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# Theoretical prerequisites in the organization of the construction of diagnostic systems, microprocessor blocks of the dialing group of railway automation and telemechanics

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Abstract: The given article gives information about the results of theoretical research in the organization of the construction of a diagnostic system, microprocessor-based blocks of the dial group used in railway automation and telemechanics. The products subject to study were made with the use of microcontroelectronic elements, microcontrollers and other electronic components using mathematical expressions to determine the criteria for evaluating the diagnostic process, were subject to research. A Petri net transition graph representing the diagnostic system of these blocks of a dial group has been developed and analyzed inside out to determine the readiness indicator.
Keywords: Railway automation and telemechanics, microcontrollers, diagnostics, availability coefficient

## 1. Introduction

Reserves to increase the efficiency of technical means of railway automation and telemechanics are laid down in the organization of their operation and maintenance as needed. In this case, the need for technical maintenance of objects is determined by their current condition, and not by the operating time or expired service life, according to the accompanying documentation, which is associated with the need to monitor their condition. It is clear that actions to assess the condition of technical objects are called diagnostics.

The current level of technology development provides grounds for the wide use of programmable microcontrollers in automatic systems; there are opportunities for developing and using fully automatic diagnostic systems, which is very important for the conditions of railway transport, with its high requirements for ensuring safe train traffic [1,4]. At the same time, the features of the technological process of railway transport allow performing diagnostic operations in the period between route assignments, which is usually calculated in the period from 8 to 10 minutes, i.e. during this period of time, the devices of the blocks that form the starting circuits of the switches are in the standby mode. The use of microelectronic technologies in the block of the dialing group for controlling the starting circuits of the switches of the route relay interlocking system allow using built-in programmable devices not only to form starting circuits, but also to assign diagnostic functions to them, i.e. to carry out diagnostic operations in the period between train operations.

## 2. Research methodology

In the case when the diagnostic process takes into account the specifics of the technological process of a railway station, namely the train schedule, as much as possible, then one can count on the high efficiency of the diagnostic process, which in turn requires a thorough analysis of the list of the state of its equipment, the algorithm for the operation of the block elements in the period between route assignments.

It is known [6-12] that the diagnostic process can be represented from several stages. At the first stage, it is supposed to consider the diagnostic process taking into account the selected criteria and on their basis the requirements for the algorithms of the diagnostic process are determined.

At the second stage, the microcontroller software is developed [4], based on the analysis of the selected evaluation criteria.

Finally, at the third stage, an analysis of the effectiveness of diagnostics and its software is carried out [5,12.

Let us evaluate the efficiency of the diagnostic process of the elements of the starting circuits of the point electric drives of the set group of the block route relay interlocking system, namely the NPS block. As a criterion for evaluating the interaction of the diagnostic elements, we will use the probability of the absence of a defect at an arbitrary point in time when the block is in working condition (the process of setting routes, switching points, or during the period of absence of a route assignment). This criterion is called the indicator of product readiness and is designated as $K_Г$ [13,14,15], it will be fair to assume that this indicator is directly dependent on the total probability of the presence of the elements of the starting circuit block of the set group at an arbitrary point in time.

In practice, an indicator close to the availability factor is often used - the utilization factor ($К_И$). ($К_И$) This is the probability that at any given moment in time $t$ it is possible to find an object in working condition. In this case, the condition must be met that all those serviceable objects that, according to the schedule, should be taken out for preventive maintenance and are not currently being used are excluded from the work cycle. Statistically, the utilization factor $K_И(t)$ is interpreted by the expression [13,14]

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$$K_И(t) = \frac{\sum_{r=1}^{l} T_{pr}}{\sum_{r=1}^{l} T_{pr} + \sum_{j=1}^{m} T_{nj} + \sum_{i=1}^{n} T_i},$$

where is $n$ −the number of failures of the switch starting circuit unit in the time interval $(0, t)$;

$m$ −the number of preventive maintenance in the time interval $(0, t)$, is determined by the schedule of technical maintenance of railway automation and telemetry devices ;

$l$ −the number of working cycles in the time interval $(0, t)$, is determined by the train schedule;

$T_{PR}$ −the time of maintaining the operability of the object in $R$ −the m cycle;

$T_{nj}$ −the duration $j$ −of the th check;

$T_i$ −the duration of repair after $i$ −the th failure of the object. It should be borne in mind that in the ideal case $K_И(t) \to 1$, due to the fact that

$$(\sum_{j=1}^{m} T_{nj} + \sum_{i=1}^{n} T_i) \to 0$$

Let's define the numerical values, for example, the time interval $(0, t)$ for the blocks of the dial group can reach several years, the variable$n$ is determined by the results of statistical observation, $m$ −is determined by the standard values of preventive maintenance, blocks of the dial group, $T_{Pr}$is determined by the results of statistical analysis, the numerical values of the variables $T_{nj}$and $T_i$are determined by regulatory documents on the implementation of preventive maintenance and equipment repair, the variable $l$ is determined by the intensity of the station operation, assuming that during the year with a time interval of 8-10 minutes routes will be set, this variable can reach values from $(24 \times 365 \times 60)/8 = 65700$to 52560 cycles.

