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MODELING OF THE PROCESS OF TECHNICAL SERVICE “IN CONDITION” WITH FIXED MONITORING PERIOD

The simulation statistical model (SSM) developed in this work is designed to obtain estimates of reliability and cost of operating an object, taking into account its composition, structure and reliability, and taking into account maintenance. The model should reproduce (simulate) the process of technical operation, which is formally described by the state and transition graph.SSM is based on the method of simulation statistical modeling, using the concept of "calendar of events".

The essence of the concept of the calendar of events and the mechanism of its application is as follows. An array (representing the calendar of events) is created in the RAM (PC) of the PC, in which the values of the scheduled time points of all the simulated events are recorded. In the process of modeling, periodically “view” of all the elements of the array, and the definition of the smallest of the planned points in time. The found minimum value is taken as the current model time, and the corresponding event is taken as the current event. Then the “processing” of the current event is performed, which consists in imitating the actions that constitute the essence of this event. The essence of TSC with a fixed periodicity of control is that at the time of the control the measurement of the determining parameters of all the elements that are potentially serviceable is taken. The model simulates (and handles) three types of events: "failure", "control" and "TS". After each event is processed, the next event of the next type of event is scheduled. If the current event is a “failure”, then a random running time of the same (failed) element is generated until the next failure. If the current event is “control” (“TS”), the time of the next corresponding event is scheduled. Obtained new values of the scheduled time are recorded in the calendar of events instead of their previous values. The described process of analyzing and modifying the calendar of events repeats cyclically throughout the entire simulation time.

Key words: simulation statistical model, modeling mode, reliability characteristics, calendar of events.

Introduction. Under complex technical objects refers to objects consisting of a large number of different types of elements (tens, hundreds of thousands), each of which can be a rather complex technical device. Elements can be electronic, mechanical, electromechanical, hydraulic, etc. The heterogeneity of the elements leads to the fact that different elements are characterized by fundamentally different physical processes (and, consequently, speed) degradation, leading to their failure.

The objects under consideration belong to the class of objects to be repaired for long-term repeated use, and during their operation, maintenance is usually provided to maintain the required level of reliability. By maintenance (MS) is meant “a complex of operations or an operation to maintain the health or performance of an object when used for its intended purpose, simple, stored and transported” [1,2]. Further, only MS will be considered when used as intended.

During operation, an object at any time can be in one of the following states: serviceable, workable, inoperable.

The object can be used for its intended purpose only in good or healthy condition. Restoration of a working or working condition is made at the expense of current repair. MS, as a rule, is carried out only when the object is in working condition. If by the moment of the start of the maintenance (or in the maintenance process) there is a complete failure, then at the beginning the object is restored, and then the maintenance is performed.

The essence of the MS is to prevent some part of the failures due to the replacement of individual elements, cleaning, lubrication, adjustment, etc. (therefore, MS is often called prevention). In modern technical objects, in the overwhelming number of cases, maintenance is reduced to the replacement of elements (liquids, oils, etc.) that are in a pre-order condition.

Formulation of the problem. The purpose and objectives of the study. The purpose of this work is the scientific substantiation of methods for determining the optimal parameters of the maintenance strategy "according to the state" of complex technical objects and the development of a mathematical (algorithmic) model of a complex technical object with a fixed periodicity of control.

Analysis of recent research. Currently, there is a decline in the number of scientific publications devoted to the issues of maintenance of complex technical objects. One of the reasons for this, in our opinion, is a sharp increase in the level of integration and reliability of components. Thanks to this, the developers of sophisticated equipment were able to solve the problems of ensuring the required level of reliability without significant maintenance costs (or no maintenance at all). However, the same reason (high integration and reliability of component elements) opened up the possibility of implementing more and more sophisticated equipment with new functions, which was not possible with the old element base. This again leads objectively to the problems of ensuring reliability and, therefore, the question of the need for maintenance and the choice of the optimal strategy for its implementation becomes again relevant.

