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Ensuring the Safety of Construction Works During the Erection of Buildings and Structures

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When constructing buildings and structures for industrial and civil purposes, it is important to ensure safe working conditions for the tower crane operator and contractors of construction and installation works on the construction site, since these conditions largely determine the performance of the tower crane and the pace of construction in general.

Accidents associated with the use of lifting equipment in construction often lead not only to injuries and death within the construction industry, but also affect passers-by who find themselves in the danger zone due to the non-compliance of the construction organization project with the requirements of existing codes of rules containing requirements for labor protection and industrial safety in construction.

The article analyzes the causes of accidents in construction that result from the operation of tower cranes, as well as ways to ensure their reliable and safe operation.

The theoretical substantiation and engineering and technical solutions of safety during construction and installation works during the construction of objects due to the improvement of the design of the tower crane cabin and its equipment are offered. The results of theoretical and experimental studies of sensorimotor activity of the operator of the construction machine, which are the basis for engineering solutions developed at the level of inventions of tower cranes cabins of increased visibility and their equipment, are presented.

Key words: system «operator-construction machine-environment»; tower crane; survey quality of cabins; entropy; information

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Analysis of the causes of accidents and injuries in the operation of lifting and transport machines in construction. The construction of high-rise objects requires the introduction of new technologies with extensive use of lifting and transport machines. However, it is known that today tower cranes of various size groups, which are objects of increased danger, are still widely used in the construction.

The construction industry needs to create Russian construction machines that provide not only high performance of construction and installation works but also meet safety requirements. At the same time, the new machines must ensure the safety of an operator and the workers of construction crews who are in the area of operation of the machine.

Modern Russian and foreign technologies for the construction of high-rise buildings and structures have differences. For example, in the United States, the construction of high-rise objects is carried out using work platforms that are installed on the metal structures of buildings or in their elevator shafts. In Russia, tower cranes of different size groups are used in the construction of high-rise buildings, depending on the height of the structure. In recent years, organizational and technological schemes and models for the construction of buildings and structures have changed significantly, but tower cranes of high size groups remain the main lifting machines, through which lifting works are carried out during the installation of building structures [6].

According to the Rostekhnadzor (the Russian Federal Service for Ecological, Technological and Nuclear Supervision), accidents during the operation of cranes are the cause of fatal injuries. For example, during the operation of lifting structures in the period from 2005 to 2016, 476 accidents and 826 fatal accidents occurred at supervised facilities (Fig.1) [2]. The greatest number of accidents is noted during the operation of tower cranes: 13 accidents (31 %) out of 42 accidents. Other accidents were distributed as follows: in the operation of crawler cranes – 11 (26 %); automobile cranes – 7 (17 %); loader cranes – 4 (9 %); gantry cranes – 3 (7 %); bridge cranes – 2 (4 %); portal and railway cranes – 2 (4 %) (Fig.2) [2, 11].

The indicator used in the analysis of statistics and causes of fatal injuries at hazardous production facilities takes into account the number of deaths and the number of equipment registered with the Rostekhnadzor and operated by supervised organizations of the corresponding type, i.e. the factor of fatal injuries per 1000 pieces of equipment. The use of this indicator allows us to draw conclusions about the level of relative threat of an accident at a construction site, depending on the types of equipment operated on it (Table 1).

Among the causes of accidents of lifting structures, the following prevail: the lack of control over the compliance with the security requirements of the organization performing the construction of a building or structure and persons responsible for the maintenance of lifting equipment; lack of control over safe execution of construction and lifting work using a lifting-transport equipment; the involvement of persons without the necessary qualifications; low level of labor discipline; violation of technology of construction and installation works; violation of the schedules of maintenance inspections, repairs, and inspections of lifting equipment; physical and moral deterioration of the lifting equipment; low level of implementation of new techniques and technologies [2].

Failures of individual elements and subsystems of the system «operator-construction machine-environment» (OCME) are among the main causes of accidents and injuries in the operation of lifting

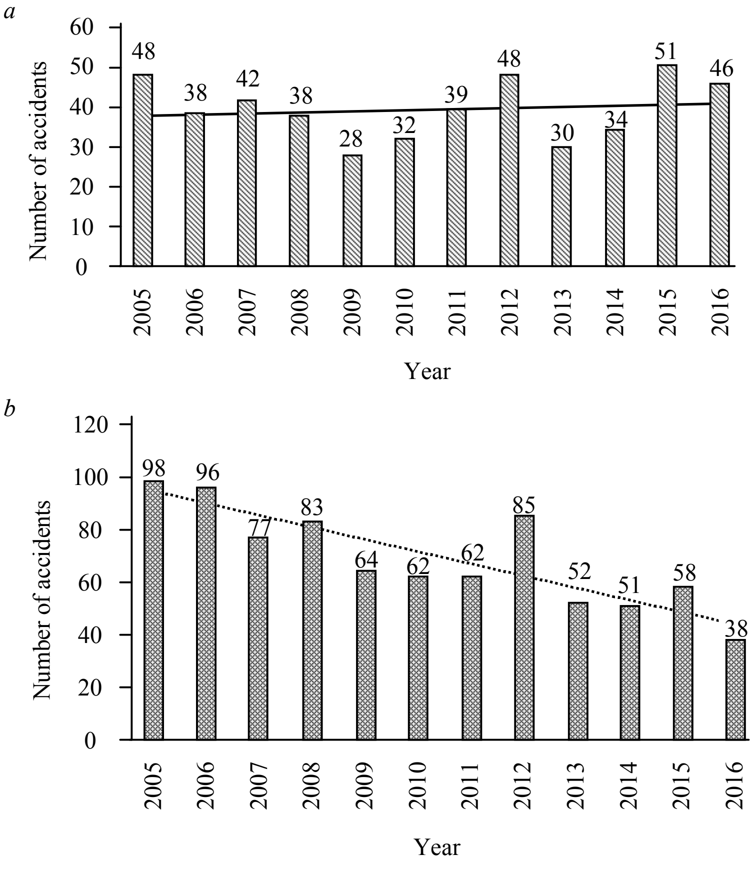

Fig.1. Diagram of accidents during operation of lifting structures (*a*) and fatal accidents on lifting facilities (*b*) in Russia (2005-2016)

