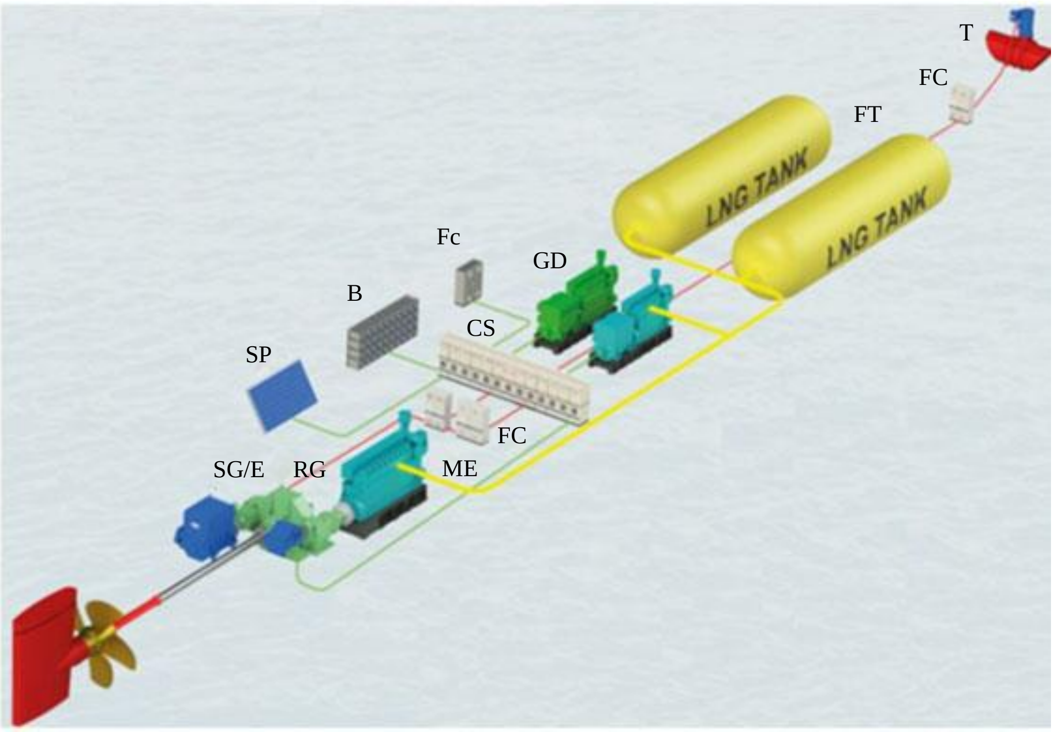


Fig. 1. Generalized ship propulsion system

To carry out research, it is necessary to determine the prime movers. Figure 2 provides typical efficiency and fields of application of prime movers in accordance with ISO 3046

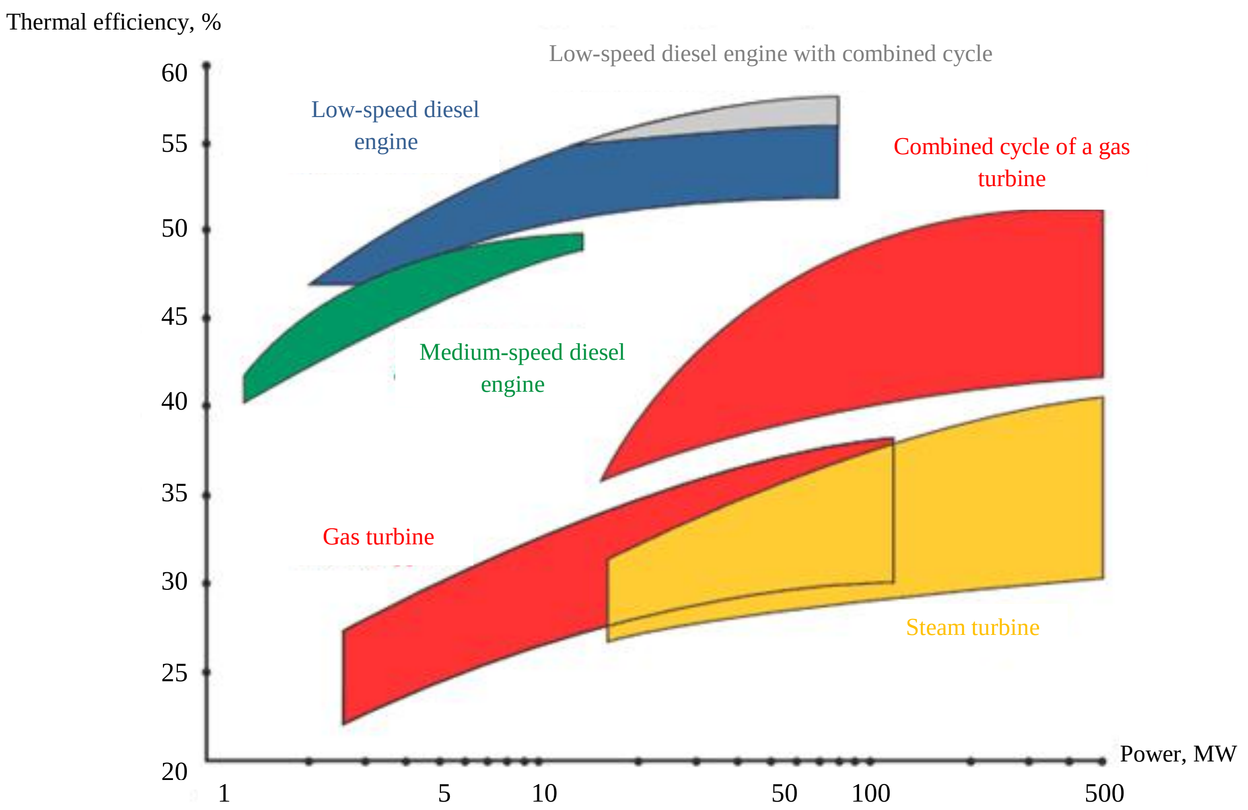


Fig. 2. Typical efficiency and fields of application of prime movers in accordance with ISO 3046

According to [1] the ME power is determined as follows:

$$N = a \cdot D_{wt} + b\,, \tag{1}$$

where *a, b* — coefficients values of the equation for different types of vessels; D_{wt} — vessels deadweight, thousand tons. The values of components *a, b* for ratio (1) are given in Table 1.

Currently, the choice of any of the methods of movement (diesel-mechanical, diesel-electric, combined with the use of batteries) will depend on its efficiency, determined by the efficiency factor.

Table 1

Parameters *a* and *b*, required to determine the minimum power of the main engines of various types of vessels [1]

№	Types of vessels	*a*	*b*
1	Bulk carriesr DWT (less than 145000 t)	0.0763	3374.3
	Bulk carriers DWT (more than 145000 t)	0.049	7329
2	Bulk carriers DWT (less than 75825 t)	0.0606	4195.2
	Bulk carriers DWT (more than 275825 t)	0.0273	13366.0
3	Gas carriers DWT (less than 29025 t)	0.23	793.6
	Gas carriers DWT (more than 129025 t)	0.0097	29224.0
4	Container carriers DWT (less than 92186 t)	0.5843	0.0
	Container carriers DWT (more than 92186 t)	0.054	48886.0
5	Liquid bulk carriers	0.0602	5495.5
6	Vessels for general cargo transportation	0.152	2399.5
7	Refrigeration	0.9809	-1831.2

One of the important environmental indicators is the amount of NO_x emissions from marine vessels. This indicator is shown in Figure 3.

