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The Efficiency Control Assessment for Electronic System

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Abstract: The data of the analytical estimation on the efficiency of providing safety control of the radio-electronic system are given. The review is based on the investigation of the information interaction of the radio-electronic system (RS) with monitoring subsystem. The problem of optimal safety operational subsystem control of the RS and the generalized criterion for the effectiveness of decision making by the control system of the RS are formulated. Analytical expressions that allow making the choice of optimal ratio between the safe and the most effective modes of the control system operation are obtained.

Key words: Radio-electronic system; information efficiency; safety; complex engineering system; operation

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Introduction

Nowadays, the information efficiency is understood to mean the content and volume of processed and displayed information as well as the quality and timeliness of these operations. The currently available experience of control systems operation of radio-electronic systems functioning in the conditions of modern high-tech production has shown that it is the information effectiveness of the control process that has a most significant impact on the quality of complex process control problems solution.

1 Statement of the Research Problem

In the operation of complex machines and complexes of different kinds, equipment and machines become integrated into one complex radio-electronic system (RS). In the process of functioning in such an RS, an adaptation of
subsystems takes place because of which the reliability of the whole system operation can be either increased or decreased. Overall, RS is recoverable and maintainable. Therefore, it has a structural, informational and functional reservation. Besides, its reliability, on the whole, can be higher than the reliability of the other RS subsystems. The operability and reliability of the RS depend to a large extent on the characteristics of its individual subsystems and on the machine maintainability to interact with the control system. Meanwhile, as a rule, the quality of decision-making (DM) by the control system is of decisive importance in terms of ensuring reliable and effective RS operation. In this regard, the efficiency assessment of the RS safety control is the objective of this paper.

The assessing criterion for the quality of DM by the control system, we choose the probability of timely and error-free (optimal) solving of control problems P . Assuming the independence of the probabilities of timely P_t and the error-free (optimal) solution P_{opt}, the integral quality criterion can be written as follows:

$$P = P_t \cdot P_{opt}. \quad (1)$$

2 The main body

The relationship between the processing time of information T_0 by the control system and its volume I is determined by the Hick-Hayman law[1]:

$$T_0 = \alpha_0 + \beta_0 \cdot I, \quad (2)$$

where α_0 and β_0 are constants, experimentally determined and depending on the nature of the problem being solved.

To determine the probability of the timely and optimal solution of control tasks by the control system we used the interpretation of its actions by a single-channel queuing system with a limited waiting time[2]. For such a system, we can write the following expression:

$$P_t = \frac{1}{1+\frac{\propto}{1+\beta}+\frac{\alpha}{1+\beta}\sum_{s=1}^{\infty}\frac{\propto^s}{\prod_{m=1}^{n}\left[1+(1+m)\beta\right]}},$$

where $\propto=\frac{\lambda}{\mu}$; $\beta=\frac{\vartheta}{\mu}$; $\vartheta=\frac{1}{T_{доп}}$; λ is the intensity of the tasks' occurrence; $T_{доп}$ is the allowed waiting time.

Increased processing information leads to the effectiveness rise of control [3, 4]:

$$Э = Э_{\max}\left[1-B_0\exp\left(\frac{I}{I_0}\right)\right], \qquad (4)$$

where $Э_{\max}$ is the efficiency of a perfectly functioning system with full and accurate information; B_0 is the initial entropy (disorder) of the system; I_0 - constant (information content before starting the operation of the system); $B_0 = 1-P_0$; P_0 is the probability of the successful (correct) solution of the control task (decision making) in conditions of complete uncertainty.

Then, the probability of an optimal solution of problems by a control system can be found from the relation:

$$P_{opt} = 1-P_0\exp(-\gamma I), \qquad (5)$$

where γ is a constant characterizing the value (significance) of information from the point of view of the decisions made by the control system.

Using the relations (1), (3) and (5), we calculated the values of $P_t(I)$, $P_{opt}(I)$ и $P(I)$ assuming that the control system solves logical problems.

The relative value of the elements of the information model can be defined as an increment of the integral performance index of the decisions made by increasing the content of processing information:

$$C_{\Delta I} = \frac{P(I+\Delta I)-P(I)}{\Delta I}. \qquad (6)$$

Considering the information control model, it should be taken into account that, as a rule, the control system is the main control element and, therefore, one of the tasks of such a system research is the task of identifying the links between various factors characterizing its behavior in the state space. Fig. 1 schematically represents the information inputs ($x_1, x_2, ..., x_m$) and outputs - control signals and solutions - $(y_1, y_2, ..., y_n)$ of the information model, taking into account that it is based on the control system[2].

