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ESTIMATION OF OPERATION RELIABILITY OF CONTROL ELECTRONIC SYSTEMS WITH THE USE OF MAXIMUM PRODUCT PROBLEM

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Abstract. In the article there are presented the results of analytical research on the operation reliability of a complex engineering system using the example of a control electronic system. Functioning of such a system is suggested to be considered with the use of a maximum product problem. At the same time an adequate balance between its reliability and efficiency is chosen as a criterion for the estimation of its reliable and efficient functioning. We consider the electronic system in the conditions of modern industry to be one of the most loaded subsystems. The analytical expressions have been obtained which allow setting the optimal balance between the reliability and efficiency of control electronic system operation.

The offered approach allows more effective and adequate estimation and prognosis of the state and performance of any electronic system at all stages of its life cycle, from the beginning of exploitation to the end of the warranty period, and, in many cases, during the extension of this period, on the basis of the continuous control of the balance in accordance with the maximum product problem.

Key words: reliability, efficiency, control electronic system, maximum product problem, evolution.

1. Introduction.

It is expedient to estimate the state of any kind of a modern control electronic systems applying a maximum product problem. In accordance with [1], this problem is defined as follows: it is necessary to find N non-negative numbers whose sum does not exceed a given number a>0 and whose product is a maximum.

2. Setting the task of research

For an electronic system, as one of the most technologically loaded control elements of modern production, this task can be formulated as follows:

Let $0 < a \le 1$ be the total probability of faultless operation; $P_1 \cdot P_2 \cdot .... \cdot P_n$ be work probabilities of faultless work of the electronic system's subsystems; n be the number of the electronic system's subsystems.

Then following conditions must be met:

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

Values $\sum_{i=1}^{n} P_i$ and $\prod_{i=1}^{n} P_i$ are phase coordinates, and the set of values $P_1, P_2, ..., P_n$ are control parameters.

If the condition (1) holds, then the balance between reliability and efficiency of the electronic system operation is optimal.

Thus, the purpose of this work is the investigation of possibilities of applying the maximum product problem to estimation and calculation of reliability of the operation of control electronic systems.

3. Theoretical fundamentals

For the optimal mode of an electronic system operation such conditions should be met:

$$\begin{cases} P_{i\,pos} \le P_i(t) \le 1 - P_i(t-1), \\ P_i(t) \in \left[P_{i\,pos}; 1 \right] = \Omega \end{cases} \quad (2)$$

where Ω is a control area.

If at every correlation instant the conditions (2) hold, then control of the system is considered possible.

The change of reliability level of an electronic system operation is expedient to be examined as an additive stochastic process of changing the probability of faultless work:

$$P(t) = P'(t) + P''(t), \quad (3)$$

where $P'(t)$ is a stationary component of the faultless work probability; $P''(t)$ is a stochastic component of the faultless work probability.

Any control electronic system is a complex technical system, which can be conditionally divided into n subsystems operating simultaneously, thus they are connected in series.

We set the instant t as a discrete series of values $t = 0;\ 1,\ \ldots, N$, where N is the period of continuous (faultless) work of the electronic system.

Then a notion of control can be expressed by means of a folllowing correlation:

$$\{P_1(t),\ P_2(t), \ldots,\ P_n(t)\} \quad (4)$$

At every instant t the state of the electronic system is characterized by n phase coordinates $x_1, x_2, \ldots, x_n$, with a point X of space E^n. Thus, at every point of time t the phase state $X(t)$ has n coordinates.

Let us assume that in each point of time t the state of each subsystem is characterized, accordingly, by sets $l, k, m, q \ldots$ of coordinates (parameters).

Then, finally, for any point of time the phase state of the electronic system's subsystems can be analytically described as follows:

$$P_1(t) = f_1\{a(t)\} = f_1\{a_1(t), a_2(t), \ldots, a_l(t)\};$$

$$\ldots..,$$

$$P_n(t) = f_n\{d(t)\} = f_n\{d_1(t), d_2(t), \ldots, d_q(t)\}, \quad (5)$$

where $f_1, \ldots., f_n$ are some functions; $a_i(t), \ldots., d_i(t)$ are functions of the change of parameters of the state of the electronic system's subsystems.

For each of electronic system's subsystem there is a sequence: that can be aggregated into a set of sequences:

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

which is the trajectory of its evolution.

The initial state $\{a(0); b(0); c(0); d(0)\}$ must be set. It is the state of the electronic system at the beginning of its operation after its placing into service.

