THEORY AND METHODS OF SIGNAL PROCESSING

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TEST FOR CONDITION DEGRADATION DETECTION OF RADIO ELECTRONIC EQUIPMENT

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Abstract**—***The paper deals with algorithms of statistical data processing for ground-based radio electronic equipment. The main attention is paid to problems of detection and parameters estimation in case of technical state deterioration of ground-based radio electronic equipment.*

Index Terms—Aviation radio electronic equipment; operation system; change-point; maintenance; statistical data processing; detection procedure; deteriorating systems.

I. INTRODUCTION

To provide safety and regularity of flights in civil aviation, complex of ground-based and airborne radio electronic equipment (REE) is used. This equipment includes radio communication systems, radio navigation systems and radar.

The main requirement to REE during its intended use is the stability of its functioning. Operation stability can be disrupted due to the impact of external and internal factors. This leads to degradation of the equipment condition. Degradation can be identified by observing the appropriate defining parameters.

In order to support effective functioning of radio electronic equipment, we can use operation system. Operation system includes following components: operation object (ground-based radio electronic equipment), processes, procedures, maintenance algorithms, staff, normative documents, resources, etc [1] – [8]. Operation system generates and implements control (corrective and preventive) actions. These actions are based on the operational data, including through the use of tests for the detection of degradation processes.

II. PROBLEM STATEMENT

To assess the technical state of ground-based radio electronic equipment and its operation system elements, data about diagnostic variables are used, and in general case these data are random processes. Therefore, the data processing algorithms should be statistical.

Realizations of diagnostic variables of ground-based radio electronic equipment are usually non-stationary random processes, which in some intervals may be considered as conditionally stationary. The more a priori information about the model of original data, the more accurate assessment of current and future technical state can be made.

Analysis of publications [9] – [12] showed that sufficient attention is paid to non-stationary processes processing problems. The type of problems about change-point detection can be considered here. As change-point we understand an event when the original process loses stationarity property.

During maintenance and operation of ground-based radio electronic equipment, change-point is associated with the process of its condition degradation. This can lead to decrease of safety and regularity of flights, as well as increase in operational costs, and these components reduce the efficiency of intended use of ground-based radio electronic equipment.

Let efficiency estimation is performed using generalized indicator of following type

$$P_{\text{ef}} = \vec{\text{E}}\text{f}(\vec{\text{T}}\text{r}^{(\text{R})}(\vec{\text{S}}\text{t}(T)); \vec{\text{T}}\text{r}^{(0)}),$$

where $\vec{\text{T}}\text{r}^{(0)}(\cdot)$ and $\vec{\text{T}}\text{r}^{(\text{R})}(\cdot)$ are required and real trends in the space of phase states $\vec{\text{S}}\text{t}(T)$ of ground-based radio electronic equipment or its operation system during the observation interval T.

State operator can be represented as

$$\vec{\text{S}}\text{t}(T) = \varphi(T, \vec{M}, \vec{A}, \vec{R}, \vec{C}),$$

where $\vec{M}$ is a model of diagnostic variables, $\vec{A}$ is a procedure of statistical data processing, $\vec{R}$ is a requirement for the values of diagnostic variables, $\vec{C}$ is a operation condition.

In the paper we consider the urgent task of designing statistical data processing procedures $\vec{A}$ in the operation system in case of technical state deterioration of ground-based radio electronic equipment to ensure maximum efficiency with a minimum of resources costs

$$\max_{A}\left(P_{\text{ef}}\right).$$

III. Block diagram of operation system

A generalized block diagram of operation system (with relationship of its basic subsystems) during maintenance was considered in [6]. The main element of operation system is ground-based radio electronic equipment.

Let's consider block diagram of ground-based radio electronic equipment's operation system in terms of statistical data processing (Fig. 1).

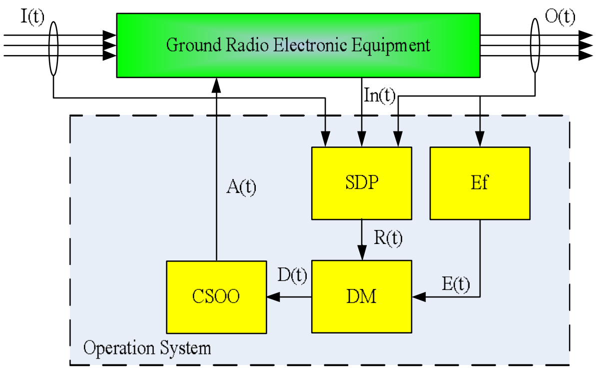

Fig. 1. Operation system of ground-based radio electronic equipment

Figure 1 shows an operation object and operation system. This object has three groups of parameters: input $I(t)$, internal $In(t)$ and output $O(t)$.

