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Control System Simulation of Technical Equipment

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Abstract

Submission is concerned to complete information system about quality, operation, automatic testing using mechatronic system and new evaluating method of vehicle subsystem. Presentation of statistic significant group of tracing commercial cars is used. Data about operational parameters were taken from this group. Numeric analysis is realized on the base of automatic collection and systematic recording of commercial car operation. Proposed new information system about operation and trial process allows verification according to proposed method. Critical components verified in laboratory conditions are detected by numeric analysis of reliability. Trial method is described and also numerically compared in three levels. Quality level increasing not only for final product, but also related automatic test laboratory for cars is the result of these principles respecting. The model of technical system operation is proposed by estimating the level of its elements' reliability. Application of the repair cycle adaptive structure creates the basis of organizing the preventive maintenance and repair and increasing the operational efficiency of technical systems.

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Keywords: Technical systems; reliability; operational efficiency; preventive maintenance and repair; repair cycle.

1. Introduction

Tendency to ensure car's high technical and operational parameters, and consequently successful realisation of any difficult technical system and mechanism comes out from perfect knowledge of operational conditions, knowledge of operation - technical characteristics and parameters of own system. This fact conditions to increase requests for technical level of measurement, actual time of measure results, precision of measurement results, possibility of measurement results processing, level of measurement automation i.e. measurement as method of objective quantification of physical values, or about relation between two or higher number of physical values. Analysis of achieved results from solving and car security area in whole scale of connectivity and relations confirms, that the role of laboratory verification is not replaceable in new quality management system. Complete access problematic to the test questions in new quality management system, continually to car production concept is getting necessary and logic part of car production process and, as analysis of development trends in car industry shows, effect of solution in testing automation has objective need.

It is urgent now to increase the operational efficiency of complex technical systems (energy systems, transfer lines, etc.) [1]. One of the ways to increase the operational efficiency of complex technical systems is to minimize the cost of their maintenance and repair. The progressive method here is application of the strategy of the preventive maintenance and repair, which is based on using the results of statistical analysis information on operation, failures and replacement of components.

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It is rather difficult to apply such an approach in real-life environment in order to enhance the operation process. These difficulties are related to the fact, that the running time (distributed according to the known law) of the machine component is a random value and failures occur arbitrarily. This results in reality to the situation, when the system with many components will be standing idle because of the failure or prior-to-failure state of only one element.

2. Model of technical system operation

As practice shows, in order to reduce the number and time of idle stands, to increase the period of efficient operation of a technical system, it is reasonable to perform within one closedown the preventive repair works of a group of components with equal or multiple or close to multiple prior to failure running time periods [2-4]. At the same time the possibility appears here to perform repair works of separate elements simultaneously, thus reducing the idle stand time of the system and increasing the production output. Therefore, the operation model can be represented as follows.

The semi-Markovian process (SMP) is taken as the mathematical model, since distribution laws for running time and repair time of the technical system components can be arbitrary, that is, differ from the exponential character and the set of possible states is calculative. The sequence of states is random. Markovian properties will be revealed only at instants of transition from one state to the other.

Let us develop the transition probability matrix by the logical-and-probabilistic method.

At the fixed initial state the further time variation of the SMP is determined by the transition probability matrix $\|p_{ij}\|$ and the distribution function matrix (DF) $\|T_{ij}\|$, (T_{ij} is the time of system staying in the state ei if the next transmitted state of the system is e_j). At the initial instant the process is in the state e_0. Then, according to the distribution $\{p_{0j}\}$ the state of the process transition e_j is chosen. Here the time of SMP staying in the state e_0 is the random value with the distribution function $T_{0j}(t)$. At the new state e_j the process behaves similarly [5,6].

With account of possible states of the system, the dimension of the transition probability matrix will be [(n+1)(n+1)]. The matrix is stochastic, since transitions of the machine from one state to the other generate a complete group of events, that is, the sum of probabilities in each line must be always equal to one.

Let us consider a system of n sequentially connected components. Failure of any element causes the whole system failure. Possible state of the system can be as follows:

"0" – the system is operable, that is, all elements are correct;

"1" – one element of the system is incorrect, the system is inoperable;

"i" – several i elements of the system are incorrect, the system is inoperable;

"n" - all n elements are incorrect, the system is inoperable.

Fig. 1 present the state and transition graph of operating the repairable continuously acting system.

