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INVESTIGATION OF RELIABILITY OF OPERATORS WORK AT FLUCTUATING TEMPERATURE CONDITIONS

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Abstract—*Mathematical models for control of respiratory, blood circulation and thermoregulation organism systems were developed. They permit ones to conduct theoretic research of parameters that characterize the average person organism and to demonstrate the reaction of organism self controlled parameters on various changes of environment.*

Index Terms—Mathematical model; self controlled parameters; operator of continuous interaction; reliability of operator work: adaptation.

I. INTRODUCTION

Reliability of human work – work of operator - provides infallibility, correctness, timeliness operator actions for the solution of professional problems in interaction with technique, as well as ability of human-operator to fulfill professional tasks in the prescribed range of process requirements without losses for mental state or health [1], [2].

The term "human operator reliability" was invented by analogy with the concept of "reliability of technical systems" [3], but it is much more complicated. In numerical studies [4] the human operator reliability is associated with resistance of physiological and mental processes that determine human work abilities.

Such notion as "functional reliability" presents in engineering psychology. It means relative stability of professionally important organism features and functions that ensure reliable fulfillment of professional tasks within defined time with a given level of quality. In particular the study of human-operator professional reliability allows investigation of work ability, study of internal environment perturbation effect (in conditions of increased situational stress, meteorology dependence, chronobiological conditioning, etc.); research of environment disturbances (hypoxibaric environment, sudden temperature fluctuations, work in conditions of high or low temperature, etc.)

II. PROBLEM STATEMENT

The approach to reliability study of operator's work in the system of continuous interaction in terms of increased situational stress was suggested in [1], [5]. As were shown in [1], [5], [6] mathematical modeling of human organism functional systems permits to explore the nature of organism mechanisms that provide a high level of reliability of its functional systems and the organism as whole. Contemporary physiology includes sufficient amount of information about the processes of respiration and blood circulation to build mathematical models of functional respiratory system. Analysis of these models allows us to set the basic rules for processes of respiration and blood circulation, the role of regulatory mechanisms in providing and maintaining of basic functions of respiration under various conditions of human life, to set the main features of this process [7].

The ***purpose*** of this paper is to propose the approach for studying of operator reliability of system continuous interaction in conditions of environment temperature changes.

III. PROBLEM SOLUTION

A. Mathematical model of functional respiratory system

For the investigation let's review some parts of functional respiratory system mathematical model [7].

It is necessary to note that following model parts relate to process that performs the basic function of respiratory system and blood circulatory system - the timely and effective oxygen delivery to the metabolized tissues and output of carbon dioxide from tissue reservoirs, formed during tissue metabolism.

In this model oxygen on respiratory cycle is transported via the airways in the lung alveolar space and then through the alveolar – capillary membranes into the blood entering the pulmonary capillaries blood. Circulatory system – arterial blood

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at branching system tissue capillaries brings oxygen to organs and tissues. Active oxygen mass transfer is going from the blood to the tissue reservoirs, where tissue respiration is presented. Carbon dioxide, which is a product of metabolism in tissues, diffuses into the blood and excretes by venous blood to the lungs, where its washout from the organism happens. A block diagram of the model is demonstrated at Fig. 1.

As phase variables by which the state of functional system of respiration and blood circulation were estimated, we took partial pressure of respiratory gases oxygen, carbon dioxide and nitrogen – in airways, alveolar space and their tension in blood and fluids of tissue capillaries.

Depending on the purposes of mathematic simulation for the estimation of the system functional state the apparatus of differential equations with concentrated or distributed parameters is used usually. Since the mathematical model of functional respiratory system (FRS) and blood circulatory system was built for the studying of organism mechanisms of self-regulation and adaptation to external disturbances and / or internal environment, the dynamics of partial pressures and tensions of respiratory gases in organism structures were described by the system of ordinary differential equations. The principles of material balance and flow continuity were used for their construction. For clarity of demonstrated mathematical model structure let's review fragments related to subsystems of external respiratory subsystem and transport, mass transport of gases in subsystems of blood tissue capillaries – tissue (tissue respiration).