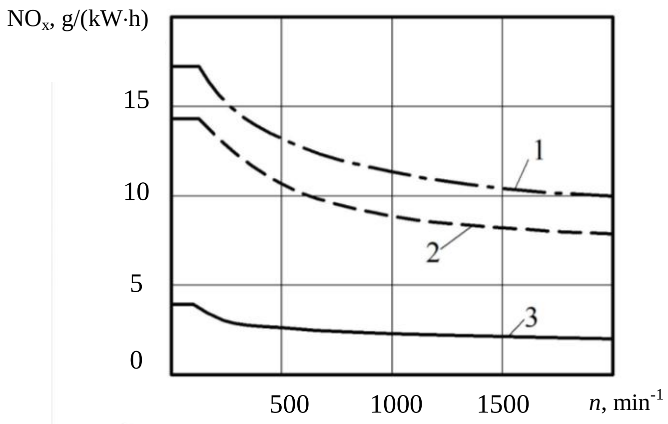


Fig. 3. NO_x emission standards from marine vessels:
1 — level I (ME > 130kW, new vessels since 2000); 2 — level II (ME > 130kW, new vessels since 2011);
3 — level III (ME > 130kW, new vessels since 2016 in emission control areas
Emission control areas (ECA): The West and East coasts of the USA, the Nordic countries)

As follows from Fig. 3, at rotation speeds of 100 rpm, which is typical for low-speed ME (LSE) produced by MAN B&W and WÄRTSILÄ-SULZER, the level of NO_x emissions remains constant. For a gas turbine with a rotation speed of 250 rpm, which is typical for Mitsubishi, emissions are significantly reduced. The greatest reduction is achieved at rotation speeds in the range of 350–2500 rpm. (This range is characteristic of medium- and high-speed ME (MSE and HSE, respectively), which is a weighty argument for switching to the EPI [4]).

Currently, one of the ways to reduce NO_x emissions is to install a selective catalytic reducer (SCR) on the ME. Basic and promising schemes of the SCR installation are shown in Fig. 4.

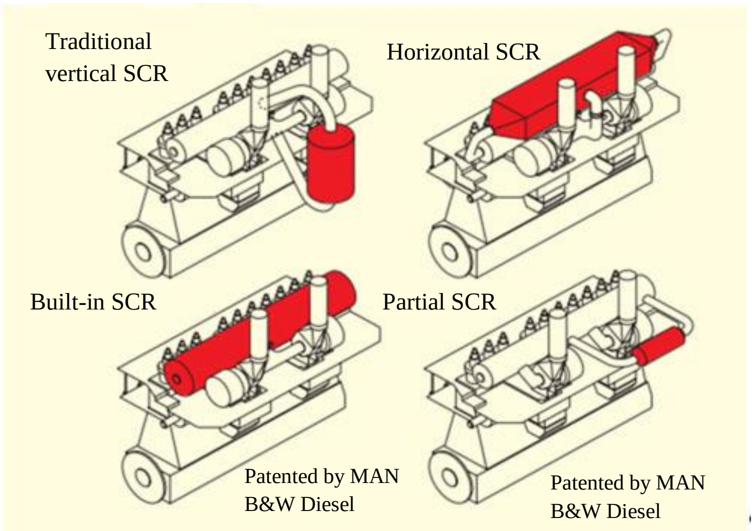


Fig. 4. Basic and promising schemes for the installation of a selective catalytic reducer

The efficiency of installation of selective catalytic reducers is shown in Table 2.

Table 2

Efficiency of installation of selective catalytic reducers

Engine type	Operating mode	Emission type	Efficiency indicator, %
6S35MC	only movement	NO_x reduction	above 93
6S50MC			93–95
9K80MC-Gl-S	movement and generation		above 93
4L35MC-S			above 93
2x7K60MC-S			above 93

Figure 5 shows a quantitative assessment of NO_x emissions depending on the load on diesel when switching to a water-fuel emulsion [6].

In addition to restrictions on NO_x emissions, new requirements have come into force since 2020, seriously limiting the permissible level of emissions of sulfur oxides, nitrogen and GHG in the Baltic, Northern and Mediterranean Seas (Fig. 6) [1–3].

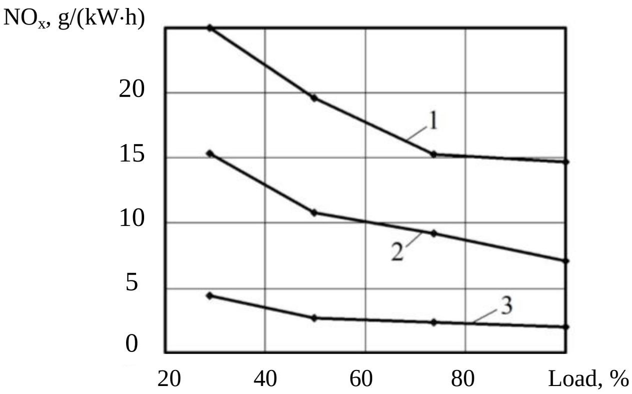


Fig. 5. Reduction of NO_x emissions during the transition to a water-fuel emulsion [6]:
1 — diesel fuel; 2 — methanol; 3 — methanol with water

The expansion of marine environmental monitoring areas and the adoption of measures to reduce the anthropogenic impact on the environment require shipowners to make cardinal decisions on this issue. At the same time, there is no universal approach and universal technical solutions for specific types of ships.

Fig. 6. Ship emissions control areas in North America and Northern Europe [3]

Reduction of GHG emissions should be determined in accordance with the amendment to Annex VI to MARPOL 73/78, which entered into force on January 1, 2013, using the Energy efficiency index (EEDI), which characterizes the energy capabilities of a technical means at the lowest cost of resources for energy generation and is determined in accordance with [1]:

$$EEDI = \frac{\left(\prod_{j=1}^{M} f_j\right)\cdot\left(\sum_{i=1}^{nME} P_{ME(i)}\cdot C_{FME(i)}\cdot SFC_{ME(i)}\right)+\left(P_{AE}\cdot C_{FAE}\cdot SFC_{AE}\right)+}{f_i\cdot f_c\cdot Capacity\cdot v_{ref}\cdot f_w}$$

$$\frac{+\left(\left(\prod_{j=1}^{M} f_j\cdot\sum_{i=1}^{nPTI} P_{PTI(i)}-\sum_{i=1}^{neff} f_{eff(i)}\cdot P_{AEeff(i)}\right)\cdot C_{FAE}\cdot SFC_{AE}\right)-\left(\sum_{i=1}^{neff} f_{eff(i)}\cdot P_{eff(i)}\cdot C_{FME}\cdot SFC_{ME}\right)}{f_i\cdot f_c\cdot Capacity\cdot v_{ref}\cdot f_w}, \quad (2)$$

where *SFC* — specific fuel consumption of the engine, g/kW h; C_F — dimensionless conversion factor between fuel consumption in the engine and CO_2 emissions determined by the carbon content in a particular fuel (grams of CO_2/ grams of fuel). Information on the carbon content in various fuels and specific CO_2 emissions is presented in [1, 3] and Table 3; P_{MEi} — power indicator of each main engine equal to 75 % of its rated power minus the power consumed by the generator (if available); P_{AE} — indicator of the required power of auxiliary engines to provide electricity at maximum load of the vessel; P_{PTI} — an indicator equal to 75 % of the rated power consumed by each electric propulsion motor, taking into account mechanical losses in it and excluding losses in the generator; P_{AEeff} — an indicator of reduction of electric energy due to the use of energy-efficient technologies (use of ME waste heat) which in [1] are called innovative.

It is noted in [4] that the stable operation of these systems is possible only at the ME rotational speed of 40–50 % of the nominal; P_{eff} — an indicator of reducing the ME power due to the use of innovative technologies in a propulsive installation at 75 % of the power of the ME (photovoltaic installations, fuel cells, wind generators). It is shown in [4] that the use of innovative technologies makes it possible to increase the energy efficiency index, but they do not have a decisive influence on their choice as the main sources due to their low power of tens to hundreds of kW; f_i — a factor that takes into account the need to meet the requirements for limiting the vessel's capacity, for example, the requirements that apply to ice-class vessels; f_j — a corrective factor that takes into account the specific design of ship elements, for example, ice-class vessels; f_w — a dimensionless coefficient that takes into account the speed reduction in a certain unfavorable sea condition, depending on the height and frequency of the wave, and also on the wind speed; f_{eff} — the coefficient of availability of each innovative technology; V_{ref} — the speed of the vessel measured in deep water, taking into account the corresponding capacity (deadweight or gross capacity, depending on the type of vessel). For more details on the calculation of the coefficients f_i, f_j, f_w and f_{eff}, see [2].