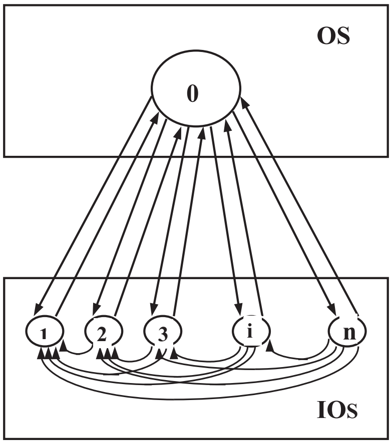

Fig. 1. State and transition graph for operating the continuously acting technical system.
OS is the set of operable states; IOS is the set of inoperable states.

As for the considered case, the transition probabilities within the time interval (t, t+Δt) will be expressed as follows:

1. If the system is in the state "0" at the time instant t, then it will remain here if no component fails within the interval (t, t+Δt). In this case, the probability of such a zero transition will be determined as follows:

$$P_{00}(\Delta t) = P_1(\Delta t) \cdot P_2(\Delta t) \ldots P_n(\Delta t) = \prod_{i=1}^{n} P_i(\Delta t) \quad (1)$$

2. If the system is in the state “0” at the time instant t, then when any i components fail within the time interval (t, t+Δt) it will transit to the state “i” with the probability:

$$P_{0i}(\Delta t)=\prod_{i=1}^{n}\left[1-p_i(\Delta t)\right] \tag{2}$$

3. If the system is in the state “i”, that is, it is being repaired, it will return to the initial state “0” during the time interval (t, t+Δt) with the probability (if the repair of all i components is finished):

$$P_{i0}(\Delta t)=\prod_{i=1}^{n}q_i(\Delta t) \tag{3}$$

4. If the system is in the state “i”, that is, all i components are being repaired, it will return to this state during the time interval (t, t+Δt) with the probability (if the repair of all i components is not finished):

$$P_{ii}(\Delta t)=\prod_{i=1}^{n}\left[1-q_i(\Delta t)\right] \tag{4}$$

5. If the system is in the state “i”, that is, all i components are being repaired, it can transit to the state j during the time interval (t, t+Δt) with the probability (if the repair of all j components is not finished):

$$P_{ij}(\Delta t)=\prod_{i=1}^{m}q_i(\Delta t)\prod_{j=1}^{k}\left[1-q_j(\Delta t)\right] \tag{5}$$

where:

m is the number of repaired components;

k is the number of unrepaired components.

The transition probability matrix is represented in Fig. 2.

$$\Pi(t)=\begin{vmatrix}
\prod_{i=1}^{n}P_i(\Delta t) & 1-P_1(\Delta t) & \dots & \prod_{i=1}^{k}\left[1-P_i(\Delta t)\right] & \dots & \prod_{i=1}^{n}\left[1-P_i(\Delta t)\right] \\
q_1(\Delta t) & \left[1-q_1(\Delta t)\right] & \dots & 0 & \dots & 0 \\
\dots & \dots & \dots & \dots & \dots & \dots \\
q_i(\Delta t) & \prod_{i=1}^{m}q_i(\Delta t)\cdot\left[1-q_1(\Delta t)\right] & \dots & \prod_{i=1}^{m}q_i(\Delta t)\cdot\prod_{j=1}^{k}\left[1-q_j(\Delta t)\right] & \dots & 0 \\
\dots & \dots & \dots & \dots & \dots & \dots \\
\prod_{i=1}^{n}q_i(\Delta t) & \prod_{i=1}^{m}q_i(\Delta t)\cdot\left[1-q_1(\Delta t)\right] & & \prod_{i=1}^{m}q_i(\Delta t)\cdot\prod_{j=1}^{k}\left[1-q_j(\Delta t)\right] & & \prod_{i=1}^{n}\left[1-q_i(\Delta t)\right]
\end{vmatrix}$$

Fig. 2. Transition probability matrix.

The matrix dimension is big and the rule of grouping the system elements according to their states is not determined.

3. Development of the repair cycle adaptive structure

We assume, that we know distribution laws for the running time up to the limiting state and the repair time for each system component. Depending on serviceability criteria, consequences of failure and operation experience, the lower boundary of the allowable probability for non-failure operation and units and parts repair is assigned. According to the known distribution law and limiting probability, values of gamma percentage prior to failure running time $t_{\gamma i}$ are calculated, characterizing indirectly the technical state and repair time of each component. The least running time is chosen from the totality of running time periods, and running time multipliers are determined according to the formula:

$$K_i^{©} = \frac{t_{\gamma i}}{t_{\gamma \min}} \tag{6}$$

where:

i = 1, 2, ..., n,

$t_{\gamma i}$ is the gamma percentage running time of the i-th element; $t_{\gamma min}$ is the minimum gamma percentage running time; K' is the calculated multiplier of the i-th element running time; n is the number of elements in the system.

