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CONCEPT OF AUTOMATED CONTROL SYSTEM WITH ANALYZING CONDITION OF THE ERGATIC COMPONENT

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Abstract. *In this work the automated control system structure and configuration together with the mathematical description of the person-operator are considered in details. The proposed concept of human-operator organism representation as an ergatic object gives the possibility to provide mathematical approach to the description of the ACS with the prognostication of human-operator cybernetic ability. It will allow to solve problems of a human factor in modern conditions of aircraft control.*

Keywords: automated control system; ergatic object; human-operator; theory of ergatic system.

1. Introduction

Progress of society during last decades is characterized by automation of person's activity in various fields due to using computer technologies.

Control systems can be characterized by automation level: automatic and automated. In most cases, from the point of view of control theory, the systems with Human-Operator (H-O) in control circuit can be considered as the Automated Control System (ACS).

The analysis of existing variety of ACS (for example air transportation) allows us to make an essential general conclusion – the presence of the H-O in the control circuit decreases the reliability of the system (Fig. 1) [5].

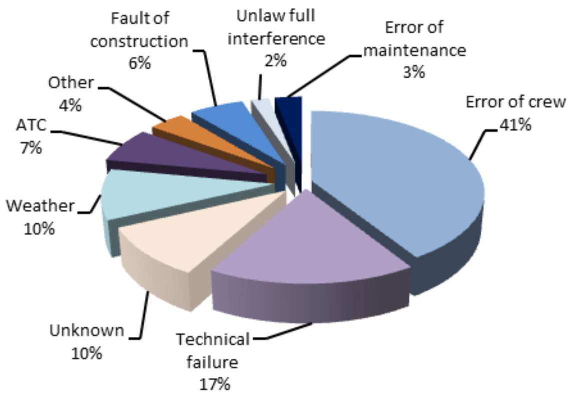

Fig. 1. Statistics of aircraft accidents

Over a long time the problems of ACS synthesis and analysis were being solved by differentiating technical and biological components because they relate to various fields of knowledge.

On the one hand these fields are mathematics, physics, electronics, and on the other hand – biology, anatomy, physiology.

2. Analysis of literature

Complex approach to analysis and synthesis problems of ACS has been suggested by such well-known scientists V. Glushkov [1], V. Pavlov [2].

Their studies have led to creation of the theory of Ergatic System (ES).

According to the ES theory, they are the class of systems that integrate the implements of object of labour, control goal, physical and information interconnection between the ergatic and technical components in a single control circuit for the optimization of efficiency function under impacting of the destabilizing factor of external environment.

3. Reasons of informational mismatching in automated control system

The first condition of ES optimum functioning is the principle of adequacy, i.e. matching of the H-O cybernetic ability with dynamic characteristics of the system.

The second condition is the principle of information concordance, i.e. matching the information streams between all ES components.

Thus, for the achievement of maximum control efficiency, ES should structurally and functionally correspond to the cybernetic, morphological and physiological features of ergatic constituent.

Or in other words, regardless of ACS purposes (the control of some processes such as aircraft, train, seacraft etc.), cybernetic resources of the human organism are integrated into the control circuit for optimizing the achievement of efficiency function.

In the mode of automatic control the mathematical description of the system generally looks like:

$$y_i = f(x_i, z_i, \varepsilon_i, t), \quad (1)$$

where y – parameters of output values;

x – parameters of input values;

z – perturbation vector;

t – time;

i – the number of controllable parameters.

The structure of such control system is shown in Fig. 2.

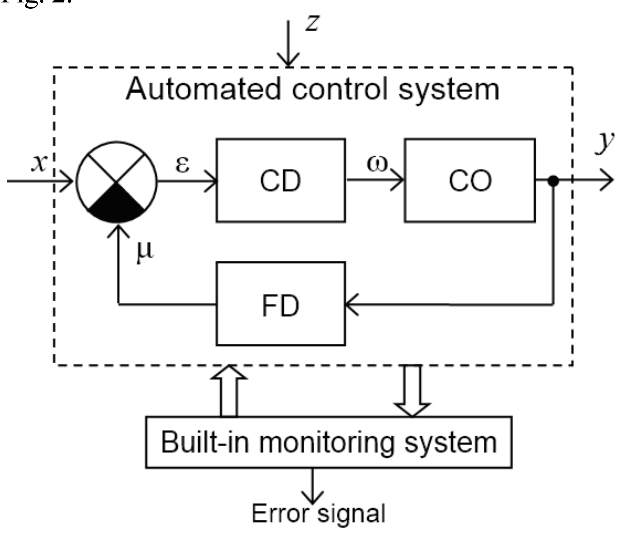

Fig. 2. Automatic control system structure:
CD – control device;
CO – control object;
FD – feedback device