Let's suppose that $p_{RW}O_2$, $p_{RW}CO_2$ and $p_{RW}N_2$ – partial pressure of respiratory gases oxygen, carbon dioxide and nitrogen in airways, p_AO_2, p_ACO_2, p_AN_2 – in alveolar space, p_aO_2, p_aCO_2, p_aN_2 – tension of respiratory gases in arterial blood, ($p_{\bar{v}}O_2, p_{\bar{v}}CO_2, p_{\bar{v}}N_2$) –respectively in mixed venous blood of lung capillaries ($p_{lc}O_2, p_{lc}CO_2, p_{lc}N_2$), blood of tissue capillaries ($p_{c_i}O_2, p_{c_i}CO_2, p_{c_i}N_2$) and ($p_{c_{t_i}}O_2, p_{c_{t_i}}CO_2$, $p_{c_{t_i}}N_2$) in tissue fluid respectively. Let's denote pO_2, pCO_2 and pN_2 as partial pressure of respiratory gases oxygen, carbon dioxide and nitrogen in respiratory mixture, supposing that

$$B = pO_2 + pCO_2 + pN_2, \quad (1)$$

where B is atmospheric pressure.

So, the equation for dynamics of respiratory gases in airways may be written as:

$$\frac{dp_{j_{RW}}}{d\tau} = \frac{\dot{V}}{V_{RW}}\left(\tilde{p}_{j_{RW}} - \tilde{p}_{j_A}\right) \quad j = 1,2,3, \quad (2)$$

where index j means the number of gas – oxygen, carbon dioxide, nitrogen, V_{RW} volume of respiratory ways, $\dot{V}$ lung ventilation

$$\dot{V} = \begin{cases} \frac{RW \cdot \tau}{T_a}\sin\frac{\tau - \tau_0}{T_a}n_i, & \text{during respiratory act (during inspiration and expiration)}, \\ 0, & \text{during respiratory pause}, \end{cases} \quad (3)$$

and

$$\tilde{P}_{j_{RW}} = \begin{cases} P_j, & \text{for } \dot{V} > 0, \\ P_{j_{RW}}, & \text{for } V \le 0, \end{cases} \quad (4)$$

$$P_{jA} = \begin{cases} P_{j_{RW}}, & \text{for } \dot{V} > 0, \\ P_{j_A}, & \text{for } \dot{V} \le 0, \end{cases} \quad (5)$$

where T_a is a length of respiratory act; τ_0 is the time of its beginning; RW is the respiratory volume. Using mentioned principles of material balance and flow continuity let's write equation for the dynamics of respiratory gases in alveolar air:

$$\frac{dp_{j_A}}{d\tau} = \frac{1}{n_j\left(V_L - V_{RW}\right)}\left[n_j\tilde{P}_{j_A}\tilde{V} - G_{j_A} - n_jP_{j_A}\frac{dV_L}{d\tau}\right], \quad (6)$$

where G_{j_A} is a gas flow through alveolar – capillary membrane, V_L lung volume, n_j coefficients of transition. For G_{j_A} algebraic analog of Fick rule is used:

$$G_{j_A} = k_jn_jS\left(p_{j_A} - p_{j_{lc}}\right), \quad (7)$$

where k, n are coefficients of gases permeability through membrane; S is the square of the surface of mass exchange.

During the formulation of equations for respiratory gases transport by blood it is necessary to take into account peculiarities of their transfer by convective way – oxygen is carried out being dissolved in blood plasma as well as being chemically bound to hemoglobin (Hb), carbon dioxide – being dissolved as well as chemically bound to hemoglobin and blood buffer bases (BH), nitrogen is dissolved in plasma only.

Here is an equation that describes the changes of respiratory gases tensions in the blood capillaries and tissue fluid:

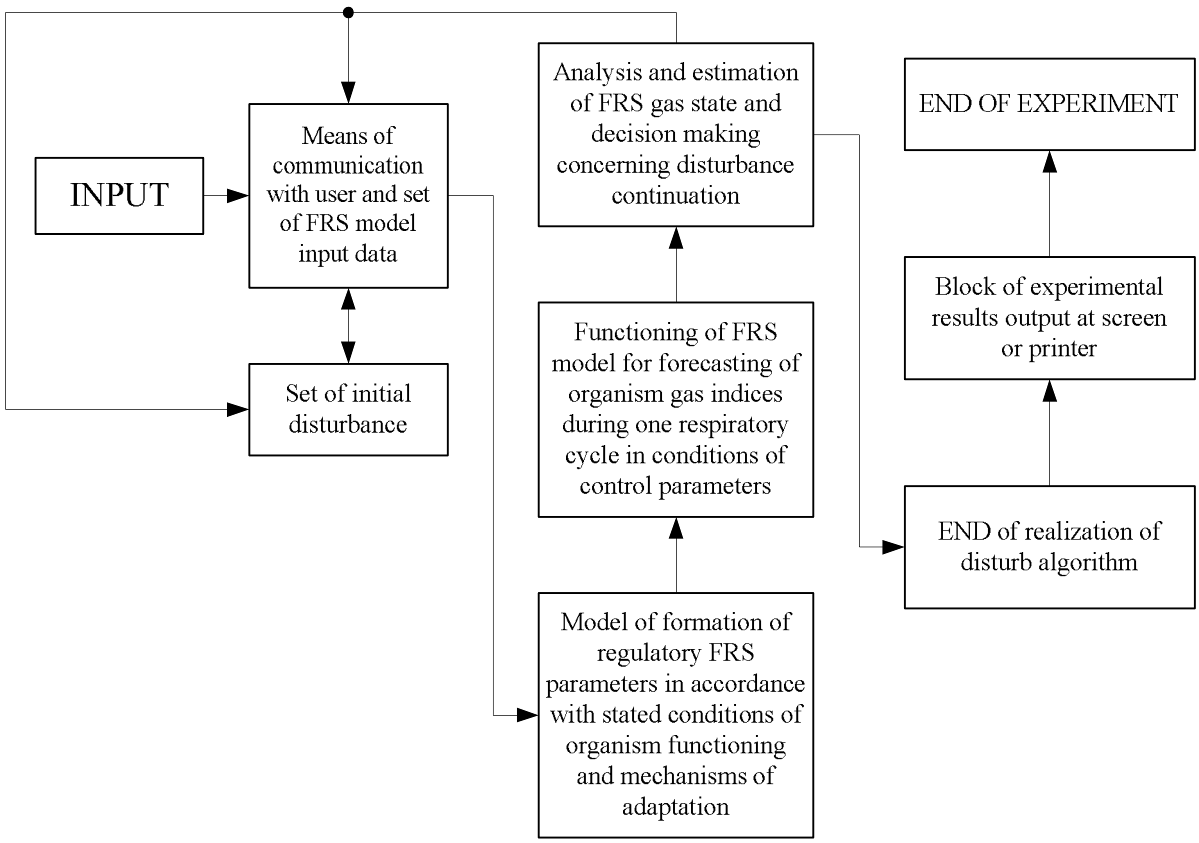

Fig. 1. A block diagram of developed model

$$\frac{dp_{ct_i}\mathrm{O}_2}{d\tau} = \frac{1}{V_{ct_i}\left(\alpha_1 + \gamma \mathrm{Hb}\dfrac{\partial \eta_{ct_i}}{\partial p_{ct_i}O_2}\right)}\left(\alpha_1 Q_{t_i}\left(p_a\mathrm{O}_2 - p_{ct_i}\mathrm{O}_2\right) + \gamma \mathrm{Hb} Q_{t_i}\left(\eta_a - \eta_{ct_i}\right) - G_{t_i}\mathrm{O}_2\right), \tag{8}$$

$$\frac{dp_{ct_i}\mathrm{CO}_2}{d\tau} = \frac{1}{V_{ct_i}\left(\alpha_2 + \gamma_{BH} BH \dfrac{\partial z_{ct_i}}{\partial p_{ct_i}\mathrm{CO}_2}\right)} \cdot \left(\alpha_2 Q_{t_i}\left(p_a\mathrm{CO}_2 - p_{ct_i}\mathrm{CO}_2\right) - G_{t_i}\mathrm{CO}_2 + Q_{t_i} BH\gamma_{BH}\mathrm{Hb} Q_{t_i} z_a - \left(1-\eta_{ct_i}\right)\gamma_{Hb}\mathrm{Hb} V_{ct_i}\frac{\partial \eta_{ct_i}}{\partial \tau}\right), \tag{9}$$