Table 4 provides a comparative analysis of the use of various types of fuel for marine ME and battery systems, as well as a reduction in emissions compared to fuel oil for level II [5]

Transition to LPG and LNG will increase the power of the internal combustion engine with minor changes to the fuel supply system according to expression [6]:

$$N_{\text{НОМ.ГАЗ}} = N_{\text{НОМ.ДИЗ}} \cdot \left(\frac{C_{\text{F,ДИЗ}} \cdot \text{НТС}_{\text{ГАЗ}}}{C_{\text{F,ГАЗ}} \cdot \text{НТС}_{\text{ДИЗ}}} \right)^{\frac{3}{2}}, \quad (3)$$

where $N_{НОМ.ДИЗ}$ — nominal power on diesel fuel, kW; C_F — dimensionless coefficient between fuel consumption in the engine and CO_2 emissions determined by the carbon content in a particular fuel (g CO_2/ g fuel); *HTC* — the lowest calorific value of fuel, kJ/kg.

Table 3

Carbon content in various fuels and specific CO_2 emissions [2]

Fuel type	Reference	The lowest calorific value, kJ/kg	Carbon content	C_F, t CO_2/t fuel
Diesel/gas oil	ISO 8217, grades from DMX to DMB	42.7	0.8744	3.206
Light liquid fuel (LLF)	ISO 8217, grades from RMA to RMD	41.2	0.8594	3.151
Heavy liquid fuel (HLF)	ISO 8217, grades from RME to RMK	40.2	0.8493	3.114
Liquefied petroleum gas (LPG)	propane	46.3	0.8182	3.0
	butane	45.7	0.8264	3.03
Liquefied natural gas (LNG)		48	0.75	2.75
Methanol		19.9	0.375	1.375
Ethanol		26.8	0.5217	1.913

Table 4

Comparison of alternative fuels for marine internal combustion engines and battery systems

Fuel types and sources	Specific energy, MJ/kg	Energy density, MJ/l	Corresponding capacity, m^3	Discharge pressure, bar	Injection pressure, bar	Emission reduction compared to fuel oil in accordance with Level II		
Fuel oil (HFO)	40.5	35	1.0	7-8	950	SO_x	NO_x	CO_2
Liquefied gas (LNG-162 °C)	50	22	1.59	300/ Methane 380/ Ethane	300/ Methane 380/ Ethane	90–99 90–97	20–30 30–50	24 15
Liquefied gas (LPG (propane/butane)	42	26	1.35	50	600–700	90-100	10–15	13–18
Methanol (wood alcohol)	18	15	2.33	10	500	90-97	30–50	5
Ethanol	26	21	1.75	10	500	-	-	-
Ammonia (liquefied -33 °C)	18.6	12.5	2.8	50	600–700	-	-	-
Hydrogen (liquefied — 253 °C)	142	10	3.5	-	-	-	-	-
High-energy marine battery system	0.5	0.54	64.8	-	-	-	-	-
Tesla 2170 elements	0.8	2.5	14.0	-	-	-	-	-

Let us touch upon the issue of hydrogen fuel. Hydrogen is not found in nature in in its pure form and it can be obtained from gaseous and liquid hydrocarbons or from water. These are the two most common and commercially important methods of hydrogen production [7]. For the successful implementation of the project, it is necessary to solve a number of problems. In order for fuel cells to provide 3 MW of power for 48 hours, about 68 m^3 of liquid hydrogen is required, which means much more storage space than for diesel fuel. To avoid leaks, special pipelines are required, and the hydrogen itself must be stored at a temperature below -253 °C. Figure 7 shows a hydrogen-air battery of BTE-P fuel cells with a capacity of 50.0 kW for megawatt-class power stations (Photo by: Krylov State Research Centre), and Figure 8 shows a marine hybrid power plant based on BTE-84 batteries with a capacity of 60 kW (Photo by: TSNII SET).

Currently, one of the pioneers of the program for testing marine internal combustion engines running on pure hydrogen is the Wärtsilä company (Finland). The company's concept is based on a combination of liquefied natural gas with steam to produce hydrogen and CO_2 [8]

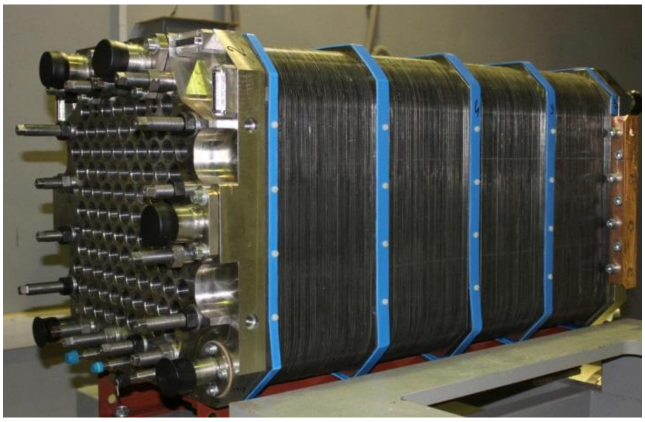


Fig. 7. Hydrogen-air battery of BTE-P fuel cells with a capacity of 50 kW for megawatt-class power stations [9]

Fig. 8. Marine hybrid power station based on BTE-84 batteries with a capacity of 60 kW/ [10]

One of the important indicators when choosing diesel engines is its price. It is these data that are the most necessary at the stage of the initial study of a project, although they are "limited" or "protected" in nature. In [11], a formula is proposed for calculating the price of marine and industrial diesel engines, based on the main functional characteristics:

$$Ц = K \cdot \frac{N_e^{0,073} \cdot T^{0,086} \cdot M^{0,763}}{g_e^{2,446} \cdot g_m^{1,138} \cdot S^{0,466}}, \quad (4)$$

where N_e — nominal effective power of the engine, kW; M — mass, kg; g_e — specific fuel consumption for the rated power mode, kg/(kW·h); g_m — specific oil consumption for the rated power mode, kg/(kW·h); S — serial production, pcs.; K — proportionality coefficient equal to 0.023; T — resource to the first reassembly, h.

The exponents characterize the weight of each argument in the formula. The order of the values included in (4) is given in the relevant regulatory and technical documentation. Information on the specific fuel consumption of LSE, MSE and HSE is presented in [4].

Analysis [5] shows that currently a significant progress in the T development is associated with the use of lithium-ion batteries. But, despite all the attractiveness from an environmental point of view, it has a limited character due to significant weight, size and price indicators. At the same time, they can be used in combined EPI both together with diesel generator installations and individually.

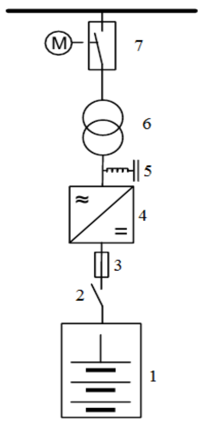
Table 5

Specific mass, volume and price of large 1MW·h heavy lithium-ion batteries

Key indicators	System level	Group level	Modular level	Element level
Specific mass, kg/kW·h	11–30	7–28	6–24	6–8
Specific volume, 1/kW	12–35	10–12	7–10	1.5–2.5
Specific price, USD/ kW·h	500			200–250

Currently, MAN B&W has developed a "solid-state" generator MAN Hybrid EcoAux (Fig. 11). Its technical characteristics are given in [12] and Table 6.

a)



b)

Fig. 11. "Solid-state" generator MAN Hybrid EcoAux: *a* — appearance; *b* — generator mix: 1 — energy storage (ES); 2 —transducer; 3 — protection system; 4 — bidirectional inverting converter; 5 — filter; 6 — separation transformer; 7 — motor-driven switch

Table 6

Technical characteristics of MAN Hybrid EcoAux "solid-state" generators

Standard size	Mains voltage, V	Frequency, Hz
625 kW·h (5C)*	400-690	50 or 60
405 kW·h (5C)	400-690	50 or 60
270 kW·h (5C)	400-690	50 or 60
135 kW·h (5C)	400-690	50 or 60

* C — charge rate. C = 12 min., i.e. 5C=5·12=60 min.

Possible layout solutions for the placement of electromechanical equipment in the engine room in the case of the use of EPI when powering the internal combustion engine from gaseous sources are given in [6, 8], and for systems that include batteries in [5, 13].

Discussion and Conclusion.

1. One of the effective ways to improve safety of technogenic and natural systems by reducing NO_x emissions is the installation of selective catalytic reducers (SCR) on the ME, which can reduce the amount of NO_x emissions to 93–98 %, depending on the design used. The transition to LPG and LNG will increase the capacity of the internal combustion engine by 22.6–49.6 % with minor changes to its design.

