UDK 681.3(07)

Procenko Ya.M.
(military institute of the national university, Kiev)

MODEL OF ADAPTIVE CONDITION BASED TECHNICAL MAINTENANCE OF RADIOELECTRONIC TECHNOLOGY OBJECTS

The article proposed adaptive strategy for condition based maintenance (ACTM) of complex objects of radioelectronic technology (RET), in which the frequency of the technical condition (TC) of the object is changed (corrected) during the operation, taking into account the current dynamics of the degradation processes in the apparatus. The basic idea of the ACTM strategy is that during each next control of the TC of the object (besides the maintenance) the forecast of reliability indices of its elements is adjusted, and according to the results of an adjusted forecast the time of the next control is calculated. The article reviews the algorithm of these calculations.

The ACTM model is implemented in the framework of the simulation statistical model of the maintenance process and the RET objects repair. Through the application of the ACTM strategy, the obtained gain of the operation cost of the object is the greater (compared with the simple, not adaptive strategy), the greater is the value of the control TC of the object. The article gives an example of the strategy ACTM modelling.

Keywords: objects of radioelectronic technology, reliability indices, operation cost, simulation statistical modelling, condition based technical maintenance.

Considered objects of radioelectronic technology (RET) belong to a class of objects long repeated use, so we assume that at each time the object is able to perform the task in accordance with its purpose or in a state of readiness to perform this task. In view of the limited reliability of objects at random times there are hardware failures that lead to the disruption of the assignment and related to these losses. It is also assumed that the performance monitoring (PM) of the object is perfect, that is, any hardware failure is detected immediately at work or when the object is activated.

When a failure is detected immediately begins the repair work which requires certain costs (financial and as well as time input). In order to improve reliability of the object (and, consequently, to reduce the losses associated with the failure) the performance of technical maintenance (TM) is provided during the operation, which in most cases is reduced to preventive replacement (renewal) of the individual elements of the reliable units. If during the TM before the preventive replacement of the unit, the measurement of a parameter characterizing the technical condition (TC) of this unit is performed, such an approach to the TM it called *strategy for condition based technical maintenance (CTM).*

In [1] was examined and investigated the model of CTM strategy with a constant frequency control, which formally is described by the following parameters

$$\mathrm{P}_{\text{CTM}} = \left\langle E_{\text{TM}}, U_{\text{TM}}, T_{\text{c}} \right\rangle, \tag{1}$$

where P_{CTM} is a notation of generalized parameter strategy CTM; E_{TM} is a bunch of maintained units; $U_{\text{TM}} = \{u_{i\,TM};\, i = \overline{1, |E_{\text{TM}}|}$ is a vector of normalized values defining parameters of maintained units in achieving that requires TM (replacement) of the unit; T_{c} is frequency of monitoring the TC of the object.

The *governing parameter* (GP) refers to the physical or functional parameter whose value is determinate by the performance capacity of the unit [2]. The limit value of GP leads to unit failure.

The set of E_{TM} is a subset of the set of all units of the object E_{o} that are taken into account in the calculation of reliability indexes (RI) of RET object. In accordance with the strategy of the CTM (1) for each maintained unit $e_i \in E$ shall be known the GP, which characterizes the actual

TC of the unit. The normalized value of the unit GP e_i denoted by $u_i(t)$ $(u_i(t) \in [0,1])$. When $u_i(t) = 1$ unit e_i considered inoperable. $U(t) = \{u_i(t);\ i = \overline{1, |E_{\text{ТМ}}|}\}$ is a vector of GP values measured at time moment *t*.

According to the strategy (1) the control of the TC (CTC) of the object RET is carried out periodically at the times $t_c = k \cdot T_{\text{c}}$, where $k = 1, 2, \ldots$. During the CTC, the first shall be performed the unit performance monitoring (PM) (if the object is inoperable, the control process is interrupted and then the object recovery shall be made), after that the CTC is performed for all maintained units $e_i \in E_{\text{ТМ}}$

CTC of the unit involves the measuring value $u_i(t)$ and check the fulfillment of condition $u_i(t) \geq u_{i\,\text{ТМ}}$, where $u_{i\,\text{ТМ}}$ is the *level* of TM, that is, a value of normalized GP, which requires preventive replacement (upgrade) the unit e_i. The level values of TM $u_{i\,\text{ТМ}} \in U_{\text{ТМ}}$ are set by parameters CTM (1).

