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Instruments of Operator's Active State Identification

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***Abstract* – In this paper the results of development of the system of tools for identification of operator's active state development were proposed. The types of delay of operator's active state (motor activity) from the point of view of their criticality for the control object were developed. Classification of approaches to correction of each type of delay of operator's active state was designed. The system of qualitative indices of identification of various types of delay was proposed. The functional scheme of technical realization of the device of operator's active state identification using defined approaches and indices was constructed. The methodology of the adaptive correction of the situation of controlling the object by the results of identification of the level of operator's ability to fulfill actions, adequate to the time, was suggested.**

Keywords* – *operator's active state; motor activity; delay; style; classification; device; adaptive correction.

I. INTRODUCTION

In the modern world of human-machine systems, particularly Automated Control Systems, there occurs an abrupt growth of psycho-physiological workload on this system's component – the human operator [1]. In the process of ergative system functioning, under the influence of destabilizing factors in the functional state of operator there occur changes, which can lead to the malfunction or non-fulfillment of regular staff algorithms of operator's activity. One of the most dangerous "failures" of the normative work of such a system is the presence of indications of inadequate operator's response to the regulated actions of the control system (drowsiness, inhibition connected with tiredness, worsening of physical or psychological state), which is identified as person's inability to conduct actions, adequate to the current situation. Such phenomena can occur even in such types of activity, when before each duty (work) period an operator has medical examination of main indices of his physical readiness to start his functional duties.

The number of researches dedicated to this problem is increasing. The biggest difficulty consists in the search of effective criteria for creation of the operator's state control system, which would allow the maximum objective and operative **identification** and **correction** of both the state of operator's working activity and the stable mode of control system operation.

Technical tools of **identification** of operator's state are usually divided into two main groups: with and without contact. Contact method includes the usage of technical control tools, which directly contact the object of examination (a human) – for instance, sensors, fastened in hats, glasses, on earlaps, fingers and wrists etc. The main disadvantage is their constant contact with a person, which may often be an irritant.

In control methods without contact the assessment of state is done distantly, i.e. without tools touching a person. Usually these tools are sensors or computer systems, analyzing eye movements of an object, change of his body, head or arms position. One of the disadvantages of such methods can be the insufficient informativity, since the information about body or body parts movements does not contain enough data about operator's functional state [1-4].

As an example of existing **methodological** tools of **identification** and correction of the level of operator's working capacity we can consider the following approaches:

– terminal supply of sound signals, the deactivation of which is controlled by a person, or the supply of alarm signal in case of absence of operator's reaction to this signal [5];

– definition of the levels of wakefulness and sleep stages, including the stage of drowsiness in the process of professional activity with the help of shifting the point of pressure of a body to the force-torque chair and returning the operator from sleep to the wakeful state or from drowsiness with the help of controlling signals [6];

– fixation of body's shifting by means of analyzing the level of deformation of the plate under operator's seat and alarm about operator leaving the "working" state [7];

– control of the level of emotional tension by means of revealing the abilities of an operator to perceive selective typical doubled information [8];

– registration of sequence of operator's actions, change of speed of his reaction to irritants and comparison of actual actions with the optimal model of operator's behavior in a particular situation [9];

– test of operator's professional suitability by means of comparing the time of operator's actual reactions to the external factors and the operation of vehicle with the standard one. The comparison is conducted by *n* levels of complexity; in case of malfunctioning or operator's belated reaction in the number, equal to the number of complexity level plus one, the testing is continued on the next, upper level of complexity [10];

– application of electrical sensor, placed in the zone where operator's fingers influence its parameters, and

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activation of the alarm signal in case when within the set time period the information about operator motor activity is absent [11];

– designing on the basis of Operator Functional State pattern recognition methods an adaptive aiding system either to remind the operator or to reduce the task load during the period of excessive mental workload, with an aim to enhance the overall system performance [12, 13, 14, 15];

– adaptive fuzzy model linking heart-rate variability and task load index with the subjects' optimal performance via a series of experiments involving process control tasks simulated on an automation-enhanced Cabin Air Management System [18, 19, 20].