Depending on the output parameters y and the given input x, the feedback device forms mismatch signal $\varepsilon = f(x, \mu)$ (where μ – signal error), that leads the rudders to the desired position and the signal ε tends to zero.

Such modern systems are the automatic monitoring of the operability of all system components and the failure warning signal originates if the some system element is in the idle mode.

In the mode of automated control the H-O performs the function of feedback device (Fig. 3).

In this system H-O is the link optimizing of the objective function Ψ, it minimizes the mismatch between input and output by means of analyzing the Display Device (DD) data.

In a dynamic system, such as the aircraft, speed eliminating of this mismatch is essential condition, and by a cybernetic ability of H-O is determined.

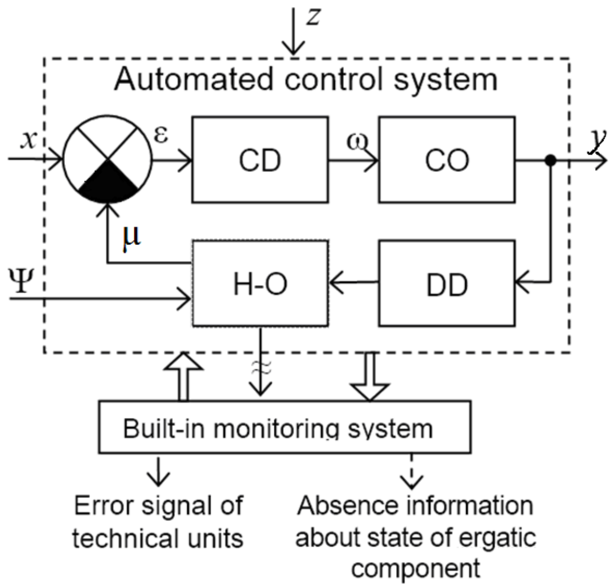

Fig. 3. Automated control system structure

The cybernetic ability of H-O is the speed of receiving and handling information and also the speed of motor responses.

The H-O cybernetic ability depends on many factors such as age, professional skills, load intensity, Destabilizing Factors of Environment (DFE) and time.

As it can be seen from the Fig. 3, in the ACS there is no link between built-in monitoring system and optimizing unit – H-O.

This is one of the main reasons leading to the emergence of aviation accidents, which then can be classified as pilot error.

The following examples may be the confirmation of the above mentioned.

Return of American astronaut Stefanyshyn-Piper Heidemarie on aboard “Atlantis” from International Space Station to the Earth resulted in the loss of consciousness during celebration ceremony.

But there was no information about worsening of her health.

It is clear that such a situation is not admissible in the open space, because aftereffects could be fatal.

“Sprut” experiment on board the International Space Station in 2005 demonstrated the possibility of H-O inability, due to decreasing the liquid volumes in the cosmonaut organism (Fig. 4).

Thus, the research goal is detailing the theoretical aspects of the formation information about H-O cybernetic ability and integration of this information the control circuit for matching information streams between ergatic and technical components in an ACS.

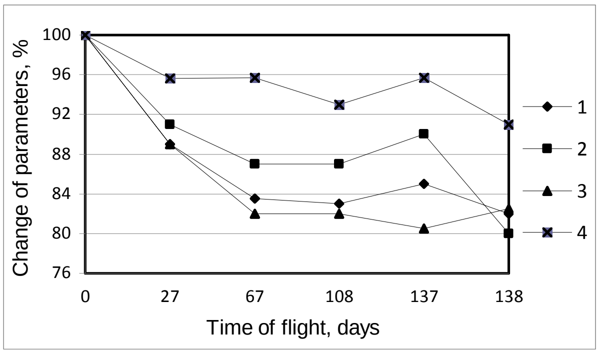

Fig. 4. Change of cosmonaut's body mass and liquid compartment state during the orbital flight:
1 – total body mass;
2 – extracellular liquid volume;
3 – total liquid volume;
4 – intracellular liquid volume

4. Solution of the problem

For an ES in which the ergatic and technical components are interconnected in a single control circuit, the expression (1) can be rewritten as follows[4]:

$$y_i = f(x_i, z_i, \varepsilon(\alpha)_i, t),$$

where α – variable, which characterizes the internal state of Ergatic Object (EO).

