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FORECASTING OF RELIABILITY AND COSTS OF OPERATION COMPLEX OBJECTS RET IN VIEW OF THEIR MAINTENANCE SERVICE AND REPAIR

For forecasting parameters of reliability and cost of operation complex objects RET in view of their maintenance service and repair it is offered to use imitating statistical model. The systems of parameters for the formal description of characteristics of complex object RET and a process of maintenance service and repair (MSaR) is entered. For modeling refusals it is used диффузионное nonmonotonic distribution. Are modeled both operating repairs (restoration of working capacity), and scheduled repairs (completion of a resource). Maintenance service « on a condition » is modeled.

The model is realized in the environment of programming Delphi. The example of results of modeling is resulted.

Introduction. The complex object of radio-electronic technics (RET) is understood as the technical Yobject consisting of a plenty polytypics completing elements (tens, hundred thousand), the overwhelming majority from which are radio-electronic elements. The structure of object RET, as a rule, includes also a quantity of mechanical, electromechanical, hydraulic and other types of elements. A typical example of such objects is the radar stations, the automated control systems of various purpose, etc.

Complex object RET almost always has the built in test system by means of which the daily control technical conditions (TC) of object is carried out, search and elimination of malfunctions (operating repair). For maintenance of a demanded level of non-failure operations of object RET during its operation maintenance service (MS) and scheduled repairs (SR) are spent.

MS intends for prevention of some part of refusals of the least reliable elements of object due to carrying out of verifying-adjusting works, replacement of technical liquids and oils, preventive replacements of the elements which are being in condition of preliminary refusal. As a result MS occurs "under pressure" of a stream of refusals of object and, hence, the level of its non-failure operation raises.

SR intend for completion of a resource of object, are spent to in advance planned moments of time. At carrying out SR replacement of a significant part of elements of object is usually made. The more quantity of replaced elements, the more size of the resource filled as a result of performance SR.

Operating repair (OR) is intended only for restoration of working capacity of object, spent to the casual moments of time, each time at occurrence of refusal of object. Unlike SR, at OR replacement of one or only a small number of elements which refusal has led to refusal of object is made.

It is obvious, that MS and repairs (MSaR) demands essential economic expenses which are desirable for minimizing. Mathematical models by means of which it would be possible to estimate are necessary for definition of ways and ways of minimization of these expenses as carrying out MS and SR can raise a level of non-failure operation of object. Presence of such models can help to compare the developer of object RET with the expenses demanded for introduction in a design of object of means, necessary for maintenance of adaptability to manufacture of operations MSaR, to that prize in a level of non-failure operation and cost of operation which can be received due to MSaR. And by results of such comparison to make optimum constructive decisions.

Thus, the mathematical model by means of which dependence of parameters of reliability and costs of operation of object РЭТ from characteristics of the object and parameters of process MSaR is established is necessary. In given clause as such model the imitating statistical model (ISM) by means of which such dependences can be received is offered.

Formal description of characteristics complex object RET. Object RET represents complex technical system which has structural, reliability and cost characteristics. In offered model set of all parameters of object is represented following in three generalized parameters:

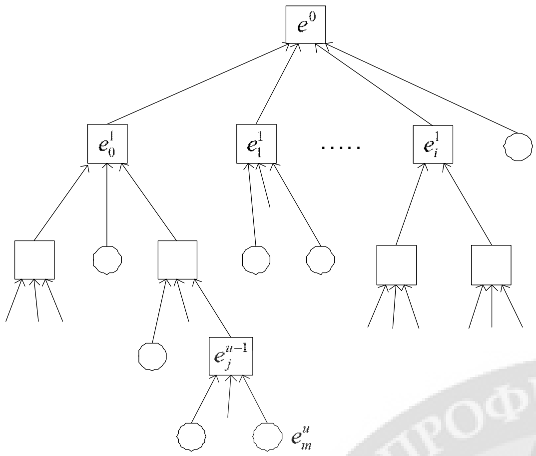

Fig. 1. A tree of constructive structure of object

The parameter Б characterize properties of non-failure operation, structure and structure of object:

$$Б = \left\{E_о, G, \left\{\left\langle T_{срi}, \nu_i, te_i, ts_i \right\rangle; i = \overline{1, |E_о|}\right\}\right\}, (1)$$

where $E_о$ - set of all *refusing* elements (the elements entering into the block diagram of reliability of object); G - the parameter defining constructive structure of object (a tree of constructive structure); $\left\langle T_{срi}, \nu_i, te_i, ts_i \right\rangle$ - the parameters describing separate elements: $T_{срi}$ - an average operating time to refusal of *i-th* element; ν_i - factor of a variation of a casual operating time to refusal; te_i - type of an element; ts_i - type of reliability structures of an element ($i = \overline{1, |E_о|}$).