The operating mode of the device of the dial group of the block route centralization system is periodic and can be diagnosed during the period of absence of movement of trains at the station, i.e. in a special mode, this operation can be performed using ideally reliable technical means. The graph of transitions of the diagnostic system from state to state, made on the basis of the theory of Petri nets, is shown in Fig. 1 [3]. The graph positions represent the following states: 1- the object is used for its intended purpose and there are no defects in it; 2- the dial block is used for its intended purpose and a defect has occurred in it, which did not lead to a failure; 3- the tested device is in the diagnostic mode, when a failure occurs in it, which is eliminated; 4- a failure of the dial block has occurred, which is restored.

In the graph, as positions that are not indicated in Fig. 1, the following are used$\lambda_0$ and $\gamma_0$- the failure rate and restoration of the starting point block of the dial group; $\mu$ - the testability of this block; $\nu$ −the organization of diagnostics.

The readiness indicator for this case is estimated by the probability of the object being in the state (position) “1” ( $r = 1$) and is calculated using formula (1).

$$K_Г = \nu/[(1/\mu)\nu^2 + (1 + \lambda/\mu)\nu + \lambda]. \quad (1)$$

From expressions (1) it is evident that the indicator of the readiness of the diagnostic system of the blocks of the assembly group depends on the organization of diagnostics $\nu$, the intensity of occurrence of defects and failures of the object $\lambda$and $\lambda_0$, as well as its testability $\mu$, i.e. more fully characterizes the proposed diagnostic system.

Let us consider the procedure for changing the state of a diagnostic object, performed on the basis of a Petri net graph.

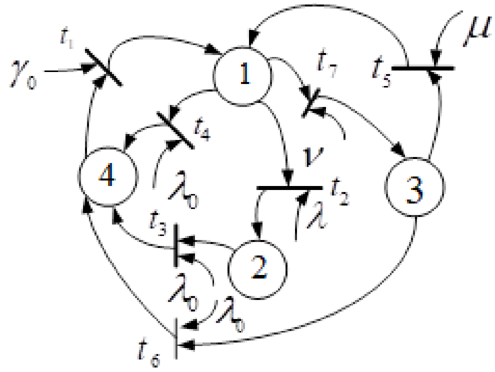


**Fig. 1. Graph of transitions of the diagnostic system of the set group blocks, for determining the readiness indicator**

$$\begin{gathered} I(1) = \{t_1, t_5\}; O(1) = \{t_4, t_7, t_2\}; \\ I(2) = \{t_2\}; O(2) = \{t_3\}; \\ I(3) = \{t_7\}; O(3) = \{t_5, t_6\}; \\ I(4) = \{t_3, t_4, t_6\}; O(4) = \{t_1\}; \\ I(t_1) = \{\gamma_0, 4\}; O(t_1) = \{1\}; \\ I(t_2) = \{\lambda, 1\}; O(t_2) = \{2\}; \\ I(t_3) = \{2, \lambda_0\}; O(t_3) = \{4\}; \\ I(t_4) = \{\lambda_0, 1\}; O(t_4) = \{4\}; \\ I(t_5) = \{\mu, 3\}; O(t_5) = \{1\}; \\ I(t_6) = \{\lambda_0, 3\}; O(t_6) = \{4\}; \\ I(t_7) = \{\nu, 1\}; O(t_7) = \{3\}. \end{gathered} \quad (2)$$

According to the system of equations (2), the starting switch block of the dial group is in a normal, serviceable working condition, i.e. the process of setting or opening the route is in progress, “1” can go to another state "3" when the transition conditions are met $t_7$, i.e. depends on the diagnostics organization according to the variable $\nu$, which facilitates the system transition to position "3", and it is also possible to change the state upon transition $t_4$in accordance with the indicators of the intensity of occurrence of defects of the dial starting point blocks $\lambda_0$, which facilitates the system transition to position "4", in addition, the system can go to position "2", upon transition $t_2$in accordance with the indicators of the intensity of occurrence of failures of the dial blocks $\lambda$ . The elements that ensure the fulfillment of the conditions of transitions from one state to another are variables $t_i$where $i = 7$, let us consider the values of these variables: the input function of the variable $t_1$is the expression $I(t_1) = \{\gamma_0, «4»\}$ from which it follows that, taking into account the intensity of restoration of the starting point block of the dial group, $\gamma_0$the device from the state with the presence of failure "4", after restoration will go to normal operation; the variable $t_2$input effects of which are described by the formula $I(t_2) = \{\lambda, «1»\}$ from which it follows that in the presence of the value of the intensity of occurrence of defects of the dial group block, the device is able to go from the normal operating state "1" to position "2" when a defect occurs in the device; variable $t_3$input actions, which is described by the formula $I(t_3) = \{«2», \lambda_0\}$from which it follows that, taking into account the intensities of occurrence of failures of the starting point block of the dial group and according to its output function, $O(t_3) = \{«4»\}$ the diagnosed device will go from state "2" when the starting point block is used for its intended purpose and a defect has occurred in it, will go to state "4" corresponding to the presence of a failure in the diagnosed device; the variable $t_4$is determined by the input function $I(t_4) = \{\lambda_0, «1»\}$ from which it follows that when the diagnostic object is in position "1" and in the presence of a variable intensity of occurrence of defects of the starting point block $\lambda_0$, the diagnosed object, according to the output function, $O(t_4) = \{«4»\}$ must move to position "4"; the variable, $t_5$in accordance with its input function , is capable of changing the state of the diagnosed object and, in the presence of $I(t_5) = \{\mu, «3»\}$ the testability $\mu$component , transfer the diagnosed object, according to the output function, $O(t_5) = \{«1»\}$ from the state of the object in the diagnostic mode, when a defect (which is eliminated) occurs in it, to position "1"; variable $t_6$in accordance with its input function $I(t_6) = \{\lambda_0, «3»\}$ in the presence of a known variable intensity of occurrence of defects of the dial blocks $\lambda_0$, capable of transferring the diagnosed object from the state in the diagnostic mode, when a defect occurs in it, which is eliminated, to position "4", corresponding to the presence of a failure in the dial block; variable $t_7$in accordance with its input function $I(t_7) = \{\nu, «1»\}$ in the presence of a component reflecting the organization of diagnostics $\nu$, according to the output function $O(t_7) = \{«3»\}$. the device will go to the state of the diagnostic mode, starting point block of the dial group. The exit of the characteristics of the elements of the starting point block beyond the boundaries of the region, limiting the space of permissible deviations, gives grounds to assume the probability of failure. The time interval determining the moment before the first intersection of the boundaries of the region with the operating parameters is a random variable, the probability of the value of which corresponds to the Gaussian distribution law, which characterizes the reliability indicators of the starting point block of the dial group.