Let's consider the EO as a unit, which tends to the optimization of an efficiency function Ψ.

We can affirm that the algorithm of Ψ function achievement is kept in the central nervous system, the receiving of the information is provided by receptors, movement in space is performed by effectors and the energy support is provided by the metabolic system. This statement can be formularized as follows:

$$\Theta(t) = \underset{\Psi}{\Phi}\{\Delta E, I, RE\}, \quad (2)$$

where $\Theta(t)$ – state space vector of EO;

Φ – Operator of functional transformation;

ΔE – Parameters of energy balance of EO;

I – Quantitative information processed by EO;

RE – integrity factor of receptor-effector organs' functioning.

Proceeding from the principles of human anatomy and physiology, and the definition of EO by means of formula (2), we can represent the structure of the human organism by the following way (Fig. 5).

Possible state space of the vector Θ can be written as a merge of sets of vectors α_l which carry information about the corresponding level of EO structural organization:

$$\Theta \in \{\alpha_0 \cup \alpha_1 \cup \alpha_2 \cup \alpha_3 \cup \alpha_4 \ldots \cup \alpha_n\}, \quad (3)$$

where there are levels: α_0 – cybernetic ability;

α_1 – common functioning;

α_2 – psychical adequacy;

α_3 – metabolic status;

α_4 – immune resistance.

It's necessary to have the quantitative characteristics (markers) for integration of the EO in the ACS control circuit.

For evaluating of the H-O cybernetic ability (α_0 level), the limited operating time of task performance t_L can be accepted.

Exceeding the time limit during the task performance can be considered as the possibility of an emergency at the expense of inconsistency H-O cybernetic ability to dynamic characteristics of the ACS.

Then, the control error in ACS, because of the H-O cybernetic inability can have mathematical formulation by means of the complementary cumulative distribution function:

$$F_{er}(\alpha_0) = p\{\, t \geq t_L \,\} = 1 - \int_0^{t_L} f(t)dt,$$

where $f(t)$ – probability density of time solutions task.

H-O cybernetic inability also depends on the state of $\alpha_1 - \alpha_4$ levels, which in turn depend on DFE. Markers $\alpha_2 - \alpha_4$ can't be used in dynamic system and therefore they are not considered in the article.

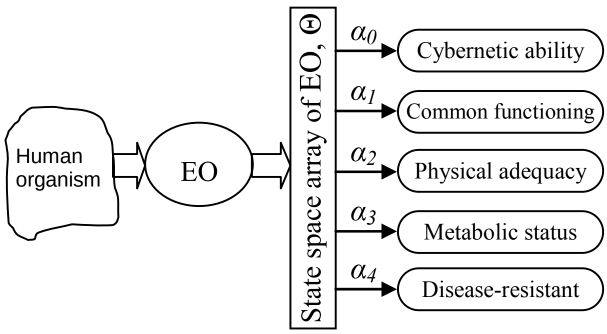

Fig. 5. Levels of representation of H-O organism for his integration into counter of ACS

We assume that they are located in the normal range because they are studied by the health centers during scheduled inspections of H-O.

For the quantitative estimation of α_1 – level, we choose the following options of H-O:

– systolic pressure sp;

– diastolic pressure dp;

– cardiac rhythm cr.

The achievement of the control efficiency function Ψ always takes place under impacting of the DFE – z.

The influence of DFE results on the shift of EO parameters α_1 from the steady position (homeostasis disbalance).

This disbalance, in turn, has an impact on the cybernetic level and can lead to slower reaction of H-O or making wrong decisions.

