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EVALUATION OF JOINT EFFECT OF FACTORS OF SMALL INTENSITY OF PRODUCTION ENVIRONMENT AND LABOR PROCESS ON WORK ABILITY AND ERROR OF ACTION OF OPERATORS OF HIGH-TECH ENERGY COMPLEXES

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ОЦЕНКА СОЧЕТАННОГО ВЛИЯНИЯ ФАКТОРОВ МАЛОЙ ИНТЕНСИВНОСТИ ПРОИЗВОДСТВЕННОЙ СРЕДЫ И ТРУДОВОГО ПРОЦЕССА НА РАБОТОСПОСОБНОСТЬ И ОШИБОЧНОСТЬ ДЕЙСТВИЙ ОПЕРАТОРОВ ВЫСОКОТЕХНОЛОГИЧЕСКИХ ЭНЕРГЕТИЧЕСКИХ КОМПЛЕКСОВ

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Increase in complexity and speed of production processes puts forward strong requirements for accuracy of operators' actions, quick decision-making in performance of management functions. Statistical analysis of data on the oil refining industry showed that a refinery with a capacity of 10 million tons of oil per year loses in average \$ 4 million only from accidents caused by operator's errors. Around 40 % of accidents and incidents occur due to operator's errors. Reasons for such errors are related to personal qualities, lack of education, training, as well as to factors of low intensity of production environment. A complex of factors of low intensity can lead to hidden up to a certain time "compensated" homeostatic disturbances or modify harmful effect with demonstration of inadequate reactions. The article presents results of study of operators of central control room of two technological departments of high-tech and hazard production (oil and gas) complex to assess combined influence of factors of low intensity of production environment and labor process on work ability and error of actions during labor process. Studies have showed that a long intense functional load on body's systems with influence of factors of low intensity of production environment and labor process lead to development of fatigue and increased tension that operators suffer during day and night shifts. Significant tension of sensory and intellectual systems of the organism with fatigue determines high physiological cost of labor of high-tech production operators. That indicates a need to develop preventive innovative methods to correct a physiological state of operators to improve their performance and take errors off labor, which reduce risk of physical illness.

Ключевые слова:

напряженность трудового процесса, факторы малой интенсивности, работоспособность операторов, энергетические комплексы, профессиональное заболевание, профилактические режимы труда и отдыха.

Увеличение сложности и скорости производственных процессов выдвигает повышенные требования к точности действий операторов, быстроте принятия решений в осуществлении управленческих функций. Статистический анализ данных по нефтеперерабатывающей отрасли показал, что нефтеперерабатывающий завод мощностью 10 млн т нефти в год теряет только от аварий из-за ошибок операторов в среднем 4 млн долл. в год, 40 % аварий и инцидентов происходят непосредственно из-за ошибок операторов. Причины таких ошибок связаны с личностными качествами человека, недостатками обучения, тренировки, а также с факторами малой интенсивности производственной среды. Комплекс факторов малой интенсивности может приводить к скрытым до определенного времени «компенсированным» нарушениям гомеостаза или модифицировать вредное действие с проявлением неадекватных реакций. В статье приведены результаты исследования операторов центрального пульта управления двух технологических отделений высокотехнологичного и опасного производственного (нефтегазового) комплекса для оценки сочетанного влияния факторов малой интенсивности производственной среды и трудового процесса на работоспособность и ошибочность действий в ходе трудового процесса. Исследования показали, что длительная напряженная функциональная нагрузка на системы организма на фоне воздействия факторов малой интенсивности производственной среды и трудового процесса приводит к развитию утомления и повышенной напряженности у операторов в дневные и ночные смены. Значительное напряжение сенсорных и интеллектуальных систем организма на фоне выраженного утомления определяет высокую физиологическую стоимость труда операторов высокотехнологичного производства. Это свидетельствует о необходимости разработки профилактических инновационных методов коррекции физиологического состояния операторов для повышения их работоспособности и безошибочности труда, позволяющих снизить риск возникновения соматических нарушений здоровья.