Even considering the limited list of given examples of methodology of identification and correction of level of operator's active state, we can point out the following disadvantages:

– improvement of only the algorithms of identification of non-typical (non-regulated) operator's behavior with the further activation of signal about anomaly detection [5, 6, 7, 9, 11, 18, 19] without realization of complex approach to the possibility of correction of the revealed behavior deflections. This approach can be optimal only in case of heightened danger of failure situation occurrence, which does not give additional time to conduct a more thorough situation analysis;

– expansion of the area of application of the methodology of controlling operator's active state by means of using technical tools and algorithms of adaptive analysis of the degree of deflection from human's regulated standard motor activity [8, 10, 12, 13] with the use of test control, doubled information perception etc.

However, each of the mentioned **methodologies** possesses **limitations** by:

– the type of the defined deflection (emotional, visual perception, information distortion);

– the classification of types of operator's anomaly behavior (the degree of closeness to sleep, the degree of emotional overload etc.);

– the time of application of the adaptive correction methodology (for instance, not in the process of work but before the beginning of operator's shift);

– the type of influencing controlling signals (doubled information, sound irritants, semantic tests);

– the type of operator's work place (vehicle, autonomous stations, boiler houses etc.).

Thus, we can make a conclusion that there exists no single methodology of **identification** and **correction** of operator's working activity.

The authors set the objective of *providing the required level of quality of control and regulation of the parameters of Automated Systems* due to the development the system of the instruments, which contains:

1. Classification of types of delay of operator's active state (motor activity) from the point of view of their **criticality for the control object**.

2. Classification of approaches of **correction** of each type of delay of operator's active state.

3. Qualitative **indices** of identification of various types of delay of operator's active state.

4. Functional **scheme** of technical realization of the **device** of operator's active state identification using defined approaches and indices.

5. Complex **methodology** of:

- identification and obtainment of quantitative indices of specific characteristics of an operator concerning his ability to *maintain the active working state during the shift*,

- adaptive *correction of the situation of controlling* the object by the results of identification of the level of operator's ability to fulfill actions, adequate to the time.

II. Basic Concepts of Identification of Operator's Active State

The suggested system of the instruments for identification of operator's active state is based on the following concepts, developed by the authors:

Concept 1. Delays in the active state of an operator (his/her motor activity) of the Automated Control System can be divided into 3 main types:

– **working (type A)** – are mostly connected with the discrete character of the control process, done by the operator;

– **non-critical (type B)** – can be connected with an accidental shift of operator's attention to the extraneous (which are not restricted by the job description) objects and actions;

– **critical (type C)** – can be connected with the operator's loss of attention and ability to carry out conscious professional actions, which can be dangerous for the process of object control.

Concept 2. **Correction** of each of the three defined types of delay of the motor activity of an operator, which may appear, can be fulfilled in accordance with the following algorithms:

– **regulated** – by means of an *independent* (without applying the identification tool) restoration of operator's motor activity in connection with the appearance of the next *regulated* operation of controlling an object;

– **test correction** – by means of the *automated* (with the help of the identification tool) restoration of operator's motor activity by using the *test* algorithm of *shifting operator's attention* from current to special non-typical tasks of decision-making and decision-realization;

– **failure correction –** by means of the *automatic* (with the help of the identification tool) interference into the process of control by indication of the *signal* of appearance of a *critical situation* or by *switching* the control system into the *automatic* regulation mode.

Concept 3. **Identification** of the defined types of the delay of motor activity of an operator of the Automated Control System is suggested to be carried out with applying the following **indices**:

– **regulated** *average* time of the possible absence of operator's motor activity T_k (defined on the basis of statistical data – results of observations of the etalon operator's work during one shift);

– **non-regulated** test time T_{test} that consists of the **regulated** average time T_k and time for the **test** correction of operator's motor activity T_r and which totally must not exceed the *maximum non-critical* regulated time T_{max} of the possible absence of operator's motor activity:

$$T_{test} = T_k + T_r, \tag{1}$$

$$T_{test} \le T_{max}. \tag{2}$$

– **failure** time T_{fail}, which consists of the **regulated** average time T_k for the test correction of operator's motor activity T_r and the time for decision-making about the choice of algorithm of failure correction T_{alarm}, and which totally must not exceed the *maximum critical* regulated time T_{A_max}, within which the Automated System can work without the operation of process control.

$$T_{fail} = T_k + T_r + T_{alarm}, \tag{3}$$

$$T_{fail} \le T_{A\_max}. \tag{4}$$

III. Main Scientific Solutions for the Operator's Active State Identification

A. Functional Scheme of the Device

To solve the technical part of the complex task of system of the instruments for identification of operator's active state development we suggest the device, which includes (figure 1):

1 – block of the electrical Sensor of operator's motor activity (for example, infrared scanning laser); placed in the zone, where the position of operator's hands can influence its parameters;

2 – block of the Timer (for instance, a specified chip, which is activated by electrical signals);

3 – block of the Programmer;

4 – Alarm block;

5 – block of Signal Elements, which is placed in the range of operator's vision and is supplemented by five signal elements, which set the position of the manual manipulator: left, right, up, zero, down.