The obvious disadvantage of CTM strategy (1) is that the frequency control T_{c} it remained constant throughout the period of operation of the object, although in reality the TC of the object may change. Once selected value of T_{c}, even if it’s the optimal one, in further operation of the strategy (1) even if it is valid, it becomes insensitive to the possible changes in the actual TC of the object. In addition it is likely that the original data of the reliability indexes of object units, which were involved in calculation of the optimal T_{c}, contained significant errors, resulting in actual losses from failure of the object increases as compared with the minimum loss possible. In this connection, instead of deterministic strategy (1) it is proposed an adaptive strategy CTM, the essence of which is summarized in the following.

After each CTC of the object at time t_c the time of the next control time is calculated basing on t_{C+1} taken into account the current TC of the object [1]. Moment of time t_{C+1} it is calculated as follows:

$$t_{C+1} = t_C + \gamma \min_i \tilde{T}_{\text{mean}\,i}(t_k),\ \ (k = 1, 2, \ldots) \tag{2}$$

where γ is factor, the value of which is selected empirically; $\tilde{T}_{\text{mean}\,i}(t_C)$ is mean time to failure of the *i*-th unit in view of its TC at the time t_C $(i = \overline{1, |E_{\text{o}}|})$.

The value $\tilde{T}_{\text{mean}\,i}(t_c)$ determined by the formula

$$\tilde{T}_{\text{mean}\,i}(t_c) = 1 / \tilde{a}_i(t_c), \tag{3}$$

where $\tilde{a}_i(t_c)$ is forecasted at time t_c average speed degradation GP of *i*-th unit, which is determined by the exponential smoothing method [3] in accordance with the equation:

$$\tilde{a}_i(t_c) = \beta\, \tilde{a}_i(t_{c-1}) + (1 - \beta)\, a_i(t_c), \tag{4}$$

where β is smoothing constant ($\beta \in [0,1]$);

$a_i(t_c)$ is value of GP measured at time t_c, which is determined by the formula

$$a_i(t_c) = \big(u_i(t_c) - u_i(t_{c-1})\big) / (t_c - t_{c-1}). \tag{5}$$

According to expression (4) value $\tilde{a}_i(t_c)$ it is defined as a weighted average wherein a weight β is recorded for the whole prehistory of *i*-th unit failure. Thereby the forecast $\tilde{a}_i(t_c)$ is updated each time, taking into account the current TC of the unit.

---

[1] In simple (non-adaptive) strategy CTM $t_{c+1} = t_c + T_{\text{c}}$.

It is easy to see that according to the equation (2) the time of the next control time t_{c+1} is calculated taking into account the reliability level of the object made in this current time t_c. The meaning of introduced empirical coefficient γ can be interpreted as a relative "margin of safety" (in the sense of prevention of possible failures of the object), taken as a criterion when planning regular TM. To be specific, let us call the coefficient γ anticipation index.

The analyzed model of CTM process described by the equation (2) - (5), let us agree to call an *adaptive strategy condition based TM* (ACTM). Generalized parameter of *ACTM* strategy is denoted by P_{ACTM} and defined as follows:

$$\mathrm{P}_{\text{ACTM}} = \langle E_{\text{TM}}, U_{\text{TM}}, \gamma, \beta \rangle . \qquad (6)$$

The strategy model of *ACTM* (6) is implemented in software (ISMPN program) in the framework of the previously developed simulation statistical model (SSM) [4].

Consider the example of modeling strategy ACTM using ISMPN program. For example, we define a simple object RET consisting of 10 serially connected (in terms of reliability) of identical units. As the law of distribution of time to failure units in ISMPN program uses *DN*-distribution (this is the most adequate model for the failure of radioelectronic equipment items [2]).