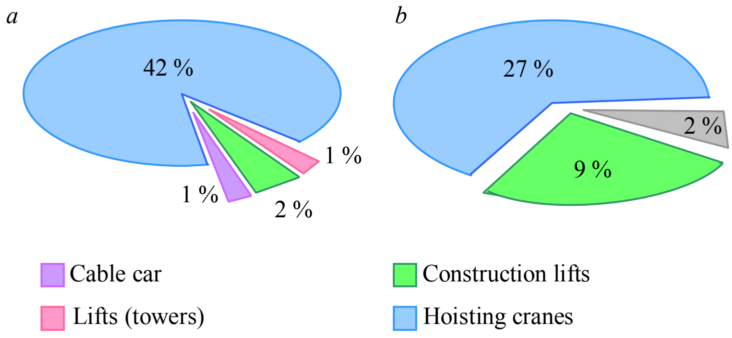

Fig.2. Distribution of accidents (*a*) and accidents with fatal injuries (*b*) by types of machines

Table 1

Analysis of fatal injuries in the operation of lifting equipment (2016)

Types of machines	Number of registered machines	Number of dead	The rate of fatal injuries
Tower cranes	17 403	10	0.57
Truck cranes	61 875	6	0.10
Bridge cranes	71 648	7	0.10
Gantry cranes	13 254	3	0.23
Crawler cranes	9 294	0	0
Loader cranes	12 413	1	0.08

structures, which once again confirms the long-overdue need for an integrated approach to the study of the OCME system with the development and implementation of organizational, technological and engineering measures aimed at ensuring its safety.

The main directions in the development of modern lifting equipment are development of new and modernization of existing machines in order to ensure the safety of construction and installation works, safety and improvement of working conditions of the operator of the lifting structure (machine) and other workers involved in the construction [6].

Theoretical justification of the concept of analysis and evaluation of the safety of the system «operator-construction machine-environment». The level of working conditions and safety of the construction crane operator, in particular, tower crane, is largely determined by the optimal choice and use of material, financial, and human resources. Therefore, a methodological approach is needed to study the state of safety of this human-machine system as a whole, allowing to perform an analysis of working conditions and propose a system of measures to prevent potential hazards [5]. The OCME system is a complex multifactorial object, and, therefore, the indicator of its reliability should not just describe the state of a system, but serve as a tool for regulating its safe operation.

The analysis of scientific publications of Russian scholars and specialists, as well as research teams dealing with occupational safety, shows that at present there are many complex methods and integrated indicators calculated on them, reflecting the level of safety and reliability of complex human-machine systems.

The article presents a generalized stability index developed on the basis of the energy – entropy theory [5, 10, 14-16], based on the methods of the information theory of C.Shannon, an American engineer and mathematician, the founder of the information theory, as a criterion for a comprehensive assessment of the safety of the OCME system. The basis for these methods is the probability function of entropy taken from statistical physics. The methods used by C.Shannon for purely applied issues of communication technology turned out to be universal: with their help, it is possible to carry out the analysis of processes of self-organization of both separate physical bodies, and the most difficult intellectual and social systems.

In addition, a theory was also taken as the basis for studying the state and development of complex engineering and social systems on the basis of informational and entropic properties, which was proposed by Prof. E.A.Sedov and shown in his famous works «Evolution and Information» and «Information and Entropy Properties of Social Systems», reflected in a speech at a meeting on the study of civilizational crises on January 28, 1993 [14].

The dynamic OCME system is in constant motion in space and time under the influence of both continuous and random disturbing internal and external factors in relation to the system, which can cause a gradual and abrupt change in it (i.e., «catastrophe»). This means that the integral properties of the OCME system are: safety, reliability, and efficiency that determine the purpose of the system-change or «vibrate». To ensure the stability of these properties, it is important to maintain the stability of the system to these disturbing factors. Such factors include material (substances, energy) and structural (information) effects.

To ensure the safe operation of the OCME system, it is necessary for the crane operator to receive constant and timely information about the state of the «construction machine» (tower crane) and about the «environment». Under the term «environment» we propose to consider «micro-environment» and «macro-environment», respectively, internal and external for the OCME system.

«Micro-environment» includes the subsystems: «operator-construction machine» and «production environment», which have an impact on the state of the OCME system, the safety level of which can be improved through new techniques, technologies, methods of labor organization.

The influence of the «macro-environment», which represents a set of climatic, economic, social and other factors that form uncertainty in the OCME system, is great, but it is difficult to manage such macro-functions, so these factors were not taken into account when justifying the stability criterion of the OCME system.

It is commonly known that energy manifests itself in various forms, and therefore can be a measure of the intensity of movement of the OCME system; information can characterize the measure of ordering of this motion [5, 10, 16]. Excess, as well as lack of information, can cause an accident when operating a construction machine (tower crane).

As a criterion of stability of the OCME system and its subsystems to «catastrophic jumps» the stability index is proposed [5]:

$$F_{\mathrm{st}} = i/a, \tag{1}$$

taking into account the influence of information and energy factors.

The severity of the accident depends on the energy consumption a of the operator to perform production activities, and the probability of an accident depends on i – the amount of information received and processed by him.

Prof. V.K.Chertykovtsev substantiates the study of dynamic systems for resistance to catastrophic jumps taking into account material and structural characteristics, i.e. by using also the energy-entropic theory, in his scientific work; he suggests evaluating complex multifactor systems by means of a generalized indicator [4, 5, 7, 10, 14-16]:

$$F = S(W)P(H), \tag{2}$$

where $S(W)$ is for the severity of an accident; $P(H)$ is for the probability of its occurrence.

The impact of the volume of information on the uncertainty of the system is obvious: the uncertainty of the OCME system decreases when the necessary information about its operation is obtained, so the amount of information is measured by the decrease in the entropy of the system [4, 5, 7, 10, 14-16]:

$$i = \Delta H(X). \tag{3}$$

When, as a result of the information received, the state of the system becomes fully defined, the amount of information received is equal to the entropy of the system, i.e. $i = H(X)$.