Unfortunately, the currently known mathematical models and methods for calculating the optimal parameters of the maintenance processes are not very suitable for application to real technical objects. The main disadvantage of these models is that they either do not take into account the complex structure of the object, or it is possible to take into account only some of the simplest structures [3,4]. In [5,6], a comparative analysis of the problems arising in solving problems of maintenance "by resource" and "by state" was made. An overview of the latest at that time work in the field of maintenance and repair of complex systems. In [7], a theoretical generalization of the well-known mathematical models of MS processes was made. However, these models do not allow to build on their basis suitable for practical use of the methodology.

Main part. The SMS is based on the method of simulation statistical modeling using the concept of "event calendar" [8]. The essence of the concept of the calendar of events and the mechanism of its application is as follows. An array (representing the calendar of events) is created in the RAM (PC) of the PC, in which the values of the scheduled time points of all the simulated events are recorded.

In the process of modeling, periodically "view" of all the elements of the array, and the definition of the smallest of the planned points in time. The found minimum value is taken as the current model time, and the corresponding event is taken as the current event. Then the "processing" of the current event is performed, which consists in imitating the actions that constitute the essence of this event.

The model simulates (and processes) three types of events: "failure" (transition 0 → 1), "control" (transition 0 → 2), and "MS" (transition 0 → 3). After each event is processed, the next event of the next type of event is scheduled. If the current event is a "failure", then a random running time of the same (failed) element is generated until the next failure. If the current event is "control" ("MS"), the time of the next corresponding event is scheduled. Obtained new values of the scheduled time are recorded in the calendar of events instead of their previous values. The described process of analyzing and modifying the calendar of events repeats cyclically throughout the entire simulation time.

The essence of MSC with a fixed periodicity of control is that at the time of the control the measurement of the determining parameters $u_i(t)$ of all the elements that are potentially serviceable is taken. If the measured value of the normalized determining parameter exceeds the specified value of the MS $u_{\text{то}\, i}$ level, the *i*-th element is updated (replaced).

We have already said that in order to model failures, we use the *D* -distribution, which is the *WF*-model of failures. This means that each failure is interpreted as an event consisting in the output of the determining parameter of the element beyond the permissible limits (the value of the normalized determining parameter $u_i(t)$ has reached the value 1). If we assume that the average resource of an element decreases linearly with time (such an assumption is the basis of the *WF*-model), then the value of the average residual resource at an arbitrary time *t* is equal to

$$\overline{R}_i(t) = T_{\text{ср}i} - t\,, \tag{1}$$

where - $T_{\text{ср}i}$ average time to failure of the *i*-th element.

If during the simulation we know that the failure of the *i*-th element will occur at the moment of time t_i (this is the planned failure time), then the residual resource of the *i*-th element at the moment of time *t* is equal *to*

$$R_i(t) = t_i - t\,. \tag{2}$$

The value $R_i(t)$ in this case is a random implementation of the residual resource.

The residual resource $R_i(t)$ can be associated with the value of the normalized determining parameter, the value of which can be determined as follows:

$$u_i(t) = 1 - \frac{R_i(t)}{R_{0i}}\,, \tag{3}$$

where - R_{0i} random implementation of the full resource of the i-th element, the value of which is equal to

$$R_{0i}(t) = t_i - t_{0i}\,. \tag{4}$$

Taking into account (2) and (4) instead of (3) we can write down:

$$u_i(t) = \frac{t - t_{0i}}{t_i - t_{0i}}\,, \tag{5}$$

where *t* - is the current monitoring time;

$t_{0\,i}$ - ast time the *i*-th item was last updated;

t_i - the scheduled failure time of i-th element.

The condition for the achievement of a given level by the determining parameter $u_i(t)$ in this case $u_{\text{то}\,i}$ is written in the form of the following inequality:

$$t \geq t_{0i} + u_{\text{то}i}(t_i - t_{0i})\,. \tag{6}$$

If the serviced element is a redundant group of elements, then the degree of group proximity to the failure state is determined by the value

$$u_i(t) = \frac{n_{\text{р}i}(t)}{n_i}\,, \tag{7}$$

where n_i - is the number of elements in the reserved group;

$n_{\text{р}\,i}(t)$- the number of workable elements in the reserved group at time *t*.

