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OPERATIONAL RELIABILITY MANAGEMENT OF THE RESERVED ELECTRONIC SYSTEM

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***Abstract*—*The errors in determination of the reserved electronic system reliability are inherent to the process of its diagnosing. It leads to system performance degradation including the faultless probability decrease. This paper covers the development and investigation of reserved system diagnostics mathematical model. This model takes into consideration the reservation order, the diagnosing tool credibility characteristics, monitoring periodicity and the system imperfect quality at functioning initial time instance. Diagnosing tool performs the electronic system operability indication function after switching to last redundant unit but not the unit switching function. This excludes the impact of the "false fault" type monitoring errors and improves the electronic system reliability. The reasonable control of a tolerance value ensures maximum probability of the system no-failure operation at every current moment of time.*

Index Terms—Electronic system; reliability; monitoring periodicity; probability of no-failure operation.

I. INTRODUCTION

Equipment technical condition diagnosing is the important part of electronic system (ES) maintenance. In process of reserved ES diagnosing there occur the errors in determination of active functional unit operability. It leads to system performance degradation including the faultless probability decrease. To evaluate the faultless probability it is necessary to have data concerning the used diagnosing tool credibility parameters and also to take into account the units' redundancy mode and the system quality at functioning initial time. Present paper describes the reserved ES diagnostics mathematical model with consideration of these factors. The purpose of this research is the development of mathematical model of reserved system diagnosing process which takes into account the reservation order, the diagnosing tool credibility parameters and also the system imperfect quality at functioning initial time instance. It allows to maximize the probability of failure-free operation of the system, taking into account the above factors.

II. PROBLEM STATEMENT

Known methods of automated and automatic diagnostics of ES allow appearing the type I and type II errors which lead to need in additional time and means for the failure detection and to the system total resource decrease [1]. Improvement of parameters characterizing the ES reliability can be achieved in a way of decreasing the diagnosing error probability and the diagnostics periodicity proper selection. This investigation deals with system which contains the certain number of redundant functional units one of which operates as intended and other units are the stand-by ones. Monitoring of the operating unit is carried out according to specified periodicity. In case of the operating unit fault the switching to stand-by unit is executed. Unlike to known models [2], [3] the proposed one shall take into account the diagnosing tool credibility parameters and monitoring periodicity, and also the system imperfect quality when the functional unit faultless probability at functioning initial time instance does not equal to 1.

The quality of the system is characterized by the probability of failure-free operation $P(t)$. In general, this probability is a function of a number of arguments

$$P(t) = f(m, \tau, p(t_0), \sigma, h),$$

where m is a reservation order; τ is the periodicity of control; $p(t_0)$ is the probability of failure-free operation at the operation start time; σ is the veracity parameter of the diagnostic tool; h is the tolerance range.

In this paper, we studied the dependence of $P(t)$ on the parameters listed above and determined the conditions for attaining the maximum of this probability.

III. THE ANALYSIS OF LAST RESEARCHES

Paper [2] proposes the method of type I and type II errors probability calculation on base of the

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measurement generalized for conditional (a posteriori) distributions of parameters. Paper [3] defines the basic tasks concerning to determination of the faults occurrence laws and to evaluation of the trouble-free operation parameters for restorable and unrestorable systems. System reliability evaluation method proposed by the authors of this paper is based on calculation of its elements operable condition probability. Authors of paper [4] have developed the mathematical models of the system maintenance at presence of detectable and latent failures which take into account the credibility of operability multiple monitoring. This paper proposes the calculation method for mean time between failures and for equipment availability factor for arbitrary law of distribution of operating time until the detectable and latent faults occur, taking into account the credibility of operability multiple monitoring.

However, the known models of the system technical condition determination do not take into consideration the following: firstly – the system redundancy possibilities and the redundant functional units operating mode, secondly – the system faultless probability at functioning initial time instance.

IV. PROBLEM SOLUTION

Model is based on the system functional unit determining parameter change approximation method suggested in the paper [5].

Functional unit working availability is characterized by $\nu = (1, ..., N)$ determining parameters $x_\nu(t)$ and is evaluated at monitoring of $l \le N$ determining parameters at the time instances t_i, $i = (1,...,n)$, where n is the number of monitoring events during interval $T = [t_1, t_n]$ of the ES diagnosing. Let's assume that the duration Δt of the l determining parameters monitoring and the redundant functional units switching (if necessary) is selected from imparity $\Delta t << \tau_I = t_{i+1} - t_i$, where τ_i is the monitoring periodicity.

