THEORY AND METHODS OF SIGNAL PROCESSING

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DATA PROCESSING DURING CONDITION BASED MAINTENANCE OF RADIO ELECTRONIC EQUIPMENT

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Abstract**—***The paper deals with the problem of necessity substantiation of statistical data processing procedures in case of radio electronic equipment operation. These procedures are used in case of realization of preventive maintenance at the use of operation strategy according to the condition with control of diagnostic variables. The basic elements of typical operation system for radio electronic equipment are considered in the paper. The analysis of models for typical elements of operation system is carried out. Radio electronic equipment is the main element of operation system, therefore the problem of statistical data processing was considered for the model of diagnostic variables trend for this equipment. The model is adopted for diagnostic variables trend, which belongs to the type of random processes with changepoint. The steady-state period of diagnostic variables trend is characterized by a random duration, which is described by normal probability density function. The period of technical state deterioration of radio electronic equipment is described by a sum of a linear function with deterministic but unknown inclination angle and uniform random variable. The quantitative estimation of data processing efficiency (availability coefficient and average operation costs) was determined by simulation modeling. The simulation results showed that there is an optimal value of preventive threshold, at which the resource costs are minimal. This result can be explained by existence of a balance between costs for repair and maintenance.*

Index Terms—Radio electronic equipment; operation system; statistical data processing; technical state deterioration; processing model; condition-based maintenance.

I. INTRODUCTION

Radio electronic equipment (REE) is used in many branches of human activity: in the defense industry, civil aviation, in the process of objects state monitoring, etc.

Stability of functioning of REE and efficiency of its intended use is provided by operation system (OS). Basic OS elements are REE (operation object), processes, documentation, personnel, expense and information resources etc. The OS is complicated according to it structure. Therefore, from the scientific point of view OS can be examined as an object of designing, development and improvement.

II. LITERATURE ANALYSIS

The problem of REE OS designing and improvement was examined both in native and foreign literature. The main attention is paid to such scientific directions: optimization of resources consumption in the process of intended use, analysis of systems with technical state deterioration, determination of the risks related to instability of equipment functioning, etc.

Analysis of the literature in the sphere of OS development and modernization for REE and others complicated technical systems [1] – [6], and the experience of practical intended use of REE show that not enough attention is paid to the problems of operation systems designing. This greatly negatively influences the final efficiency of REE use.

The articles [1] – [3] deal with basic concepts of technical system reliability and maintenance theory. Publications [4] – [6] deal with current issues of UAV development and maintenance. Papers [6] – [10] consider data processing procedures in operation system of different equipment, synthesis and analysis of reliability indices (mean time to failure, availability factor, etc.) estimation algorithms.

The process of operating data processing plays an important part in the procedure of making and realization of control decisions in OS. Therefore, the carried out analysis of literature lets us conclude that not enough attention is paid to methodological aspects of OS designing in the part of processing data about equipment operation.

III. Problem Statement

Synthesis and analysis of processing algorithms for data about REE operation should be realized within the limits of generalized methodology of OS designing. Really, methodological issues are the basis for solving specific scientific and practical tasks. The problems of OS methodology designing were analyzed in [4].

Absence of data processing methodology in REE OS leads to uncertainty during decisions making process; this can negatively influence the risks of air navigation services during REE usage. That is why the task of data processing efficiency proof in OS is urgent.

Mathematical statement of substantiation of data processing in the operation system will be considered in terms of OS describing from the control points of view.

In the paper, the main attention will be paid to the approach of describing OS as a system of control. Such statement is based on the fact that OS is a system that forms corresponding managing orders and influences on the basis of equipment state monitoring results and the state of own OS constituents. Then we can present all the elements of the operation system according to the building-block principle in a particular standardized manner.

So these components contain enumeration of states and columns of their changes, the matrix of incoming conditions, control signals, etc. According to this approach, every element has the trajectory of state changes in phase space.

The OS task is to ensure state changes trajectory location in the given boundaries in such a way, so that the main efficiency index of REE usage was also not less than some given level.