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Introduction

Increase in complexity and speed of industrial processes causes strong requirements for accuracy of actions that an operator does and quick decision-making in management [1-5]. The degree of responsibility for actions is increased greatly, because operator's mistake can lead to disruption of the entire system human-technology-environment, create an emergency situation with a threat to people's lives. According to the statistics 70 % of world accidents and incidents at hazard industrial sites are caused by operators' faults [5-9].

According to Honeywell, a typical oil refinery with a capacity of 10 million tons of oil a year loses around \$ 4 million per year from accidents only due to operator's errors, 40 % of accidents and incidents occur directly due to operator's errors [10-14].

Analysis of causes of such errors showed that most of them are related to qualities of a person, lack of education, training. But quite often the issue of influence of a complex of factors of the low-intensity production environment is ignored. At the same time, a complex of low intensity factors can lead to "compensated" disturbances of homeostasis hidden up to a certain time or modify a harmful effect and cause inadequate reactions [10-13]. Therefore, screening for characteristics and indicators that allow to identify the negative impact of low-intensity factors and ensure optimization of efficiency and prevention of error actions of personnel is considered as a promising one [11, 12, 14-18].

It is known that the factors of low intensity should be considered those with concentration levels are much lower than permissible and do not cause firm biological changes in case of isolated action. However, a complex effect in the conditions of long time (12-hour shifts) can lead to negative results that are not so known. At the same time, work features can contribute to a change in a functional state of an organism, tension of adaptation mechanisms, formation and development of diseases that have complex multifactorial etiology such as hypertension,

disorders of nonspecific resistance, metabolism, musculoskeletal system and formation of diseases caused by a specialty [19-23].

The purpose of the research is to evaluate joint effect of factors of low intensity of the production environment and labor process on work ability and error of action of operators of high-tech energy complexes.

The object of the research were operators of a central control room (CCR) of two technological departments of high-tech and dangerous industrial complex.

Results and discussion

Personnel of CCR is represented mainly (almost 80 %) by young people (up to 25 years) and only 3 % of employees belong to a category who are over 50.

Among the factors of low intensity affecting operators of a high-tech production complex, it is necessary to note sanitary and hygienic state of the thermal environment with low relative humidity of 30%; long impact of low levels of electromagnetic fields of radio frequencies on personnel; an unfavorable state of an aeroionic composition of the air with predominance of average aeroions of positive charge [1-3].

Assessment of work conditions of operators in terms of ergonomics and aesthetics

Since the main activity of operators is related to remote monitoring of a technological process, assessment of *ergonomics provided* and placement convenience of workplace is important especially. The analysis showed that up to 30% of work places did not meet the anthropometric parameters of workers. Long stay in a forced sitting position contributes to increase in load on the musculoskeletal apparatus and development of fatigue especially when recently the duration of shifts of operators of high-tech production complexes is increased up to 12 hours. Performed ergonomics assessment of work conditions revealed a number of disturbances in a composition of workplaces, balance of static and dynamic parameters and placement of video

equipment. There are 30 % of workplaces incompatible to anthropometric parameters of operators, lack of adjustment in height and angle of inclination, disturbance of placement of control elements, borders of reach zones.

The aesthetic characteristic of the production environment has shown that color and composition solutions of the production environment and equipment do not contribute to optimization of work conditions and prevention of intensity of the labor process.

Thus, a complex of factors of low intensity (sanitary hygienic, ergonomic and aesthetic), affecting the operators of the CCR was revealed. The regime of work of studied personell should also be classified as unfavorable.

Analysis of the impact of low-intensity factors on health of operators

Hours-long shifts with night duty lead to disruption of habitual biorhythms (sleep, wakefulness, working capacity), changes in metabolic processes and hormonal metabolism, contribute to a more rapid development of fatigue [1, 3, 4, 6, 7]. Most often employees complain for drowsiness. The impact of shift work on sleep disorder is more often seen in employees that have small amount of work experience. The most tough demonstration of circadian desynchrony can be decrease in efficiency, attention but also that could be the background for development of pathological states, in particular, diseases of a cardiovascular system and oncopathology [6, 18, 19]. According to the International Agency for the Study of Cancer, night shift work belongs to the category of probable carcinogenic factors (group 2A) [24-27].