Let's designate the functional unit working availability a priori probability regarding to determining parameter number ν at t_i time instance as $P_\nu(t_i)$ and start the model construction.

Let the determining parameter number ν of the functional unit number j at the monitoring time instance t_i does not belong to tolerance range, i.e. $x_\nu(t) \notin d_\nu$. In this case the diagnostics facility disconnects the operative functional unit number j and connects the unit number $(j+1)$ upon the clause of $(j+1) \le m$. Otherwise, when $x_\nu(t) \in d_\nu$, switching to the unit number $(j+1)$ does not occur.

System functioning process at $m = 2$, $n = 2$ for general case

$$P_\nu(t_1) \ne 1, \quad (1)$$

and with the use of "imperfect" diagnostics tool, which has the determining parameter number ν measurement error, is shown by means of graph in Fig. 1.

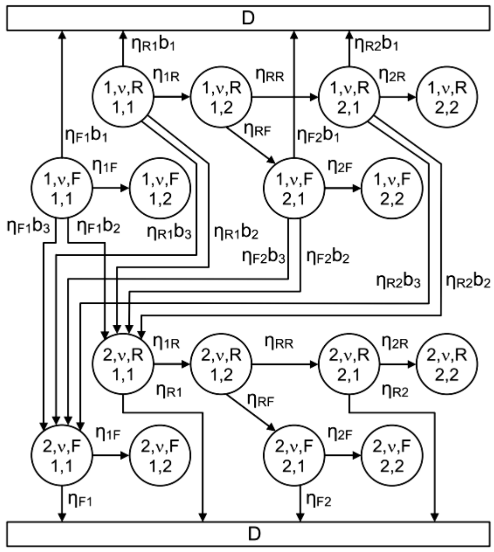

Fig. 1.The graph of the diagnostic process

The $(j, \nu, R, i, 1)$ and $(j, \nu, R, i, 2)$ states display the belonging of determining parameter number ν of functional unit number j to tolerance range at instances of redundant unit switching process number i start and finish respectively. The $(j, \nu, F, i, 1)$ and $(j, \nu, F, i, 2)$ states display the outlet of determining parameter number ν of functional unit number j out of the tolerance range at the same moments.

The state D corresponds to ES fault due to reserve depletion. The transfer intensities are calculated as follows:

$$\eta_{1R} = \eta_s P_\nu(t_1)[1 - P_{f\nu}(t_1)],$$

$$\eta_{2R} = \eta_s \frac{P_\nu(t_2)}{P_\nu(t_1)}[1 - P_{f\nu}(t_2)],$$

$$\eta_{1F} = \eta_s[1 - P_\nu(t_1)]P_{u\nu}(t_1),$$

$$\eta_{2F} = \eta_s \left[1 - \frac{P_\nu(t_2)}{P_\nu(t_1)}\right] P_{u\nu}(t_2),$$

$$\eta_{R1} = \eta_s P_\nu(t_1) P_{f\nu}(t_1), \qquad \eta_{R2} = \eta_s \frac{P_\nu(t_2)}{P_\nu(t_1)} P_{f\nu}(t_2),$$

$$\eta_{F1} = \eta_s[1 - P_\nu(t_1)][1 - P_{u\nu}(t_1)],$$

$$\eta_{F2}=\eta_s\left[1-\frac{P_\nu(t_2)}{P_\nu(t_1)}\right][1-P_{u\nu}(t_2)],$$

$$\eta_{RR}=\eta_1\frac{P_\nu(t_2)}{P_\nu(t_1)},\qquad \eta_{RF}=\eta_1\left[1-\frac{P_\nu(t_2)}{P_\nu(t_1)}\right],$$

where the functional unit switching intensity $\eta_s=\Delta t^{-1}$, $P_{f\nu}(t_i)$ and $P_{u\nu}(t_i)$ are the conditional probabilities of the "false fault" and "undetected fault" at t_i moment, branching coefficients b_j, $j=(1,...,(m+1))$ for the switching intensity η_s are selected on the base of parity $\Sigma b_j=1$, and for concerned graph equal to:

$$b_1=P_n(t_1)P_{fn}(t_1)+[1-P_n(t_1)][1-P_{un}(t_1)],$$
$$b_2=P_n(t_1)[1-P_{fn}(t_1)],\ b_3=[1-P_n(t_1)]P_{un}(t_1). \qquad (2)$$