Since sensorimotor activity is the main activity in the production of the operator of the construction machine (tower crane), it is important to determine the entropy of visual activity and work of the musculoskeletal system, in particular, the upper limbs (hands), in the process of performing crane operations. This will allow calculating the stability factor of the OCME system for known data on the energy costs of the operator to perform this activity. If the actual value of the stability factor of the OCME system is less than the normalized, then the system is in a stable state, and it can be stated that it is safe. If this figure exceeds the normalized value, then there is a probability of creating an emergency situation («catastrophic jump»).

The generalized stability index of the OCME system when performing a visual task is determined by the formula [5, 7]:

$$F_{\mathrm{st(vis)}} = i_{\mathrm{vis(gen}}/a_{\mathrm{vis)}}, \tag{4}$$

where a_{vis} is for the energy consumption of the operator to perform visual activities and self-service of the body; $i_{\mathrm{vis(gen)}}$ is for the entropy of the system when performing a visual task.

The energy consumption of the operator to perform sensorimotor activity can be determined using known techniques, as well as using mathematical models obtained by programming the spatial motion of the human operator of the construction machine when performing visual and motor tasks, in particular using the method of designing the workplace of the human operator, proposed By N.V.Adamovich [1], and the theory of programming the purposeful activity of the operator, developed by a specialist in mechanics and management, lecturer of the Department of Theoretical Mechanics of the Moscow Institute of Physics and Technology G.V.Korenev.

The rationale for determining the entropy of the system was based on the hypothetical assumption that there is an analogy between the laws of thermodynamics, regulating thermal processes, and the provisions of the theory of information, regulating information processes [5, 7].

According to the theory of statistical physics, entropy as a function of the state depends on the parameters that determine the state of the system. To determine the degree of order of the system through entropy, it is necessary to establish its relationship with the nature of the movement of the elements of the system [4, 5, 8 -11].

The American physicist – the creator of modern thermodynamics and statistical mechanics – J.Gibbs in his monograph «Elementary Principles in Statistical Mechanics» explains the relationship between the entropy of a system and its ordering [17].

It is known that the state of an ideal gas according to J.Gibbs is a function of its pressure, temperature, and volume: $S\ (p,\ T,\ V)$. When heat is transferred to a gas volume, the thermal motion of molecules increases, and as a consequence, uncertainty in the system increases. Entropy depends thus on absolute values of speeds, the direction of movement and spatial orientation of moving particles and grows in the process of increase in a disorder of movement of its elements. The growing range of possible values of coordinates and pulses, and hence the volume of phase space, is determined by the formula:

$$d\omega = dv_q dv_p, \tag{5}$$

where $dv_q = dv_{q1}dv_{q2}dv_{q3}\ \ldots\ dv_{qN}$; $dv_p = dv_{p1}dv_{p2}dv_{p3}\ \ldots\ dv_{pN}$; q is for geometric coordinates of molecules; p is for dynamic coordinates of molecules (pulses); k is for the Boltzmann constant.

The amount of information impact on the operator of the tower crane in the process of performing a visual task when observing the «participants of the production process» (moving cargo-construction structure, crew members, crane boom, cargo suspension, objects on the construction site, etc.) is determined by the formula:

$$i_{\text{vis}1} = H_{\text{vis}1} = \frac{(-\ln\int d\omega)}{k_1} = \frac{(-\log_2\int d\omega)}{k_1}, \tag{6}$$

where $d\omega$ is for the elementary volume of phase space defined by expression (5); q is for the geometrical coordinates of the objects on the construction site; p is for the coordinates of the dynamic objects; k_1 is for factor of proportionality, depending, for example, physical, physiological status and professional level of team members, the technical condition of machines and mechanisms [5].

However, this expression is not enough to take into account not only the objects themselves but also their size and distinctness in the background, as well as the error in the measurement procedure of the human operator.

Therefore, in order to streamline the OCME system, the larger amount of visual information processed by the operator is important:

$$i_{\text{vis}2} = H_{\text{vis}2} = \sum_j^N \log_2\frac{2L_j}{D_j} + \delta H_{\text{meas}}, \tag{7}$$

where L is for the distance of the j-th object from the operator; D is for the size of the j-th object of observation δH_{meas} is for the error in the measurement procedure of the human operator.

The operator in the process of performing production tasks, it is necessary to monitor a display device (DD) placed on the control panel of the crane, so the entropy of the visual task increases:

$$i_{\text{read}i} = H_{\text{read}i} = \log_2\frac{x_{\max} - x_{\min}}{2\delta}, \tag{8}$$

where $x_{\max}$, $x_{\min}$ are for readings; δ is for the absolute error of reading readings from the device. The entropy n of the devices will be [5]:

$$i_{\text{read(gen)}} = H_{\text{read(gen)}} = \sum\nolimits_{i=1}^{n} H_{\text{read}i} . \tag{9}$$

Thus, the following expression is proposed to calculate the entropy of the visual problem [5]:

$$i_{\text{vis(gen)}} = H_{\text{vis(gen)}} = \frac{(-\log_2 \int d\omega)}{k} + \sum\nolimits_{j}^{N} \log_2 \frac{2L_j}{D_j} + \delta H_{\text{meas}} + \sum\nolimits_{i=1}^{n} H_{\text{readi}} . \tag{10}$$

Stability of the subsystem «operator-construction machine» in the performance of motor functions (work on the management of the construction crane by means of control levers) is determined by the formula [5]

$$K_{\text{stab(mov)}} = \frac{i_{\text{mov}}}{a_{\text{mov}}}, \tag{11}$$

where a_{mov} is for the energy consumption of the operator when working with the levers of control and self-service of the body; i_{mov} is for the entropy of the system when performing a motor task, determined according to [1]

$$i_{\text{mov}} = H_{\text{mov}} = \log_2 \frac{2A}{W}, \tag{12}$$

where A is for the amplitude of the movement of the hand; W is for the width of the target (width of control).

This model takes into account the fact that the entropy is greater the farther the operator is from the controls.