Each element $e_i \in E_о$ can be *simple* ($te_i = 0$), that is to be considered as the whole, without specification of its internal structure, or *compound* ($te_i = 1$), containing other elements which, in turn, can be both compound, and simple. On fig.1 the provisional kind of a tree of constructive structure of object G is shown. Components are represented by triangles, simple elements - mugs.

Reliability of structure of a component can be three types: a single element ($ts_i = 0$), consecutive connection of the same elements ($ts_i = 1$) or parallel the connected same elements ($ts_i = 2$ - constant reservation; $ts_i = 3$ - replacing reservation). Thus, represented to models reliability of structure objects as a whole is series-parallel.

The parameter В defines property restoration (maintainability) of object. The parameter is represented a following data set:

$$В = \left\{\tau_{ктс}, \tau_{пн}, \left\{\left\langle \tau_{замi}, \tau_{тоi}, p_{замi} \right\rangle; i = \overline{1, |E_о|}\right\}\right\}, \quad (2)$$

where $\tau_{ктс}$ - average duration of the control of a technical condition of object; $\tau_{пн}$ - average duration of troubleshooting; $\tau_{замi}$ - average time of replacement *i-th* element; $\tau_{тоi}$ - average duration of operation MS; $p_{замi}$ - probability of replacement of an element at carrying out MS.

The parameter C defines cost characteristics of object:

$$C = \left\{C_{ктс}, C_{пн}, \left\{\left\langle C_{0i}, C_{замi}, C_{тоi} \right\rangle; i = \overline{1, |E_о|}\right\}\right\}, \quad (3)$$

where $C_{ктс}$ - cost of operation control of a technical condition of object; $C_{пн}$ - cost of operation of troubleshooting; C_{0i} - cost *i-th* element; $C_{замi}$ - cost of operation of replacement *i-th* element; $C_{тоi}$ - cost of operation MS *i-th* element ($i = \overline{1, |E_о|}$).

Formal parameters of process MS. MS of object RET is spent according to a principle MS « on a condition » (MSC) which essence consists in the following [1]. The periodic control of the

TC of object and over results of the control is while in service made are carried out (or those or other operations MS are not carried out). We shall believe, that for object the set of served elements $E_{\text{то}}$ ($E_{\text{то}} \subset E_{\text{о}}$) is certain and for each element $e_i \in E_{\text{то}}$ there is *a defining parameter* (DP). According to [2] under DP the physical or functional parameter which value defines working capacity of an element (an element is understood becomes disabled at achievement in the defining parameter of critical value). We shall designate $u_i(t)$ normalization value DP *i-th* element measured during the moment of time *t*. Value $u_i(t) = 0$ corresponds to rating value DP, value $u_i(t) = 1$ is critical at which achievement there comes refusal of an element. Function $u_i(t)$ describes casual process of degradation *i-th* element, coming to an end sooner or later by its refusal. In [2] the concept of is likelihood-physical model of refusals (LP-model) in which likelihood characteristics DP with function of distribution of an operating time to refusal of an element communicate is entered. By means of fig. 2 the physical sense of this communication is explained. Most universal of LP-models is diffusion nonmonotonic distribution *(DN-distribution)*. In [3] it is shown, that by means of *DN-distribution* laws of refusals both electronic elements, and mechanical units are well described. As criterion of necessity of carrying out MS (or replacements) an element we shall enter concept *of a level MS* $u_{\text{то}i}$. If current value DP *i-th* element $u_i(t)$ has reached or has exceeded a level $u_{\text{то}i}$ in this case it is necessary to spend MS (replacement) of an element.