Differential equation system which describes the system functioning process has the form (3). System (3) solution allows determining the ES probability of no-failure operation (PNFO) $P_\nu^*(t)$ regarding to determining parameter number ν by means of formula

$$P_\nu^*(t)=\sum_j\sum_i\sum_k P_{j\nu Rik}(t),$$
$$j=(1,...,m),$$
$$i=(1,...,n),$$
$$k=(1;2).$$

Probabilities $P_{f\nu}(t_i)$ and $P_{u\nu}(t_i)$ in (3), which are determined by the measuring tool error value per determining parameter number ν and the test tolerance range $[a_{m\nu}, b_{m\nu}]$, can be calculated using the known formulas [1], [2].

$$\begin{cases}
\frac{d}{dt}P_{1\nu R11}(t)=-\eta_s P_\nu(t_1)P_{1\nu R11}(t),\\
\frac{d}{dt}P_{1\nu F11}(t)=-\eta_s[1-P_\nu(t_1)]P_{1\nu F11}(t),\\
\frac{d}{dt}P_{1\nu R12}(t)=-\eta_1 P_{j\nu R12}(t)+\eta_s P_\nu(t_1)\left[1-P_{f\nu}(t_1)\right]P_{j\nu R11}(t),\ j=\overline{1,m},\\
\frac{d}{dt}P_{j\nu F12}(t)=\eta_s[1-P_\nu(t_1)]P_{u\nu}(t_1)P_{j\nu F11}(t),\ j=\overline{1,m},\\
\frac{d}{dt}P_{j\nu Ri1}(t)=\frac{P_\nu(t_i)}{P_\nu(t_{i-1})}\left[-\eta_s P_{j\nu Ri1}(t)+\eta_{i-1}P_{j\nu R,i-1,2}(t)\right],\ j=\overline{1,m};\ i=\overline{2,n},\\
\frac{d}{dt}P_{j\nu Fi1}(t)=\left[1-\frac{P_\nu(t_i)}{P_\nu(t_{i-1})}\right]\left[-\eta_s P_{j\nu Fi1}(t)+\eta_{i-1}P_{j\nu R,i-1,2}(t)\right],\ j=\overline{1,m};\ i=\overline{2,n},\\
\frac{d}{dt}P_{j\nu Ri2}(t)=-\eta_i P_{j\nu Ri2}(t)+\eta_s\frac{P_\nu(t_i)}{P_\nu(t_{i-1})}\left[1-P_{f\nu}(t_1)\right]P_{j\nu Ri1}(t),\ j=\overline{1,m};\ i=\overline{2,n-1},\\
\frac{d}{dt}P_{j\nu Fi2}(t)=\eta_s\left[1-\frac{P_\nu(t_i)}{P_\nu(t_{i-1})}\right]P_{u\nu}(t_i)P_{j\nu Fi1}(t),\ j=\overline{1,m};\ i=\overline{2,n},\\
\frac{d}{dt}P_{j\nu Rn2}(t)=\eta_s\frac{P_\nu(t_n)}{P_\nu(t_{n-1})}\left[1-P_{f\nu}(t_n)\right]P_{j\nu Rn1}(t),\ j=\overline{1,m},\\
\frac{d}{dt}P_{j\nu R11}(t)=-\eta_s P_\nu(t_1)P_{j\nu R11}(t)+\eta_s P_\nu(t_1)\left[1-P_{f\nu}(t_1)\right]\left[a_{j-1}+\sum_{k=1}^{j-2}a_k b_1^{j-1-k}\right],\ j=\overline{2,m},\\
\frac{d}{dt}P_{j\nu F11}(t)=[1-P_\nu(t_1)]\left[-\eta_s P_{j\nu F11}(t)+\eta_s P_{u\nu}(t_1)\left(a_{j-1}+\sum_{k=1}^{j-2}a_k b_1^{j-1-k}\right)\right],\ j=\overline{2,m},\\
\frac{d}{dt}P_D(t)=\eta_s\left(a_m+\sum_{k=1}^{m-1}a_k b_1^{m-k}\right),
\end{cases} \qquad (3)$$

where $\eta_1=\tau_1^{-1}$, $\eta_{i-1}=\tau_{i-1}^{-1}$, $\eta_i=\tau_i^{-1}$; coefficient b_1 is determined by (2); coefficients a_k, $k=(1,...,m)$ are equal to