At the initial data for ISMPN program for all units are specified the following parameters of *DN*-distribution: the expectation value of time to failure μ (scale parameter), and the coefficient of variation ν (shape parameter). In this example, we define values $\mu = 10000\ h$ and $\nu = 0{,}8$. As well as the following same data for all units is specified: the cost of unit C_{0i} = 1 c.u.; replacement operation cost $C_{\text{repl}\,i}$ = 1 c.u.; TM operation cost $C_{\text{TM}\,i}$ = 1 c.u.; the probability of unit replacement with TM $p_{\text{repl}\,i}$ = 0.

The duration of object operation to be 20 years.

The following prediction estimate of indicators is obtained as a result of the simulation at the "without TM " mode:

$$T_{\text{o}} = 1010\,\text{h}\,; \qquad c_{\text{ex}} = 0{,}00693\,\text{c.u./h}\,.$$

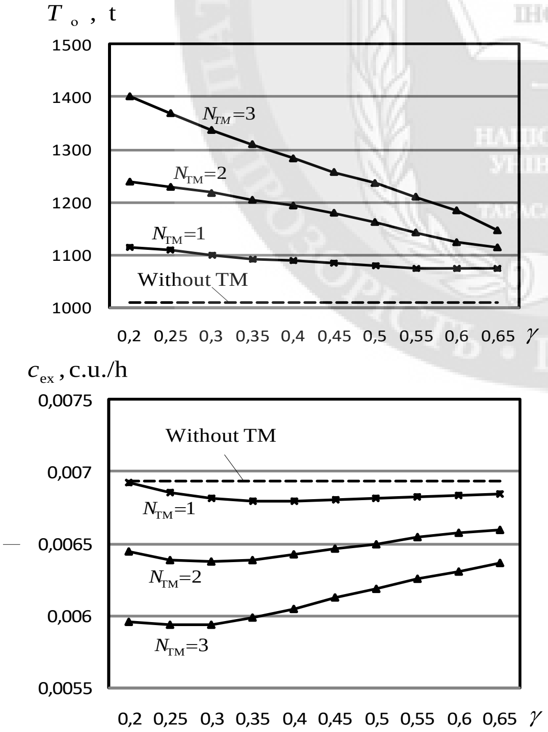

Fig. 1. The graphs of indicators T_{o} and c_{ex} from strategy parameters ACTM N_{TM} and γ.

Then we perform the calculations in the ACTM simulation mode with preset parameters P_{ACTM}. The goal is to determinate the nature of the parameter P_{ACTM} influence on performance T_{o} and c_{ex}. The only parameters E_{ACTM} и γ of all the parameters included in P_{ACTM} shall vary.

The calculations shall be made for three values of the parameter $E_{\text{TM}} : E_{\text{TM}\,1} = \{e_1\}$, $E_{\text{TM}\,2} = \{e_1, e_2\}$ и $E_{\text{TM}\,3} = \{e_1, e_2, e_3\}$, wherein the parameter γ will be varied within [0,2 ÷ 0,65]. Since all of the elements are the same, in the notation instead of the set $E_{\text{TM}\,i}$ we will use a number of maintained units $N_{\text{TM}\,i} = \left| E_{\text{TM}\,i} \right|$ ($i = 1, 2, 3$).

Fig. 1 shows the graphs obtained from the results of these calculations. The obtained graph clearly shows these patterns:

1) The most significant impact on performance T_{o} and c_{ex} has a number of maintained units N_{TM}. With increasing N_{TM} increases the

mean time to failure of the object T_o is reduced, the specific cost of operation c_{ex}. This is consistent with the physical sense of the researched process.

2) With increasing coefficient γ of mean time to failure T_f decreases monotonically, striving asymptotically to the value of T_f without TM. This also corresponds to the physics of the processes, as it grows γ, and the average frequency of TM with an increase. The indicator c_{ex} has an extremum (minimum) at a certain value γ. It is also easy to explain: the average loss due to losses in a failed condition, with an increase in frequency of TM are beginning to prevail over the corresponding losses in the condition of TM.

In general, these following conclusions may be drawn based on the article content:

1. The proposed strategy ACTM is quite suitable for its possible implementation in practice in the design of RET objects. Obviously, the ACTM strategy will be even more effective than are the more significant costs of monitoring the TC of the object.
2. The comparing of the effectiveness of CTM strategies and ACTM has meaning only when the values of their parameters are optimal. The issue of optimization parameters CTM and ATCM strategies are not considered in the article.
3. The example ACTM strategy modeling using ISMPN program confirms the overall adequacy of the developed model and the correctness of its software implementation.