6 – block of Control Keys;

7 – block of the Manual Manipulator with five finite positions: left, right, up, zero, down, which are placed in the zone of influence of operator's free hand fingers;

8 – Comparator block;

9 – Accumulator block.

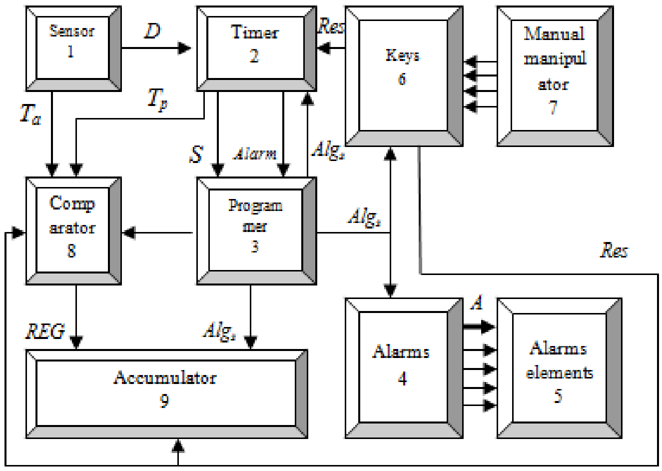

Fig. 1. Functional Scheme of the Device for Identification of the Operator's Active State

B. Algorithm of the Complex Methodology Indetification

On the basis of the proposed concepts and technical solutions of the research goal, the **algorithm** of the suggested methodology of operator's active state identification is propose. It includes the following steps:

1. To ensure work of the device before the process of identification the preparatory works are carried out:

– conduction of experiments and calculation of indices of the average **regulated** time T_k of the possible absence of operator's motor activity; **non-critical** *regulated* time T_{max} of the possible absence of operator's motor activity; **maximum critical** *regulated* time T_{A_max}, within which the automated system can work without the operation of process control; optimal time T_{opt} for the recognition and perception of information from the signal element, and also directly the conduction of commutation by the manual manipulator.

– keeping these indices in the blocks of the timer, programmer and comparator.

2. In the Timer the initial recording time is set – **regulated** *average* time T_k of the possible absence of operator's motor activity

3. Conduction of each ***(i)*** regulated professional action (movement) of an operator is accompanied with the transfer of the time signal D from the Sensor of operator's movement to the timer.

4. Within the time from the moment of transfer of the previous signal about professional actions (movements) of an operator the timer conducts the countdown (starting from zero) with the constant **control** of the absence of exceeding of the regulated average time T_k by the current time in the Timer $T_p(i)$:

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$$T_p(i) \le T_k\,. \quad (5)$$

5. In case when the moment of arrival of the signal $T_p(i)$ from the Sensor of operator's movement to the timer conforms the condition (5), the Comparator identifies the ***(i)*** current state of the operator with the type of **working** delay of operator's activity (type *A).*

6. At the same time, the *current* value of delay time, saved in the Timer, is nullified $T_p(i) = 0$ and the timer starts the new countdown.

Restoration of operator's motor activity is carried out following the **regulated** algorithm – i.e. by means of an *independent* restoration of motor activity connected with the appearance of the next *regulated* operation of controlling an object.

7. Information about each ***(i)*** current stare of an operator goes from the movements Sensor and the Timer, is saved in the Accumulator of the device in the format of tuple REG, which keeps *quantitative* characteristics of the delay of operator's motor activity – the period of time before the action $T_p(i)$ and the action time $T_a(i)$, as well the *qualitative characteristic* – the type of delay of motor operator's activity:

$$REG = \langle T_a(i), T_p(i), A \rangle\,. \quad (6)$$

8. In case the time signal D from the movement Sensor does not come by the moment when the *current* time in the timer $T_p(i)$ equals to the regulated average time T_k, the timer sends signal D to the Programmer, informing about the necessity to use the algorithm of **test correction** of the delay of operator's motor (working) activity.