$$a_k=P_\nu(t_1)P_{f\nu}(t_1)P_{j\nu R11}(t)+[1-P_\nu(t_1)][1-P_{u\nu}(t_1)]P_{j\nu F11}(t)+\sum_{i=2}^{n}\left\{\frac{P_\nu(t_i)}{P_\nu(t_{i-1})}P_{f\nu}(t_i)P_{j\nu Ri1}(t)\right.$$
$$\left.+\left[1-\frac{P_\nu(t_i)}{P_\nu(t_{i-1})}\right][1-P_{u\nu}(t_i)]P_{j\nu Fi1}(t)\right\},$$

probability $P_D(t)$ represents the ES fault probability due to reserve depletion; probabilities $P_{j\nu Ri1}(t)$, $P_{j\nu Fi1}(t)$, $P_{j\nu Ri2}(t)$ and $P_{j\nu Fi2}(t)$ are determined by expressions

$$P_{j\nu Ri1}(t) = P\{x_\nu(t) \in d_\nu \cap m_{x\nu}(t) \in [m_{x\nu}(t_i), m_{x\nu}(t_{i+1})]\},$$

$$P_{j\nu Fi1}(t) = P\{x_\nu(t) \notin d_\nu \cap m_{x\nu}(t) \in [m_{x\nu}(t_i), m_{x\nu}(t_{i+1})]\},$$

$$P_{j\nu Ri2}(t) = P\{x_\nu(t) \in d_\nu \cap m_{x\nu}(t+\Delta t) \in [m_{x\nu}(t_i), m_{x\nu}(t_{i+1})]\},$$

$$P_{j\nu Fi2}(t) = P\{x_\nu(t) \notin d_\nu \cap m_{x\nu}(t+\Delta t) \in [m_{x\nu}(t_i), m_{x\nu}(t_{i+1})]\},$$

where $m_{x\nu}(*)$ is an expected value of the parameter $x_\nu(t)$ at appropriate time.

Initial conditions with consideration of (1) have the form

$$P_{j\nu R11}(0) = P_\nu(t_1), \qquad P_{j\nu F11}(0) = 1 - P_\nu(t_1),$$

$$P_{j\nu R11}(0) = 0, \quad P_{j\nu F11}(0) = 0, \quad j = (2,...,m),$$

$$P_{j\nu Ri1}(0) = 0, \quad P_{j\nu Fi1}(0) = 0, \quad j = (1,...,m), \quad i = (2,...,n),$$

$$P_{j\nu Ri2}(0) = 0, \quad P_{j\nu Fi2}(0) = 0, \quad j = (1,...,m), \quad i = (2,...,n).$$

Figure 2 shows the curves of PNFO $P_\nu^*(t)$ dependencies upon time for $m = 3$, single-side tolerance range $h = [a_{m\nu}, \infty]$, where $a_{m\nu} = 15$ conditional units, "perfect" diagnostics tool with $P_{f\nu}(t_i) = P_{u\nu}(t_i) = 0$, $i = (1,...,n)$ (curve 1), and for "imperfect" tool with mean-square error of measurement $\sigma_{m\nu} = 0.4$ conditional units at $\tau_i = 120$ hrs (curve 2) and $\tau_I = 20$ hrs (curve 3).

The errors in determination of functional unit working availability lead to ES PNFO decrease, and the monitoring periodicity decrease causes of the accelerated reserve depletion due to monitoring error of the "false fault" type.

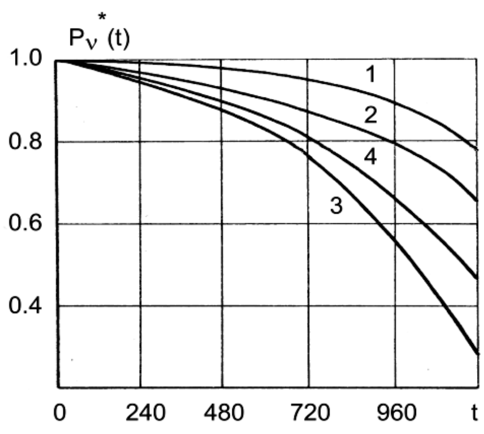

Fig. 2. Dependence of PNFO on the monitoring periodicity and mode of the diagnostic tool

Increase of PNFO at short monitoring periodicity is possible by such change of the diagnostics tool operation mode that at connecting to the last redundant functional unit the diagnostics tool does not carries out switching but serves as the ES fault indicator only. In this case the ES shutdown due to monitoring error of "false fault" type does not occur. In Figure 1 this case corresponds to zero intensities of transfers from (2, ν, R, i, 1), $i = (1;2)$ states to D state, and in the equation system (3) the conditional probabilities $P_{f\nu}(t_i)$, $i = (1,...,n)$ at $j = m$ are equated to zero. The achieved result is illustrated by the curve 4 in Fig. 2 constructed for the monitoring periodicity τ_i=20 hrs.