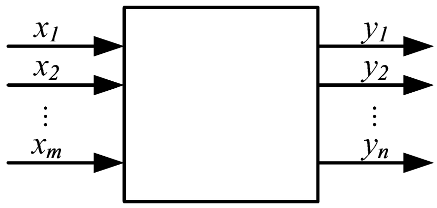

Fig.1 Inputs and Outputs of Information Model

In our opinion, when studying the control process with control system participation, it is most appropriate to use the mathematical tool of nonlinear multifactor regression, which makes it possible to investigate the influence of several factors on one control signal. In this case, the dependence of the output control signals $y_1, y_2, ..., y_n$ on the input disturbances $x_1, x_2, ..., x_m$ can be expressed by the following system of equations:

$$y_1 = f_1(t)+\sum_{i=1}^{m}a_{11}x_i+\sum_{i=1}^{m}a_{12}x_i^2+...+\sum_{i=1}^{m}a_{1k}x_i^k;$$

$$y_2 = f_2(t)+\sum_{i=1}^{m}a_{21}x_i+\sum_{i=1}^{m}a_{22}x_i^2+...+\sum_{i=1}^{m}a_2 \qquad (7)$$

$$y_n = f_m(t)+\sum_{i=1}^{m}a_{n1}x_i+\sum_{i=1}^{m}a_{n2}x_i^2+...+\sum_{i=1}^{m}a_{nk}x_i^k.$$

where $f_m(t)$ is a function taking into consideration the stochastic nature of the input signals of disturbances); a_{nk} is a group of unknown coefficients of the nonlinear regression equation, which are determined by the least squares method by solving the system of algebraic equations[2]; t is the time.

The effectiveness of the control system functioning depends on the timely and correct solution of emerging information-control problems by means of this system:

$$W = F(P_1, ..., P_i, ..., P_N), \qquad (8)$$

where P_i is the probability of a timely and correct DM by the control system for the i-task($i = 1...N$).

Having expanded (8) into a Maclaurin series and restricting ourselves to the first terms of the series, we obtain the following expression:

$$W \approx W_0 + \sum_{i=1}^{N}\frac{\partial W}{\partial P_i}P_i, \qquad (9)$$

where $W_0 = F(x_i)$ is the effectiveness of the RS

functioning without the participation of control system in the control process; $\frac{\partial W}{\partial P_i} = C_i$ is a value characterizing the degree of influence of the i-th problem on the efficiency of the system operation (the degree of problem importance).
To simplify further mathematical calculations, it is appropriate to unite the similar control tasks into groups. Then, the expression (9) can be rewritten in the form:

$$W \approx W_0 + \sum_{i=1}^{N} C_i N_i K_i P_i, \quad (10)$$

where N_i, P_i is the number of i-th group problems and the probability of their timely and correct solution, respectively; K_i is a coefficient characterizing the intensity of data traffic on the human operator when control problems of the i-
th group arise.
The sum in expression (10) is an increase in the efficiency increment of the control system due to the actions of the control system and, thus, can serve as a generalized DM efficiency criterion for control system:

$$Q = \sum_{i=1}^{N} C_i N_i K_i P_i. \quad (11)$$

It should be noted that to date, the coefficients, C_i, is usually determined by experts, and, in fact, are the so-called "weighting coefficients", the low information efficiency of which is well known[7].
Based on this fact, in our opinion, it is more appropriate to consider the issues of increasing the efficiency and reliability of the RS functioning using the maximum product problem, which is formulated as follows[6]:

$$\begin{cases} 0 < \prod_{i=1}^{n} P_i \le 1 \\ \prod_{i=1}^{n} P_i \to \max \end{cases} \quad (12)$$