Taking into account the condition (1), the expression (5) can be rewritten in a different way:

$$\begin{cases} 0 < P_1(t) = f_1\{a(t)\} = \\ = f_1\{a_1(t), a_2(t), \ldots., a_l(t)\} \le 1, \\ 0 < P_2(t) = f_2\{b(t)\} = \\ = f_2\{b_1(t), b_2(t), \ldots., b_k(t)\} \le 1, \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ 0 < P_n(t) = f_n\{d(t)\} = \\ = f_n\{d_1(t), d_2(t), \ldots., d_q(t)\} \le 1. \end{cases} \quad (6)$$

Further development (evolution) of control electronic system is certain, if there is control over $P_1(t), \ldots, P_n(t)$, set by means of correlations:

$$P_1(t) = f_{1t}[P_1(t-1), P_1(t)];$$

$$P_2(t) = f_{2t}[P_2(t-1), P_2(t)],$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..;$$

$$P_n(t) = f_{nt}[P_n(t-1), P_n(t)].$$

$$J = \sum_{i=1}^{n} P_i(t), \quad (7)$$

where f_{it} is a vector-function.

Thus, the task of optimal control reliability of electronic system operation consists in choosing such possible control over $\{P_1(t), P_2(t), \ldots, P_n(t)\}$ which, by its given initial state $\{P_1(0), P_2(0), \ldots,\ P_n(0)\}$, will provide a maximal value of the functional (7).

More correctly, the correlation (7) is of the form:

$$\begin{cases} J_1 = \sum_{i=1}^{l} a_i(t), \\ J_2 = \sum_{j=1}^{k} b_j(t), \\ \ldots\ldots\ldots\ldots \\ J_n = \sum_{h=1}^{q} d_h(t). \end{cases} \quad (8)$$

Let us consider a stationary process which, according to [2], [3], [4], [5],[6], can be subdivided into $n = \frac{t}{\Delta t}$ intervals, where t is the duration of the process; Δt is the duration of the interval.

Let us designate as P_1 the probability of not exceeding the level x of the process during the time period Δt. Then it is possible to write down such approximate expression $P_x(t) \approx P_1^n$.

For the evaluation of probability P_1 we use the estimation [3]:

$$P_x(t) \geq P_0 - N_x(t),\ if\ \ t \leq P_0\left[N_x(t)\right]^{-1}, \qquad (9)$$

where P_0 is the probability of not exceeding the fixed level in the initial point of time.

$$N_x(t) = \int_0^t n_x(t)\,dt, \qquad (10)$$

where $n_x(t)$ is an average number of events of exceeding the level x during a time unit.

Thus:

$$P_x(t) = \left(F_x - n_x \Delta t\right)^{t/\Delta t}, \qquad (11)$$

where F_x is a distribution function of the size x.

Considering $\Delta t = 1$, we will obtain:

$$P_x(t) = \left(F_x - n_x \Delta t\right)^{t}. \qquad (12)$$

For a stationary process the expression (12) can be rewritten as follows:

$$P_x(t) = \exp\left[t \ln\left(F_x - n_x\right)\right]. \qquad (13)$$

For a transient process:

$$P_x(t) = \exp\left\{\int_0^t \ln\left[F_x(t) - n_x(t)\right]dt\right\}. \qquad (14)$$

It should be stressed that we have obtained these dependences without making any assumptions about the probability distribution of ordinate of process and its duration. Therefore, the expression (14) can be used for an arbitrary process of any duration, which satisfies the conditions of electronic system operation.

Thus, the conditions (1) and (6) are the conditions of optimal balance between the reliability and efficiency of a control electronic system operation.

4. Conclusions

As a result of the undertaken study, some analytical expressions have been obtained allowing us to establish an optimal balance between reliability and efficience of a control electronic system for providing safe and most effective modes of its operation.

The offered approach allows more effective and adequate estimation and prognosis of the state and performance of any electronic system at all stages of its life cycle, from the beginning of exploitation to the end of the warranty period, and, in many cases, during the extension of this period, on the basis of the continuous control of the balance in accordance with the maximum product problem.

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ОЦІНКА НАДІЙНОСТІ ФУНКЦІОНУВАННЯ СИСТЕМ ЕЛЕКТРОННОГО КОНТРОЛЮ ШЛЯХОМ ЗАСТОСУВАННЯ ЗАДАЧІ МАКСИМАЛЬНОГО ДОБУТКУ

Сергій Мещанінов

Показано результати аналітичних досліджень надійності роботи складної електронної системи на прикладі електронної системи управління та контролю. Функціонування такої системи пропонується розглянути із застосуванням задачі про максимум добутку. Водночас адекватне співвідношення між її надійністю та ефективністю обирається як критерій для оцінювання її надійної та ефективної роботи. Прийнято, що електронна система в умовах сучасної промисловості є однією із найбільш навантажених підсистем. Отримано аналітичні вирази, що дають змогу встановити опти-

мальне співвідношення між надійністю та ефективністю роботи електронної системи управління та контролю.

Запропонований підхід надає можливість ефективнішого й адекватнішого оцінювання та прогнозування стану і поведінки електронної системи на всіх стадіях її функціонування, від початку життєвого циклу до закінчення гарантійного періоду ексдлуатації, а також у багатьох випадках, за межами цього періоду, на підставі постійного контролю за вибраним співвідношенням, отриманим за допомогою задачі про максимальний добуток.

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Areas of scientific interest: reliability of complex engineering systems, eniology, analysis and prognosis of psycho-emotional behaviour of a human being impacted by conditions of modern industry, biometrics.

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