Thus, the resilience index for evaluation of OCME system security defined by expression (1) is complex because it is determined by the amount of processed information by the operator and its energy consumption in the multi-media dock «operator» with «machine» (means of influence, control, and communications), and can characterize the degree of controllability and level of perfection of the machine.

Justification of the availability of visual information by the tower crane operator. With the aim of designing the cabin of the tower crane and any other lifting or hoisting machine used in construction works and providing the necessary visibility from the operator's station, there are known ways of getting a flat circular pattern overview (visual, black and white, photographic, and graphical). These methods allow not only to determine the factor of visibility of cabins but also to identify shortcomings in the existing geometric shape of the cabin and its glazing and make recommendations for their change [5, 8, 9].

The article proposes for consideration a simulation model of the operator's visual apparatus, which allows already at the design stage of tower crane cabins to make recommendations on changing the shape and area of the cabin glazing, the position of the seat in the cabin relative to the windshields and the cabin floor in order to maximize the availability of visual information [5, 8, 9].

For stable operation of a tower crane operator in performing the visual tasks necessary to create conditions that enable him to capture the visual apparatus of the object of observation with the physiologically possible poses, resting and moving in any direction in the range of arrows.

To model the visual apparatus of the tower crane operator, well-known mathematical devices of purposeful human mechanics were used, proposed by G.V. Korenev in the work «Introduction to the Mechanics of a Controlled Body», as well as in the dissertations of Z.I.Shukis «Development and Research of Measuring Transducers of Coordinates of the Position of the Observer's Head Relative to the Object of Observation» and S.A.Medvedkin «Design of the Control Post Based on Geometric Analysis of Visibility with Binocular Vision» [12].

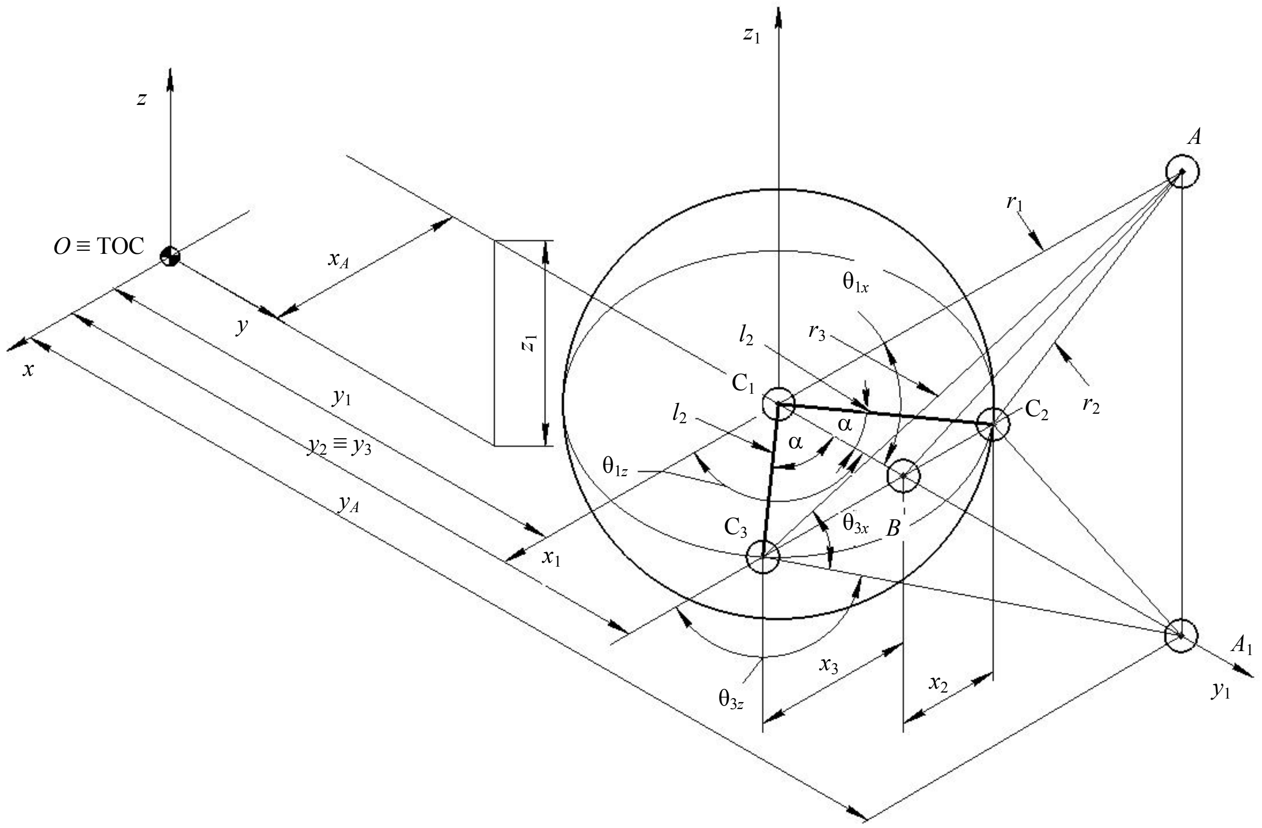

Fig.3. Basic model of a visual analyzer

The model of the visual apparatus of the operator of the construction machine, partially presented in this article, allows to investigate the survey quality of the cabin and assess the degree of availability of visual information from the workplace and the level of compliance of obtaining this information to the physiological capabilities of a person. With the help of this model, it is possible to show how the observation of objects is carried out, randomly located in space within the possible turns of the eyes and head [8, 9, 12].

The visual apparatus is modeled by three solid bodies, imitating the eyes and head, connected pivotally (Fig.3): the axis of the angular and translational coordinates are combined; at the points C$_2$, C$_3$ are the centers of movement of the eye through which the visual axis, they are immobile relative to the head (C$_1$ is the center of the head); point of fixation of sight *A* is an object observed by the human operator, relative to which the orientation of the entire field of view is made; the line connecting the points C$_2$ and C$_3$ is a baseline [5, 8], and the point *B* lying on the middle of it is the cyclopean eye [5, 8, 9, 12].