$$\frac{dp_{ct_i}\mathrm{N}_2}{d\tau} = \frac{1}{\alpha_3 V_{ct_i}}\left(\alpha_3 Q_{t_i} p_a\mathrm{N}_2 - \alpha_3 Q_{t_i} p_{ct_i}\mathrm{N}_2 - G_{3t_i}\right), \tag{10}$$

$$\frac{dp_{t_i}\mathrm{O}_2}{d\tau} = \frac{1}{V_{t_i}\left(\alpha_{t_i} + \gamma_{Mb} Mb \dfrac{\partial \eta_{t_i Mb}}{\partial p_{t_i}\mathrm{O}_2}\right)} \cdot \left(G_{t_i}\mathrm{O}_2 - q_{t_i}\mathrm{O}_2\right), \tag{11}$$

$$\frac{\partial p_{t_i}\mathrm{CO}_2}{\partial \tau} = \frac{G_{t_i}\mathrm{CO}_2 + q_{t_i}\mathrm{CO}_2}{\alpha_{2t_i} V_{t_i}}, \tag{12}$$

$$\frac{\partial p_{t_i}\mathrm{N}_2}{\partial \tau} = \frac{G_{t_i}\mathrm{N}_2}{\alpha_{3t_i} V_{t_i}}, \tag{13}$$

where

$$\eta_{ct_i} = 1 - 1{,}75\exp\left(-0{,}052 m_{ct_i} p_{ct_i} O_2\right) + 0{,}75\exp\left(-0{,}12 m_{ct_i} p_{ct_i} O_2\right), \quad (14)$$

$$m_{ct_i} = 0{,}25\left(pH_{ct_i} - 7{,}4\right) + 1, \quad (15)$$

$$pH_{ct_i} = 6{,}1 + \lg\frac{BH}{\alpha_2 p_{ct_i} CO_2}, \quad (16)$$

$$z_{ct_i} = \frac{p_{ct_i} CO_2}{p_{ct_i} CO_2 + 35}. \quad (17)$$

In equations (8) – (17) $\alpha_1, \alpha_2, \alpha_3, \alpha_{1t_i}, \alpha_{2t_i}, \alpha_{3t_i}$ are permeability coefficients of respiratory gases in blood and tissue fluid; Q_{t_i} is the blood flow volume velocity in capillary flow of tissue reservoir t_i; V_{ct_i}, V_{t_i} is the volume of blood and tissue fluid respectively.

Tissue blood that has given oxygen and was saturated by carbon dioxide is concentrated in the venous system and flow back to the lungs due to the circulation, where it's saturated by oxygen and losses carbon dioxide during the next respiratory cycle:

$$\frac{dp_{\bar v} O_2}{d\tau} = \frac{1}{V_{\bar v}\left(\alpha_1 + \gamma_{Hb} Hb \dfrac{\partial \eta_{\bar v}}{\partial p_{\bar v} O_2}\right)} \cdot \left[\alpha_1\left(\sum_{t_i} Q_{t_i} p_{ct_i} O_2 - Q p_{\bar v} O_2\right) - \gamma Hb Q \eta_{\bar v}\right], \quad (18)$$

$$\frac{dp_{\bar v} CO_2}{d\tau} = \frac{1}{V_{\bar v}\left(\alpha_2 + \gamma_{BH} BH \dfrac{\partial z_{\bar v}}{\partial p_{\bar v} CO_2}\right)} \left[\alpha_2\left(\sum_{t_i} Q_{t_i} - Q p_{\bar v} CO_2\right) + \left(\sum_{t_i} \gamma_{BH} BH_{ct_i} Q_{t_i} z_{2ct_j} - \gamma_{BH} BHQ z_{2\bar v}\right) + \left(\sum_{t_i} \left(1 - \eta_{ct_i}\right) \gamma_{Hb} Hb Q z_{\bar v} - \left(1 - \eta_{\bar v}\right) \gamma_{Hb} Hb Q z_{\bar v}\right) + \sum_{t_i} \gamma_{Hb} Hb_{ct_i} V_{ct_i} \frac{\partial \eta_{ct_i}}{\partial \tau}\right], \quad (19)$$

$$\frac{dp_{\bar v}}{d\tau} = \frac{1}{\alpha_3 V_{\bar v}}\left(\sum_{t_i} \alpha_3 Q_{t_i} p_{ct_i} N_2 - \alpha_3 Q p_{\bar v} N_2\right). \quad (20)$$

System equations (1) – (20) with stated $\dot V, Q, Q_{t_i}, i = \overline{1, m}, RW, q_{t_i}, T_0$ describes the changes of partial pressures and tensions of respiratory gases in the blood and tissue fluids for regions and organs of respiratory cycle.