2. The existing innovative technologies for the production of electrical energy on board, such as solar panels, wind generators, etc., have an insignificant power of about 102 kW. The operation of the heat recovery system and the shaft generator begin to work steadily only at a rotation speed of 40-50% of the nominal. They have a significant impact on the energy efficiency index, and, consequently, on the reduction of CO_2 emissions. Thus, they cannot claim to be the driving motors of generators. Diesel generators with hydrocarbon fuels will remain the main source of energy production for the ME in the near future.

3. The use of battery systems alone is limited due to significant weight and size and price indicators. Their capabilities can be significantly expanded in combination with diesel generators. The use of MAN Hybrid EcoAux "solid-state" generators opens up wider prospects in this matter.

4. In the long term, hydrogen fuel cells can be considered as a real alternative to hydrocarbon fuels, but economic factors will limit the deployment of new expensive infrastructure. However, if hydrogen is produced directly on board, this alternative to diesel fuel becomes much more attractive for investors and users.

References

1. Air pollution and energy efficiency. Background information to document MEPC 64/4/13. Submitted by the International Association of Classification Societies (IACS), 2012. Available from: https://www.researchgate.net/publication/315642914_Background_information_to_document_MEPC_64413 (accessed 30.03.2020).

2. MARPOL. Book III, revised Annex VI to MARPOL "Rules for the Prevention of Air Pollution from Ships". Electronic fund of legal and regulatory documents. Available from: http://docs.cntd.ru/document/499014496 (accessed 30.03.2020). (In Russ.).

3. Guidelines on the Application of the Provisions of the International Convention MARPOL 73/78. ND No.2-030101-026. Russian Maritime Register of Shipping. Saint-Petersburg, 2017. 163 p. (In Russ.).

4. Trudnev S. Yu., Rak A. N., Marchenko A. A. Sudovye avtomatizirovannye elektroenergeticheskie sistemy: Sudovye istochniki elektricheskoi energii. Chast' I. Novokuznetsk: Znanie-M, 2021. 188 p. (In Russ.).

5. MAN Energy Solutions. Batteries on board ocean-going vessels. Available from: https://www.man-es.com/docs/default-source/marine/tools/batteries-on-board-ocean-going-vessels.pdf (accessed 22.03.2020).

6. MAN Energy Solutions. MAN B&W ME-LGIP dual-fuel engines. Available from: https://www.man-es.com/marine/products/planning-tools-and-downloads/technical-papers/2 (accessed 22.03.2021).

7. Radchenko R. V., Mokrushin A. S., Tyulpa V. V. Vodorod v energetike: ucheb. posobie. Ekaterinburg: Ural University Publishing house, 2014. 229 p. (In Russ.).

8. Wärtsilä razrabatyvaet sistemu dlya proizvodstva vodorodnogo topliva na bortu korablei. Available from: https://building-tech.org/Tekhnologii/wärtsilä-razrabativaet-systemu-dlya-proyzvodstva-vodorodnogo-toplyva-na-bortu-korabley (accessed 22.03.2022). (In Russ.).

9. V 2023 godu my smozhem predstavit' pervoe polnotsennoe sudno na vodorodnom toplive. Available from: https://www.korabel.ru/news/comments/v_2023_godu_my_smozhem_predstavit_pervoe_ polnocennoe_sudno_na_vodorodnom_toplive.html (accessed 22.03.2022). (In Russ.).

10. Suda na vodorode — uzhe real'nost'. Available from: https://www.korabel.ru/news/comments/vodorod_na_flote_uzhe_davno_ne_fantaziya_kak_v_rossii_razvivaetsya_vodorodnaya_energetika.html (accessed 22.03.2022). (In Russ.).

11. Dorokhov A. F., Provatar A. G., Vorobyyov A. V. Quality and reliability of marine diesel engines. Vestnik of Astrakhan State Technical University. Series: Marine engineering and technologies. 2015;2:48–55. (In Russ.).

12. MAN Energy Solutions. MAN Hybrid EcoAux. Available from: https://www.man-es.com/docs/default-source/document-sync/man-hybrid-ecoaux-eng.pdf?sfvrsn=98d91b1c_0 (accessed 22.03.2022).

13. Gutarevich V. O., Ryabko K. A., Ryabko E. V., Zakharov V. A. Review of structural battery designs used on mine electric locomotives. News of the Higher Institutions. Mining Journal. 2020;2:109–118. (In Russ.).

Received 29.09.2022.
Revised 10.10.2022.
Accepted 10.10.2022.

About the Author:

Rak, Aleksandr N., Associate professor, Department of Technological Machines and Equipment, Kamchatka State Technical University (35 Klyuchevskaya Str., Petropavlovsk-Kamchatsky, 683003, RF), Cand. Sci. (Eng.), ORCID, lion15ua@rambler.ru

MACHINE BUILDING

Original article
UDC 692.66:006.354
https://doi.org/10.23947/2541-9129-2022-4-61-70

Substantiation of Passenger Elevators Maintenance Intervals Based on Studies of Modes and Conditions of Their Operation

Dmitriy S. Apryshkin[1] ✉, **Grigoriy Sh. Khazanovich**[1], **Aleksandr V. Otrokov**[2]

[1] Don State Technical University (Rostov-on-Don, Russian Federation)

[2] M. I. Platov South Russian State Polytechnic University (NPI) (Novocherkassk, Rostov Region, Russian Federation)

✉ aprechnik@mail.ru

Abstract

Introduction. Maintenance is one of the factors of elevator systems safe operation. In regulatory documents, the influence of the loading mode of elevators on the frequency of maintenance is not taken into account and is assumed to be the same for objects operating in disparate conditions. This suggests the need to determine rational intervals between maintenance to ensure safe and economically feasible operation of the equipment in question. The work objective is to substantiate the required maintenance frequency of passenger elevators based on comprehensive assessments of their technical condition.

Materials and Methods. The domestic and foreign experience of choosing the maintenance frequency of elevator units is considered. The paper evaluates the possibilities of substantiating the required maintenance intervals on the basis of established comprehensive assessments of technical condition, taking into account the conditions and operating modes. Since the problem has no direct analytical solution, an alternative approach is proposed. It is based on the hypothesis of the interrelation between the regulatory resource characteristics of assemblies and the modes and conditions of their operation. The authors obtained the necessary indicators through measurements in high-rise apartment buildings in Rostov-on-Don, experiments and adequate simulation modelling.

Results. A structural and logical model has been developed to solve this problem. It consists of procedures that can be described in detail and clarified. A method for adjusting the maintenance frequency of elevators is proposed and tested. The standards of the system resource in terms of time and number of work cycles for the control time are summarized and tabulated. In this light, the gearbox, electric motor, brake, door drive and elevator ropes in 9-storey buildings are described at a cabin speed of ≤ 1 m/s. For example, the paper provides the calculated normative indicators:

– $K_{mср\ норм}$ — coefficient of net machine time (NMT);

– $n_{ср\ норм}$ — specific number of switching-on of the main drive and the door mechanism.

According to the calculation results, $K_{mср\ норм}$ for the electric motor is 0.228; $n_{ср\ норм}$ for the brake is 1.065 per NMT minute. To assess the overall load level, the resulting technical condition of the elevator and its main components, a single generalized indicator is proposed — the load index W_{Σ}. It is calculated as the sum of coefficients reflecting the relative level of load on the elevator assembly. It is established that as the resource is being depleted, while maintaining the value of time and power indicators, the estimated maintenance frequency will decrease. The recommended change threshold is 15–20 %.

***Discussion and Conclusion*.** The developed methodology for assessing the technical condition of the elevator unit allows us to develop a complex index by which we can judge the need to revise the regulatory intervals of the elevator unit assemblies. The proposed procedures are applicable to existing, installed and designed elevators. Simulation modeling in a specially developed computer program determines the main indicators of the technical condition of the power units of the elevator: the coefficient of net machine time, switching-on specific number, the power load and the share of the expired service life. Simulation modelling also takes into account the parameters of the building: population density and random external and internal influences. The method of adjusting the maintenance frequency allows you to quickly plan and optimize the costs of operating elevator equipment without losing the level of reliability and safety.