In view of all told for the formal description of strategy MSC with constant periodicity of the control we shall enter following parameters:

$$\text{P}_{\text{то}} = \{\tau_{\text{то а}}, E_{\text{то}}, U_{\text{то}}, T_{\text{к}}\}, \tag{4}$$

where $\text{P}_{\text{то}}$ - a designation of the generalized parameter of system MSC; $\tau_{\text{то а}}$ - administrative time MS (preparatory operations); $E_{\text{то}}$ - set of potentially served elements; $U_{\text{то}} = \{u_{\text{то}i}; i = \overline{1, |E_{\text{то}}|}\}$ - a vector of levels $u_{\text{то}i}$ what are generally various for various elements $e_i \in E_{\text{то}}$; $T_{\text{к}}$ - periodicity of the control of object.

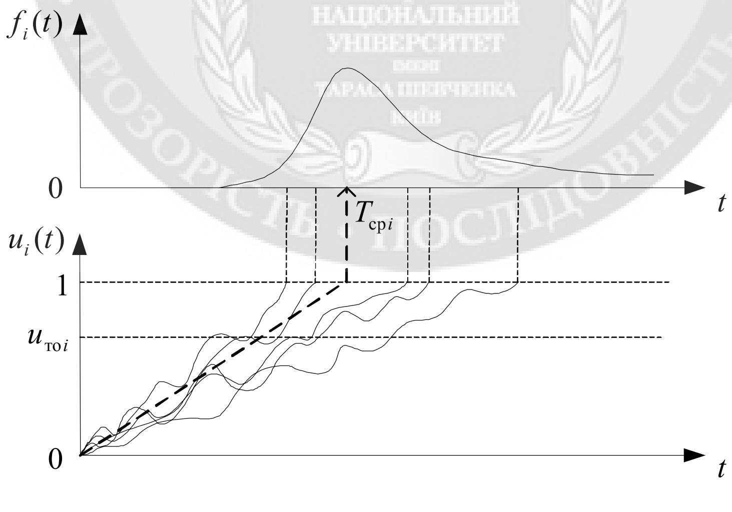

Fig. 2. The degradation process defines objects

In practice it is far not for all elements exist DP and for even their smaller part DP it is possible to measure easily. Owing to application of model *of DN-distribution* there is an opportunity to postulate existence DP for any element and to use it at modeling. The developer (the user of model) can include in set $E_{\text{то}}$ and elements for which are absent DP. And if by results of modeling it will appear, that service of the given element can lead significant (from the point of view of the developer) to a prize in a level of non-failure operation of object, it can serve as a convincing substantiation for development and introduction in the equipment of means for measurement DP of the given element.

Formal parameters of process SR. The system of scheduled repairs (SSR) which is modeled in ISM, is described by following parameters:

$$\mathrm{P}_{\text{пр}} = \left\{ N_{\text{пр}}, \left\{ \left\langle P_{\text{пр}\,j}, R_{\text{пр}\,j}, C_{\text{пр}\,j}, \tau_{\text{пр}\,j} \right\rangle ; j = \overline{1, N_{\text{пр}}} \right\} \right\}, \quad (5)$$

where $N_{\text{пр}}$ - number of kinds SR; $P_{\text{пр}\,j}$ - percent of replacement of elements at SR *j-th* kind; $R_{\text{пр}\,j}$ - the between-repairs resource established for SR *j-th* kind; $C_{\text{пр}\,j}$ - cost SR *j-th* kind; $\tau_{\text{пр}\,j}$ - duration of carrying out SR *j-th* kind.

It is supposed, that the percent of replacement of elements $P_{\text{пр}\,j}$ unequivocally defines set repaired (replaced) at SR elements $E_{\text{пр}\,j}$. The set $E_{\text{пр}\,j}$ is defined as a subset of the least reliable elements taken from set $E_{\text{о}}$. The number of elements of a subset $E_{\text{пр}\,j}$ for a preset value $P_{\text{пр}\,j}$ is defined by following expression:

$$\left| E_{\text{пр}\,j} \right| = \left[\left| E_{\text{о}} \right| \cdot P_{\text{пр}\,j} / 100 \right], \quad (6)$$

where square brackets designate operation of a capture of the whole part.

Thus, the set $E_{\text{пр}\,j}$ can be defined as the first $\left| E_{\text{пр}\,j} \right|$ the elements, taken of the set $E_{\text{о}}$ ordered on increase of an average operating time before refusal of elements. Parameters $C_{\text{пр}\,j}$ and $\tau_{\text{пр}\,j}$ in (5) are defined through percent of replacement $P_{\text{пр}\,j}$ (опосредованно through subsets $E_{\text{пр}\,j}$), but can and be set as initial data.