The direction of the operator's gaze is determined by the vector, the beginning of which coincides with the cyclopean eye, and the end – with the point of fixation of the gaze. Straights C$_2A$ and C$_3A$ are the visual axis of the left and right eyes that intersect at the point of fixation of the eye. The position of the visual axes is determined by the angles between the visual axis and the line parallel to the direction vector of the eye and passing through the center of the eye movement: θ_{2z}, θ_{3z} are the angles of rotation of the left and right eyes in the horizontal plane, respectively; θ_{2x}, θ_{3x} are the angles of rotation of the eyes in the sagittal plane (Table 2).

Table 2

Reference coordinates of the centers of inertia of the head and eyes

Link	Center of inertia	Reference coordinates
Head	C$_1$	$x_1, y_1, z_1, \theta_{1x}, \theta_{1y}, \theta_{1z}$
Left eye	C$_2$	$x_2, y_2, z_2, \theta_{2x}, \theta_{2z},$
Right eye	C$_3$	$x_3, y_3, z_3, \theta_{3x}, \theta_{3z},$

The point C_1 can remain stationary, and then its coordinates will be represented as constants and can move, and in this case they will be given as functions of time. There are three links superimposed on the movement of the C_1 point. The motion of the points C_2 and C_3 is related to the movement of the head, which gives an additional six connections, and then all nine connections can be represented by a system of equations:

$$\begin{aligned}
&x_1 = x_1(t)[b_1 = \text{const}]; && y_1 = y_1(t)[b_2 = \text{const}]; && z_1 = z_1(t)[b_3 = \text{const}];\\
&x_2 = x_1 + l_2\sin(\theta_{1z} - \alpha); && y_2 = y_1 + l_2\cos(\theta_{1z} - \alpha); && z_2 = z_1;\\
&x_3 = x_1 + l_2\sin(\theta_{1z} + \alpha); && y_3 = y_1 + l_2\cos(\theta_{1z} + \alpha); && z_3 = z_1.
\end{aligned} \tag{13}$$

We present the program of spatial movement of the visual apparatus when the operator of the construction machine performs the visual activity, in particular when the visual apparatus fixes the observed object A (Fig.3).

Provided smooth tracking, the program can be represented by the following expressions:

$$\begin{gathered}
\mathrm{tg}(\theta_{2z}) = -\frac{x_A - x_2}{y_A - y_2};\ \mathrm{tg}(\theta_{3z}) = -\frac{x_A - x_3}{y_A - y_3};\\
\mathrm{tg}(\theta_{2x}) = -\frac{z_A - z_2}{\sqrt{(x_A - x_2)^2 + (y_A - y_2)^2}};\ \mathrm{tg}(\theta_{3x}) = -\frac{z_A - z_3}{\sqrt{(x_A - x_3)^2 + (y_A - y_3)^2}}
\end{gathered} \tag{14}$$

or

$$\begin{gathered}
(x_A - x_2)\cos(\theta_{2z}) + (y_A - y_2)\sin(\theta_{2z}) = 0;\ (x_A - x_3)\cos(\theta_{3z}) + (y_A - y_3)\sin(\theta_{3z}) = 0;\\
(x_A - x_2)\cos(\theta_{2x}) + r_2\sin(\theta_{2x}) = 0;\ (x_A - x_3)\cos(\theta_{3x}) + r_3\sin(\theta_{3x}) = 0,
\end{gathered} \tag{15}$$

where $r_2 = \sqrt{(x_A - x_2)^2 + (y_A - y_2)^2}$; $r_3 = \sqrt{(x_A - x_3)^2 + (y_A - y_3)^2}$ are the distances from the center of the eyeballs to the observed object.

The program of movement of the visual apparatus when observing the load on the hook of the rope of the construction crane can be supplemented by a system of equations:

$$\begin{aligned}
&x_A = [R + \alpha_R(t)L]\sin\varphi(t) + \alpha_T(t)L\cos\varphi(t);\\
&y_A = [R + \alpha_R(t)L]\cos\varphi(t) + \alpha_T(t)L\sin\varphi(t);\\
&z_A = -L\cos\alpha_R(t)\cos\alpha_T(t),
\end{aligned} \tag{16}$$

where R is the length of the crane boom, m; L is the length of the cable, m; φ is the angle of rotation of the crane, rad; α_T, α_R are the angles of deviation of the load in the radial and tangential directions, rad. The angles of deflection of the load and rotation of the crane can be given by some constant values or as a function of time.

With known boundaries of the observation zone, it is possible to propose a program for tracking objects of the entire zone, similar to the program for tracking the object [5, 8, 9].

The analysis of survey qualities of cabins of tower cranes with use of this program allowed to draw the following conclusions: to obtain visual information in any arrangement of objects in the front hemisphere can be due to the rotation of the eyeballs within the physiologically possible angles in the horizontal plane; to obtain visual information in the sagittal plane of physiologically possible values of the angles of rotation of the eyeballs is not enough; when transfering the location of the eye vertically (up or down), meaning that the «standing» or «crouching down» objects become more visually available; it is necessary to improve the review quality of the cabins through the development of changes in the shape of booths and glass as well as by improving the operator's seat, allows you to adjust the location of the point of gaze of the operator.

Engineering and technical solutions of cab structures of high visibility tower cranes and their equipment. Currently, the cabs of both Russian and foreign lifting and transport machines

