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THE MODEL OF RADIOELECTRONIC SYSTEM RELIABILITY CONTROL EFFECTIVENESS

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Abstract: The article is concerned with the analytical evaluation data of the effectiveness of the electrodynamic system reliability control. The basis of the consideration is a study of information efficiency of interaction between a radioelectronic system and that of electronic control. The analytical expressions obtained allow the optimal ratio between the reliable and most effective operating mode of control systems to be chosen. The problem of optimal control of reliability of functioning the radioelectronic control system is stated.

Key words: information efficiency, radioelectronic system, reliability, complex technical system, operation.

1. Introduction

Nowadays the need to ensure trouble-free operation of machines, various technological and other equipment used in different fields of production and other areas of human activity becomes more and more acute. The currently available operating experience of managing the operation of electrodynamic systems in modern high-tech production shows that it is the information efficiency of the control process having the most significant impact on the quality of solving complex problems concerning technological process control. In this case by the information efficiency we mean the composition and amount of processed and displayed information, as well as the quality and timeliness of these operations.

2. Statement of research problem

While operating complex machines and systems of various kinds, the equipment and machines are combined in one complex radioelectronic system (RS). With such a PS operating, there occurs an adaptation of the subsystems. This results either in the enhancing or in the lowering of the reliability of the system as a whole. In general, the RS is restored and maintained. Therefore, it has structural, information and functional redundancy, and its reliability, in general, may be higher than the reliability of the rest of the RS subsystems. The effectiveness and reliability of the RS, to a large extent, depend on the characteristics of its individual subsystems and on the machines' facilities to interact with the control system. At the same time, the quality of control system decision-making (DM) is usually of crucial importance in terms of ensuring reliable and efficient operation of the RS. In this context, the aim of this paper is to evaluate the control effectiveness of RS operation reliability.

3. Main part

For the control system to assess the DM quality, we choose the probability of timely and error-free (optimal) solution of the control tasks P as a criterion. Assuming the independence of probabilities of timely and error-free (optimal) solutions, P_t and P_{opt} respectively, an integral quality criterion can be written as follows:

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

The relationship between the time T_0 the control system requires to process the information, and its amount I is determined by the Hick-Hyman Law [1]:

$$T_0 = a_0 + b_0 \cdot I, \qquad (2)$$

where a_0 and b_0 are the constants determined experimentally and depending on the nature of the problem being solved.

To determine the probability of timely and optimal solutions of management tasks by the control system, we used 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:

$$P_t = \frac{1}{1 + \frac{\propto}{1+b} + \frac{a}{1+b} \sum_{s=1}^{\infty} \frac{\propto^s}{\prod_{m=1}^{n} \left[1 + (1+m)\, b\right]}}, \qquad (3)$$

where $\propto = \frac{l}{m}$; $b = \frac{J}{m}$; $J = \frac{1}{T_{perm}}$; l stands for the intensity of the occurrence of tasks; T_{perm} denotes the permissible waiting time.

An increase in the amount of data processed leads to an increase in the control effectiveness [3, 4]:

$$\acute{Y} = \acute{Y}_{\max} \left[1 - B_0 \exp\left(I / I_0\right)\right], \qquad (4)$$

where $\acute{Y}_{\max}$ is the efficiency of a perfectly operating system in the presence of complete and accurate information; B_0 represents the initial system entropy (disorder); I_0 stands for the constant (the amount of information before operation of the system); $B_0 = 1 - P_0$; P_0 is the probability of a successfull (correct) solution of the control tasks (decision-making) in the conditions of complete uncertainty.

Then the probability of an optimal solution of the tasks by the control system can be found from the relationship below:

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

where g is the constant characterizing the value (importance) of information in terms of the decisions made by the control system.

Expressions (1), (3) and (5) were used to calculate the values of $P_t(I)$, $P_{opt}(I)$ and $P(I)$ assuming that the control system solves logical problems.