Modeling SR within the limits of ISM consists in imitation of replacement by sets $E_{\text{пр}\,j}$ new all elements during the moments of time of performance SR.

Block diagram of algorithm ISM. In ISM generates process which structure is described графом conditions and the transitions, represented on fig. 3 (is simulated).

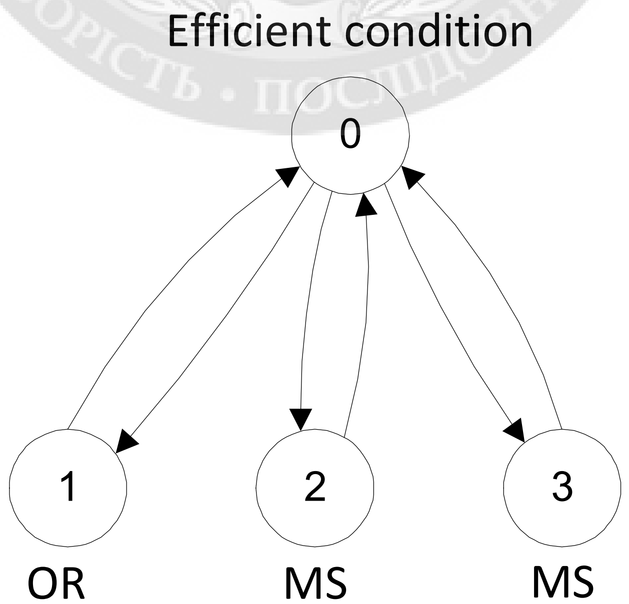

Fig. 3. Columns of conditions and transitions of modeled process

In model the concept of " a calendar of events" (CE) which essence briefly consists in the following is used. In operative memory of the personal computer the file (a representing calendar of events) in which values of the planned moments of time of modeled events enter the name is created. During modeling "viewing" all elements of a file and definition of the least time (nearest) from the planned moments is periodically carried out. The found minimal value is accepted as current modeling time, and event corresponding it - as current event. Then "processing" of current event which consists in imitation of the actions making an essence of this event is made. After processing event it is made it re-planning - the moment of time of following approach of event of this type and preservation of new value of time in CE pays off.

Events "refusal" are simulated for all elements $e_i \in E_{\text{o}}$. Processing of event "refusal" consists accumulation of statistics about refusals and generating and storing in CE casual value of an operating time of an element before following refusal.

Event "restoration" obviously is not planned, implicitly considered at planning following refusal. Processing of event "restoration" consists in accumulation of statistics about duration of restoration.

Events „MS" are planned differently, depending on the chosen strategy MS. If strategy MSC, time of the following MS is chosen is casual, its value depends on the current TC of object.

Events «SR» are planned according to set determined parameters SSR. Planned time of following SR is defined as current time plus the between-repairs resource established for given kind SR. Processing of event «SR» consists in imitation of updating of all elements which are a subject replacement at data SR. Updating of elements (the same as and at MS) is simulated by перепланирования planned before the moments of time of their refusals, new values of time of refusal of elements are kept (are remembered) in CE.

The described process of consecutive "viewing" CE and processing's of events "refusal", "MS" and "SR" repeats cyclically during all time of modeling.

The initial information for model is:

- parameters of Б, В and С;
- parameters of system MSaR $\text{Р}_{\text{то}}$ and $\text{Р}_{\text{пр}}$;
- parameters of modeling to which concern:

$T_{\text{э}}$ - set duration of operation of object;

$\varepsilon^{\text{тр}}$ - demanded accuracy of results (a relative mistake);

$N_I^{\max}$ - maximal number of realizations of modeling.

The target information of model are estimations of following parameters of quality of process MSaR:

$T_0 = T_0(\text{Б}, \text{В}, \text{Р}_{\text{то}}, \text{Р}_{\text{пр}})$ - average time between failures of object;

$T_{\text{в}} = T_{\text{в}}(\text{Б}, \text{В}, \text{Р}_{\text{то}}, \text{Р}_{\text{пр}})$ - average time of restoration;

$K_{\text{г}} = K_{\text{г}}(\text{Б}, \text{В}, \text{Р}_{\text{то}}, \text{Р}_{\text{пр}})$ - factor of readiness;

$K_{\text{ти}} = K_{\text{ти}}(\text{Б}, \text{В}, \text{Р}_{\text{то}}, \text{Р}_{\text{пр}})$ - factor of technical use;

$c_{\text{э}} = c_{\text{э}}(\text{Б}, \text{В}, \text{С}, \text{Р}_{\text{то}}, \text{Р}_{\text{пр}})$ - specific cost of operation of object.