Efficiency of operation depends on purpose of OS control. There are following purposes of control: given level of availability providing, average risk minimization, etc.

Efficiency of OS

$$Ef = \Theta(Tr^{(r)}(A, D/\Delta t), Tr^{(0)}),$$

where $Tr^{(r)}$ is an objective trend of diagnostic variable change, $Tr^{(0)}$ is an required trend of diagnostic variable change, A are data processing procedures, D is a rule for decision making about control action, Δt is a time of observation.

According to the purpose of OS control we need to provide the maximum of functional Θ, i.e.

$$\Theta(Tr^{(r)}(A, D/\Delta t), Tr^{(0)}) \to \max .$$

In this paper, there is the aim of mathematical substantiation for appropriateness of the operation data processing procedures A usage for reaching the REE OS control purpose.

IV. Models of OS Elements

Models of OS elements influence on determination of data processing algorithms.

Analysis of REE functioning and operation shows that the model of operation system is usually described in corresponding operation rules. Thus, there are Technical Operation Rules (TOR) for ground flight support radio equipment in civil aviation, TOR for telecommunication devices, TOR for radio broadcasting and television, etc. The basic attention in these rules is paid to devices. These rules establish generalized standpoints as for organizing and functioning of OS, however do not describe the models from the mathematical point of view.

Basic OS elements are:

1. REE.
2. Technological procedures.
3. Documentation.
4. Personnel.
5. Operation conditions.

During analyzing OS models of elements, it is necessary to take into consideration such features:

1) is the process random;
2) is the process continuous or discrete;
3) is the process stationary;
4) are the models parameters known or unknown;
5) is the process under control?

Models of REE description can be conditionally divided into three groups: models of diagnostic variables, reliability indexes models and REE condition models.

Models of diagnostic variables are usually described by the help of non-stationary random processes. In this case describing diagnostic variables, the positions of probability theory and Markov's processes can be used. In addition, in practice different variants of non-stationarity are possible. These variants associate with the changes of mathematical expectation, variance (heteroscedasticity), correlation functions, etc.

It is should be noted that there are not enough models of diagnostic variables for REE, which are designed on the basis of experimental measurements of such quantities as sensitivity, power, frequency instability, modulation depth, etc.

Models of diagnostic variables are the basis for successful solving problems of synthesis and analysis of data processing algorithms, so these models research is urgent task.

Models of REE condition are usually described by quantized processes, which have two or three levels of quantization. In case of three levels of quantization these levels are “Normal operation”, “Pre failure condition” and “Failure”. Such models are described by the help of Markov’s and half-Markov chains.

Reliability indexes models were studied in [7] – [10]. In the general case, non-stationary random processes also can describe them. Among reliability indexes, researcher’s attention is paid to: mean time between failures, availability coefficient, availability function, coefficient of technical usage, failure rate, etc.

In the literature during analyzing non-stationary processes, the tasks of their detection and estimation of models parameters are called the tasks with change-points.

Technological processes (TP) are important component parts of operation system. The main TP is a process of intended use. The other processes are directed for providing serviceability of REE and maintainability of main OS elements. For quantitative description of the processes, indexes of effectiveness, efficiency and quality are used. In general case quantitative characteristics of process are random variables.

According to the process approach every TP has input, output, recourses for its fulfillment and control influences. During processes monitoring (input and output signals), it is necessary to take into consideration a possibility of non-stationarity occurrence.

Documentation plays an important part in providing safety and regularity of flights. Conscientious execution of documentation requirements decreases risks during air navigation services of flights.

The model of documentation description is quantized with finite number of possible states. The model can be considered from two aspects:

1) “Documentation requirements are executed” / “Documentation requirements aren’t executed”;

2) “International standards are fulfilled” / “International standards aren’t fulfilled”. Change of states can occur in unexpected moments of time.

Taking into consideration documentation role it is necessary to detect the moments of state changes on time.

Personnel are characterized by quantitative index of its number and professional suitability, effectiveness and efficiency of practical actions during operation, etc. These indexes can be deterministic (number and qualification requirements) and random (efficiency and effectiveness).