Keywords: passenger elevator, simulation modeling, operating mode, technical condition, workload indicators, maintenance frequency, adjustment of the repair interval, net machine time coefficient, switching-on specific number, power load, share of the expired service life.

For citation. Apryshkin D. S., Khazanovich G. Sh., Otrokov A. V. Substantiation of Passenger Elevators Maintenance Intervals Based on Studies of Modes and Conditions of Their Operation. Safety of Technogenic and Natural Systems, 2022, no. 4, pp. 61−70. https://doi.org/10.23947/2541-9129-2022-4-61-70

Introduction. Passenger elevators safety and operating costs depend on their technical condition. Each cycle of operation of the elevator system is accompanied by multiple efforts to start and brake it. Passenger elevators operate in the mode of random impacts on the duration, magnitude and frequency of loads. Simulation modeling (SM) methods are widely used to study the functioning of such machines. This allows us to obtain reliable results at significantly lower costs and time of research. For passenger elevators, the established frequency of maintenance does not depend on the operating conditions and modes. It is determined by regulatory documents[1, 2] and operating manuals[3], and is assumed to be the same for all elevators and does not depend on the number of floors of the building, the occupation rate, the parameters of the elevator unit (load capacity, speed), as well as the current technical condition of the object.

For a comprehensive assessment of the current technical condition of the elevator unit in a specific period, the following time indicators are used: net machine time (NMT), switching-on frequency, load and level of resource development [1]. It is advisable to express them in terms of dimensionless values: K_m — NMT coefficient; n — specific number of switching-on of the main drive and the door mechanism, per minute of NMT; $\lambda_{экв}$ — relative value of the power load; K_{RO} — share of the of regulatory resource development.

The authors of this work used two methods to establish the listed indicators formed during the operation of the object as a result of a sequence of random cyclic impacts:

– regular observations —machines in operation [2];

– IM — for the designed elevator installations [3, 4].

Depending on the combination of the values of these random indicators, the rates of equipment wear, the frequency and severity of failures change. Therefore, it makes sense to sometimes adjust the maintenance frequency (in particular, repair and maintenance work). However, as noted above, the regulations do not provide for the variability of

[1] GOST R 55964-2014. Lifts. General safety requirements in service. Technical Committee for Standardization TC 209. Moscow: Standartinform, 2019. 30 p. (In Russ.).

[2] GOST 34303-2017. Lifts. General requirements for maintenance lifts instruction. Technical Committee for Standardization TC 209. Moscow: Standartinform, 2019. 12 p. (In Russ.).

[3] Operation manual. 0621EM.00.00.000 RE. Passenger elevator. OAO "MEL". Available from: https://www.burmistr.ru/upload/forum/fc5/fc50d9b45781d2c11cafb3b2651567f7 (accessed 14.11.2022). (In Russ.)

the maintenance schedule[4]. Perhaps, in some cases, this leads to a higher than necessary frequency of maintenance and, accordingly, to costs that could have been avoided. A more significant objective of adjustments is to exclude an unreasonable increase in the intervals between maintenance, which is associated with the risks of premature loss of performance and a decrease in the level of safety.

A. I. Antonevich, P. V. Arkhangelskiy, D. P. Volkov, N. A. Lobov, A. V. Mechiev[5], P. I. Chutchikov[6], N. A. Shpet and others studied the dynamics of elevator equipment and the improvement of its reliability [1, 5–10].

In some publications [1, 6] and regulatory documents, it is noted that the intervals between the scheduled maintenance should take into account such characteristics of objects as the number of floors of the building, lifting height, load capacity, occupation rate. At the same time, it is not reported exactly how they should be taken into account, and the examples are not given.

The work objective is to substantiate the required frequency of maintenance of passenger elevators on the basis of the established comprehensive assessments of technical condition, taking into account the conditions and modes of their operation.

Materials and Methods. To realize the work objective, it is necessary, firstly, to scientifically substantiate the relationship of conditions, modes of operation of elevator units with the maintenance frequency. Then, based on the data obtained, it is necessary to develop methods for determining the appropriate maintenance frequency, which will ensure the maintenance of the necessary technical condition of the passenger elevator.

Domestic and foreign authors proposed analytical methods for solving the problem of optimizing the frequency of maintenance of machines, including elevator units. Fundamental developments were carried out at the Institute of Mechanical Engineering of the USSR Academy of Sciences[7, 8]. The authors of this article propose to be guided by the scheme presented in Fig. 1.

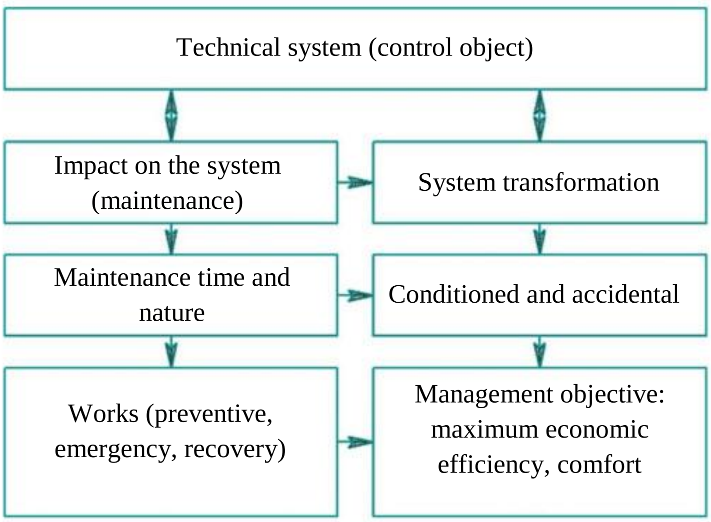


Fig. 1. Block diagram of the analytical solution to the problem of establishing the optimal maintenance frequency of elevator equipment

[4] Ob organizatsii bezopasnogo ispol'zovaniya i soderzhaniya liftov, pod"emnykh platform dlya invalidov, passazhirskikh konveierov (dvizhushchikhsya peshekhodnykh dorozhek), eskalatorov, za isklyucheniem eskalatorov v metropolitenakh. Government of the Russian Federation. Available from: https://base.garant.ru/71707662/ (accessed 03.09.2022). (In Russ.).
[5] Mechiev A. V. Razrabotka putei obespecheniya bezopasnoi ekspluatatsii liftov. Author's abstract. Moscow, 2018. 18 p. (In Russ.).
[6] Chutchikov P. I. Issledovanie passazhirskikh liftov s tsel'yu povysheniya ikh ekspluatatsionnoi nadezhnosti. Author's abstract. Moscow, 1973. 148 p. (In Russ.).
[7] Gnedenko B. V. (Ed.) Matematicheskie metody v teorii nadezhnosti i effektivnosti. Nadezhnost' i effektivnost' v tekhnike: spravochnik. In 10 vol. Vol. 2. Moscow: Mashinostroenie, 1987. S. 165–180. (In Russ.).
[8] Kuznetsov V. I. (Ed.), Barzilovich E. Yu. (Ed.) Ekspluatatsiya i remont. Nadezhnost' i effektivnost' v tekhnike: spravochnik. In 10 vol. Vol. 8. Moscow: Mashinostroenie, 1990. P. 112–146. (In Russ.).

Analytical decisions on the justification of the maintenance intervals are based on the idea of a specific function of the evolution of the system over time. Conditional transformations are possible — $x(t)$ or random ones — $\xi(t)$. Solving the problem based on such an algorithm requires detailed formalized representations of the behavior of a technical system in time, which is described by a random function $\xi(t)$. These data are unknown if we are talking about elevator units.

In the last 10–15 years, the problem of optimizing the maintenance frequency of elevators has been actively discussed in the People's Republic of China [11–14]. The solution involves changing the system failure rate function by introducing an adjustment coefficient depending on the failure rate. As an objective function, a mathematical model of maintaining the technical condition of the equipment is used, built with respect to the repair costs and losses from the elevator equipment downtime.

The above brief analysis allows us to assert that the task of frequency substantiating does not have a direct analytical solution, because the elevator functions cyclically, in the mode of stochastic changes in external and internal influences. Therefore, the resulting time and power indicators of the elevator characterizing its technical condition are random variables with previously unknown distribution laws.