Then, the solution of the equation (3) will be correct if the α_1 – level parameters are within the allowable range:

$$F(\alpha_1) = p\{\ \Theta_{LL} \le \Theta \le \Theta_{LH}\} = \int_{h_{LL}}^{h_{LH}} f_{\alpha 1}(\Theta)dh,$$

where

$$\Theta \in \{sp, dp, cr\}.$$

Then we can assert that the pilot error can be predictable if we know the mathematical expectations $f(t)$, $f_{\alpha 1}(\Theta)$ and separate their limitations.

The structure scheme of the ASC is based on mentioned above conception and shown Fig. 6 [3].

At present there are some technical applications in which the similar approach is partially used.

The system for medico-biological provision of manned orbital flight can be the example. The built-in monitoring system of H-O state is based on the α_1 estimation parameters in the on-line mode. But it has not information about H-O cybernetic ability, i.e. – α_0 level.

In the case of orbital flight they are quite enough to solve the problem.

But in the interplanetary flight with the maximum degree of isolation and the flight duration for some years the on-line monitoring of all levels $\alpha_0 - \alpha_4$ of H-O will be necessary.

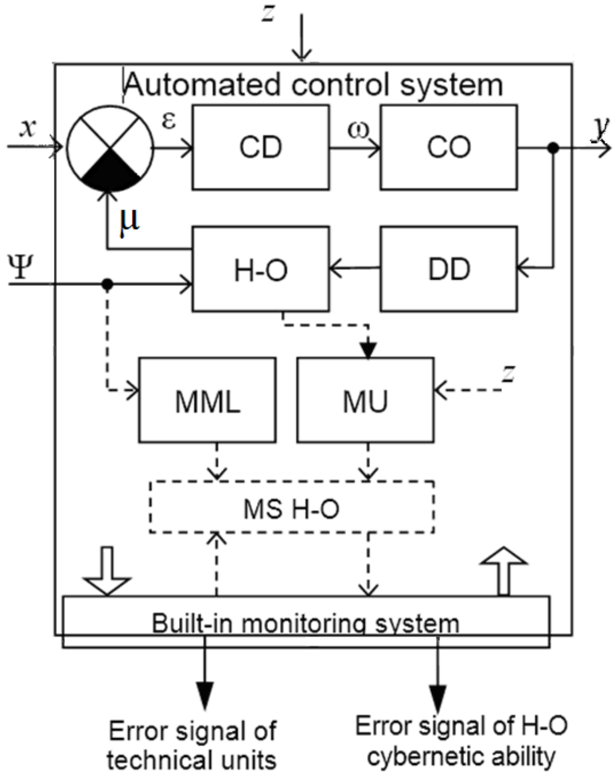

Fig. 6. ACS with the evaluation of EO state:
MML – mathematical models of particular limit value Ψ;
MU – measure unit of α_1 parameters;
MS H-O – measure system of H-O cybernetic ability

5. Conclusions

The configuration of modern ACS has limitations related to estimation of H-O state.

The deficiency of quantitative information on the human organism in the control circuit of ACS can lead to the decrease of control efficiency.

The proposed concept of H-O organism representation as the EO gives the possibility to provide mathematical approach to the description of the ACS with the prognostication in space and time of H-O cybernetic ability.

The realizability of the proposed approach to the construction of ACS will be confirmed in subsequent studies.

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Л.В. Благая[1], С.Т. Поліщук[2]. Концепція автоматизованої системи управління з аналізом стану ергатичної компоненти

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Детально розглянуто структуру та конфігурацію автоматизованої системи управління повітряним кораблем. Запропоновано математичний опис людини–оператора як ергатичного об'єкта. Показано, що цей підхід дозволить розв’язувати проблеми людського фактору в сучасних умовах керування повітряним кораблем.

Ключові слова: автоматизована система управління; ергатичний об'єкт; людина–оператор; теорія ергатичних систем.

Л.В. Благая[1], С.Т. Полищук[2]. Концепция автоматизированной системы управления с анализом состояния эргатической компоненты

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Детально рассмотрена структура и конфигурация автоматизированной системы управления воздушным судном. Предложено математическое описание человека–оператора как эргатического объекта. Показано, что такой подход позволит решать проблемы человеческого фактора в современных условиях управления воздушным судном.

Ключевые слова: автоматизированная система управления; теория эргатических систем; человек–оператор; эргатический объект.

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