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Laboratory approbation of a new visualization form of hazardous objects control operator current psycho-emotional and functional state

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Abstract

The paper suggests a new form of visualization of the current psycho-emotional and functional state of operators for managing dangerous objects. Integral assessment of the current psycho-emotional and functional state of the operator is carried out on the basis of the registered bio-parameters analysis. These bio-parameters characterize the current functioning of its cardiovascular system, the respiratory system and the peripheral nervous system. Registration of these bio-parameters is carried out on the basis of passive remote non-contact technologies, typical of which are acoustic and optical ones.
The proposed form of visualization allows the display of both the indicators reached within a certain time interval and their change in dynamics, which significantly expands the scope of its possible application. The considered form of visualization also makes it possible to display the trends of a possible change in the state of the operator in the short and long-term perspectives.
Experimental approbation of visualization technology in solving problems of optimization of educational and training sessions, as well as in developing methodological tools for assessing the level of acquired professional knowledge and in adapting educational process to groups of various specializations, confirmed its high efficiency.

Keywords: human state visualization, human factor, pie charts, human resources management.

1. Introduction

Prevention of accidents and catastrophes of anthropogenic origin, caused by the so-called human factor, is today an actual scientific, methodological and technical task. Analysis of major recent accidents shows that the range of potentially hazardous facilities is not limited to the traditionally considered objects of the nuclear, chemical, oil and gas industries. At the present time, it is also necessary to consider the possibility of accidents caused by the human factor on public transport, during mass sports events, on hydro and thermal power stations and also in virtually all harmful industries.
The most effective solution to the problem should be considered the implementation of the approach consisting in the continuous monitoring of the current psycho-emotional and functional state of the operator directly during the performance of his production or official duties [1]. The most indicative in this regard is modern high-speed transport [2-5]. The basis for implementing this approach in practice is the use of remote, non-contact technologies for recording current bio-parameters of the operator in real time. The most informative and safe from the medical point of view technologies for remote registration of human bio-parameters nowadays are acoustic [6] and optical [7] ones. It should be noted that, for example, acoustic technology of stress diagnostics is quite actively used nowadays in sports [8-10] and ballet [11]. Optical technologies of the visible

range are mainly oriented to the recognition of human emotions [12-21], or an analysis of the direction change dynamics of the view [22, 23]. These technologies are passive, do not have any effect on humans and suggest only the registration of natural radiation emanating from it in the corresponding spectra. As registered bio-parameters, the image of the operator's face in the visible and infrared [24, 25] optical radiation range, as well as speech information, usually appear. The possibility of processing the latter is due to the accepted order of communication between operators and the group leader (the shift supervisor). This order, as a rule, provides for mandatory repetition by the executor of received voice commands and orders.

Unfortunately, the practical approaches to recording current human bio-parameters are oriented mainly to the simultaneous use of an extremely limited number of remote non-contact technologies or in general only one of them. For example, only processing an image of a person's face in the visible range of optical radiation [13-24], or only acoustic technology [8-11].

This situation largely limits the possible applications of remote non-contact technologies. In practice, the effective application of technology for the listed options for their use is possible only in the case of a quasi-static arrangement of the operator. In the case of active human movements, the presence of sharp turns and inclinations of his head, the use of individual technologies is ineffective. The main reason is the occurrence of so-called "dead" time intervals, during which the registration of bio-parameters is impossible.

In [1, 6, 7], an author's integrated approach is proposed, which makes it possible to increase the efficiency of recording human bio-parameters and, as a consequence, the reliability of the evaluation of its current psycho-emotional and functional state. The essence of the integrated approach is the simultaneous registration of bio-parameters in three areas - acoustic, optical visible range and infrared. This makes it possible to minimize or completely eliminate dead time intervals.