B. Regulatory mechanisms of respiratory system main function and their mathematical model

In [7] – [9] experimental data obtained by physicians and physiologists evidence that in response to disturbances – external (changes in barometric pressure, qualitative changes in inspired gas mixture) and / or internal (intensity changes of metabolic processes in tissues, characterized by the velocity of oxygen utilization), significantly increased (decreased) the value of alveolar ventilation $\dot V$, volume velocity of systemic bleeding Q, vasodilation (vasoconstriction) of vascular tissues and, consequently, the volume velocity of blood in them Q_{t_i} is changed.

That is why parameters $\dot V, Q, Q_{t_i}$ are stated as parameters of control during mathematic simulation. Other parameters are seen as executive organs of active regulation: respiratory muscles, cardiac muscle and smooth muscles of vessels – their functions stabilize main respiratory function at disturbed system. The system of equations (1) – (20) is asymptotically stable, so, it is possible to suppose that the aim of regulation is transformation of disturbed system into the relatively equilibrium state. This state happens when

$$\left|G_{t_i} O_2 - q_{t_i} O_2\right| \le \varepsilon_1, \quad \left|G_{t_i} CO_2 + q_{t_i} CO_2\right| \le \varepsilon_2,, \quad \left|G_{t_i} N_2\right| \le \varepsilon_3, \quad (21)$$

where $\varepsilon_1, \varepsilon_2, \varepsilon_3$ are indiscriminately small positive numbers. The set of system states for which (21) is true, let's determine as terminal set M in the task of dynamic system control. It is natural to assume that parameters of control are limited

$$\dot V_{\min} \le V \le V_{\max}, \quad Q_{\min} \le Q \le Q_{\max}, \quad \sum_{t_i} Q_{t_i} = Q. \quad (22)$$

It is easy to demonstrate that the problem of control for output of disturbed dynamic system to the set M with limitations (22) has a solution because the conditions of Filipov's theorem are true for it.

From all solutions of the task of control for optimal parameters $\dot{V}_{\text{opt}}$, $Q_{\text{opt}}, Q_{t_i\text{opt}}$ let's pick up those ones that provide minimal functional on trajectories of dynamic system state changes

$$\dot{I}=\int_{\tau_0}^{T}\left[\rho_1\sum_{t_i}\lambda_{t_i}\left(G_{t_i}\mathrm{O}_2-q_{t_i}\mathrm{O}_2\right)^2+\rho_2\sum_{t_i}\lambda_{t_i}\left(G_{t_i}\mathrm{CO}_2+q_{t_i}\mathrm{CO}_2\right)^2+\rho_3\sum_{t_i}\lambda_{t_i}\cdot G_{t_i}\mathrm{N}_2\right]d\tau, \quad (23)$$

where ρ_1, ρ_2, ρ_3 are coefficients of sensitivity to hypoxia, hypercapnia and nitrogen excess; λ_{t_i} are coefficients that characterize the importance for the life of any organ or tissue. Coefficients λ_{t_i} are were formed during evolution. It is known that destruction of cardiac muscle, brain tissues, liver, kidneys and some other leads to loss of life and, probably, that is why the density of capillaries in them is enough large. In mathematic simulation such dependence is used

$$\lambda_{t_i}=\frac{V_{ct_i}}{V_{t_i}}. \quad (24)$$

C. Model for heat exchange

The system of heat exchange is linked tightly with functional system of respiration and blood circulation; heat energy is the result of tissue metabolism and, like respiratory gases from respiratory mixture it receives additional heat from the environment. Like breathing mixture, the heat is distributed in organism by circulating blood. But constructing of the heat exchange mathematical model and thermal regulation, it is necessary to take into account the differences also – if oxygen enters organism through the respiratory tract, and carbon dioxide is excreted in the same way, the heat evaporates mostly through the skin and may be distributed not only by blood, but also by convection from one organism part to another.