Besides the specified dot parameters as the target information as a result of modeling the estimation of function of parameter stream of refusals object $\Omega(t) = \Omega(t / \text{Б}, \text{В}, \text{Р}_{\text{то}}, \text{Р}_{\text{пр}})$, which

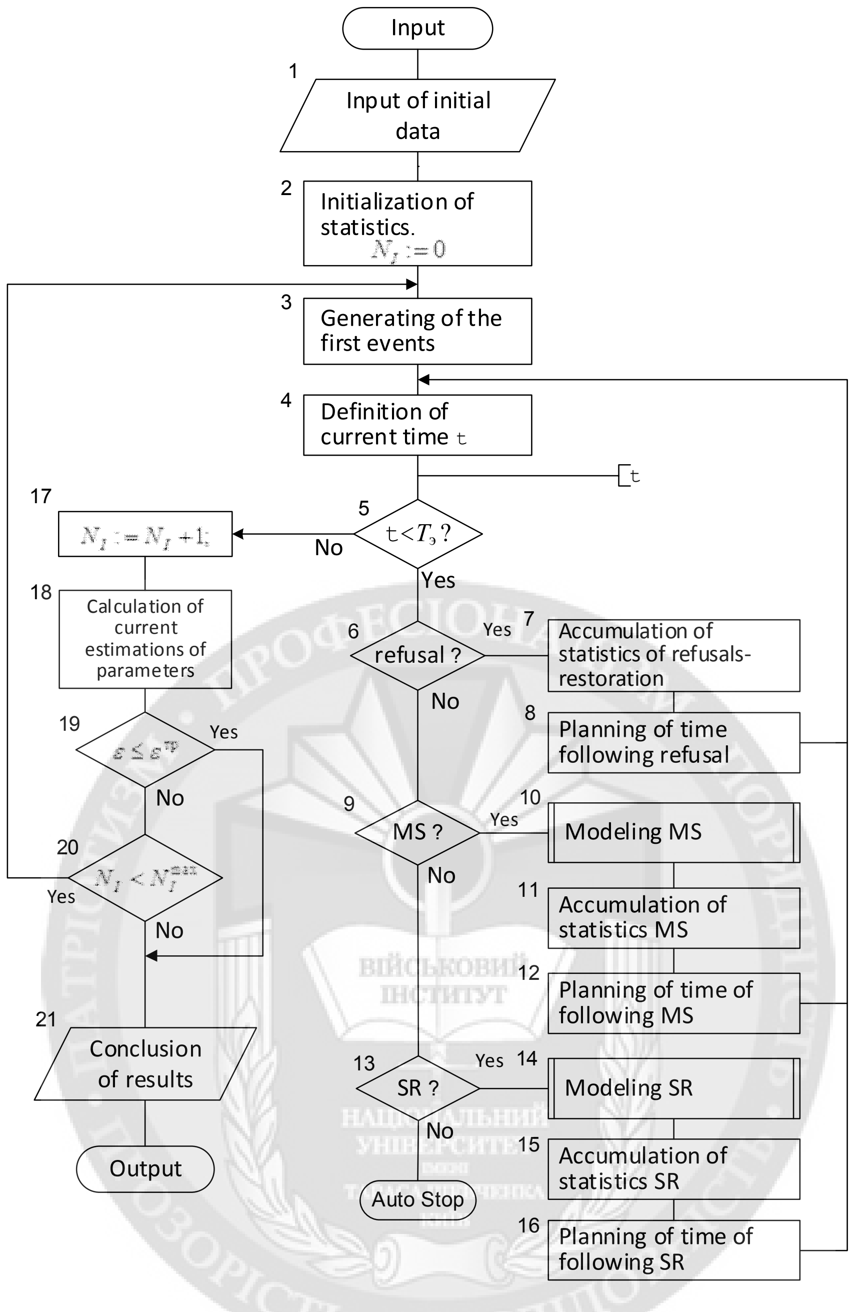

Fig. 4. The Block diagram of algorithm of imitating statistical model

comprises rather important information on dynamics of property of non-failure operation of object during its operation is formed.