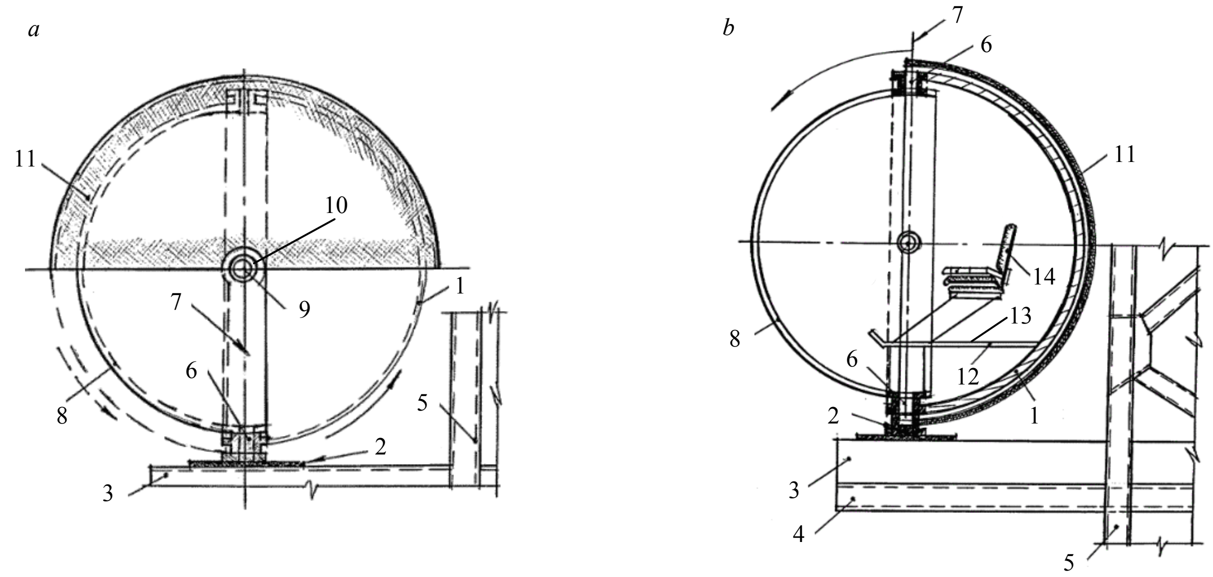

Fig.4. The spherical cabin of a tower crane: *a* – side view with a protective hemisphere; *b* – section of the cabin

1 – hemisphere is rigidly fixed; 2 – base; 3 – frame; 4 – outrigger supports; 5 – metal frame; 6 – hinges; 7 – vertical axis; 8 – transparent rotary hemisphere; 9 – horizontal axis; 10 – hinges; 11 – protective hemisphere (protective screen); 12 – cabin floor; 13 – viewing hole; 14 – operator's seat

have the same geometry in general, a shape of a conventional parallelepiped. In some of them, the windshield has a curved surface, which improves the reflectivity of the latter (in particular, the reflection of the wave solar, thermal and sound effects) and increases the viewing quality of the front zone.

Based on the results of the patent search, the analysis of existing cab designs of construction and road vehicles allowed us to offer several variants of the cab of increased visibility (Patent of the Russian Federation N 2175946; Patent of the Russian Federation N 2230021; Patent of the Russian Federation N 2272779).

The cabin of the tower crane consists of two hemispheres, one of which (opaque) is rigidly fixed on the base, and the other (transparent), hinged to it, can rotate relative to the vertical axis of the cabin. The transparent hemisphere has a protective shield in the shape of a hemisphere, which can be rotated relative to the horizontal axis of the cabin (Fig.4) (Patent of the Russian Federation N 2230021). Such a protective screen can reduce the impact of blinding light on the visual apparatus of the crane operator, thereby reducing his fatigue during prolonged observation of the progress of construction and installation works, and, as a consequence, eliminate the possibility of erroneous actions of the latter.

In addition, this design allows you to increase the thermal stability of the cabin due to the presence of a protective hemisphere and the air gap between the front transparent and retractable protective hemispheres. The lower part of the transparent hemisphere remains open, which provides an unobstructed view of the observed objects to the operator.

Since the technology of manufacturing the structure of the spherical cabin and its installation on the tower of the crane is complex and not always economically expedient, we have developed another cabin tower crane (Patent of the Russian Federation N 2272779) (Fig.5) of cylindrical shape.

The development of the new design was preceded by theoretical and experimental studies carried out on the basis of the constructed mathematical models of cabins, as well as using laboratory samples of spherical and cylindrical cabins. Studies have shown that the survey quality of the cylindrical cabin due to its transparent front cylindrical surface, which serves as frontal glazing, does not significantly decrease in comparison with the spherical cabin.

In addition, it is known that the microclimate in the cabin is an important factor characterizing the conditions of the production environment of the operator of the tower crane, it affects the comfort and efficiency of the operator in the course of work.