As input parameters $I(t)$ can be following parameters: power supply parameters, noise level, temperature, humidity, atmospheric pressure and other environmental parameters.

As internal parameters $In(t)$ can be considered the parameters that characterize the operation of ground-based radio electronic equipment: values of currents and voltages at given points of equipment, power, carrier frequency, etc.

There are two types of output parameters $O(t)$: 1) parameters that characterize measured or tactical characteristics; 2) operation parameters. Operation parameters are following parameters:

– times between failures;
– recovery times after damages and failures;
– regulatory failure rate and recovery rate;
– availability, etc.

Operation system (see Fig. 1) must perform the functions of on-line collecting and processing each of three vectors of parameters. Therefore, in operation system we propose to use statistical data processing (SDP) block. This block can be presented in the form of four interconnected elements: statistical data model analyzer (SMA), data model selection sub-block (DMSS), nonstationarity detector (ND), parameter estimation sub-block (PE).

Then we can make appropriate decisions (in DM block), and these decisions $D(t)$ is carried out on the basis of processed data $R(t)$ in the operation system. On the basis of this in the control preventive and corrective actions (PCA) block guidance of corresponding actions are formed (respectively in preventive actions PA and corrective actions CA sub-blocks).

The last step in statistical data processing and effect assessment after preventive and corrective actions $A(t)$ implementation must be evaluation of the efficiency. This process is carried out in corresponding PE block. So PE block should give out appropriate signals of efficiency evaluation $E(t)$ to the consumers of navigation services.

Let's consider the process of information exchange in SDP block in the case of analysis of operation parameters. At the same time, we assume that deterioration of technical state of operation object can occur.

In this case input signals of SDP block are times between damages or failures t_i of ground-based radio electronic equipment. This signal is input to SMA sub-block.

SMA sub-block performs following procedures: calculating probability density function of analyzed parameters, its cumulative distribution function, finding numerical characteristics (mathematical expectation, variance, correlation coefficient, etc.).

Obtained data with the original statistics are input to DMSS sub-block. Verification of data on the possibility of their approximation by given distribution is carried out there. Thus, the analysis shows that in most cases, researchers use exponential and occasionally DN-distribution to describe the times between failures. In addition, DMSS sub-block performs selection of possible technical state deterioration model to be able to solve the problem of detection.

The analysis shows that the most commonly used models of the technical state deterioration are hopping, linear, linear-hopping, quadratic and cubic models. Analysis of procedures for detection and estimation of parameters for some deterioration models were considered in [13] – [15].

After selecting the model of technical state deterioration and the model of analyzed statistical data, corresponding signals are received in ND sub-block. This sub-block generates signals of two types: logic zero, if there isn't technical state deterioration and logic one otherwise.

The final stage of statistical data processing is parameters estimation in PE sub-block. This sub-block performs the functions of reliability parameters estimation (mean time between failures, failure rate, the probability of failure-free operation in a given observation interval, etc.) and estimation of deteriorating technical state model parameters (deterioration beginning time, deterioration intensity, etc.).

In general, it should be noted that one of the important tasks in operation systems of ground-based radio electronic equipment in the case of analysis of its possible technical state deterioration is the design of algorithmic support for SMA, DMSS, ND and PE sub-blocks. For these purposes we use CAD. In addition, the information obtained in SMA and DMSS sub-blocks greatly simplifies algorithms design for ND and PE sub-blocks.

IV. Recurrent test for degradation detection

Let's consider example of recurrent procedure for technical state deterioration detection.

In general case beginning time of technical state deterioration t_{det} is random variable, which is characterized by a probability density function, mathematical expectation, variance and other numerical characteristics. In this example, we assume that degradation occurs in an unknown but fixed time moment. Assume that in this case there are statistical data about operating times between failures t_i, with the sample size N.

Also, we assume that the model of technical state deterioration of ground-based radio electronic equipment is hopping [13]. This model is characterized by two parameters: deterioration beginning time t_{det} and deterioration parameter α (jump amplitude).

The test for technical state deterioration detection includes following steps:

– smoothing statistical data using the method of least squares;

– finding the efficiency E estimate;

– comparing efficiency E with given threshold H. If as a result of entire sample processing $E < H$, then a decision is made about presence of technical state deterioration.