Let's write a mathematical model of heat exchange in the form [10]. Let's suppose that $T_A, T_{LC}, T_a, T_{ct_i}, T_{t_i}, T_{\bar{v}}$ is an average temperature in alveolar space, pulmonary capillary blood, arterial blood, tissue blood capillaries t_i in reservoir of tissue, tissue fluid and in mixed venous blood – they all characterize the state of heat exchange system.

Let's denote as c, ρ heat capacity and density of blood in certain structures; $c_{t_i}, \nu_{t_i}, \mu_{t_i}$ is the respectively heat capacity, mass and speed of heat production for t_i tissue reservoir; γ_{t_i} is the coefficient of thermal conductivity between the volumes of blood and tissues; S_{t_i} is the surface area on which the heat exchange in system "blood-tissues" is realized. Let's suppose that $D_{t_i,t_i-1}(\tau), D_{t_i,t_i+1}(\tau)$ are heat flows that form the heat exchange between t_i and tissue volumes t_{i-1} and t_{i+1}, that are close to the generalized capillary length, and Q_{t_i} is a blood volume speed in tissue capillaries.

Then the equation for changes of arterial blood temperature may be written as:

$$c\rho V_a\frac{dT_a(\tau)}{d\tau}=c\rho\left(Q_{LC}T_{LC}(\tau)+Q_{Sh}T_{\bar{v}}(\tau)-Q_aT_a(\tau)\right), \quad (25)$$

where Q_{Sh} is a blood volume velocity in a lung shunt.

Temperature changes in structures tissue blood - tissue is described by a system of ordinary differential equations

$$c\rho V_{ct_i}\frac{dT_{ct_i}(\tau)}{d\tau}=c\rho Q_{t_i}\left(T_a(\tau)+T_{ct_i}(\tau)\right)+G_{ti}\left(T(\tau)\right), \quad (26)$$

$$c_{t_i}V_{t_i}\frac{dT_{t_i}}{d\tau}=\mu_{t_i}-G_{t_i}\left(T(\tau)\right)-D_{t_i,t_{i-1}}(\tau)+D_{t_i,t_{i+1}}(\tau), \quad (27)$$

$$G_{t_i}\left(T(\tau)\right)=\gamma_{t_i}S_{t_i}\left[T_{t_i}(\tau)-T_{ct_i}(\tau)\right], \quad i=\overline{1,n}. \quad (28)$$

The equation for temperature changes in mixed venous blood and pulmonary blood may be written as:

$$c\rho V_{\bar{v}}\frac{dT_{\bar{v}}(\tau)}{d\tau}=c\rho\left(\sum_{t_i}Q_{t_i}T_{t_i}(\tau)-QT_{\bar{v}}(\tau)\right), \quad (29)$$

$$c\rho V_{LC}\frac{dT_{LC}(\tau)}{d\tau}=c\rho Q_{LC}\left(T_{\bar{v}}(\tau)-T_{LC}(\tau)\right)-G_{\mathrm{Res}}, \quad (30)$$

where $Q=\sum_{t_i}Q_{t_i}=Q_{Sh}+Q_{LC}, G_{\mathrm{Res}}$ is a heat flow value, which represents the heat loss to the environment through respiratory ways.

The main flows of heat exchange with the environment are realized through the skin – that is why in mathematical model of heat exchange has to be present an equation for temperature changes in the skin:

$$c_k V_k \frac{dT_k}{d\tau} = \mu_k - G_k(\tau) - D_{k,k-1}(\tau) + D_{k,k+1}(\tau) - G_{KON\bar{v}}(\tau) - G_{RAD}(\tau) - G_{EV}(\tau), \quad (31)$$

where index k relates to tissue region – skin surface, $G_{KON\bar{v}}, G_{RAD}, G_{EV}$ are flows that form heat exchange with environment, convection, irradiating and evaporation from human skin surface respectively.