The processing of the bio-parameters obtained in this way with the help of specialized software makes it possible to determine a whole set of parameters, first of all, characterizing the operation of the cardiovascular system of the operator, the work of his respiratory system, and the level of excitation of his peripheral nervous system [1]. Typical parameters that characterize the current state of the cardiovascular system of the operator are, for example, heart rate, blood pressure, heart rate variability. The most informative parameters characterizing the current state of the peripheral nervous system are: a reaction similar to GSR (skin-galvanic reaction), the dynamics of the pupil size change, the level of the so-called tremor in the speaker's voice. The total number of parameters characterizing the current psychoemotional and functional state of the operator at each moment of time is about 30 [1].

The complexity of displaying and analyzing the time dynamics of changes in all of these parameters for each shift operator (brigade) makes it practically impossible to carry out their constant monitoring by authorized specialists. For this reason, in practice, integral estimates of the current state are used, which are more convenient for rapid analysis and forecasting of possible undesirable changes in the state of operators [1, 6, 7]. Unfortunately, the graphical representation of these estimates in the form of graphs of time dependencies [2-5, 8-25] does not fully allow the realization of the results comparison function. Especially it concerns the comparison of the results obtained during the training sessions on the simulators and directly in the process of production activity, as well as the results obtained at different times by different operators.

The purpose of the work is to analyze the possibilities, as well as present the results of laboratory testing of the proposed visualization form of the current psychoemotional and functional state of the dangerous objects management operators in the form of multifunctional pie charts.

2.Traditional presentation of monitoring results

Figure 1 shows the working window of specialized software, which displays the results of bio-parameters processing using infrared technology for their registration [1, 7]. This software is an integral part of the experimental software and hardware complex for continuous assessment of the current psycho-emotional and functional state of a person on the basis of using remote, non-contact technologies for bio-parameters recording developed by the authors. This form of graphical representation of the temporary change in human bio-parameters is typical for the monitoring and visualization means used in practice [2-5, 8-25]. As part of the specialized software, this form of graphical representation is implemented mainly for test and diagnostic purposes.

Specificity of registration and processing of biological parameters in the infrared radiation range is that such natural radiation is almost completely absorbed by human clothing. As a result, to register bio-parameters it is possible to use practically only the infrared image of the face, sometimes the neck and hands.

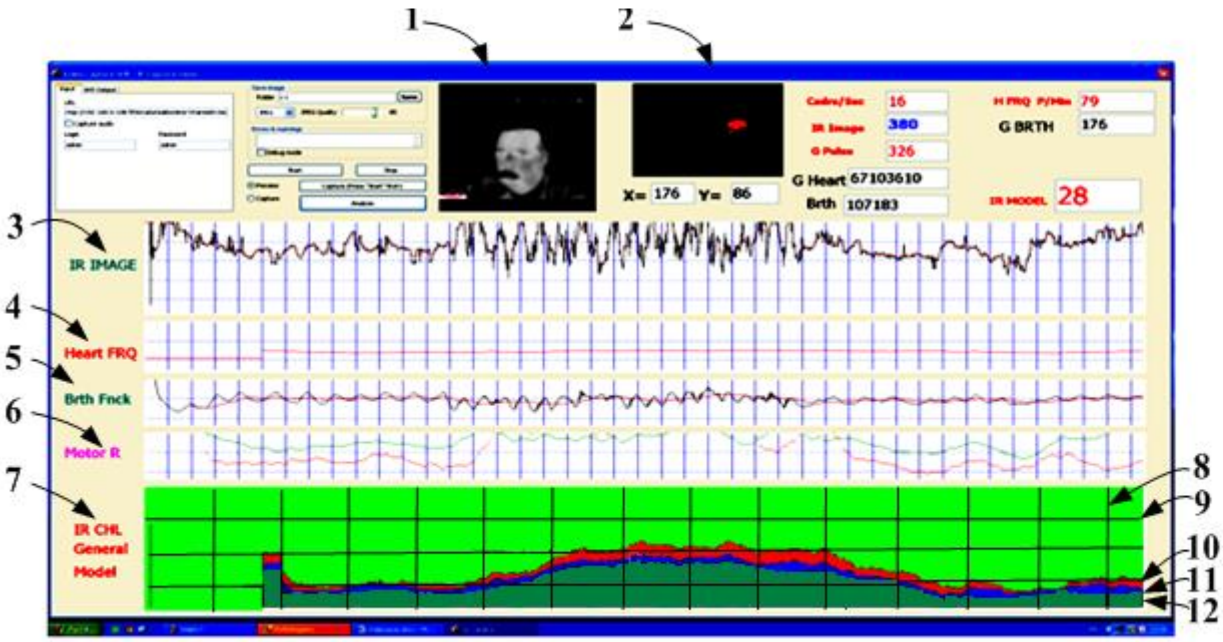


Fig.1. Human bio-parameters registration process visualization during the training sessions (with a high load in the middle of classes)