The piecewise linear function was chosen as approximating functions for statistical data. This function consists of k straight line segments connected without discontinuities. The width of each segment is n failures.

For the first segment, approximating function is straight line of following type:

$$y_0(t) = \frac{\sum_{i=1}^{n} t_i \sum_{i=1}^{n} i^2 - \sum_{i=1}^{n} i t_i \sum_{i=1}^{n} i}{n\sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} + \frac{n\sum_{i=1}^{n} i t_i - \sum_{i=1}^{n} t_i \sum_{i=1}^{n} i}{n\sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} t,$$

where i is a number of failure.

The extreme right point of this segment coincides with the extreme left point of the next, so all subsequent equations can be obtained from following expression:

$$y_j(t) = y_{j-1}(nj) + \frac{\sum_{i=kj}^{kj+n-1} t_i - n\, y_{j-1}(nj)}{\sum_{i=1}^{n} i} t.$$

So the approximating function in general form can be written as:

$$y(t) = \frac{\sum_{i=1}^{n} t_i \sum_{i=1}^{n} i^2 - \sum_{i=1}^{n} i t_i \sum_{i=1}^{n} i}{n\sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} + \frac{n\sum_{i=1}^{n} i t_i - \sum_{i=1}^{n} t_i \sum_{i=1}^{n} i}{n\sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} t \cdot h(t)$$

$$+ \sum_{j=1}^{k-1} \left(\frac{\sum_{i=kj}^{kj+n-1} t_i - n\, y_{j-1}(nj)}{\sum_{i=1}^{n} i} \bigl(t - kj\bigr) h(t - kj) \right),$$

where $h(t)$ is Heaviside function.

As an indicator of efficiency, we select value which characterizes the deviation of approximating function from regulatory value of mean time between failures T_0:

$$E = \frac{1}{kn} \int_0^{kn} (y(t) - T_0)\, dt.$$

The block diagram of recurrent algorithm is shown in Fig. 2.

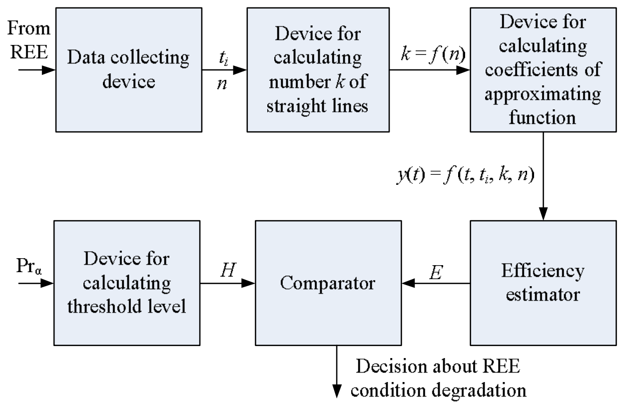

Fig. 2. Block diagram of recurrent algorithm

In Figure 2 $\Pr_\alpha$ is a probability of first kind error.

The next step in the formation of efficiency indicator can be taking into account risks associated with managing the operation of ground-based radio electronic equipment [16].

V. Results

Examples of statistical data and their approximation of piecewise linear functions with the width of each segment equaled to 5 and 10 failures are shown in Figs 3 and 4 ($N = 40$, $T_0 = 1000$, $t_{\det} = 20$, $\alpha = 2$).

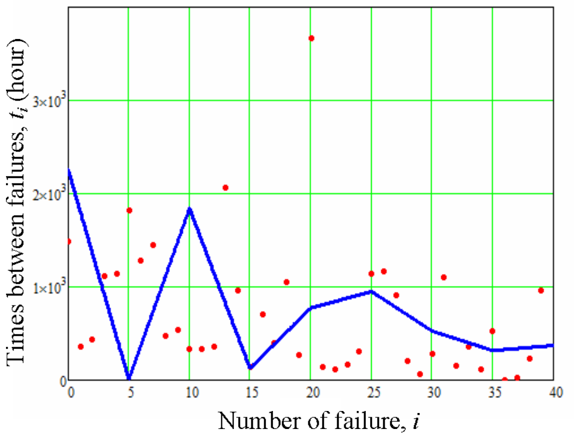

Fig. 3. Piecewise linear approximation of statistical data (width of segment is 5 failures)