Like functional respiratory system, the heat exchange system in organism may be seen as regulated system. Unlike models in which the aim of regulation is maintaining of organism internal environment temperature or temperature of individual organs (including a brain) at defined level, in the model proposed below the aim of the regulation is a transformation of disturbed system of heat exchange in a state of equilibrium where for all tissue regions is true:

$$\theta(\tau) = \mu_{t_i} - G_{t_i}(T(\tau)) - D_{t_i,t_{i-1}}(\tau) + D_{t_i,t_{i+1}}(\tau) = 0. \quad (32)$$

Were as regulatory parameters for the effector physiological responses may be used:

– evaporation $G_{EV}(\tau)$ from the skin as the main organism function that protects it from overheating;

– velocity of heat production in the muscles μ_{t_i} (taking into account the effect of heat trembling);

– volumetric tissue blood flow velocities $Q_{t_i}, i = \overline{1,m}$.

Quality of heat exchange processes regulation may be estimated by the system ability to support minimum of functional

$$\dot{J} = \int_{\tau_0}^{\tau^*} \left[\sum_{t_i} \lambda_{t_i} \theta_{t_i}^2(\tau) + \sum_{t_i} \omega_{t_i} \left(\mu_{t_i}(\tau) - \mu_{t_i}^N \right)^2 \right] d\tau, \quad (33)$$

where the first summand of integrand characterizes the violation of thermal balance in all studied tissue regions, and the second summand – organism energy losses. In equation (33) λ_{t_i} are coefficients that determine the sensitivity of various tissues to thermal imbalance, and ω_{t_i} is the sensitivity to energy imbalance and energy losses.

If to simulate the system of thermoregulation and heat exchange in isolation from the respiratory system, all the regulatory parameters that were listed above are really significant. But we can assume that skin evaporation is one of the main functions of this tissue, which requires metabolic processes intensity changes for certain internal disturbances (intensive unskilled unproductive work) or external ones (changing of temperature conditions). Similarly, heat production velocity is a part of energy release as a result of tissue metabolism; possibly it is slightly higher than required level during appearance of cold trembling. Abovementioned allows us to see the respiratory, blood circulation and heat exchange systems in cooperation and to present the problem of regulation of these systems as output of dynamic systems (1) – (20), (25) – (32) from disturbed state into the state of equilibrium. As optimal regulatory parameters may be seen $\dot{V}$, Q, Q_{t_i}, and possibly components μ_{t_i} that make minimal functional $\dot{I} + \dot{J}$ defined by relations (23) and (33).

During mutual interaction of respiratory, blood circulation and heat exchange systems may occur systemic conflicts because the maintaining of steady state in these systems are provided by the same active executive mechanisms – respiratory muscles, cardiac muscle, smooth muscle of blood vessels; also heat output by evaporation and irradiation may be added to these effects.

Obviously, the realization of heat equilibrium state in organism depends greatly on the environment temperature. In computing experiment with mathematical model of heat exchange and thermal regulation were found some conditions under which organism begins to stabilize own state, and activity of thermoregulatory mechanisms is minimal. It was found that for organism the most comfortable environment temperature is $30 \pm 2°C$.

IV. CONCLUSIONS

Abovedescribed models allow us to demonstrate the reaction of self controlled organism parameters on various changes of environment. Mathematical models of respiratory, blood circulation and thermoregulation system permit ones to conduct theoretic research of parameters that characterize the average person organism and to predict adaptation processes for any individual to various perturbation effects during the simulation of these effects on individualized respiratory system functional model.

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Н. І. Аралова, О. М. Ключко, В. Й. Машкін, І. В. Машкіна. Дослідження надійності роботи операторів при змінах температурних умов

Розроблено математичні моделі керування для систем організму: дихальної, кровообігу та терморегуляції. Вони дозволяють виконувати теоретичні дослідження параметрів, які характеризують середньостатистичний організм людини та демонструють реакцію його саморегульованих параметрів на різні зміни оточуючого середовища.

Ключові слова: математична модель; саморегульовані параметри; оператор безперервної взаємодії; надійність роботи оператора; адаптація.

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Н. И. Аралова, Е. М. Ключко, В. И. Машкин, И. В. Машкина. Исследование надежности работы операторов при изменениях температурных условий

Разработаны математические модели управления для систем организма: дыхательной, кровообращения и терморегуляции. Они позволяют выполнять теоретические исследования параметров, характеризующих среднестатистический организм человека и демонстрируют реакцию его самоконтролируемых параметров на различные изменения окружающей среды.
Ключевые слова: математическая модель; саморегулирующиеся параметры; оператор непрерывного взаимодействия; надежность работы оператора; адаптация.

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