Thus, CCR operators are exposed to factors of low intensity of production environment and labor process, which creates objective conditions for development of hypodynamia, monotones,

fatigue, desynchronosis and subsequent formation of professionally conditioned pathology.

Assessment of key health indicators of operators in the dynamics of shifts

We performed an assessment of organism functioning in dynamics of work shifts and conducted a study of health status of personnel by age groups (Fig.).

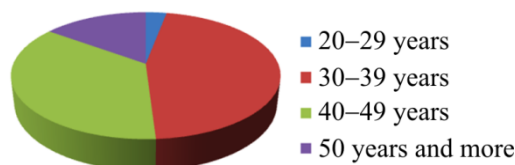


Fig. Age structure of CCR personnel

Health indicators of personnel should be consider as an integral indicator of the assessment of influence of factors in the production environment.

Dynamics of health indicators of personnel over a five-year period indicates an increase in heart disease, varicose veins and diseases of analyzers such as an eye and nose. According to medical examination material it was determined that only 12.1 % of the total number of people can be classified as absolutely healthy, even though the age of composition of CCR personnel, as noted above, can be characterized as close to the optimal one (see Fig. 1). Up to 70 % of the operators were overweight, which indicates a violation of metabolic processes.

An analysis of available information of contingent studied most often showed deviations from physiological norm for a cardiovascular system, vision organs, nose; varicose disease of lower extremities was recorded. Frequency of heart disease was 36.56 per 100 examined, eye diseases – 29.8 per 100, diseases of a nasal cavity – 12.43, varicose disease of lower extremities – 12,56 (Table 1).

Table 1

Frequency of registered diseases per 100 examined in different age groups

Age group, years	Frequency of cardiovascular diseases	Frequency of diseases of vision organs	Frequency of varicose veins	Frequency of nasal cavity diseases
30-39	33.30	23.30	8.50	6.70
40-49	37.90	27.60	10.50	13.80
50 and older	38.50	38.50	18.70	16.80
Average value	36.56 ± 2.84	29.8 ± 7.83	12.56 ± 5.40	12.43 ± 5.18

It was noted in a number of studies that body mass index is significantly higher for persons working on night shifts or with long shift ($p < 0.001$) [28, 29]. The inverse relationship between lack of sleep and body mass index was revealed. The sleep duration of workers with obesity was 18 minutes less each day ($p < 0.05$) than their colleagues with normal body weight [24, 28]. To ensure work ability, reliability and efficiency of operators at work the problem of assessing the functional state is fundamental. Quantitative assessment of the parameters allows us not only to estimate, but also to predict the level and volume of functional reserves in professional activity [29-32].

During the research performed a functional state was determined by the time of simple and

complex sensorimotor reactions to light and sound stimuli, reactions to a moving object, critical frequency of light flashes, stability of attention and error in actions. The data obtained were estimated by methods of mathematical statistics with use of an application package Statistica v. 6.0. The probability of a null hypothesis (p) was determined using the Mann-Whitney criteria and Student's t -criterion depending on the normality of sample distribution.

The studies were conducted during shifts (beginning, end) in two departments and two age groups such as up to 35 (1st) and after 35 years (2nd).

The rate of a simple sensorimotor reaction in all age groups of people working in day shifts increased by the end of the work shift, but worsened during the night shifts (Table 2).

Table 2

Psychophysiological characteristics of operators during day and night shifts

Age group	Working shift period	Visual-motor reaction, ms	Hearing-motor reaction, ms	Differentiation and noise stability		Stability of attention and error in actions	
				total volume	%	total volume	number of errors
1 st	Beginning	362 ± 2	206 ± 3	2308 ± 7	12	406 ± 2	6
	End	296 ± 1.5	196 ± 2	2048 ± 6	8	496 ± 4	7.7
2 nd	Beginning	488 ± 2	208 ± 2.5	3801 ± 10	9	380 ± 4	4
	End	542 ± 3	286 ± 2	2794 ± 8	9.7	458 ± 3	6.7
3 rd	Beginning	303 ± 2	192 ± 2.5	2200 ± 10	9	570 ± 4	5
	End	267 ± 1	191 ± 2	1601 ± 5	10	621 ± 5	9
4 th	Beginning	347 ± 2	181 ± 1.5	3360 ± 9	6	424 ± 2	2.5
	End	514 ± 3	198 ± 3	2478 ± 7	14.5	450 ± 3	4.5

Change in the state of operators in the end of the work shift can be traced by the reaction of stability of attention and error in actions.