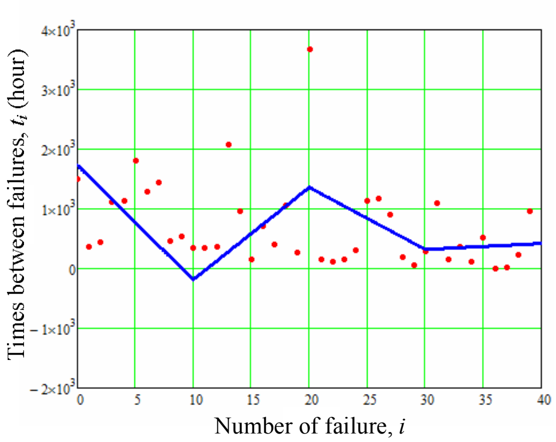

Fig. 4. Piecewise linear approximation of statistical data (width of segment is 10 failures)

Analysis of probability density functions of efficiency indicator allows determining decision threshold for technical state deterioration detection procedure.

For example, if width of segment is 5 failures (first procedure) or 10 failures (second procedure), mean time between failures is 1000 hours, deterioration beginning time is 20th failure and the sample size is 40 failures, we can construct operating characteristics shown in Fig. 5.

Operating characteristics analysis shows that second procedure on the one hand has greater probability of correct detection, and on the other hand – greater probability of false alarm. Overall, operating characteristics view corresponds to the process physics: the greater deterioration parameters α, the greater the probability of its detection.

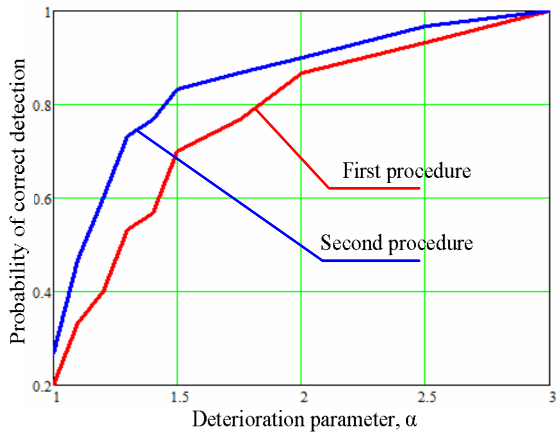

Fig. 5. Operating characteristics of change-point detection

The problem of parameters estimation for this deterioration model using maximum likelihood method has been considered in [13]. The estimates of deterioration beginning time and deterioration parameter are following formulas:

$$t_{\det} = \arg\max\left(\frac{N-y}{y}\frac{\sum_{i=0}^{y} t_i}{\sum_{i=y+1}^{N} t_i}\right), \quad \alpha = \frac{T_0\,(N - l(t_{\det}))}{\sum_{i=l(t_{\det})+1}^{N} t_i},$$

where $l(t_{\det})$ is a number of failure that corresponds to deterioration beginning time $t_{\det}$.

Moreover, probability density function of deterioration parameter estimate is described by expression

$$f(x) = \frac{(N - l(t_{\det}))^{N-l(t_{\det})}\alpha^{N-l(t_{\det})}}{x^{N-l(t_{\det})+1}(N - l(t_{\det})-1)!}e^{-\frac{\alpha(N-l(t_{\det}))}{x}}.$$

VI. Conclusion

Considered statistical data processing structure and in particular proposed procedure for technical state deterioration detection can be used during the design and modernization of operation systems of ground-based radio electronic equipment.

The presence of proposed statistical data processing procedures will contribute to a timely and correct decisions making during operation control of ground-based radio electronic equipment.

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О. В. Соломенцев, М. Ю Заліський, Т. С. Герасименко, І. В. Чекед. Тест для виявлення погіршення стану радіоелектронного обладнання

Розглянуто процедуру статистичного оброблення даних в системах експлуатації наземного радіоелектронного обладнання. Основну увагу було приділено задачам виявлення та оцінювання парламентів під час погіршення технічного стану наземного радіоелектронного обладнання.

Ключові слова: авіаційне радіоелектронне обладнання; система експлуатації; розладка, статистична обробка даних, процедура виявлення, системи з погіршенням.

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А. В. Соломенцев, М. Ю Залисский, Т. С. Герасименко, И. В. Чекед. Тест для обнаружения ухудшения состояния радиоэлектронного оборудования

В статье рассматривается процедура статистической обработки данных в системах эксплуатации наземного радиоэлектронного оборудования. Основное внимание было уделено задачам обнаружения и оценивания парламентов в случае ухудшения технического состояния наземного радиоэлектронного оборудования.

Ключевые слова: авиационное радиоэлектронное оборудование; система эксплуатации; разладка, статистическая обработка данных, процедура обнаружения, системы с ухудшением.

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