The result of the algorithm are:

1) actions - rescheduling the time points of failures of elements subjected to maintenance, and

2) information - the duration of maintenance $\tau_{\text{то}}$ and cost of maintenance $C_{\text{то}}$.

The main provisions of the considered MSC model were published in [8,9,10] and were tested [11,12].

Conclusions. The methodical accuracy of SSM is determined by such factors:

- the initial reliability of the object (given by the indicators of the reliability of the elements);
- the number of implementations (duration) of the simulation;
- the specified duration of operation of the object.

Of these factors, the most significant is the first. In most practically interesting cases, the relative error of the simulation results does not exceed 10–20%.

In this section IMS is designed to predict the reliability and cost of operation of a complex technical object, depending on the parameters of the selected maintenance strategy.

The mode of modeling the regulated maintenance has been introduced in order to ensure the completeness of the analysis of possible maintenance strategies of the projected object and predict the possible gain in reliability and cost of operation of the facility by applying the strategy MSC.

REFERENCES:

1. Forecasting to reliability complex object radio-electronic texnology and optimization parameter their technical usage with use the simulation statistical models: [monography] in English / Sergey Lenkov, Konstantin Borjak, Gennady Banzak, Vadim Braun, ets.; under edition S.V. Lenkov. – Odessa: Publishing house "VMV", 2014. – 252 p.
2. Jason Brown, Lucas Mol On the roots of all-terminal reliability polynomials / Discrete Mathematics, Volume 340, Issue6, June 2017, pages 1287-1299.
3. Lirong Cui, Yan Li, Jingyuan Shen, Cong Lin Reliability for discrete state systems with cyclic missions periods / Applied Mathematical Modtlling, Volumt 40, Issues 23-24, December 2016, Pages 10783-10799/
4. Iris Tien, Armen Der Kiureghian Algorithms for Bayesian network modeling and reliability assessment of infrastructure systems / Reability Engineering & System Safety, Volume 156, December 2016, Pages 134-147.
5. Волох О.П. Method of justification of rational values of periodicity of technical maintenance of engineering armament machinery during operation // Collection of scientific works MIKNU named after T. Shevchenko. Whip 2. K .: MIKNU, 2005. - P. 29-32.
6. Boryak K.F. The reliability model of a complex recoverable object of electronic equipment Boryak K.F. The reliability model of a complex recoverable object of electronic equipment // К.: MIKNU 2009. - № 21. – P. 33-41.
7. Reliability and efficiency in technology. Directory. T.2. Mathematical methods in the theory of reliability and efficiency / Ed. B.V. Gnedenko. M .: Engineering, 1988. - 280 p.
8. Computational methods for the study and design of complex systems. Mikhalevich V.S., Volkovich V.L. - M .: Science, 1982. 286 p.
9. Brown V.O., Boryak K.F., Lantvoit O.B, Tsytsarev V.N. Modeling of the processes of maintenance of complex recoverable objects of electronic equipment // News of Engineering Academy of Ukraine .- K., 2008. - №1. - p. 47 - 52.
10. Boryak K.F. Dedicating to the process of technical service of folding interconnecting sites of radio electronic technology for additional statistical models // Bulletin of the Engineering Academy of Ukraine. - K., 2008. - №2. - P.85 - 91.
11. Banzak G.V. Database on the reliability of complex objects electronic equipment / G.V. Banzak, K.F. Borjak, V.N. Tsytsarev. Collection of scientific works MIKNU named after T. Shevchenko. Whip 2. K .: MIKNU, 2010. - № 27. - P.89 - 97- 2010.

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МОДЕЛЮВАННЯ ПРОЦЕСУ ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ «ЗА СТАНОМ» З ФІКСОВАНОЮ ПЕРІОДИЧНІСТЮ КОНТРОЛЮ

Розробляється в даній роботі імітаційна статистична модель (ІСМ) призначена для отримання оцінок показників надійності і вартості експлуатації об'єкта з урахуванням його складу, структури та надежностних характеристик і з урахуванням проведення ТО. У моделі повинен відтворюватися (імітуватися) процес технічної експлуатації, який формально описується графом станів і переходів.