LITERATURE:

1. Lenkov S.V., Cicarev V.M., Zaycev D.V., ProcenkoY.M. Modelling of the maintenance process as objects of electronic appliances with redundant elements. *System of information processing,* no. 7 (144), pp. 61-65 (in Russian).
2. GOST 27.005-97. (1999) Reliability in technique. Model failures. The main provisions. – Introduced. – 45 p. (in Russian).
3. Sarkisian S.A. (1977) The theory of forecasting and decision-making. M.: High school. – 351 p. (in Russian).
4. Lenkov S.V., K.F. Boryak, G.V. Banzak, V.O. Braun (2014) Forecasting the reliability of complex objects electronic equipment and optimization of parameters of their technical operation, simulation of statistical models. Monography / [etc.] :– Odessa : Publisher «ВМВ»,. – 256 p. (in Russian).

Рецензент: д.т.н., проф. Лєнков С.В., начальник науково-дослідного центру Військового інституту Київського національного університету імені Тараса Шевченка

Проценко Я.М.

МОДЕЛЬ АДАПТИВНОГО ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ ЗА СТАНОМ ОБ'ЄКТІВ РАДІОЕЛЕКТРОННОЇ ТЕХНІКИ

У статті запропонована адаптивна стратегія технічного обслуговування за станом (АТОС) складних об'єктів радіоелектронної техніки (РЕТ), в якій періодичність контролю технічного стану (ТС) об'єкта змінюється (коригується) в процесі експлуатації з урахуванням поточної динаміки деградаційних процесів в апаратурі. Основна ідея стратегії АТОС полягає в тому, що при черговому контролі ТС об'єкта (крім самих робіт з технічного обслуговування) проводиться уточнення прогнозу показників надійності його елементів і з урахуванням отриманого уточненого прогнозу розраховується час наступного контролю. У статті розглядається алгоритм цих розрахунків.

Модель АТОС реалізована в рамках імітаційної статистичної моделі процесу технічного обслуговування і ремонту об'єктів РЕТ. За рахунок застосування стратегії АТОС виграш у вартості експлуатації об'єкта виходить тим більшим (в порівнянні з простою, що не адаптований стратегією), чим більше величина вартості контролю ТС об'єкта. У статті наводиться приклад моделювання стратегії АТОС.

Ключові слова: об'єкт радіоелектронної техніки, показники надійності і вартості експлуатації, імітаційне статистичне моделювання, технічне обслуговування за станом.

Проценко Я.Н.

МОДЕЛЬ АДАПТИВНОГО ТЕХНИЧЕСКОГО ОБСЛУЖИВАНИЯ ПО СОСТОЯНИЮ ОБЪЕКТОВ РАДИОЭЛЕКТРОННОЙ ТЕХНИКИ

В статье предложена адаптивная стратегия технического обслуживания по состоянию (АТОС) сложных объектов радиоэлектронной техники (РЭТ), в которой периодичность контроля технического состояния (ТС) объекта изменяется (корректируется) в процессе эксплуатации с учетом текущей динамики деградационных процессов в аппаратуре. Основная идея стратегии АТОС состоит в том, что при очередном контроле ТС объекта (помимо самих работ по техническому обслуживанию) производится уточнение прогноза показателей надежности его элементов и с учетом полученного уточненного прогноза рассчитывается время следующего контроля. В статье рассматривается алгоритм этих расчетов.

Модель АТОС реализована в рамках имитационной статистической модели процесса технического обслуживания и ремонта объектов РЭТ. За счет применения стратегии АТОС выигрыш в стоимости эксплуатации объекта получается тем большим (по сравнению с простой, не адаптивной стратегией), чем больше величина стоимости контроля ТС объекта. В статье приводится пример моделирования стратегии АТОС.

Ключевые слова: объект радиоэлектронной техники, показатели надежности и стоимости эксплуатации, имитационное статистическое моделирование, техническое обслуживание по состоянию.