9. For this purpose the Programmer, in accordance with the set in it programs, forms (chooses) the algorithm Alg_s of the **test correction** within the time T_r, which presupposes transmission of the signal to the Alarm block concerning the sequence and time of activation of the signal elements *Left, Right, Zero, Down, Up* within the time, which does not exceed T_r (with the condition $T_k + T_r \le T_{max}$):

$$ALG_s = \{Seq, \langle t_1, t_2, t_3, t_4, t_5 \rangle\}. \quad (7)$$

The difference between the time moments of signal elements activation must not exceed T_{opt}:

$$t_i - t_{i-1} \le T_{opt}\,. \quad (8)$$

10. The Programmer also sends the signal Alg_s to the Timer when the algorithm starts and it begins the countdown with the constant **control** of absence of the exceeding of the *maximum non-critical* regulated time T_{max} by the current time in the Timer $T_p(i)$:

$$T_p(i) \le T_{max}\,. \quad (9)$$

11. The same signal Alg_s is sent by the Programmer also to the block of Control keys.

12. In case the operator conducts the **correct** commutation – i.e. the concurrency of the complex of indices of sequence Seq and the commutation time:

$$Res = \{Seq, \langle t_1 + t_{opt}, t_2 + t_{opt}, t_3 + t_{opt}, t_4 + t_{opt}, t_5 + t_{opt} \rangle\} \quad (10)$$

– the signal Res from the Manual Manipulator through the open proper key of the block gets to the Timer, after that the current value in the Timer is nullified $T_p(i) = 0$ and the timer starts the new countdown;

– the signal Res from the Manual Manipulator and signal Alg_s from the programmer get to the Comparator, which, it the condition (9) is confirmed, identifies the *(i)* state of the operator by the type of the **non-critical** delay of operator's activity (type *B*);

– the signal Res from the Manual Manipulator gets to the Accumulator and is saved there in the format of tuple REG, which keeps *quantitative* characteristics: of duration of the *non-critical* delay of operator's motor activity $T_p(i) = T_a(i) + T_k$; the algorithm of test correction and the moment of time, when it will be successfully conducted $T_r(i) = T_p(i) + T_r$; *qualitative* characteristics – the type of delay of operator's motor activity:

$$REG = \langle T_p(i), T_r(i), B \rangle\,. \quad (11)$$

Thus the fulfillment of the **correct** commutation by the operator proves the fact that the operator possesses the ability to conduct conscious adequate professional actions, which was identified and corrected by means of the automated *test* algorithm of *shifting operator's attention* from current to non-typical tasks of decision-making and decision-realization.

13. In case the operator conducts the **incorrect** commutation – i.e. the non-concurrency of the complex of indices of the set sequence Seq and/or the commutation time (7):

– the signal from the Manual Manipulator does not reach the Timer, that is why the timer continues the countdown with the constant **control** of the fact that the current time in the timer $T_p(i)$ does not exceed the *maximum critical regulated* time T_{A_max},within which the Automated System can work without conducting the process of operation regulation:

$$T_p(i) \le T_{A\_max}\,; \quad (12)$$

– the timer send the signal $Alarm$ to the Programmer, meaning that it is necessary to use the **alarm correction** – by means of the automatic interference into the object control;

– in the Programmer (according to the installed programs) the algorithm Alg_s is formed (chosen); it presupposes the transmission of the signal to the Alarm block with the help of the signal element, informing about the

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critical situation within the time period that does not exceed T_{alarm};

– Alg_s signal gets from the programmer to the **comparator**, which in case of confirmation of the condition (6) identifies the ***(i)*** current state of an operator by the type of a **critical** delay of operator's activity (type *C*);

– on the basis of signals from the Timer and the programmer Alg_s the Accumulator stores information REG, which keeps *quantitative* characteristics of the duration of *failure* delay of operator's motor activity $T_p(i)=T_a(i-1)+T_{fail}$ and *qualitative* characteristics – the type of delay of operator's motor activity:

$$REG=\langle T_p(i),C\rangle. \qquad (13)$$

14. Parameters of the algorithm of **test** correction can vary depending on:

– the number of idle moments in operator's motor activity during the current shift K_v;