Operation conditions include the following indexes: temperature, pressure, vibration level, parameters of electromagnetic compatibility, etc. These indexes are random and in some cases have uncontrolled trends.

V. Efficiency of Statistical Data Processing in OS

Let’s consider quantitative estimation of efficiency of condition-based maintenance with control of diagnostic variables.

According to this strategy, there are warning and operation thresholds, which determine the bounds of three ranges of diagnostic variables. If the diagnostic variables are in the bounds of warning thresholds, then preventive maintenance isn’t fulfilled. In case of warning thresholds are exceeded (if the operation thresholds aren’t exceeded), preventive maintenance is planned and fulfilled (regulation, planned replacement of REE components, etc). If the value of one of the diagnostic variables exceeds operation threshold, then it is considered that there is REE failure and the current repair is fulfilled.

Let us suppose that making decisions rule is a simplified procedure of operating data processing.

Let us consider the correlation that allows quantitatively estimate efficiency of data processing procedures in case of condition-based maintenance.

Let us suppose that technical state is characterized by one diagnostic variable $u(t)$. Let us assume that normative documentation sets the allowance for possible changes of this variable in form of lower and upper operation thresholds $D_{\text{o}-}$ and $D_{\text{o}+}$. Preventive thresholds we will mark as $D_{\text{p}-}$ and $D_{\text{p}+}$.

Let the model of diagnostic variable change will be described by the following correlation:

$$u(t) = s(t) + n(t), \qquad s(t) = a_0 + a_1(t-\tau)h(t-\tau),$$

where $s(t)$ is a deterministic component of trend change of the diagnostic variable; $n(t)$ is a random component of the diagnostic variable (with zero mathematical expectation and standard deviation σ); a_0, a_1 are random unknown coefficients; τ is a random moment of REE technical state deterioration beginning; $h(t-\tau)$ is Heaviside’s function.

This model is sufficiently generalized; it doesn’t exclude possibility of change-points appearance in trends of diagnostic variables, which is connected with the random moment τ.

If $D_{\text{o}-} \le u(t) \le D_{\text{o}+}$, then it is assumed that REE is in operating condition. Otherwise the failure appears. Let’s assume that after the failure, REE recovery begins, and the value of diagnostic variable will be equal to the initial value a_0.

In case if $D_{\text{p}+} \le u(t) \le D_{\text{o}+}$ or $D_{\text{o}-} \le u(t) \le D_{\text{p}-}$, then this event is connected with REE technical state deterioration. In this case preventive maintenance is planned. After it fulfillment, the value of diagnostic variable will be equal to initial value a_0.

In Fig. 1 example of diagnostic variable change is shown ($a_0 = 0$, $a_1 = 1$, $D_{p+} = 300$, $D_{p-} = -100$, $D_{o+} = 350$, $D_{o-} = -120$, τ is normal with $m_\tau = 100$ and $\sigma_\tau = 30$).

For comparing efficiency of REE operation with statistic data processing and without statistic data processing, it is necessary to determine indexes and criterions of efficiency. Efficiency index is used for quantitative estimation of operation procedures effectiveness. Different variants of this index determination are possible, for example, average costs for operation, availability coefficient, etc. In this paper we chose availability and average costs as efficiency indexes.

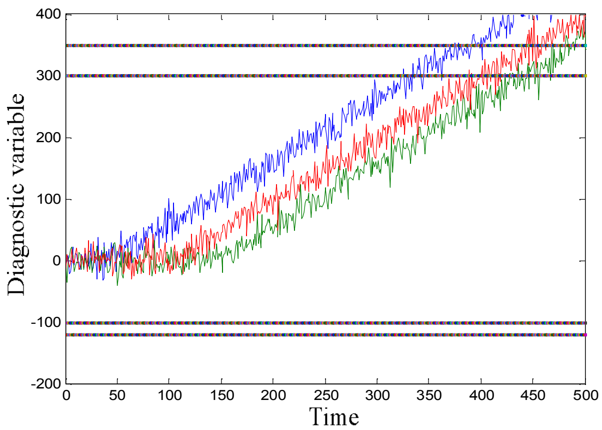

Fig. 1. Examples of diagnostic variable change

Average costs is calculated according to formula

$$m_1(C/T_\Sigma) = m_1(C_r/T_\Sigma) + m_1(C_m/T_\Sigma),$$

$$m_1(C_r/T_\Sigma) = \frac{k_r}{kT_\Sigma} C_r, \; m_1(C_m/T_\Sigma) = \frac{k_m}{kT_\Sigma} C_m,$$