As an alternative to the direct use of reliability indicators to determine the required intervals, the hypothesis of the relationship between the normative resource indicators of individual assemblies and the entire unit with the probabilistic characteristics of modes and operating conditions is adopted in this work. The authors integrated this information with the analysis of experimental data and adequate to them SM results [3, 4]. This approach made it possible to determine the characteristics of the load and operating conditions of elevators, as well as to develop methods and SM programs for their reproduction[9]. This makes it possible to formulate the task of adjusting the regulatory maintenance intervals. It is based on the statement that the mentioned probabilistic indicators of the elevator load determine its technical condition. For specific conditions, the solution of the problem of the necessary periodicity will take into account the data of regulatory documents, the results of observations or SM (Fig. 2).

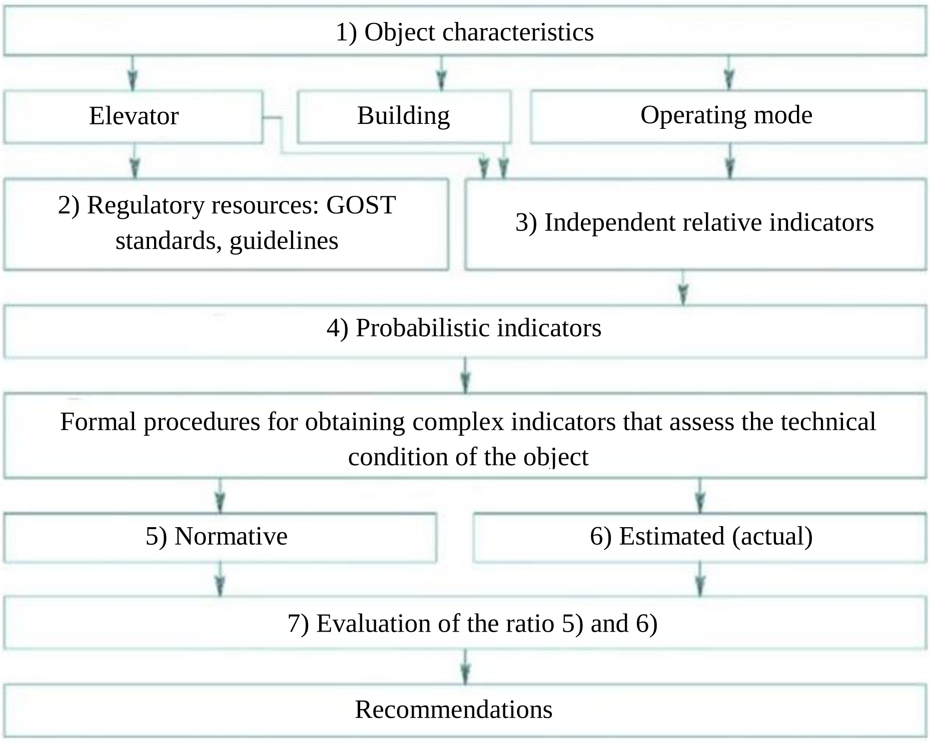


Fig. 2. Block diagram of an approximate solution to the problem of correcting the elevator units maintenance intervals based on probabilistic indicators of their technical condition

Figure 2 shows the necessary procedures to solve the problem of establishing the elevator unit maintenance frequency based on complex indicators of the technical condition of the object. Here is a brief description of them.

1) A description of the object, conditions and operating mode to assess its technical condition and adjust the

[9] Otrokov A. V., Khazanovich G. Sh., Apryshkin D. S. Imitatsionnoe modelirovanie rezhimnykh kharakteristik passazhirskikh liftov. Computer Program State Registration Certificate No. 202661811. Russian Federation. Don State Technical University, 2022. (In Russ.).

maintenance frequency. We are talking about an elevator unit with the following parameters: R, $Q_{п}$, v, $N_{дв}$, $i_{ред}$, $r_{КВШ}$ (load capacity, weight of the counterweight, cabin speed, engine power, gear ratio of the gearbox, radius of the traction sheave), etc. in a residential building with the parameters H, N, $h_{эт}$, Z (lifting height, number of floors, interfloor distance, number of residents). Operating mode: time of day, alternation of cycles by type, cab loading function, etc.

2) Determination of the regulatory resources of the units in accordance with GOST and other regulatory documents: by net operating time (τ), by the switching-on number (n), by nominal long-term load (M), by service life before overhaul or replacement — T (for engine, gearbox, brakes, doors, ropes and other units).

3) Justification of the nomenclature and the number of independent relative indicators for assessing the technical condition of the object (K_i).

4) Determination of probabilistic indicators to assess the estimated (actual) technical condition of the object based on SM or regular observations ($K_{mф}$, $n_{ф}$, $\lambda_{ф}$).

5) Justification of formal procedures to determine a complex indicator assessing the normative technical condition of the object — $W_{\Sigma.норм}$.

6) Justification of formal procedures to determine a complex indicator-index that evaluates the estimated (actual) technical condition of the object — $W_{\Sigma расч}$.

7) Evaluation of the ratio of normative and actual indicators of the technical condition of the main components of the elevator unit.

The results of these procedures allow us to formulate recommendations for adjusting the maintenance frequency ($K_{кор}$).

The main indicators characterizing the operability and durability of the object and its individual components are the standards established by the manufacturer or the specialized documents. In general, the following maximum resource characteristics should be given for each elevator unit before major repairs or replacement: net operating time τ, switching-on number (starts-brakes) n, nominal long-term load M, service life T. The nomenclature of resource indicators may be different for units operating in different conditions.

According to the regulatory documents[10] the actual technical condition is assessed based on the results of direct control, diagnostics and monitoring of the facility based on a comparison of the recorded indicators with those stated in the regulatory and technical documentation. A different approach is needed to select indirect indicators of the technical condition of the elevator and its components. Main requirements: indirect indicators should be independent and should characterize the technical condition of the object more fully. In our case, this is the net machine time coefficient, the specific number of switching-on of the main drive and the door mechanism, the level of power load and the degree of development of the normative resource, that is, K_m, n, $\lambda_{экв}$ and K_{RO}. All of them are determined by direct observation of a group of elevators or based on SM These indicators are accepted as basic according to the results of the analysis of their mutual independence and sufficiency for an indirect assessment of the technical condition of the elevator. They describe the main characteristics of the loading of the object. Each of them can be correlated with an analogue recorded in the elevator passport or regulatory document and presented in a different form, dimension. So, for example, GOST provides the standard indicators for electric motors: net operating time is 30 thousand hours, service life is 15 years. The conditional normative coefficient of the machine time of the electric motor is determined by calculation.

Results. The authors justified the approach to solving the issue of adjusting the elevators maintenance intervals. The methodology is based on four indicators: K_m, n, $\lambda_{экв}$ and K_{RO}.

According to the sequence of procedures (see Fig. 2) first, the regulatory resources of the main elevator assemblies are specified. These data are used to determine the corresponding values of time parameters: $K_{m\ норм}$, $n_{норм}$. According to GOST R 55964-2014[11] the elevator should serve for 25 years. Its components and mechanisms should serve from 5 to 15 years.

The dimensions of the resource indicator of the assembly can be:

– duration of equipment operation in hours (NMT);

– the number of switching-on per unit of time or for the entire period of operation.

[10] GOST 27.002–2015. Dependability in technics. Terms and definitions. Interstate Council for Standardization, Metrology and Certification. Moscow: Standartinform, 2016. 31 p. (In Russ.).

[11] GOST R 55964-2014. Lifts. General safety requirements in service. Technical Committee for Standardization TC 209. Moscow: Standartinform, 2019. 30 p. (In Russ.).

So, for example, according to GOST 31592-2012[12] for worm gearboxes used in elevator equipment, the resource before major repairs is at least 10 thousand hours. This value can be taken as the minimum regulatory resource that must be provided for the entire established service life of the gearbox (12.5 years). For electric motors, a service life of 15 years is set. At the same time, according to paragraph 5.1.4 of GOST 31606-2012[13] the resource before major repairs is at least 30 thousand hours.

Another source for determining the normative switching-on number is GOST 59155-2020[14]. So, for elevators in 9-storey buildings with a nominal speed of 0.67–1.0 m/s, the switching-on number $n_{норм}$ should not exceed 120 hour^{-1} or 2 min^{-1}. The switching-on of the elevator engine and all kinematically related components: gearbox, brakes, traction sheave (TS), ropes — occur only during machine time, therefore, the requirement of $n_{норм} \leq 2$ on/min should apply to NMT. That is, for all these units in the elevators of 9-storey buildings, the basic value of the switching-on number for the engine, brake, gearbox, TS should be taken $n_{норм} = 2$ on/(min NMT).