– the average number of idle moments in operator's motor activity during the shifts $\overline{K_v}$;

– the current time of a shift which corresponds to the five types of operator's functional state, notably:

– initial reaction (I) – a short-term decrease of the actual level of confidence and accuracy of operator's actions;

– hyper-compensation (II) and compensation (III) – gradual increase and stabilization of indices of confidence and accuracy of operator's professional activity to his individual actual level (the period of norm maintenance);

– sub-compensation (IV) and de-compensation (V) – decrease of operator's normal level of confidence and accuracy of professional activity, connected mainly with the tiredness.

15. In parameters of the algorithm of **failure** correction the variants of realization of operation of *switching* the system of object control into the *automatic* mode can also be presupposed.

Technical results of the suggested system of the instruments for identification of operator's active state consists in *the increase of quality of regulating the work parameters of automated systems of control* by means of expanding the area of application of the tools of operator's active state identification within the shift with the aim of giving the possibilities of *control* and *correction* of situations, which happen in the process of control, by the results of analyzing the type of delay of operator's motor activity and his ability to conduct conscious actions.

The tables 1 and 2 include results of the imitation experiment with the identification of operator's active state according to the given functional scheme (figure 1).

TABLE I. SOURCE DATA OF TIMETABLE (C)

Regulated average time of the possible absence of operator's motor activity T_k	0:00:10
Time for the test correction of operator's motor activity T_r	0:00:15
Maximum non-critical regulated time of the possible absence of operator's motor activity T_{max}	0:00:30
Time for decision-making concerning the choice of algorithm of failure situation correction T_{alarm}	0:00:10
Maximum critical regulated time within which the automated system can work without the operations of process control T_{A_max}	0:00:50
Optimal time for recognition and perception of information from the signal element and also the direct conduction of commutations by the manual manipulator T_{opt}	0:00:03

TABLE II. RESULTS OF THE IMITATION EXPERIMENT OF OPERATOR'S ACTIVE STATE IDENTIFICATION

i	$T_a(i)$	T_r	Algorithm Alg_s of test correction					Time period of successful test fulfillment $T_t(i)$	$T_p(i)$	Total time	Value of the timer signal	Type of motor activity delay	Signal about the critical situation occurrence
			$t_{1\ LEFT}$	$t_{2\ RIGHT}$	$t_{3\ ZERO}$	$t_{4\ TOP}$	$t_{5\ DOWN}$						
1	0:00:03	-	-	-	-	-	-	-	0:00:03	0:00:03	D	A	-
2	0:00:06	-	-	-	-	-	-	-	0:00:06	0:00:09	D	A	-
3	-	0:00:09	0:00:00	-	0:00:03	0:00:06	-	0:00:09	0:00:19	0:00:37	S	B	-
4	0:00:05	-	-	-	-	-	-	-	0:00:05	0:00:42	D	A	-
5	0:00:06	-	-	-	-	-	-	-	0:00:06	0:00:48	D	A	-
6	0:00:06	-	-	-	-	-	-	-	0:00:06	0:00:54	D	A	-
7	0:00:04	-	-	-	-	-	-	-	0:00:04	0:00:58	D	A	-
8	-	0:00:15	0:00:00	0:00:03	-	0:00:06	0:00:09	0:00:12	0:00:22	0:01:35	S	B	-
9	0:00:06	-	-	-	-	-	-	-	0:00:06	0:01:41	D	A	-
10	-	0:00:15	0:00:00	0:00:06	0:00:03	0:00:12	0:00:09	-	0:00:15	0:01:56	Alarm	C	A

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IV. Conclusions

Therefore, the suggested system of the instruments for identification of operator's active state and the methodology of its application allows to:

1. Provide the increase of **quality** of control and regulation of parameters of Automated Systems by means of introducing algorithm and tools:

– of identification of the type of motor activity delay of an operator of automated control system;

– of adaptive correction of non-critical and critical types of delay of operator's motor (working) activity by means of test and failure correction.

2. Increase the **efficiency** of operator's work by means of implementing the technology of maintaining the active state of work within the shift as well as by means of prompt interference into the process of control in case of defining the critical situation of the absence of operator's possibility to conduct actions, adequate to the time requirements.

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