where C_r and C_m are costs of one repair and maintenance, k_r and k_m are quantities of repairs and maintenances, k is a total quantity of repairs and maintenances, T_Σ is a observation time.

For quantitative estimation of efficiency index, calculation and analytical methods and methods on the basis of statistical simulation (for example, according to Monte Carlo method, as the analyzed samples are random variables) can be used. The first method is more complicated and needs difficult mathematical calculations. That is why in this paper we will use the second method. This method gives an opportunity to take into consideration big number of parameters, which characterize the operation process of REE.

Let us consider the scheme on making decisions during REE diagnostic variable monitoring. In the monitoring process moments τ_1 and τ_2 of warning and operation thresholds intersection are fixed. The difference between these moments

$$\Delta t = \tau_2 - \tau_1 .$$

Let us assume that stuff for fulfillment preventive maintenance needs time recourse ΔT . If $\Delta t > \Delta T$, then the failure doesn't occur, and REE comes back to its initial state (the value of diagnostic variable will be equal to the initial value a_0). In the opposite case failure occurs. After the failure, current repair is fulfilled. Duration of current repair ξ in general case is a random variable.

During simulation process the number of failures, times between failures, the number of successful preventive procedures, mean time between failures, mean time of repair and availability coefficient are calculated. These are used for estimation of efficiency of condition-based maintenance.

Initial parameters for simulation are $a_0 = 0$, $a_1 = 1$, $|D_o| = 500$, $C_r = 100$, $C_m = 50$, $\Delta T = 100$, τ is normal distributed random variable $m_\tau = 200$ and $\sigma_\tau = 60$, n is uniform distributed random variable in the range [–40; 40], ξ is exponentially distributed random variable with parameter $\lambda = 0.005$, . Results of simulation are shown in Figs 2 and 3.

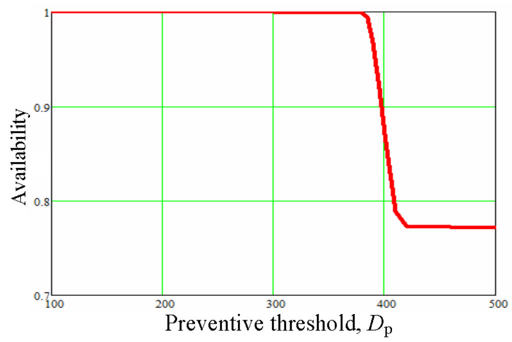

Fig. 2. Availability estimation for different values of preventive threshold

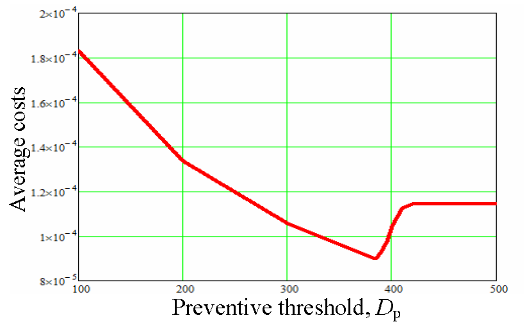

Fig. 3. Average costs estimation for different values of preventive threshold

According to Figs 2 and 3, we can make such conclusions. Use of data processing algorithm, which realizes condition-based maintenance strategy with control of diagnostic variables, leads to increase of mean time between failures, and thus to availability increasing in case of preventive threshold value decreasing.

Analysis of average costs dependence on preventive threshold shows that there is minimum of function $m_1(C/T_\Sigma)$ for given initial parameters of condition-based maintenance strategy. Nature of this minimum can be explained by existence of a balance between costs for repair and maintenance.