The working window presented in Fig. 1 allows the instructor, who is currently monitoring the operator's condition, to check the quality of the original infrared image (1), as well as the correct positioning of the operator's head in the field of view of the thermal imaging camera (2). Control over the position and possible head inclinations is carried out automatically in the analysis of the total heat flux recorded by the camera (Graph 3). This information is necessary to identify the moments of time during which the most reliable registration of bio-information is possible [1, 6, 7]. Charts 4-6 show the change in time of heart rate (Heart Frq), respiration rate (Brth Fnc) and motor activity (Motor R). Figure 7 shows the time variations of the integral characteristic (IR Channel General Model), which allows you to assess the current psycho-emotional and functional state of the operator. The values of the integral characteristic are calculated on the basis of a model that takes into account the deviations of the current bio-parameters from their values for the normal quiet state of the operator [1, 6]. The length of time slots 8 is set by the instructor before the start of the monitoring process. It is chosen based on the planned total duration of the monitoring process. For example, for an 8-hour work shift, it is usually 25-30 minutes. For training sessions with a total duration of 2 hours, it can be 5-7 minutes. As a result of such time intervals settings, the instructor has the opportunity to observe and analyze the entire production or educational process. Levels 9 correspond to different degrees of the operator fatigue [1, 7]. The contribution of each of the parameters characterizing the work of the cardiovascular system, nervous system and respiratory system, in the integral characteristic 7 is shown respectively in red (10), blue (11) and green (12) colors.

The software under consideration also allows displaying the results of remote measurement of bio-parameters with the help of acoustic technology, as well as optical technology of the visible range, in a similar graphical form. In Fig. 2 shows an example of the resulting function Q(t), which assesses the current psycho-emotional and functional state of the operator on the basis of bio-parameters monitoring using optical and acoustic technologies. The values of this function are determined on the basis of a linear model that takes into account the contribution of each of the above mentioned measuring technologies (1, 2, 3) [1, 6, 7].

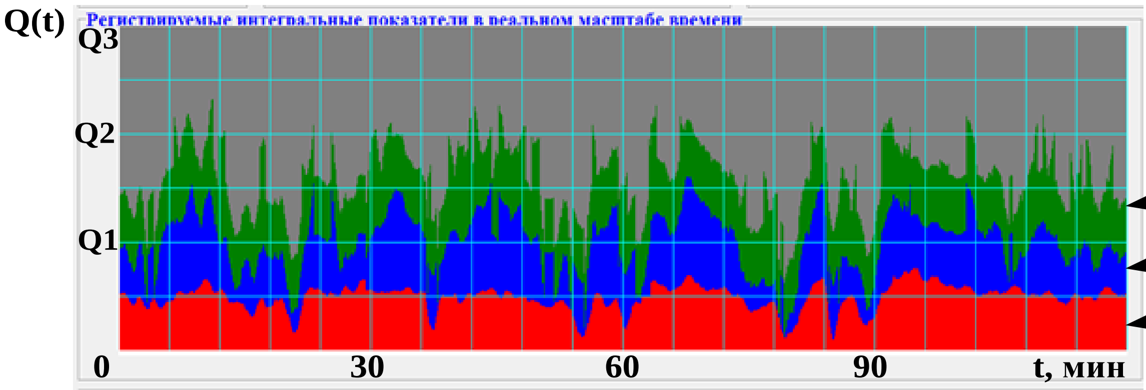


Fig.2. Monitoring of the current psycho-emotional and functional state during the medium intensity training sessions conduction for 2 hours.