The relative value of the elements of the information model can be defined as the increment of the integral decision quality index by increasing the amount of processed information:

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

When considering the information model, one should bear in mind that its main control element is, as a rule, a control system, and therefore one of the tasks of research into such a system is that of identifying the links between various factors characterizing its behaviour in the state space. Fig. 1 represents schematically information inputs $(x_1, x_2, ..., x_m)$ and outputs of the control signals $(y_1, y_2, ..., y_n)$ of the information model.

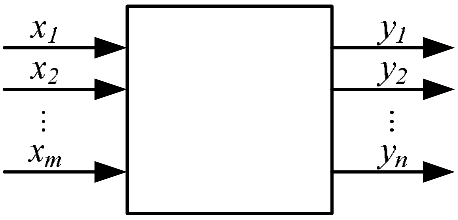

Fig. 1. Inputs and outputs of the information model

While studying the control process employing the control system, it is the most expedient, in our opinion, to use the mathematical apparatus of nonlinear multivariable regression that makes it possible to investigate the influence of several factors on one control signal. In this case, dependences 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:

$$\begin{aligned} y_1 &= f_1(t) + \sum_{i=1}^{m} a_{11} x_i + \sum_{i=1}^{m} a_{12} x_i^2 + ... + \sum_{i=1}^{m} a_{1k} x_i^k; \\ y_2 &= f_2(t) + \sum_{i=1}^{m} a_{21} x_i + \sum_{i=1}^{m} a_{22} x_i^2 + ... + \sum_{i=1}^{m} a_{2k} x_i^k; \qquad (7) \\ y_n &= f_m(t) + \sum_{i=1}^{m} a_{n1} x_i + \sum_{i=1}^{m} a_{n2} x_i^2 + ... + \sum_{i=1}^{m} a_{nk} x_i^k. \end{aligned}$$

where $f_m(t)$ is the functional taking into account the stochastic nature of the input disturbance signals; a_{nk} stands for the group of unknown nonlinear regression equation coefficients that are determined by the method of least squares by solving a system of algebraic equations [2]; t represents the time.

The control system effectiveness depends on how timely and correctly the system is capable to soluve the emerging information-management problems:

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

where P_i is the likelihood of timely and correct solution of the i-task by the control system: $(i = 1...N)$.

Expanding (8) in the Maclaurin series and restricting ourselves to the first terms of the series, we get the following expression:

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

where $W_0 = F(x_i)$ expresses the effectiveness of the system without the control system's being involved in the management process; $\frac{\partial W}{\partial P_i} = C_i$ represents the quantity that characterizes the degree of influence of the i-th task on the effectiveness of the system (the degree of the its importance).

To simplify further mathematical calculations, it is advisable that the same type of management tasks be combined into groups. Then, expression (9) can be rewritten as:

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

where N_i, P_i are the number of i-th group tasks and the probability of their timely and correct solution respectively; $\boldsymbol{K_i}$ denotes the coefficient characterizing the intensity of the information load on a human operator in the event of arising management tasks of the i-th group. The sum in expression (10) is an increase in the effectiveness of the control system through its actions and may thus serve as a general criterion for the effectiveness of the decisions made by the control system:

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

It should be noted that today the coefficients C_i are usually defined by experts and are, in fact, the so-called “weight coefficient”, the low information efficiency of which is well known [7, 8].

Accordingly, in our opinion, it is more appropriate that the issues of improving the efficiency and reliability of the RS functioning be considered by employing the problem of maximum product, which is formulated as follows [6]:

Let $0 < a \le 1$ be the probability of fail safety; $P_1 \cdot P_2 \cdot \ldots \cdot P_n$ is the product of probabilities of trouble-free operation of the subsystems RS; n represents the number of its subsystems. Then, the following condition must be met:

$$\begin{cases} 0 < \sum\limits_{i=1}^{n} P_i \le 1 \\ \prod\limits_{i=1}^{n} P_i \to \max \end{cases} . \tag{12}$$

The values $\sum\limits_{i=1}^{n} P_i$ и $\prod\limits_{i=1}^{n} P_i$ are the phase coordinates, and the products of $P_1 \cdot P_2 \cdot \ldots \cdot P_n$ are the control parameters.