ІСМ розроблена на основі методу імітаційного статистичного моделювання, що використовує поняття "календаря подій". Суть поняття календаря подій і механізму його застосування полягає в наступному. В оперативній пам'яті (ОП) ПК створюється масив (який представляє календар подій), в який записуються значення запланованих моментів часу всіх модельованих подій. В процесі моделювання періодично здійснюється "перегляд" всіх елементів масиву, і визначення найменшого із запланованих моментів часу. Знайдене мінімальне значення приймається в якості поточного модельного часу, а відповідне йому подія - в якості поточного події. Потім проводиться "обробка" поточного події, яка полягає в імітації дій, що становлять суть цієї події. Суть технічного обслуговування „по стану” (ТОС) з фіксованою періодичністю контролю полягає в тому, що в момент контролю проводиться вимірювання визначальних параметрів всіх елементів, потенційно які користувач може обслуговувати.

У моделі імітуються (і обробляються) три типи подій: «відмова», «контроль» і «ТО». Після обробки кожної події проводиться планування часу наступного настання події відповідного типу. Якщо поточну подію «відмова», то генерується випадкова напрацювання цього ж (який відмовив) елемента до наступної відмови. Якщо поточну подію «контроль» («ТО»), планується час наступного відповідного події. Отримані нові значення запланованого часу записуються в календарі подій замість їх колишніх значень. Описаний процес аналізу та модифікації календаря подій повторюється циклічно протягом усього часу моделювання.

Ключові слова: імітаційна статистична модель, режим моделювання, характеристики надійності, календар подій, технічне обслуговування

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МОДЕЛИРОВАНИЕ ПРОЦЕССА ТЕХНИЧЕСКОГО ОБСЛУЖИВАНИЯ «ПО СОСТОЯНИЮ» С ФИКСИРОВАННОЙ ПЕРИОДИЧНОСТЬЮ КОНТРОЛЯ

Разрабатываемая в данной работе имитационная статистическая модель (ИСМ) предназначена для получения оценок показателей надежности и стоимости эксплуатации объекта с учетом его состава, структуры и надежностных характеристик и с учетом проведения ТО. В модели должен воспроизводиться (имитироваться) процесс технической эксплуатации, который формально описывается графом состояний и переходов.

ИСМ разработана на основе метода имитационного статистического моделирования, использующего понятие “календаря событий”. Суть понятия календаря событий и механизма его применения состоит в следующем. В оперативной памяти (ОП) ПК создается массив (представляющий календарь событий), в который записываются значения запланированных моментов времени всех моделируемых событий.

В процессе моделирования периодически осуществляется “просмотр” всех элементов массива, и определение наименьшего из запланированных моментов времени. Найденное минимальное значение принимается в качестве текущего модельного времени, а соответствующее ему событие – в качестве текущего события. Затем производится “обработка” текущего события, которая заключается в имитации действий, составляющих суть этого события. Суть технического обслуживания „по состоянию” (ТОС) с фиксированной периодичностью контроля состоит в том, что в момент контроля производится измерение определяющих параметров всех элементов, потенциально подлежащих обслуживанию. В модели имитируются (и обрабатываются) три типа событий: «отказ», «контроль» и «ТО». После обработки каждого события производится планирование времени следующего наступления события соответствующего типа. Если текущее событие «отказ», то генерируется случайная наработка этого же (отказавшего) элемента до следующего отказа. Если текущее событие «контроль» («ТО»), планируется время следующего соответствующего события. Полученные новые значения запланированного времени записываются в календаре событий вместо их прежних значений. Описанный процесс анализа и модификации календаря событий повторяется циклически в течение всего времени моделирования.

Ключевые слова: имитационная статистическая модель, режим моделирования, характеристики надежности, календарь событий