Higher efficiency of control over functional status of locomotive crew members

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Abstract. The objective of the study is research into psycho-physiological methods of control over the functional status of a person for higher efficiency of a pre-trip control of locomotive crew members. It is related to the fact that today’s medical methods do not reveal some states which decrease a functional reliability level, particularly, a fatigue level and borderline states. The authors selected parameters which, according to the functional system theory, give information on conditions of two regulation levels in the human body, physiological and higher nervous activity, and correspond to the formulated requirements in terms of the procedure. The study experimentally proved the informative value of 27 psycho-physiological parameters for estimation of exhaustion and borderline states. For a state of exhaustion the hemodynamic parameters, including those of arrhythmia, both sinus and slow waves, were of the most informative value. The study revealed the parameter of arterial pressure pulse, the value of which in the post-trip group decreased by 25%. While identifying existence of borderline states by sinus arrhythmia parameters, it turned out that much more people with borderline states were in the exhaustion zone, rather than in the control group (42% and 16% respectively).

1. Introduction
Higher professional reliance of locomotive crew members is a pressing challenge, as its lower level leads to emergencies and accidents. The most important component of the professional reliance of an employee is functional reliability, specifically, the functional status, as the most labile element identifying the general level. Nowadays the functional status of a locomotive crew member is controlled through a pre-trip examination, which is often ineffective, as it does not reveal certain statuses, which decrease a functional reliance level while remaining within the physical standards. It refers to such statuses as fatigue, stresses, borderline states, etc. The article deals with some extra parameters which may reveal the above-mentioned statuses during a pre-trip control.

2. The analysis of publications and problem statement
The priority task for railway transportation is safety, and nowadays 80% of safe transportation depends on the human factor [1-3]. One of the most important components of the human factor is the professional reliability level of an employee. The ‘professional reliance’ concept is a system with a number of sub-systems, namely, biomedical, psycho-physiological, education and qualification,
functional, etc.[2]. But the functional reliability is underestimated, though it is the reason for 90% of erroneous actions of an operator. And the most important component of functional reliability is the functional status. Taking into account its great significance, the functional status should be carefully controlled. Today the functional status of locomotive crewmembers in railway transport is controlled through a pre-trip medical examination [4]. When implemented such an examination yielded positive results in terms of greater transportation safety, but it turned out insufficient, as it had a number of serious shortcomings, namely:

1) strong influence of the human factor (the examiner’s);
2) use of merely traditional diagnostics methods which could not reveal the statuses decreasing a performance level though remaining within the physical standards.

Therefore, there is a need to equip a pre-trip medical examination with some methods which may solve the problem. Control of the functional status of an operator includes a series of approaches, particularly, one-parameter and poly-parameter ones, each with positive and negative aspects. In the former case only one parameter is under control; it considerably facilitates the procedure and technical support [5]. However, such an ease leads to poor reliability in terms of results, it does not consider the vegetal dynamic stereotype, i.e. individual response reactions.

The poly-parametrical approach means the use of some parameters; it overcomplicates the procedure and technical support, but produces more reliable results. The functional status assessment integrates certain factors of functional systems. Thus, the assessment is a measured analysis of the parameters from functional systems. A great amount of studies stress the importance of the poly-parametrical approach for evaluating the functional status [5, 6]. It was mentioned that such an approach is extremely efficient for diagnostic procedures. However, a choice of parameters characterizing different functional systems is not substantiated [6].

It is evident that the objective evaluation of the functional status is dependent on the informative value of parameters under control. And the integral estimate should be reasonably made with a certain massive of data [7]. Among the existing methodological approaches to the functional status diagnostics of a person the most adequate is the functional system theory according to which the body is considered as a complex hierarchical self-regulation system, evolutionarily formed of several levels. The experts distinguish from two to six such hierarchical levels [8].

A choice of diagnostic methods, providing information on the levels selected, is of primary importance. One of the methods for simultaneous estimation of several regulation levels is the psychomotor response measurement. These measurements characterize the overall condition of the body, as the motion analyzer is an integrator; all neurophysiologic mechanisms which relate to the effective performance of an operator affect this integrator. It also refers to the functional status of the central nervous system and the psychomotor apparatus.

Deeper levels are characterized by hemodynamic parameters, particularly, ones of heart rhythm variability. They are more sensible indicators of the health status. Moreover, these parameters can indicate a high risk of sudden ischemic death which is typical for transport industry [9].