Table 1 summarizes the resource standards for time, number of cycles of units and aggregates for a certain control period of time. On the basis of these indicators, the normative power and time parameters of the operation of assemblies of the elevator unit are calculated. For example, the calculated normative indicators $K_{mср\ норм}$ and $n_{ср\ норм}$ of elevators of 9-storey buildings with a cabin speed of ≤ 1 m/s are given.

Table 1

Normative resources and time parameters of the elevator unit assemblies operation

No.	Elevator unit or assembly	Standard (indicator /for the period)		Calculated normative time parameters		Nominal load
		In NMT hours	In switching-on number	$K_{m\ ср\ норм}$	$n_{ср.\ норм}$	$M_{ном}$, H·м or $P_{ном}$, H
1	Gearbox	10^4/12,5 years	–	0.09	2	According to the equipment passport
2	Electric motor	$3\cdot10^4$/15 years	–	0.23	2	
3	Brake	–	7×10^6/12,5 years	0.77	1.07	
4	Brake	–	400/1 hours	28.2	6.7	
			2/1(min NMT)	0.47	4	
5	Ropes	–	6×10^5/1 years	0.3	1.14	According to 56943-2016

The control period of time is set in regulatory documents and technical passports of equipment. This can be:

– the full service life before replacement or overhaul;

– a specific value (year, hour, minute).

The calculated normative parameter $K_{mср\ норм}$ is determined as the quotient of dividing the net annual operating time of the unit by the number of hours per year. For example, for an electric motor:

$$K_{mср\ норм} = (30\cdot10^3/15)/(365\cdot24) = 0.228.$$

Similarly, the standard switching-on number is determined — 1/(min NMT). As an example, we will give switching-on per minute for the brake, NMT:

$$n_{ср\ норм} = (7\cdot10^6/12.5)/(365\cdot24\cdot60) = 1.065.$$

For door drive $n_{ср.норм}$ is chosen the minimum one of two options:

1) according to the elevator passport — at least 400 1/h or 6,7 1/(min NMT);

2) min NMT — 2 1/(min NMT).

For one switching-on of the elevator drive, there are two switching-on of the door drive, so $n_{ср\ норм} = 4$ 1/(min NMT). For ropes, the standard annual switching-on number (600 1/year) is given in the instructions

[12] GOST 31592-2012. Machine reducers. General specifications. Federal Agency for Technical Regulation and Metrology. Moscow: Standartinform, 2014. 22 p. (In Russ.).
[13] GOST 31606-2012. Rotating electrical machines. Asynchronous motors of power from 0,12 to 400 kW inclusive. General technical requirements. Federal Agency for Technical Regulation and Metrology. Moscow: Standartinform, 2013. 22 p. (In Russ.).
[14] GOST R 59155-2020. Lifts. Specifications. Technical Committee for Standardization TC 209, 2020. 15 p. (In Russ.).

for the maintenance of steel ropes[15].

Let us find the coefficients reflecting the relative level of load on the elevator assembly. They are determined as relationships:

– calculated or experimental values of time and power indicators to the normative ones;

– the spent resource to the full normative resource.

$$K_1 = \frac{K_{m.ср.мод}}{K_{m.ср.норм}}, K_2 = \frac{n_{ср.мод}}{n_{ср.норм}}, K_3 = \frac{M_{экв}}{M_{ном}} = \lambda_{экв}, K_{RO} = \frac{P_{отр.р}}{P_{норм.р}}.$$

For each power unit, it is necessary to calculate a combination of four coefficients: K_1, K_2, K_3, K_4. This is necessary for a comparative assessment of the load levels of units or elevators. If such data is not available in regulatory documents, then it is necessary to take as basic the values corresponding to the average values of a group of elevators with similar parameters operating in similar conditions.

Summing up the relative coefficients of the influence of various mode and time factors and the state of resource development suggests, that the final result is considered according to the principle: the lower the value W_Σ is, the less stressful the operating mode of this unit of the elevator installation will be. According to the method of summation of K_1, K_2, K_3 and K_{RO} the normal, not overloaded technical condition of the elevator should be considered such that the sum of the coefficients does not exceed 4.

Elevator assemblies are divided into groups:

1) working continuously during the NMT (motor, gearbox, TS and ropes);

2) pulse-operated, for example elevator doors.

For the 1st group, the calculation of W_Σ must be carried out by the sum of 4 coefficients, for the 2nd one — 2 coefficients, excluding K_m and $M_{экв}$. Accordingly, the normative sum W_Σ will also change: for the first group $W_\Sigma = 4$, for the second group $W_\Sigma = 2$. The option $W_\Sigma = 3$, is also possible, which takes into account the load of two types and the level of resource development.

Figure 3 shows a block diagram of the methodology for determining the adjusted maintenance frequency of elevator equipment based on regulatory documents, the results of their power and time performance indicators.

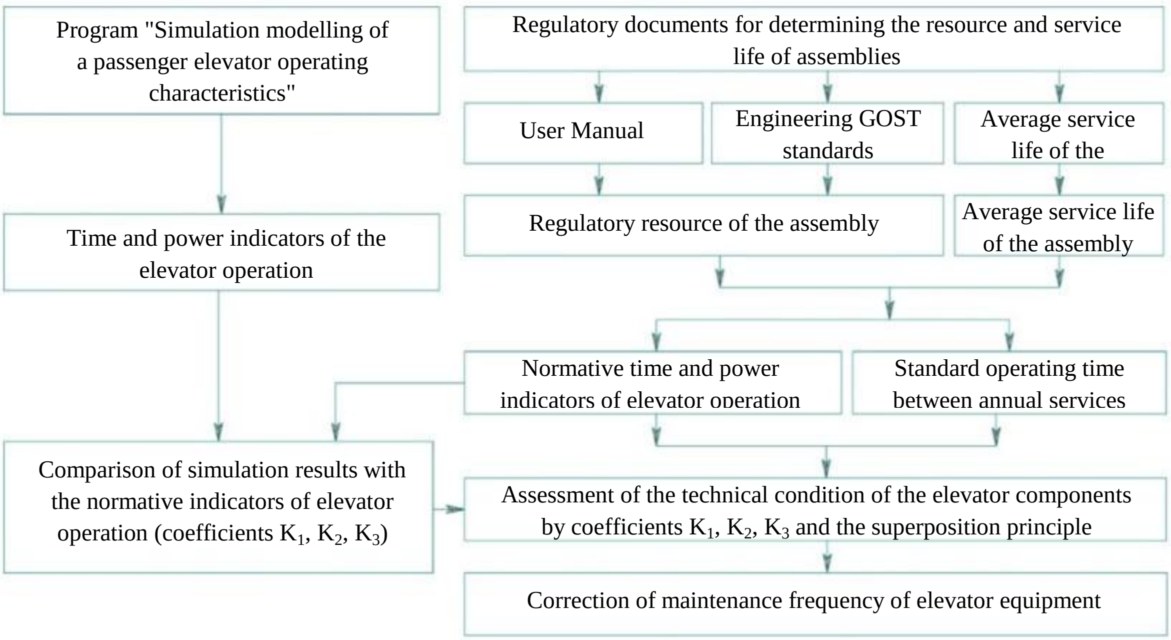


Fig. 3. Block diagram of decision-making on the adjustment of the maintenance frequency of elevator equipment

For example, Table 2 shows the results of a comparative assessment of the loading of units and the coefficients of adjustment of maintenance frequency performed in accordance with the stated methodological provisions for elevators that have worked for 5 years.

[15] Stal'nye kanaty Gustav Wolf. Instruktsiya po ekspluatatsii. Revator. Available from: https://revator.ru/upload/docs/Rope_inst_GW_v4.pdf (accessed 03.09 2022). (In Russ.).