Threshold values of Q1, Q2 and Q3 determine the boundaries of a possible change in the state of the operator. The entire range of possible values of the function Q(t) is usually subdivided into three regions. The range of $Q1 \leq Q(t) \leq Q2$ corresponds to the normal operating state of the operator. The ranges $0 \leq Q(t) < Q1$ and $Q2 < Q(t) \leq Q3$ characterize the current state of the operator, respectively, as strongly relaxed (sleepy) and stressed. The values of $Q(t) > Q3$ correspond to strong mental and physical fatigue.

The main drawbacks of this visualization technique are difficulties in comparing the results obtained during training, training and work shifts of different duration, as well as their low visibility.

In the paper, the use of unified pie charts is proposed to present monitoring results. With the help of such diagrams, it is possible to visualize, analyze and compare the results obtained at all stages of preparation, testing and operational activities of operational personnel.

3. Unified pie chart

In Fig. 3 is presented a view of a unified pie chart showing the change in the current functional and psycho-emotional state of the operator (function Q (t)).

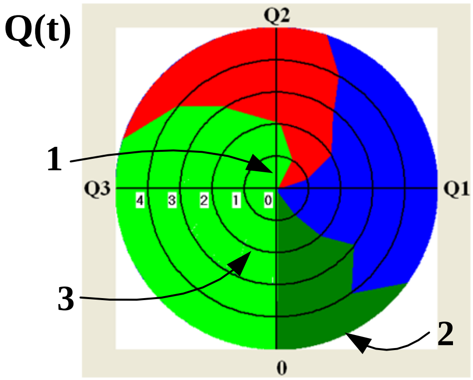
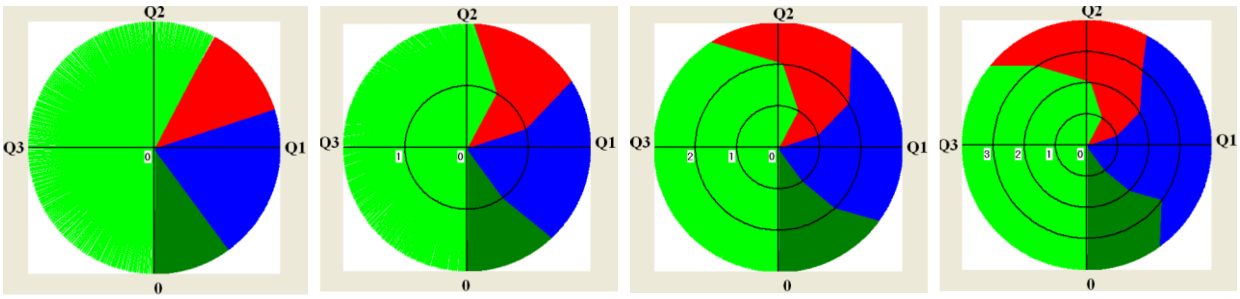


Fig. 3. An example of a unified pie chart showing the change in the psycho-emotional and functional state of the operator during a high intensity training session for 5 hours

The center of the pie chart corresponds to the beginning of the monitoring (1). The peripheral part of the pie chart (2) corresponds to the current time, or the time of the end of monitoring. Circles (3) correspond to different moments of time. The quadrants 0-Q1, Q1-Q2, Q2-Q3 and Q3-0 correspond to the characteristic domains of the operator possible states considered earlier. Different colors show the contribution of different bioparameters groups, similar to the information shown in Fig. 2.

If the pie chart is in the formation stage, it is dynamic. If the diagram is fully formed, it is static (Fig. 3). Fig. 4 illustrates the process of a static circular diagram forming, shown in Fig. 3. For this purpose, a series of intermediate dynamic diagrams (a), (b), (c) and (d) are shown for the time points of 1 hour, 2 hours, 3 hours and 4 hours, respectively. Analysis of chart data allows you to trace trends in the operator current state changes, as well as assess trends in its further change, for example, when conducting training sessions on the simulator.



a) b) c) d)

Fig. 4. A static chart forming process illustration

From the above sequence of diagrams it is clearly visible that the operator performing the training tasks has started to work in a normal working condition. His indicators at this time were in the range of Q1-Q2 (Figure 4a). By the end of the second hour of training, the operator's condition became more tense and approached the Q2 border (Figure 4b). During the third and fourth hours of exercise, fatigue began to increase. Integral estimates of the current state were in the range Q2-Q3 (Fig. 4c, d). The obtained data allow the instructor to make a reasonable conclusion about the level of professional training of this operator, and also to compare these results with previous ones, as well as with the results obtained by other operators.