All received by means of ISM estimations of parameters depend both on parameters of object RET, and from parameters of process MSaR.

On fig. 4 the integrated block diagram of algorithm ISM is represented. Work of algorithm briefly consists in the following.

The operator 1 carries out input of initial data. The basic part of initial data is entered from databases (DB) of model. The operator 2 establishes initial values of all variables in which the necessary statistics will collect. Initial value of a variable N_I - numbers of the executed iterations of modeling is established also.

The operator 3 generates and keeps in CE the moments of time of the first events. The moments of time of the first refusals are defined by generating the random numbers, subordinated to *DN-distribution* with parameters $T_{срi}$ and ν_i elements $e_i \in E_о$. The operator 4 defines current

modeling time t by search of the least value in CE. The type of current event is simultaneously defined.
The operator 5 checks a condition of end of current iteration of modeling. If time t has not fallen outside the limits the set period of operation $T_э$ ($t < T_э$), it means, that current iteration yet has not come to the end, and operators 6-16 further are carried out. If current event "refusal" operators 7 and 8 are carried out, carrying out its processing.

Operators 10-12 process event "MS". Modeling MS consists in check for all served elements e_i of a condition $u_i(t) \geq u_{тоi}$ ($\forall e_i \in E_{то}$).

For those elements for which this condition was executed, in CE it is made перепланирование the moments of time of their refusal (it simulates their updating). Measurement DP $u_i(t)$ is simulated by calculation under the formula

$$u_i(t) = (t - t_{0i}) / (t_i - t_{0i}), \tag{7}$$

where t - current time of the control; t_{0i} - time of last updating *i-th* element; t_i - planned (modelling) time of refusal *i-th* element.

Operators 13-16 process event «SR».

If at performance of the operator 5 the condition $t \geq T_э$ management is transferred operators 17-21 was satisfied. Purpose of these operators should be clear from the block diagram of algorithm without additional explanatory.

ISM programs it is realized in programming system Delphi [4] (program ISMPN). Program ISMPN is integrated from a DB, into which the information on object RET (parameters Б, В and С) and parameters $P_{тос}$ is entered and $P_{пр}$. The DB of model is realized by means CSDB InterBase [5].

Example of results modeling. For an example it has been created by a DB for test object which constructive structure is represented on fig. 5. All components have consecutive of reliability structure. For all simple elements (elements of the bottom constructive level) preset values of an average operating time to refusal $T_{ср}$ in a range 20 ÷ 100 thousand hours, factor of a variation ν = 1,0.

Parameters of modeling we shall set the following:

$T_э$ = 20 years; $\varepsilon^{тр}$ = 0,01; N_I^{max} = 200.