VI. CONCLUSION

Experience of REE and other technical systems operation shows that the systems of their operation can reasonably be considered from control theory point of view. It gives an opportunity to formulate OS synthesis and analysis tasks, including statistics data processing algorithms for possibility of making on time and correct control decisions. Substantiation of these algorithms expediency was performed for example of condition-based maintenance usage. The comparative analysis of data processing efficiency was made through statistical simulation. The analysis of simulation results in wide range of initial data showed that operating data processing increases efficiency indexes of REE OS.

The obtained results can be used during designing and improvement of REE operation systems.

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О. В. Соломенцев, М. Ю. Заліський, О. В. Кожохіна, Т. С. Герасименко. Обробка даних під час технічного обслуговування радіоелектронних засобів за станом

Розглянуто задачу обґрунтування доцільності використання процедур статистичної обробки даних під час експлуатації радіоелектронного обладнання. Ці процедури використовуються у випадку реалізації превентивного технічного обслуговування за станом з контролем визначальних параметрів. У роботі визначені основні елементи типової системи експлуатації радіоелектронного обладнання. Проведений аналіз моделей типових елементів системи експлуатації. Радіоелектронне обладнання є основним елементом системи експлуатації, тому задача обробки статистичних даних розглядалась для моделі зміни визначальних параметрів цього обладнання. Прийнята модель зміни визначальних параметрів, що належить до класу випадкових процесів з розладкою. Етап стаціонарного розвитку тренду визначального параметра характеризується випадковою тривалістю, що описується гаусівською щільністю розподілу ймовірностей. Етап погіршення технічного стану радіоелектронного обладнання описується адитивною сумішшю лінійної функції з детермінованим, але невідомим кутом нахилу, та рівномірної випадкової величини. Числове оцінювання показників ефективності обробки даних (коефіцієнта готовності та середніх витрат на експлуатацію) виконано шляхом статистичного моделювання. Результати моделювання показали, що існує оптимальне значення превентивного порогу, при якому затрати ресурсів мінімальні. Цей результат можна пояснити існуванням певного балансу між витратами на ремонт та витратами на технічне обслуговування обладнання.
Ключові слова: радіоелектронне обладнання; система експлуатації; статистична обробка даних; погіршення технічного стану; модель тренда визначального параметра з розладкою; технічне обслуговування за станом.

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А. В. Соломенцев, М. Ю Залисский, Е. В. Кожохина, Т. С. Герасименко. Обработка данных при техническом обслуживании радиоэлектронных устройств по состоянию

Рассмотрена задача обоснования целесообразности использования процедур статистической обработки данных во время эксплуатации радиоэлектронного оборудования. Эти процедуры используются в случае реализации превентивного технического обслуживания по состоянию с контролем определяющих параметров. В работе определены основные элементы типовой системы эксплуатации радиоэлектронного оборудования. Проведен анализ моделей типовых элементов системы эксплуатации. Радиоэлектронное оборудование является основным элементом системы эксплуатации, поэтому задача обработки статистических данных рассматривалась для модели изменения определяющих параметров этого оборудования. Принята модель изменения определяющих параметров, которая относится к классу случайных процессов с разладкой. Этап стационарного развития тренда определяющего параметра характеризуется случайной длительностью, которая описывается нормальной плотностью распределения вероятностей. Этап ухудшения технического состояния радиоэлектронного оборудования описывается аддитивной смесью линейной функции с детерминированным, но неизвестным углом наклона, и равномерной случайной величины. Численные оценки показателей эффективности обработки данных (коэффициента готовности и средних затрат на эксплуатацию) выполнены путем статистического моделирования. Результаты моделирования показали, что существует оптимальное значение превентивного порога, при котором затраты ресурсов минимальные. Этот результат можно объяснить существованием баланса между затратами на ремонт та затратами на техническое обслуживание оборудования.

Ключевые слова: радиоэлектронное оборудование; система эксплуатации; статистическая обработка данных; ухудшение технического состояния; модель тренда определяющего параметра с разладкой; техническое обслуживание по состоянию.

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