Thus, the proposed form of visualization of the current psycho-emotional and functional state of the dangerous object managing operator is more convenient and visual. It makes it possible to simplify the analysis and comparison of various results obtained during the conduct of training sessions of various types and duration. This circumstance is also of great importance for the decision-making process automation.

4. Trends analysis and forecast of possible changes in the operator state

The form of information visualization can also be used to display possible change trends in the operator state when the same operating conditions are maintained. Under working conditions, one should understand the complexity of the production or training tasks being solved, as well as climatic and noise conditions. In Fig. 5 shows an example of a pie chart containing both actual data about the current state of the operator and their forecast values.

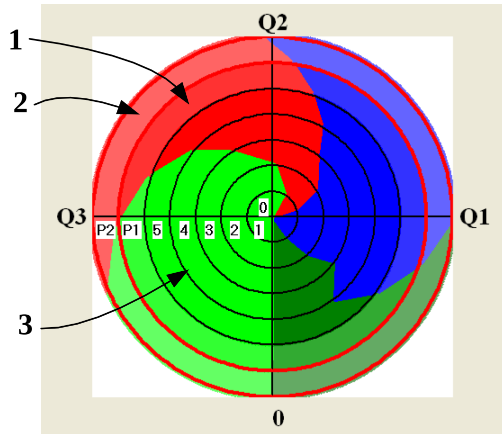
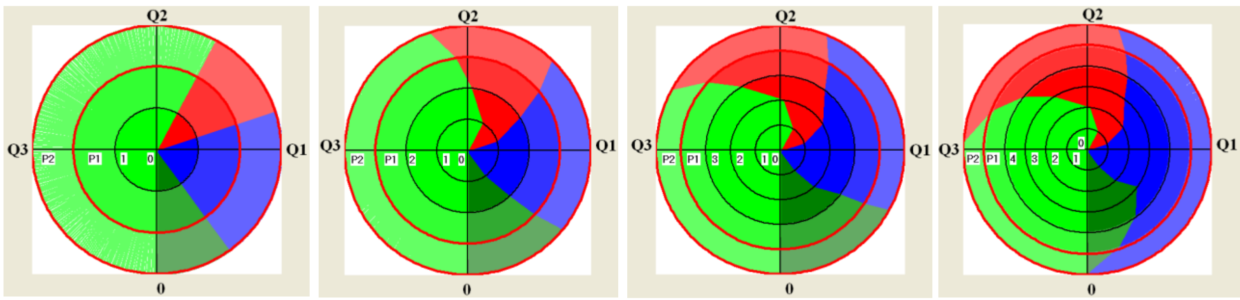


Fig. 5. Visualization of current and forecast indicators: 1, 2 – areas of forecast values; 3 – the area of achieved indicators within 5 hours

Areas of predicted values (1 and 2) on the pie chart are marked with red circles and have a less bright color in comparison with the areas showing the achieved results. To obtain predicted values, one of the extrapolation methods is used. The area of the nearest forecast 1 allows the instructor to assess a possible change in the operator's state within 0.5-1 hours. The region of the long-range forecast 2 allows obtaining similar estimates within 2-3 hours. As can be seen from the diagram above, the status of the operator in question can be qualified as very tense, which indicates either a low level of professional training, if it is a question of training sessions, or about the need to change the conditions of production activities, including the organization of breaks and rest.