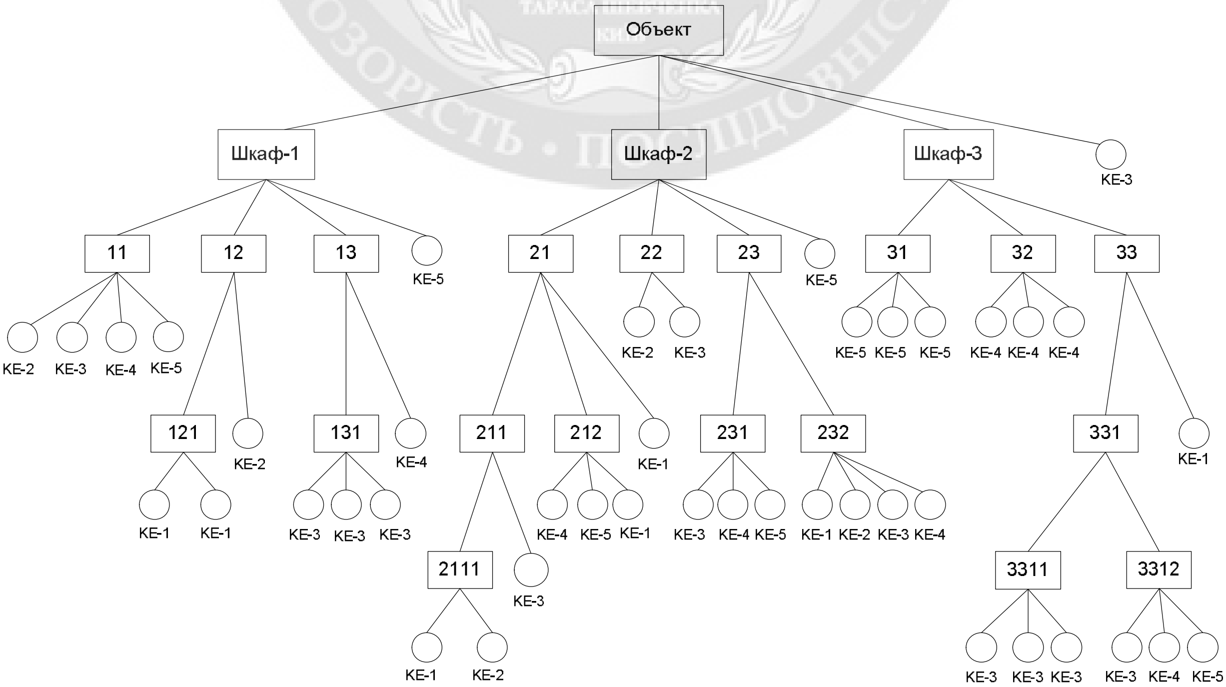

Fig. 5. Constructive structure of test object

Results of modeling are displayed on the screen of the personal computer (fig. 6). In the central part of the screen the schedule of function parameter of a stream refusals $\Omega(t/\text{Б}, \text{В}, \text{Р}_{\text{то}}, \text{Р}_{\text{пр}})$ is displayed, the estimations of parameters of reliability received as a result of modeling and costs of operation of object RET at the left are below displayed.