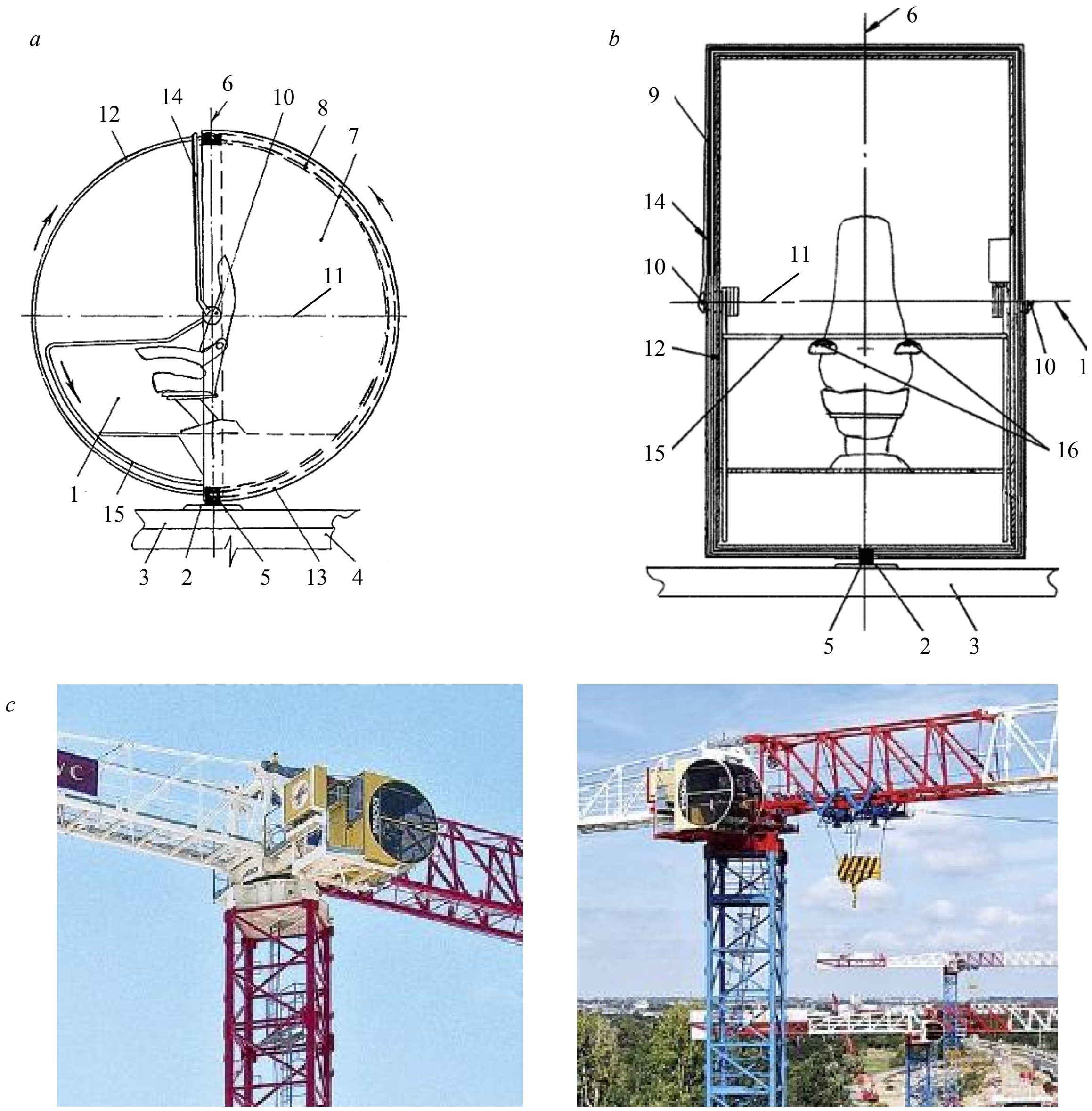

Fig.5. The cylindrical cabin of a tower crane: *a* – side view, *b* – front view, *c* – elevated cabin (Raimondi, Milan, Italy)

1 – cabin; 2 – base; 3 – frame; 4 – metal frame; 5 – vertical hinge; 6 – vertical axis; 7 – rear opaque part of the cabin; 8 – end wall; 9 – side wall; 10 – hinge; 11 – horizontal axis; 12 – front transparent part of the cabin; 13 – protective cover; 14 – wiper; 15 – protective guard; 16 – push-button controls

The efficiency of heat transfer resistance depends on the geometric shape of the cabin: it increases 2.6 times in the cylindrical cabin and 4.5 times in the spherical cabin compared to the traditional cabin in the shape of a parallelepiped [3].

Given the results of the research, we have developed cylindrical design of the cab of the crane (Patent of the Russian Federation N 2272779), the most optimal from the point of view of providing an overview of the qualities of the cabin, microclimate parameters in it and techno-economic efficiency of manufacture, installation and dismantling of booth.

The cylindrical cabin of our design consists of two parts. The first is rigidly fixed on the base, and the other, transparent, is pivotally connected to it and is rotary. The front swivel transparent and rear fixed opaque parts of the cabin are made in the shape of semi-cylinders, and their sidewalls are made in the shape of semicircles.

The cabin has a protective cover made of a material with high reflective properties, pivotally connected to a rigidly fixed on the base of the rear cab opaque part to rotate relative to the horizon-

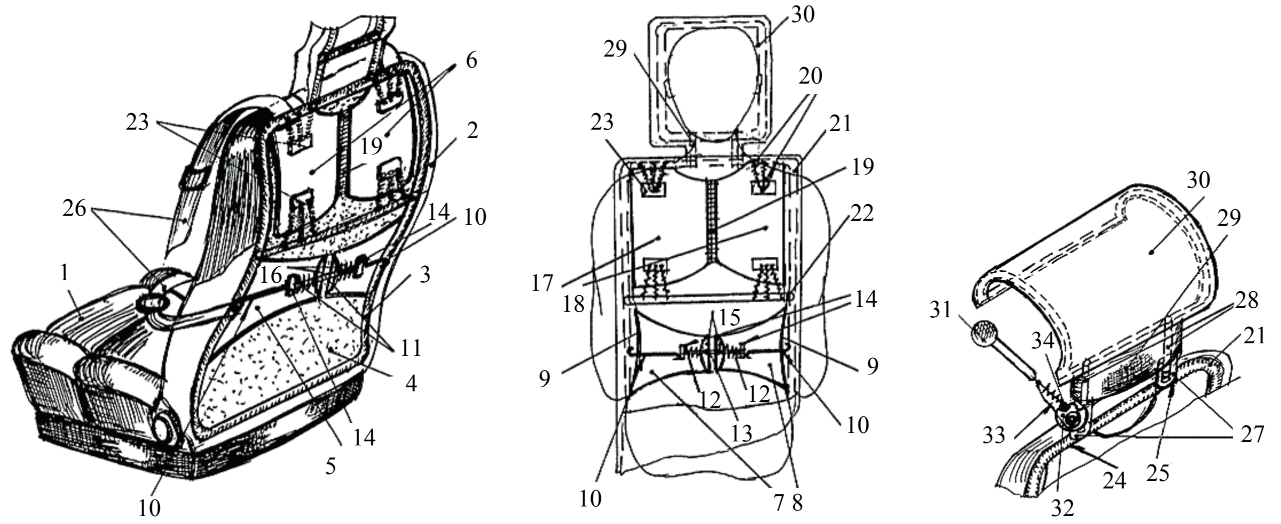

Fig.6. Operator seat in a construction machine

1 – pillow; 2 – back; 3 – frame; 4 – gasket; 5 and 6 – support elements; 7, 8, 9 – details of the support element; 10 – rod; 11 – tie; 12 – spring; 13 – holes; 14 – widened end; 15 – flange; 16 – hole; 17, 18 – components of the element 6; 19 – hinge; 20 – spring; 21 and 22 – upper and horizontal guide frame 3; 23 – strap; 24, 25 – upper ends of the upper support element 6; 26 – seat belts; 27 – tubular vertical racks; 28 – rods; 29 – support element of curvilinear form for fixing the neck; 30 – headrest; 31 – handle; 32 – Cam; 33 – return spring; 34 – spring-loaded roller

tal axis of the cab. Such a device allows reducing the influence of the main part of electromagnetic radiation on the upper and frontal part of the cabin of a tower crane, which in turn will reduce the fatigue of the crane during long-term monitoring of construction works and also will reduce the likelihood of erroneous actions. Movement control of the front transparent part of the cabin and the protective cover is carried out by means of push-button controls of the control panel mounted in the side handrails of the operator's seat.