In Fig. 6 shows the corresponding dynamic diagrams with a projection of the predicted values.



a) b) c) d)

Fig. 6. Dynamic diagrams with prediction values 1 and 2 according to the achieved indicators, respectively, during 1, 2, 3 and 4 hours of operation - respectively, diagrams a) – d)

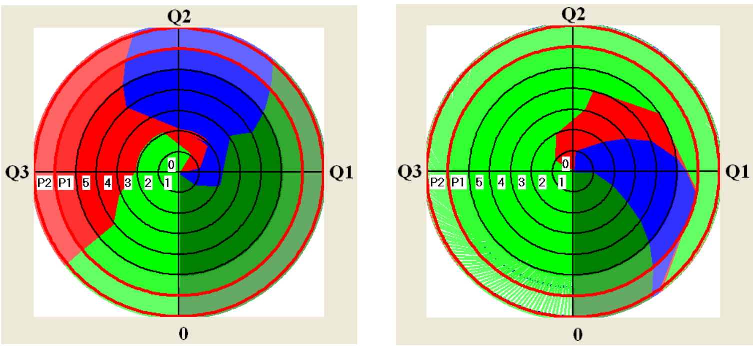
It should be noted that the forecasting of a possible change in the psycho-emotional and functional state of the operator is carried out taking into account personal data stored in a specialized database. Such a database usually contains information on the results of periodic scheduled medical examinations, the results of testing in laboratories of psycho-physiological support, as well as the results of all training sessions. This allows you to accurately implement the forecast, taking into account personal characteristics.

5. Possible spheres of application

It is most expedient to apply this graphical form of the operator current state visualization when solving the following tasks:
- assessment of the professional suitability and professional growth of employees [1, 26];
- an assessment of the complexity of educational and training sessions [26];
- realization of biological feedback [1, 7, 26].

Assessment of the professional growth of employees can be carried out using the dynamic pie charts discussed above, in which longer time intervals, for example, 0.5-2 years, are used as the time samples. In this case, as the integral characteristic of Q(t), it is necessary to use the achieved results in carrying out scheduled periodic test and certification activities. As components of the integral characteristic Q(t), in practice, such indicators as the time of malfunctions elimination in case of emergency modes of a hazardous object operation, the reaction time, the level of self-control are used. Threshold values Q1, Q2 and Q3 in this case determine the achieved professional level of preparation: range 0-Q1 - not high enough; Q1-Q2 - satisfactory; Q2-Q3 is good and Q3-0 is excellent.

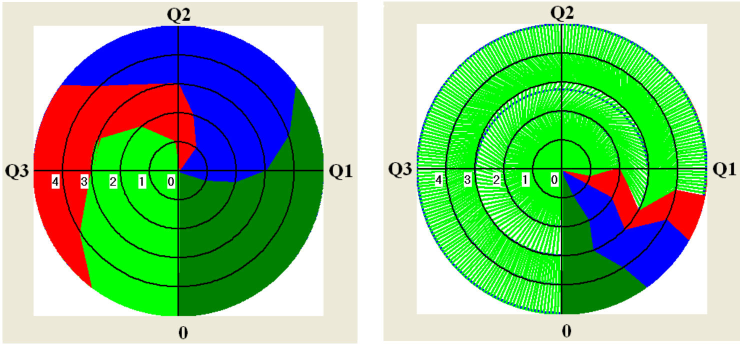
In Fig. 7 shows two demonstration variants of changes in the level of professional training over a time interval of about 20 years (each time interval is 4 years). Option a) corresponds to the constant growth of professional skills, which reaches a maximum in the region of 15 years. In the future, according to statistical data, usually due to age-related changes, this level may undergo some changes. Option b) illustrates the gradual professional degradation of a person. The forecast shows a probable deterioration in the level of vocational training to an unsatisfactory degree.



a) b)

Fig. 7. Examples of predicted changes in professional skills

Assessment of the complexity of training and training sessions is carried out on the basis of analysis of static diagrams. As an integral estimate in this case, we should use the function Q(t), averaged over all participants in the class. In Fig. 8 shows typical examples of the training sessions complexity assessment based on this approach. The diagrams thus obtained can also be used to assess the level of training of teaching personnel. To do this, it is necessary to compare the diagrams obtained by carrying out the same trainings by different instructors.