If condition (12) is satisfied, then the ratio between reliability and efficiency of RS functioning is optimal from the viewpoint of using the maximum product problem.
Thus, the following conditions must be fulfilled for the optimal mode of RS operation:

$$\begin{cases} P_{i\ allow} \le P_i(t) \le 1 - P_i(t-1); \\ P_i(t) \in [P_{i\ allow}; 1] = \Omega. \end{cases} \quad (13)$$

where Ω is the control field while $P_{i\ allow}$ is the tolerance probability of trouble-free operation.
Expression (13) is the formulation of the optimal RS control problem.
If we assumed that time t can take only a discrete set of values: $t = 0;\ 1,\ ..., N$, where N is the time of continuous (trouble-free) operation of the system.
Then, the control can be expressed by the following relation:

$$\{P_1(t),\ P_2(t), ...,\ P_n(t)\} \quad (14)$$

At each moment of time, the state of the RS is characterized by n phase coordinates: $x_1, x_2, ..., x_n$, i.e. point X of E^n space. So, every moment of time t, the phase state $X(t)$ has n coordinates. Thus, the state of each subsystem of a controlled technological system is characterized by sets of l, k, m, q .... coordinates (parameters), respectively.
Finally, for any moment of time, the phase states of the RS can be analytically described as follows:

$$P_1(t) = f_1\{a(t)\} = \{a_1(t), a_2(t), ..., a_l(t)\};$$
$$P_n(t) = f_n\{d(t)\} = \{d_n(t), d_n(t), ..., d_n(t)\}, \quad (15)$$

where $f_1, ..., f_n$ are some functions; $a_i(t), ..., d_i(t)$ is the functions for changing parameters of the corresponding subsystems state.
For each of the subsystems, the sequence:

$$\left.\begin{matrix} a(0), a(1), ..., a(t), ...; b(0),\ b(1), ... b(t), ...; \\ c(0), c(1), ... c(t), ...; d(0), d(1), ..., d(t), ...; \end{matrix}\right\} (16)$$

is the trajectory of its evolution. The initial state $\{a(0);\ b(0);\ c(0);\ d(0)\}$ must be specified, where this is the state of the RS before its operation immediately after commissioning.
Expression (16) can be rewritten in a different form:

$$\begin{cases} 0 < P_1(t) = \{a(t)\} = f_1\{a_1(t), a_2(t), ..., a_l(t)\} \le 1; \\ 0 < P_2(t) = \{b(t)\} = f_2\{b_1(t), b_2(t), ..., b_k(t)\} \le 1; \\ ... \\ 0 < P_n(t) = \{d(t)\} = f_n\{d_1(t), d_2(t), ..., d_q(t)\} \le 1. \end{cases} \quad (17)$$

Let us consider a stationary process and divided into $n = t / \Delta t$ intervals, where t is the duration of the process; Δt is duration of the interval. Let us denote that P_1 is the probability of not x level exceeding per Δt time. Then, we can write the following approximate expression:

$$P_x(t) \approx P_1^n \quad (18)$$

To estimate the probability P_1, we use the value [6, 7]:

$$P_x(t) \geq P_0 - N_x(t), \text{ under } t \leq P_0[N_x(t)]^{-1}, (19)$$

where P_0 is the probability of not exceeding the given level at the initial time.
Where

$$N_x(t) = \int_0^t n_x(\tau)d\tau, \quad (20)$$

where $n_x(\tau)$ is the average number of emissions per unit time per x level.
Then:

$$P_x(t) = (F_x - n_x \Delta t)^{t/\Delta t}, \quad (21)$$

where F_x is the distribution function of the quantity x.
Setting $\Delta t = 1$, we get:

$$P_x(t) = (F_x - n_x \Delta t)^t . (22)$$

For the stationary process, expression (22) can be rewritten as:

$$P_x(t) = \exp[t \ln(F_x - n_x)]. (23)$$

For non-stationary process:

$$P_x(t) = \exp\left\{\int_0^t \ln[F_x(\tau) - n_x(\tau)]d\tau\right\}. (24)$$

Expressions (23) and (24) are analytic relations with the help of which one can find the probability of the RS trouble-free operation for stationary (23) and non-stationary processes of RS functioning (24).
When justifying these dependencies, no assumptions were made about the law of ordinate process distribution and its duration. Therefore, expression (23) can be used for the arbitrary process of any duration.
Thus, the dependencies (12) and (17) can be considered as the optimal conditions of the relationship between reliability and efficiency of RS operation.

Conclusion

The problem of optimal control of RS safety functioning was formulated.
Analytical expressions, allowing the estimation of the optimal ratio between the reliable and the most effective operating modes of RS, as well as expressions for determining the probability of RS trouble-free operation in the case of the stationary and non-stationary processes of its operation were deduced.
The generalized criterion of the DM efficiency for RS control system was set up.

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