If condition (12) is satisfied, the ratio between reliability and efficiency of RS functioning is optimal in terms of using the problem of maximum product.

Thus, for a RS to operate optimally, the following conditions must be met:

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

where Ω is the control domain, $P_{i\,allow}$ is the allowable probability of fail safety. Assume that the time t may take only a discrete set of values: $t = 0;\ 1,\ \ldots, N$, with N being the continuous (trouble-free) operation of the system. Then, the control can be expressed by the following equation:

$$\left\{P_1(t),\ P_2(t), \ldots,\ P_n(t)\right\}. \tag{14}$$

At each time point t, the RS state is characterized by n phase coordinates: $x_1, x_2, \ldots, x_n$, i.e. the point X of the space E^n. So, at each time point t, the phase state $X(t)$ has n coordinates. Therefore, the state of each of the subsystems of the controlled technological system is characterized by the sets l, k, m, q .... of the coordinates (parameters).

Then, finally, for any moment of time, the phase states of the RS can be analytically described in the following way:

$$\begin{matrix} P_1(t) = f_1\{a(t)\} = \{a_1(t), a_2(t), \ldots, a_l(t)\} \\ P_n(t) = f_n\{d(t)\} = \{d_n(t), d_n(t), \ldots, d_n(t)\} \end{matrix} ; \tag{15}$$

where $f_1, \ldots, f_n$ are some functions; $a_i(t), \ldots, d_i(t)$ are the functions of changes in the state parameters of the corresponding subsystems.

For each of the subsystems the sequence

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

is the trajectory of its evolution. The initial state $\{a(0);\ b(0);\ c(0);\ d(0)\}$ should be set. Expression (16) can be rewritten in a different form:

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

Consider a stationary process which, using the results of [10], will be divided into $n = t/\Delta t$ intervals, where t stands for the process time; Δt represents the interval duration. Let P_1 denote the probability of not exceeding the level x during Δt. Then we can write the following approximate expression:

$$P_x(t) \approx P_1^n . \tag{18}$$

To assess the probability P_1, we use the following assessment [6, 7]:

$$P_x(t) \ge P_0 - N_x(t), \text{ under } t \le P_0\left[N_x(t)\right]^{-1}, \tag{19}$$

where P_0 is the probability of not exceeding a predetermined level at the initial time point;
where

$$N_x(t) = \int_0^t n_x(t)\,dt, \tag{20}$$

where $n_x(t)$ is the average number of peaks per unit time per level x. Then:

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

where F_x is the function of value distribution x.

Let $\Delta t = 1$, we get:

$$P_x(t) = \left(F_x - n_x \Delta t\right)^t . \tag{22}$$

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

$$P_x(t) = \exp\left[t \ln\left(F_x - n_x\right)\right]. \tag{23}$$

For a non-stationary process:

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

Justifying these relationships, no assumptions have been made about the law of ordinates distribution of the process and its duration. Therefore, expression (23) can be used for any arbitrary process of any duration. Thus, dependencies (12) and (17) can be considered as conditions of the optimal balance between reliability and efficiency of RS operation.

4. Conclusion

1. The analytical expressions to assess the optimal balance between the reliable and most efficient modes of RS operation have been obtained.

2. The problem of optimal control of the RS operation reliability has been stated.

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МОДЕЛЬ ЕФЕКТИВНОСТІ УПРАВЛІННЯ НАДІЙНІСТЮ РАДІОЕЛЕКТРОННОЇ СИСТЕМИ

Сергій Мещанінов, Віктор Співак

Наведено дані аналітичної оцінки ефективності забезпечення управління надійністю електродинамічної системи. В основу розгляду покладено дослідження інформаційної ефективності взаємодії радіоелектронної системи з електронної контрольно-керуючою системою. Отримано аналітичні вирази, що дають змогу вибирати оптимальне співвідношення між надійним і найбільш ефективним режимами експлуатації систем управління. Сформульовано задачу оптимального управління надійністю функціонування системи управління радіоелектронної системи.

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