Curve 3 corresponds to the ES mean time of no-failure operation determined by $P_\nu^*(t)$ function integration is equal to 896.4 hrs; curve 4–976.8 hrs. Thus, the change of the diagnostics tool operation mode mentioned above allows increasing the ES mean time of no-failure operation approximately by 9 %.

In Figure 3 are shown the PNFO $P_\nu^*(t)$ dependencies upon time for $m = 3$, $\sigma_{m\nu} = 0.4$ conditional units, $\tau_i = 20$ hrs, and $a_{m\nu} = [14, 15, 16]$ conditional units (curves 1, 2, 3 respectively).

The obtained graphs indicate that for every monitoring instance it is possible to determine the measuring tolerance optimal value at which the ES PNFO per determining parameter number ν is maximal. This method also provides partial compensation of the monitoring error of "false fault" type negative influence on the ES PNFO.

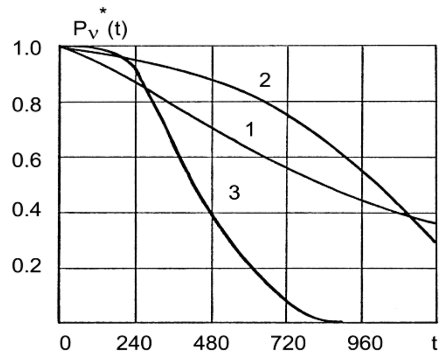

Fig. 3. Dependence of PNFO on the measuring tolerance value

V. Conclusions

The paper presents a mathematical model of the reserved electronic system diagnosing process. The case of unloaded redundancy with periodic monitoring of the system working capacity is considered. The proposed model in practical application takes into account the reservation order, the veracity parameters of the diagnostic tool, the periodicity of control, as well as the imperfect quality of the system at the operation start time. The functioning mode of the diagnostic tool without switching the last backup unit eliminates the destructive impact of the monitoring errors of the "false fault" type, when this unit is working. The reasonable control of a tolerance value ensures maximum probability of the system no-failure operation at every current moment of time. This management of the diagnosing process parameters increases the average uptime of the system, i.e. its reliability.

The results of the study allow us to practically calculate the probability of no-failure operation of the reserved electronic system taking into account a certain set of the diagnosing process parameters, and can be used in the development of tools for automatic diagnosis of electronic systems.

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А. Г. Тараненко, Є. І. Габрусенко, О. Г. Голубничий, О. Ю. Лавриненко. Керування експлуатаційною надійністю резервованої електронної системи

Процес діагностування резервованої електронної системи здійснюється з помилками в оцінці її надійності. Це призводить до погіршення експлуатаційних характеристик системи, зокрема до зменшення ймовірності безвідмовної роботи. Дана стаття присвячена розробці і дослідженню математичної моделі діагностування резервованої електронної системи. Ця модель враховує характеристики достовірності засобу діагностування, періодичність діагностування, а також неідеальну якість системи у початковий момент функціонування. Засіб діагностування виконує функцію індикації працездатності системи після перемикання на останній резервний блок, але не функцію комутації блоку. Це виключає вплив помилок контролю вигляду «помилкова відмова» і підвищує надійність системи.

Ключові слова: електронна система; надійність; періодичність діагностування; ймовірність безвідмовної роботи.

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А. Г. Тараненко, Е. И. Габрусенко, А. Г. Голубничий, А. Ю. Лавриненко. Управление эксплуатационной надежностью резервированной электронной системы

Процесс диагностирования резервированной электронной системы осуществляется с ошибками в оценке ее надежности. Это приводит к ухудшению эксплуатационных характеристик системы, в том числе к уменьшению вероятности безотказной работы. Данная статья посвящена разработке и исследованию математической модели диагностирования резервированной электронной системы. Эта модель учитывает характеристики достоверности средства диагностирования, периодичность диагностирования, а также неидеальное качество системы в начальный момент функционирования. Средство диагностирования выполняет функцию индикации работоспособности системы после переключения на последний резервный блок, но не функцию коммутации блока. Это исключает влияние ошибок контроля вида «ложный отказ» и повышает надежность системы.

Ключевые слова: электронная система; надежность; периодичность диагностирования; вероятность безотказной работы.

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