а) б)

Fig. 8. Assessment of the training sessions intensity with high (a) and low (b) complexity

Biological feedback in practice is widely used in conducting training sessions in order to increase stress resistance on the basis of developing skills of self-control and self-regulation. The use of compact diagrams reflecting the current state of the trainee makes it possible to automate the learning process using a wide range of software and hardware systems and simulators. In Fig. 9 visualization of the training stress resistance process with the use biological feedback technology [26] is presented. For this purpose, dynamic pie charts with a prediction function are usually used, which allows the trainee to develop self-monitoring skills for his condition.

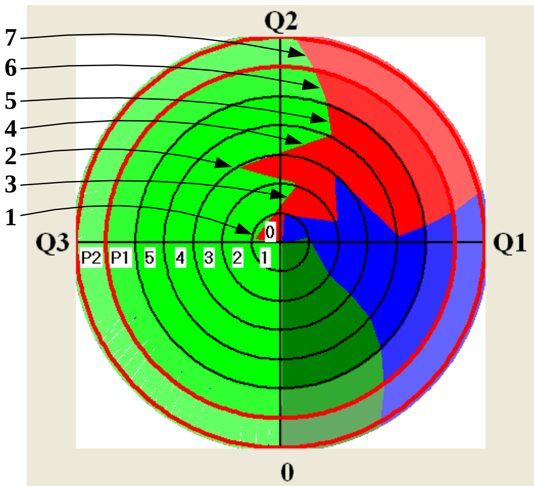


Fig. 9. Example of training stress resistance: 1, 2 – moments of time of strong stress; 3, 4 – activation of the self-control and self-regulation processes; 5 – return to normal operating mode; 6. 7 – near and far forecasts of changes in the current state of the trainee operator

6. Laboratory approbation of the proposed visualization form

The visualization technology under consideration has undergone laboratory testing in the framework of specialized laboratory classes on the design of modern high-speed digital devices on FPGAs with the SoC structure of the Altera, Xilinx and MicroSemi (Actel) families. The visualization technology was used to solve the following problems:

- creation of a set of training and test tasks for the design of nodes and blocks of digital devices based on modern FPGAs;
- development of methodological tools for assessing the level of acquired professional knowledge and practical competencies when working with CAD FPGAs of specified manufacturers;
- adaptation of educational and training sessions to groups of different specializations that have different sets of engineering competences in the design of electronic devices.

The relevance of the proposed visualization technology when conducting practical exercises on the electronic nodes and blocks design using modern CAD FPGA Quartus, Xilinx and Libero is due to the following factors. First of all, this is a large amount of processed graphic information, as well as frequent change of working windows in CAD when switching from one level of presentation of information to another. These factors lead to a strong permanent eye strain and, as a result, to rapid fatigue and the growth of erroneous actions.

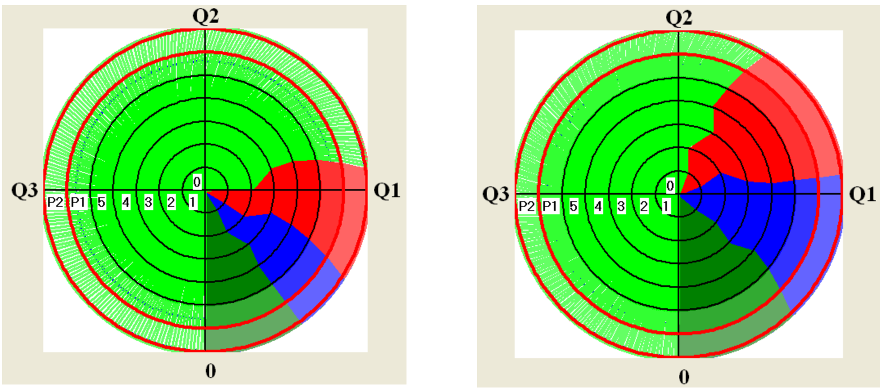
The application of the considered visualization technology allowed creating sets of educational and training tests oriented at 2, 4, 6 and 8 hour of practical exercises with controlled complexity. Managing the complexity of test tasks was accomplished by adding or removing additional electronic nodes. As a result, it was possible to develop a balanced set of test tasks with increasing complexity, focused on cycles of practical exercises. The application of the developed set in practice makes it possible to ensure that the integral assessments of the current state of the training group on average during the whole class will be in the area determined by the boundaries of Q1 and Q3. Practical approbation of this approach has shown that it is possible to reduce the number of erroneous actions up to 2-5 times.