In 2016, one of the oldest manufacturers of lifting equipment in the world, the Italian Raimondi company, founded in 1863, presented at the exhibition in Germany a new tower crane with a panoramic cylindrical cabin of increased visibility Panoramic XL (Fig.5, *c*), which confirms our idea and the appropriateness of the use of this design [13].

In order to improve the comfort and safety of the operator of the construction machine when performing visual and motor tasks in the process of production activities, we have developed at the level of inventions of the seat of the operator of the construction machine (Patent of the Russian Federation N 2137624; Patent of the Russian Federation N 2180623; Patent of the Russian Federation N 2210510).

The main objective of the inventions is to improve the view of the objects of observation by increasing the range of adjustment of the seat angle, by height and horizontally.

The seat is designed at the level of inventions (Patent of the Russian Federation N 2137624), the task is achieved by the presence of a flat lever mechanism in the form of two parallel four-bar parallelograms, which allows expanding the operational capabilities of the structure by adjusting the seat position in height and depth cabin, an amount equal to twice the length of the side links of the parallelogram, maintaining parallelism of the seat relative to the base.

The seat is equipped with a lever with which it can occupy three positions on the angle of inclination: «work with slope»; «work without slope»; «rest» that allows to improve working conditions of the operator and to increase visibility from a workplace.

Regulation of the position of the seat by the angle of inclination is carried out by the work of the worm pair.

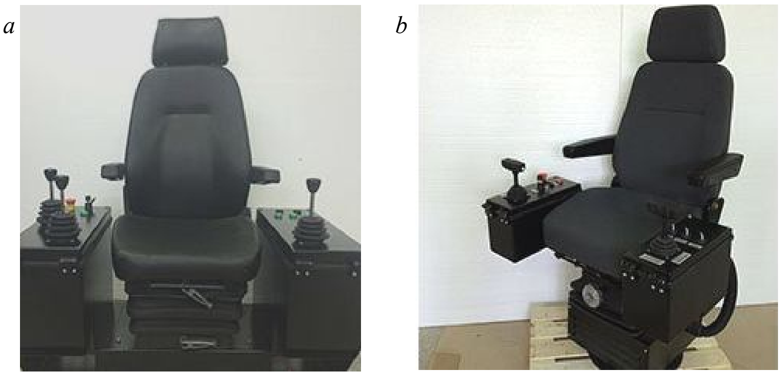

Fig.7. Chair with the remote control by OOO «BRIZ»: *a* – chair-remote control AH1 (AR1); *b* – compact chair-remote control AH2 (AR2)

The improved design of the seat allows the operator to fix the position of the body on the seat with a pneumatic vest, thereby to protect the chest and to prevent the slightest slipping off the operator's seat when operating in the «work inclination» when the inclination angle of the seat becomes greater than the maximum allowable (over 15-17°) (Patent of the Russian Federation N 2180623).

Another proposal is a seat that can be used primarily in the cabins of cranes and earthmoving equipment (Patent of the Russian Federation N 2210510) (Fig.6). The comfort of the seat is achieved by the special design of the seatback, the frame of which has a wavy convex at the top and a wavy concave vertical guides at the bottom. To ensure a tight fixation of the shoulder, a support element is elastically mounted in the upper wavelike convex part of the frame. Safety belts are rigidly fixed on the shoulder and side ends of the lower and upper support elements, being necessary for fixing the operator of the construction machine when performing work in the tilt position, as well as in case of sudden jolts or rocking the cabin. It is known that sharp shocks, which are possible for various reasons during the operation of the machine, can cause displacement of the vertebrae of the cervical spine or lead to bruises of the head on the hard surfaces of the cab rigging. In order to prevent such situations, a height-adjustable curved support element is provided in the upper part of the seatback to fix the neck section, with which the arc-shaped headrest is rigidly connected.

The seat presented by OOO «BRIZ» is similar to our proposal. Development of chairs with the remote control of various modification by OOO «BRIZ» has found a wide application on bridge and tower cranes (Fig.7).

The remote control is a solid metal structure with fixed consoles (bases) and an operator's seat installed on it. Standard dimensions of the base surface allow to place controls and displays for almost any application; if necessary, the width can be increased up to 400 mm. In the lower compartments of the cabinets are provided recesses for installation of two heaters, which provide heated crane cab, and serve as a quick thawing of the cockpit glazing in winter (chair units can be made without niches). The operator's seat has an anatomical shape, backrest angle adjustment, longitudinal movement mechanism, height adjustment, mechanical springing system, adjustable armrests, headrest, and fabric or vinyl upholstery. In the AR1 version, the product is equipped with a ball bearing rotation system (rotary device) with a rotation angle of 180-350°. The supply of control cables to the chair-consoles is realized from the bottom through the base (through the middle of the rotary device in the AR1 version).

Conclusions

1. The analysis of conditions and labor protection of operators of tower cranes used in the construction of high-rise objects indicates a high level of occupational morbidity and injuries, which is caused by low ergonomics of cabins and insufficient visibility.

2. The energy-entropy approach to assessing the stability of the OCME system allows establishing a correlation between the severity of the accident and the energy intensity of the machine, which makes it possible to assess the degree of danger of both operated and newly designed construction machine.

3. The program of spatial movement models of the visual apparatus allows to perform an analysis of accessibility by the operator visual information provided physiologically acceptable coordinate orientation, whereby it is possible to optimize the shape and size of the glass cockpit, technical characteristics of the control of the operator and its orientation in space of the cab to ensure maximum availability of visual information.

4. Accidents and injuries associated with the operation of tower cranes can be reduced through the development and introduction of new models of construction crane cabins and their equipment.

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