As it is shown in the Table 2, speed of work performance by the end of the shift grows in both age groups by 10-15 %, which indicates the effect of training principles. Nevertheless, at the end of the work shift stability of attention and the number of errors increase, which indicates fatigue caused by hypodynamia that is almost twice higher in the first age group of up to 35 years. Thus, a high level of neuro emotional tension of personnel and increase in speed of work performance is accompanied by an increase in errors in actions, which proves that functioning of body regulatory systems was changed, a central nervous system and analyzers are loaded, and objectively indicates

the onset of fatigue. Important results were obtained in evaluation of the noise resistance reaction. Attention and efficiency at the beginning of work shifts against the background of visual and auditory noise were fairly steady. By the end of the shift attention in surveyed groups was decreased as by 12 % for the first group and more than by 20 % for the second group. At the same time, the operator's error in actions with the background of visual and sound noise in the first group was 12-18 % higher and almost twice as high in the second group. That reaction indicates the onset of a change in fatigue and the need to activate physiological reserves of the body for the fulfillment of professional duties by the workers.

Results of the personnel survey confirm the established class of work conditions in terms of

indicators of intensity of the labor process. It is established that on the background of nervous emotional, sensory tension of personnel the number of errors in actions increases at the end of shifts when personnel performs specific tasks that reveal functional reserves of an organism, which allows to talk about the signs of monotony.

The research conducted showed that during work operations CCR personnel suffer fatigue by the end of the work shift. Nevertheless, strong-willed efforts, attention, concentration, purposefulness of actions, operators control a technological process adequately.

At the same time, reactions caused by fatigue among the whole team of operators testify the need to justify and develop measures to prevent development of fatigue, hypokinesia and monotony during work shifts.

Thus, development of fatigue during shifts leads to a significant decrease in the excitability of the central nervous system (thresholds of perception increase), decrease in the quality of cognitive processes and difficulty in heuristic thinking. Reliability and efficiency of operators' activity is reduced, but the probability of missing significant signals increases, especially in tracking and monitoring regimes. The state of health and mood is deteriorating, asthenovegetative state is developed. There is an increased number of errors noted by the end of the shift.

Performed studies have shown that during the day and night shifts operators suffer fatigue. At the same time, physiological indicators of the organism's activity and parameters of assessment of activity of sensory systems indicate significant

loads, but operators activate attention, focus on a task and control the technological process adequately. Consequently, it should be considered that the physiological value of the labor process of operators is quite high and the need for the optional activation of physiological reserves of the organism to perform professional tasks significantly increases the intensity of labor.

Conclusion

Evaluation of factors of the production environment and the labor process at workplaces of operators at CCR of high-tech energy complexes allowed to classify them as a group of low-intensity factors.

Health as an integral indicator shows the generation of a number of negative states of operators including cardiovascular, sensory systems and metabolic syndrome.

Long tough functional load on body systems against the backdrop of the influence of factors of low intensity of the production environment and labor process lead to the development of fatigue and increased tension that operators suffer during day and night shifts.

Significant tension of sensory and intellectual systems of the organism against the backdrop of strong fatigue determines the high physiological cost of labor of high-tech production operators. That indicates the need to develop preventive innovative methods for correction of physiological state of operators to improve their ability to work and error-free work that can reduce the risk of somatic disorders of health.

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Оценка сочетанного влияния факторов малой интенсивности производственной среды и трудового процесса на работоспособность и ошибочность действий операторов высокотехнологичных энергетических комплексов / Н.Л. Вишневская, Л.В. Плахова, П. Поledняк, А. Бернатик // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2017. – Т.16, №2. – С.183–190. DOI: 10.15593/2224-9923/2017.2.9