Table 2

Results of the study of elevator units in two 9-storey buildings in Rostov-on-Don: assessment of the loading of units and adjustment of maintenance frequency *

Assembly	$K_{m/мод}$/ $K_{m.норм}$	K_1	$n_{мод}/n_{норм}$, inc./min NMT	K_2	Load, $M_{мод}$/ $M_{ном}$, Н·м* or $P_{мод}/P_{ном}$, Н**	K_3	$P_{RO\ расч}$/ $P_{RO.норм}$, years	K_{RO}	$W_{\Sigma расч}$	КТО = $W_{\Sigma расч}$/ $W_{\Sigma норм}$
14, Kapustina str.										
Engine	0.187/0.23	0.81	2.89/2	1.46	16.73/30.172*	0.55	5/15	0.33	3.15	0.79
Gearbox	0.187/0.09	2.07	2.89/2	1.46	216.3/1114*	0.19	5/12.5	0.4	4.12	1.03
Brake	0.813/0.77	1.06	2.89/1.07	2.7	478/960*	0.5	5/12.5	0.4	4.66	1.17
Ropes	0.187/0.30	0.62	2.89/1.14	2.54	11.70/30.17**	0.4	5/5	1	4.56	1.14
Door	0.337/0.47	0.72	2.89/4	0.72	2.2/2.2*	1	5/6	0.83	3.27	0.82
68, Orbitalnaya str.										
Engine	0.05/0.23	0.22	2.96/2	1.48	16.73/30.17*	0.55	5/15	0.33	2.58	0.65
Gearbox	0.05/0.09	0.06	2.96/2	1.48	216.3/1114*	0.19	5/12.5	0.4	2.13	0.53
Brake	0.95/0.77	1.23	2.96/1.07	2.8	478/960*	0.5	5/12.5	0.4	4.47	1.12
Ropes	0.05/0.30	0.17	2.96/1.14	2.6	11.70/30.17**	0.4	5/5	1	4.17	1.04
Door	0.345/0.47	0.73	2.96/4	0.74	2.2/2.2*	1	5/6	0.83	3.30	0.83
КТО — the coefficients of maintenance frequency adjustment. At 0.95 ≤ КТО ≤ 1.05 no adjustment is required. When КТО < 0.95 — the frequency is adjusted downward by 1 КТО. When КТО > 1.05 the frequency is adjusted upward by 1 КТО.										

As the resource is being worked out, while maintaining the values of time and power indicators, the estimated maintenance frequency will be reduced to ensure the necessary level of technical condition of the equipment. Let us consider, for example, an elevator speed reduction gear in a building on 14, Kapustina. We should take into account that $W_{\Sigma норм} = 4$. If K_{RO} increases from 0.4 to 0.9, then the ratio $W_{\Sigma\ расч}/W_{\Sigma\ норм}$ will increase from 1.03 to 1.15. The final decision on changing the maintenance intervals of the elevator, depending on the increment, is made by the service organization. The recommended threshold for changing КТО is 15–20 %.

Discussion and Conclusion. The programs developed by SM for operation modes of passenger elevators and the methodology for adjusting the maintenance frequency make it possible to predict the real load of elevator units over a long period of operation, taking into account the number of floors, the population density of the building and the technical characteristics of the elevator. This makes it possible to set the forecast speed of working out the normative resource of each elevator unit and determine the service intervals for it that ensure the maintenance of the elevator units in working condition throughout the entire service life.

The applied value of the results of scientific research described in the article is due to the fact that regulatory documents, requiring the stated frequency of maintenance, do not take into account the modes and operating conditions of elevator units.

The characteristics of the modes and operating conditions for elevator units are determined by the data obtained on the basis of SM and checked for adequacy during dispatching monitoring. We are talking about such indicators as the net machine operating time, the switching-on specific number, the level of the power load of the drive and kinematically related assemblies, as well as the amount of the determined resource development. Before the elevator is put into operation, it is possible to build a maintenance schedule in the program created by the authors "SM of operating characteristics of a passenger elevator".

References

1. Volkov D. P. Lifty. Moscow: Assotsiatsii stroitel'nykh vuzov Publishing house, 2009. 463 p. (In Russ.).

2. Khazanovich G. Sh., Apryshkin D. S. Assessment of load of load-bearing elements of the passenger elevator based on regular monitoring results. Safety of Technogenic and Natural Systems. 2020;1:32–42. (In Russ.).

3. Khazanovich G. S., Aprishkin D. S., Otrokov A. Computer Modeling of Dynamic Processes of Passenger Elevators at Casual External Influence. In: Proceedings of the 2018 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), 2018. P. 1–6. 10.1109/FarEastCon.2018.8602877

4. Apryshkin D. S., Khazanovich G. Sh. Method and algorithm of simulation simulation of passenger elevator operation mode. Engineering and Construction Bulletin of the Caspian Region. 2020;3(33):84–92. (In Russ.).

5. Antonevich A. I. Analiz sovremennykh konstruktsii liftov i tendentsii ikh razvitiya. Vestnik Belorusskogo natsional'nogo tekhnicheskogo universiteta. 2010;5:18–31. Available from: http://rep.bntu.by/handle/data/1408 (accessed 21.11.2022). (In Russ.).

6. Arkhangelskii G. G., Vainson A. A., Ionov A. A. Ekspluatatsiya i raschet liftovykh ustanovok. Moscow: MISI, 2010. 328 p. (In Russ.).

7. Lobov N. A. Passazhirskie lifty. Moscow: Publishing house MGTU named after. N. E. Bauman, 2009. 183 p. (In Russ.).

8. Shpet N. A., Muravev O. P. Investigation of passenger lift failure by the operation data. Bulletin of the Tomsk Polytechnic University. 2013;323(4):123–125. (In Russ.).

9. Kudryavtsev E. M. GPSS World. Osnovy imitatsionnogo modelirovaniya razlichnykh system. Moscow: DMK Press, 2014. 320 p. (In Russ.).

10. Almgren T., Andréasson N., Palmgren M. et al. Optimization Models for Improving Periodic Maintenance Schedules by Utilizing Opportunities. In: Proceedings of the 4th Production and Operations Management World Conference, 2012, Amsterdam, the Netherlands. Available from: https://www.researchgate.net/publication/264888547_Optimization_models_for_improving_periodic_maintenance_schedules_by_utilizing_opportunities (accessed 21.11.2022).

11. Liu G. S. Three M-Failure Group Maintenance Models for M/M/N Unreliable Queuing Service Systems. Computers & Industrial Engineering. 2012;62(4):1011–1024. https://doi.org/10.1016/j.cie.2011.12.028

12. Lim J. H., Dong H. P. Optimal Periodic Preventive Maintenance Schedules with Improvement Factors Depending on Number of Preventive Maintenances. Asia-Pacific Journal of Operational Research. 2007;24(01):111–124. https://doi.org/10.1142/S0217595907001139

13. Liu H., Wu J. Research on Preventive Maintenance Strategy of Elevator Equipment. Open Journal of Social Sciences. 2018;06(01):165–174. http://dx.doi.org/10.4236/jss.2018.61012

14. Li R., Zhang X. Preventive Maintenance Interval Optimization for Continuous Multistate Systems. Mathematical Problems in Engineering. 2020;1:1–10. 10.1155/2020/2942940

Received 10.09.2022.

Revised 21.10.2022.

Accepted 21.10.2022.

About the Authors:

Apryshkin, Dmitriy S., Senior lecturer, Operation of Transport Systems and Logistics Department, Don State Technical University (1, Gagarin Sq., Rostov-on-Don, 344003, RF), ORCID, aprechnik@mail.ru

Khazanovich, Grigoriy Sh., Chief researcher, Center for Scientific Competencies, Don State Technical University (1, Gagarin Sq., Rostov-on-Don, 344003, RF), Dr. Sci. (Eng.), Professor, ORCID, hazanovich@mail.ru

Otrokov, Aleksandr V., Associate professor, Mining Technology Department, M. I. Platov South Russian State Polytechnic University (NPI) (132, Prosveshcheniya str., Novocherkassk, 346428, RF), Cand. Sci. (Eng.), Associate professor, ORCID, oav-71@mail.ru

Claimed contributorship:

D. S. Apryshkin — formulation of the basic concept, goals and objectives of the study, participation in the development of algorithms and simulation programs, calculations, text preparation, formulation of the conclusions. G. S. Khazanovich — academic advising, analysis of the research results, revision of the text, correction of the conclusions. A.V. Otrokov — participation in software development, formulation of simulation modeling results.

Conflict of interest statement

The authors do not have any conflict of interest.

All authors have read and approved the final manuscript.