The developed methodological tools for assessing the level of acquired professional knowledge and practical competencies when working with CAD FPGAs are based on the use of test tasks of a given complexity. The use of pie charts makes it possible to correlate the achieved results with the time of execution of the test project, its technical level of implementation, as well as the number of mistakes made and with mental and physical costs incurred. The application of these methodological tools permits one to more objectively assess the depth of acquired professional knowledge and skills, as well as the ability to apply them in practice.

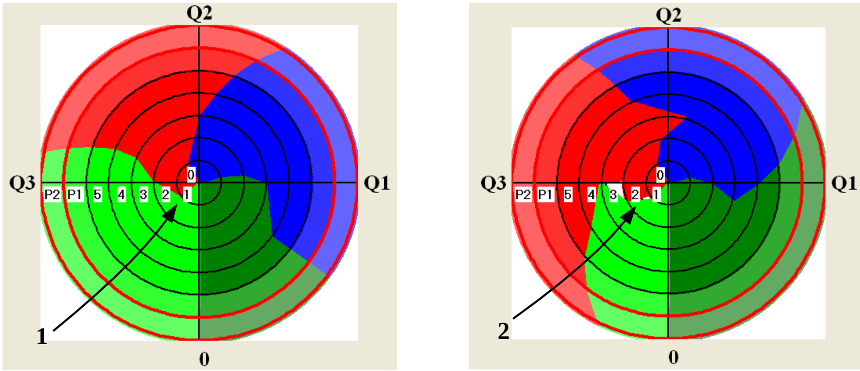
The analysis of the visualization results of the final psycho-emotional and functional state obtained during the practical sessions with the contingents of the listeners of various specializations made it possible to adapt the content and structure of the training and practical training on CAD to different groups possessing a different set of engineering competencies in the design of electronic devices.

The analysis of the visualization results of the psychoemotional and functional state of listeners of various specializations made it possible to adapt the content and structure of educational and practical training on CAD to the available level of preparation.

Figure 10 presents typical examples of averaged results visualization of the changes dynamics in the psycho-emotional and functional state for two groups of listeners. The listeners of the first group specialized in a deep study of electronics. They studied various disciplines on the basics of digital and analog electronics, as well as on automated means for designing electronic devices. Typical visualization results for the first group are shown in Fig. 10a, b. At the same time, Fig.10a corresponds to the most successful trainees, and Fig. 10b - less successful.



a) b)



c) d)

Fig.10. Laboratory approbation of the visualization method

The second group of students did not specialize in a deep study of electronics. For her, electronic competencies were not the main ones. Figure 10c, d shows the visualization results for this group. It can be seen that the process of designing electronic devices for the second group of listeners was more intense. Figure 10c corresponds to the most successfully trained listeners of the second group, and Fig.10g - less successful. A characteristic sign of insufficient preparation for the second group is the presence of emissions (1, 2) at the initial moments of the test task. These emissions indicate some fright, stress in the listeners when they become acquainted with the conditions of the test task. They are evidence, among other things, of insufficient experience in performing such tasks, as well as insufficient free possession of the material and the ability to apply the knowledge gained in practice.

7. Conclusion

The technology of visualization of the current psycho-emotional and functional state of the operator is the basis for solving the problems of managing the reliability of the human factor, which is an integral part of the modern strategy to ensure the safe operation of dangerous objects that could potentially cause technogenic accidents and disasters.

The technology of results visualization in the form of static and dynamic pie charts is multifunctional and makes it possible in practice to improve the efficiency of educational and training sessions of all kinds. The technology allows automation and integration with most modern computer educational tools and techniques.

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