Skin electrical activity parameters give great diagnostic opportunities for identifying statuses which are not included in the pathological zone. These parameters are essential in diagnostics of emotional states, especially stresses [10].

Therefore, there is a need to integrate in a pre-trip examination psycho-physiological parameters for identification of states directly influencing a professional reliability level and ability to solve problems in the specific conditions in which locomotive crews work.

3. The objective and research tasks
The objective of the study is efficiency of control techniques used for identification of the functional status of an operator, based on the functional system theory, in order to improve efficiency of a pre-trip control.

The following tasks were set to achieve the objective:

1. Formation of a complex of methods which allow the health worker to obtain information on performance of two regulation levels of the body, physiological and higher neurological, which make it possible to perform diagnostics in real conditions of rail industry.
2. Determination of the informative value of suggested methods for revealing states which decrease a functional reliability level of an operator, i.e. fatigue and borderline states.

4. Materials and methods
The methodological basis of the study is the concept that diagnostics of the actual functional status of an operator is limited to a level of certain state development from a given number of situations [11, 12]. These states, first of all, are fatigue and borderline ones.

For obtaining needed information the authors selected examination methods according to the functional system theory. And decision was taken to consider two regulation levels, physiological and higher nervous function, which united the psychomotor apparatus and higher psychic functions (perception and brainwork).

The study considered a specific character of diagnostics conditions which imposed some restrictions. Thus, the study formulated requirements for the methods with consideration of existing restrictions. Besides, a number of mutually conflicting conditions were taken into consideration: on the one hand, strict time frame and on the other – information awareness. It required some information which could be obtained without any extra time and examination.

The authors analyzed the methods used for the functional status diagnostics and selected those which met the formulated requirements more sufficiently. The selected methods were divided into two groups: basic and extra. The parameters from the first group characterized the basic performance level. They included heart activity parameters which characterized the life support system, and were considered as a sensitive indicator of the overall condition of the body.

The second group of parameters was complementary. These parameters could substantially complement the basic information, though they were obtained without any additional time and procedures.

During the research in the field the computer appliance Gamma was developed. It is intended for functional status diagnostics within a pre-trip examination [7]. The database was formed for each test person, which made it possible to analyze results and forecast statuses impacting a human operator’s reliability.

5. The results of research into the informative value of methods for a pre-trip control over locomotive crew members
The efficiency of the suggested diagnostics methods for identifying an actual state of locomotive crew members was tested in several locomotive depots. The original assumption was to obtain some needed information through a pre-trip examination by a health worker with the system under development. This information was used for an argumentative conclusion on a person’s potential workability at a specific moment, and also for forecasting on a period of a shift. Besides, the health worker evaluated possible statuses in a test person, which were especially risky for an engineman. The conditions under identification were, first of all, fatigue and borderline states. It was supposed that, as far as probability characteristics were concerned, with time and statistical data, artificial intelligence elements, particularly neuronal networks, could be applied.

The first study defined the ability of the developed system to reveal a fatigue level accumulated during a working shift. It was supposed that a fatigue level, achieved in the course of a working shift, was unacceptable for most workers. Besides, individual characteristics were taken into account. The same scope of work could differently affect people; some of them became unreliable, while the others could maintain a sufficient level of reliability. Therefore, it referred to probable parameters. Thus, as far as the parameters might distinguish the pre-trip and post-trip groups, they also could be used to identify an appropriate fatigue level.

Generally 74 enginemen were examined before and after a trip for 27 psychological parameters. The results were later compared and analyzed. Some parameters differentiated, though the average values differentiated slightly; there were areas where probability of one state was considerably higher than probability of the other. A patterns of the distribution obtained is presented in Figure 1 and Figure 2.
Figure 1. Distribution of the sinus arrhythmia parameter.

Figure 2. Distribution of cardio intervals duration.

For example, an average heart rate interval in two groups differentiated by 6%, but members of one group could get into a zone of 600 msect ice as often as members of the other group. The same pattern could be traced with parameters of the heart rhythm variability; and different arrhythmias had different dynamics. It was interestingly that the distribution of breath and sinus arrhythmias had zones which differentiated from ones of the normal distribution. It can be explained by the fact that these arrhythmias were physiological and pathological, and the later might give such a zone.