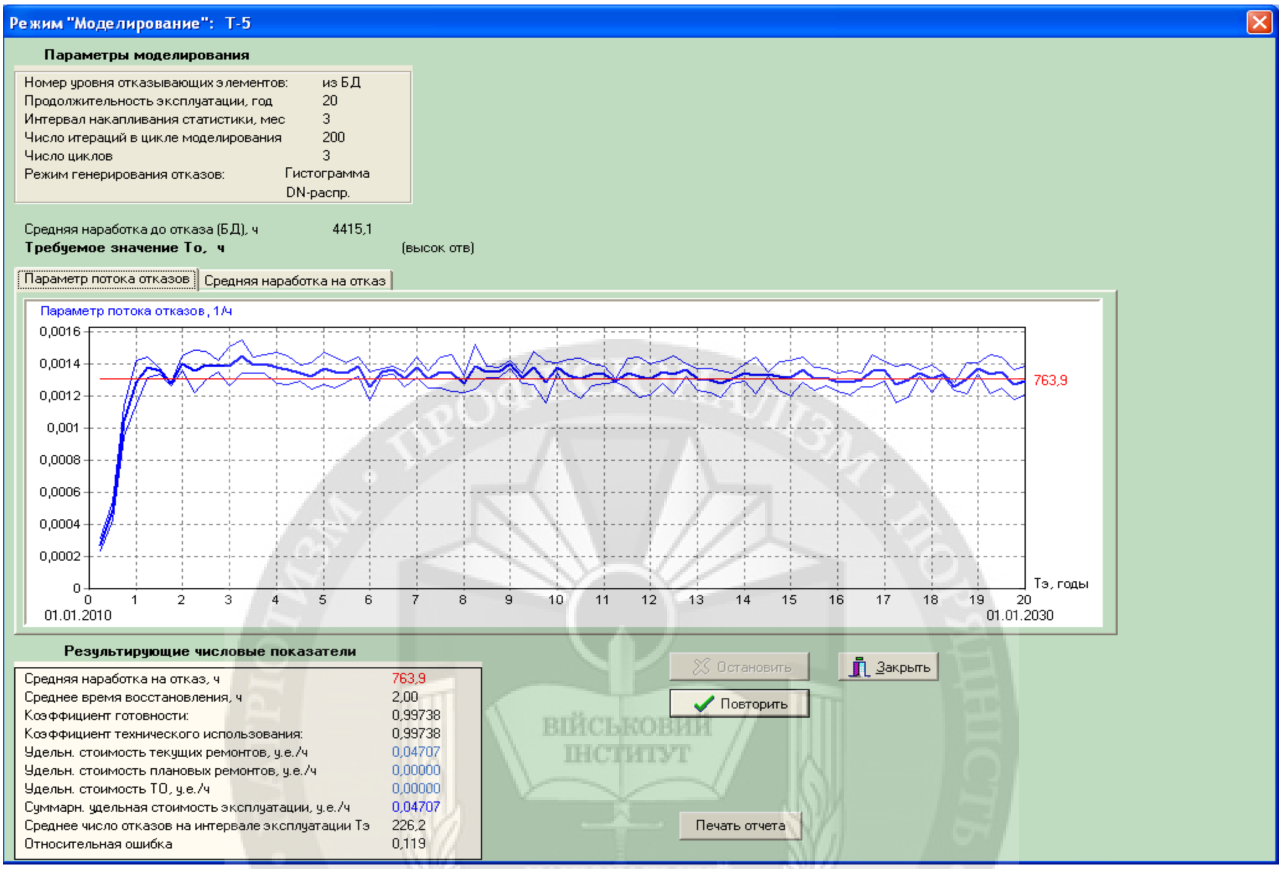

Fig. 6. Kind of the screen of the personal computer after end of modeling

On fig. 6 the results received for a case if MS and SR are not spent are shown. For this case we have received predicted value of an average time between failures $\widetilde{T}_0 \approx$ 760 hours.

To result and analyses results of modeling in view of MS and SR within the limits of one clause it is not obviously possible. Examples of modeling about MS and SR can be found in [6].

Accuracy and adequacy of the developed model was checked by results of modeling at the task экспоненциального distributions of a casual operating time to refusal of elements of object. Statistical accuracy of received estimations of parameters (a defined 95 %-s' confidential interval) essentially depends on number of refusals of object during the period $T_э$, and in most cases does not exceed 10-20 %.

Conclusions. Developed ISM MS is the effective tool for forecasting and the analysis of parameters of reliability and cost of operation of complex object RET in view of carrying out and so forth

In model in enough full measure parameters of the systems accepted for given object MS are considered both characteristics of object RET and SR. Model can be used both at a stage of creation of object RET, and at a stage of its operation.

ISM it can be used also at the decision of problems optimization of parameters MS and SR.

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Без рецензії.

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ПРОГНОЗИРОВАНИЕ НАДЕЖНОСТИ И СТОИМОСТИ ЭКСПЛУАТАЦИИ СЛОЖНЫХ ОБЪЕКТОВ РЭТ С УЧЕТОМ ИХ ТЕХНИЧЕСКОГО ОБСЛУЖИВАНИЯ И РЕМОНТА

Для прогнозирования показателей надежности и стоимости эксплуатации сложных объектов РЭТ с учетом их технического обслуживания и ремонта предлагается использовать имитационную статистическую модель. Введена система параметров для формального описания характеристик сложного объекта РЭТ и процессов технического обслуживания и ремонта (ТОиР). Для моделирования отказов используется диффузионное немонотонное распределение. Моделируются как текущие ремонты (восстановление работоспособности), так и плановые ремонты (восполнение ресурса). Моделируется техническое обслуживание «по состоянию».

Модель реализована в среде программирования Delphi. Приводится пример результатов моделирования.

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ПРОГНОЗУВАННЯ НАДІЙНОСТІ І ВАРТОСТІ ЕКСПЛУАТАЦІЇ СКЛАДНИХ ОБ'ЄКТІВ РЕТ З УРАХУВАННЯМ ЇХ ТЕХНІЧНОГО ОБСЛУГОВУВАННЯ ТА РЕМОНТУ

Для прогнозування показників надійності та вартості експлуатації складних об'єктів РЕТ з урахуванням їх технічного обслуговування і ремонту пропонується використовувати імітаційну статистичну модель. Введена система параметрів для формального опису характеристик складного об'єкта РЕТ і процесів технічного обслуговування і ремонту (ТОіР). Для моделювання відмов використовується диффузионное немонотонна розподіл. Моделюються як поточні ремонти (відновлення працездатності), так і планові ремонти (заповнення ресурсу). Моделюється технічне обслуговування «за станом».

Модель реалізована в середовищі програмування Delphi. Наводиться приклад результатів моделювання.