The calculated multiplier value of the gamma percentage running time is rounded to the nearest least integer number according to operation experience, thus reducing the failure probability (degree of risk). Elements are further grouped according to the feature of equal multiplicity. They are multiplicities K=1; K=2; ...; K=K and they characterize the system state. The number of elements involved into each group will be different. Within such an approach the system operation can be considered as a discrete process, that is, within discrete (specific) time instants, multiple of $t_{\gamma min}$, the system transits to the state when elements of the group R will be considered as failed.

Since running time periods are random, then failure or replacement of certain components can appear within the time period Δt adjacent to the last repair. For these parts running time periods ti are calculated and added to the existing ones, statistical manipulation of supplemented arrays is performed, which can result either in variation of components running time $t_{\gamma i}$, or in variation of $t_{\gamma min}$. When the value $t_{\gamma min}$ is varied, the running time multiplier is recalculated. According to the obtained results, the repair schedule and repair services content are corrected. Such a correction of the periodicity and bulk of maintenance and repair is performed after the failure or repair of any component. Organization of maintenance and repair by the considered technique allows considering the technical state of components and the system as a whole based on their reliability factors. Repair periodicity and bulk are not constant here.

In operation of a continuously acting system, its running time intervals ($t_1, t_2, ..., t_n$) are alternated with repair time intervals ($\tau_1, \tau_2, ..., \tau_k$) and idle time intervals ($\tau_{01}, \tau_{02}, ..., \tau_{0r}$).

Adding the corresponding time intervals, one can obtain the total values of system running, repair and idle time periods within a certain interval. Evidently, that in our case the sum of intervals of running, repair and idle time periods is equal to the calendar time of operation.

$$t_k = \sum_{i=1}^{n} t_i + \sum_{i=1}^{k} \tau_i + \sum_{i=1}^{r} \tau_{oi} \tag{7}$$

where:

t_k is the calendar time of the system operation;

$\sum_{i=1}^{n} t_i$ is the sum of the machine running time periods;

$\sum_{i=1}^{k} \tau_i$ is the sum of the machine repair time periods;

$\sum_{i=1}^{r} \tau_{oi}$ is the sum of the machine idle time periods;

n, k, r are numbers of periods for operation, repair and idle time correspondingly.

Based on the given above considerations, one can obtain the labor consumption of the i-th repair as the sum of labor consumptions of replacements and repair of components involved into the repair group:

$$\tau_i = \sum_{j=1}^{r} Z_j \tau_{ij} \qquad (8)$$

where:

Z_j is the number of workers involved into repair or replacement of the j-th component;

τ_j is the time of replacement or repair of the j-th component; r is the number of components within the repair group.

As for operation of complex technical systems, prior to failure running time periods are of a random character. Hence, the value $t_{\gamma min}$ can be varied depending on the technical state of the element and its lifetime. In this connection, the time intervals Δt between preventive and repair works and contents of repair groups are variable. The information basis to implement the developed operation models is the statistical analysis of operation and repair data and diagnostics results. The proposed approach allows implementing the flexible adaptive structure of the repair cycle with account of components technical state (indirectly) for a wide range of technical systems.

4. Conclusions

The base for evaluation, formulate and parameters assurance of technical level, running quality and technical system reliability or its components, is knowledge of their technical and running parameters and running conditions. It is important knowing in operating mode, dynamic stress, the way of operating and use during running.

Quality requirements are increasing also requirements to function models laboratory testing, their parts, prototypes and their new components. This comes out of facts.

1. Fundamentals of developing the adaptive schedule of the technical system repair are proposed based on estimation of its components reliability level. The proposed principles and algorithms of determining the repair bulk based on multiplicity of the machine elements increase the operation efficiency of the equipment.

2. Semi-Markovian representations of the operation model implement the concept of the single technical system efficiency. Possibility of the concept implementation is grounded by the independence, unique character and complexity of technical systems.

3. Development of the adaptive strategy of maintenance and repair organization with account of estimating the technical state of structural elements provides the operation according to the state and maximum operation efficiency of the technical system.

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