Considerable variations were in the pulse pressure parameter, which decreased by 25% in the post-trip group. It can be explained by the fact that the parameter characterizes a stroke rush of the cardiac muscle, and naturally, in the state of fatigue the heart worked less efficiently.

All these finest details may influence the result and reveal a certain state of a person. The pattern of dependencies and the ratio of data before and after a trip present a possibility, with a
comprehensive approach, to reveal a certain state and, thus, to forecast the functional reliability in performing responsible professional operations.

The second study dealt with an ability of the suggested methods to identify borderline states (lower standard of health). During the study some patients with a light form of tuberculosis from a TB dispensary (33 men of the borderline state group) were examined. The results were compared with those of healthy persons (a control group included 28 men). The most valuable information was in heart rhythm variations, first of all, in sinus arrhythmia. It is known that sinus arrhythmia has a series of zones: optimum zone, stress zone and exhaustion zone. Much more people with the borderline state were in the exhaustion zone \( V_{RR} \leq 0.04 \) than in the control group (42 % and 16 %, respectively). An opposite situation was in the stress zone \( V_{RR} \geq 0.08 \). This group included much more healthy and rested people (26 % and 12 %, respectively). These data can use probable parameters from various groups for objective functional state diagnostics.

The distinctions manifested themselves more obvious with a slight physical activity. Even a change in position from sitting to standing moved 58 % persons from the borderline state group and 32 % from the healthy group to the exhaustion group. The situation was opposite with the stress group \( V_{RR} \geq 0.08 \) – 12 % and 36 % respectively.

6. The discussion of results of the research into methods of control over the functional state of locomotive crew members

The obtained results testify that the chosen methodological approach can control locomotive crew members in real working conditions. It gives information for estimation of existence and intensity of real states which ensure the required functional reliability level. Particularly, it refers to fatigue and borderline states. Fatigue states cannot be persuasively confirmed by parameters of the cardiovascular system. Thus, in the pre-trip group the pulse was higher than that in the post-trip group (86 and 80.8 BPM respectively), though it would be reasonable to expect the opposite. It can be explained by the examination effect. Many enginemen took the examination very emotionally, although such behavior is typical, with time it can be taken as a routine. In that particular case it was intensified by the fact that many took the examination as a hidden agenda, which might affect their occupational status. Therefore, the pulse of some enginemen reached up to 120 BPM.

A high excitation level bordering a stress was confirmed by the skin electric impedance parameters (the coefficient of variation by the skin electric impedance 15.28 in the pre-trip group versus 8.9 in the post-trip group). After a trip enginemen did not have that emotional state, besides, they were not afraid to be suspended from a trip; therefore the examination effect was less evident.

The pulse pressure parameter, which characterizes the heart performance efficiency and equals the difference between systolic and diastolic pressure, had a high informative value. Most enginemen had 40 mmHg before a trip and about 30 mmHg after a trip. A level of fatigue can be efficiently evaluated at an individual level with appropriate mathematical methods, for example, a prior probability (Bayer’s theorem).

Thus, the study suggests a complex of parameters for a pre-trip control which have certain advantages, and by applying these psycho-physiological parameters the health worker can reveal states decreasing a functional reliability level though remaining out of the pathological zone, and, therefore, undetectable by an existing control.

7. Conclusions

1. The authors substantiated methods of control over an operator’s state (including psycho-physiological ones), which can be realized in real conditions of rail industry and related to serious industrial obstacles. Methods for assessment of the functional state are divided into two levels: basic and extra. The basic methods include sensomotor reactions and hemodynamic parameters, and extra methods include parameters of heart rhythm variation, skin electric activity and bilateral asymmetry.

2. The study experimentally proved the informative value of hemodynamic parameters including those of arrhythmia, sinus and slow waves for estimation of a fatigue level. The authors singled out the pulse pressure parameter, which was changed by 25 % in the post-trip group.
3. The authors proved the informational value of the suggested parameters for estimation of a depressed health level. The most valuable information was observed in parameters of heart rhythm variation, first of all, in intensity of sinus arrhythmia. The exhaustion zone \((V_{RR} \leq 0.04)\) included 42% of borderline states and 16% of the control group; the stress zone \((V_{RR} \geq 0.08)\) had an opposite situation – 12% and 36% respectively. Such differences were more obvious with physical activity. About 58% of the borderline state group and 32% of the healthy group joined the exhaustion group while changing a pose from sitting to standing. The situation was opposite in the stress group – 12% and 36% respectively.

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