Another pressing issue is determining how often the diagnostic procedure needs to be carried out.

To calculate the frequency of diagnosis, the following expressions are proposed

in [6, 9]:

$$\nu_0 = 1/T_{ОПТ} = \sqrt{\lambda/\tau_Д} - \xi;$$

$$R = R_P/R_Д,$$

$$\lambda_\Sigma = \lambda + R\lambda^{'}$$

$$\nu_0 = \sqrt{\frac{\lambda_\Sigma}{\tau_Д}(1+R)},$$

where is $\nu_0$ –the frequency of diagnosis;

$T_{ОПТ}$ –period of optimal interrogation of the diagnosed unit;

$\lambda$ –failure rate of block elements;

$\tau_Д$ –time of diagnostics of the starting pointer block;

$\xi$ –intensity of use of the starting point block (number of pointer movements per day);

$R_P$ –probability of the presence of the starting switch block during the period of route assignment (probability of switching switches)

$R_Д$ –probability of block presence during the period of no route assignment

$\lambda^{'}$ –the rate of failures during the period when there is no need to change the direction of the switches and defects in the diagnostic device in standby mode.

If periodically, with a constant period of time (T), with the help of reliable microelectronic means, in a special mode, diagnostics of the elements of the starting point block of the dial group is performed, provided that it is in the mode of constant use, then the process of interaction of the diagnostic elements can be in one of three positions, namely, the blocks of the dial group are in the operating mode, a defect is possible in them; the diagnosed block is in good condition; the constituent elements are in the diagnostic state and, based on the results of this action, are restored, if necessary. In this case, the mathematical formula for determining the probability of a failure in the starting point block for the time interval T will take the form

$$F(T) = 0.5 + \int_m^T \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{(t-m)^2}{2\sigma^2}\right] dt, \quad (3)$$

where and $m$ $\sigma$ - mathematical expectation and standard deviation of the random variable of time until a failure occurs in the diagnosed device.

It is known [8] that a semi-Markov process is a random process that changes its states in accordance with a previously known probability distribution law, while the time spent by a random process in one of the states is also a random characteristic, the distribution law of which depends on both the current state and the state to which it will move at the next moment in time.

The following postulates are taken as the basis for constructing a model, which allow us to consider the functioning of the blocks of the set group of the route centralization system as semi-Markovian:

- the change in the states of the blocks of the set group occurs randomly (stochastic process);
- the change of states and the duration of the presence of elements of the assembly group is provided by two independent sets of flows with arbitrary probability distributions (the time of transition from the waiting state to the working state is random, the time spent in the working state is also random, since it depends on the type of route, the number of switches in the route);
- statistical properties of the processes of the blocks of the dialing group, occurring in the process of their change (setting or canceling routes) and determining the time the system stays in states, which is determined by the time of action of the station duty officer, during the period of setting or canceling routes, and do not depend on the number of already established routes (the system is homogeneous) and on the method of the system getting into each of the possible states;
- actions during which the state of system elements changes when performing control functions, which occurs within a period of time equal to several seconds.

Using the apparatus of the theory of semi-Markov processes, we obtain an expression for determining the readiness coefficient

$$K_Г = \omega_1(T + [1 - F(T)]\tau_Д + F(T)\tau_B, \quad (4)$$

where is $\tau_Д$ –testability ;

$\tau_B$ –maintainability;

$\omega_1$ –the average time an object remains in good working order over a period of time $T$, we obtain from the following expression

$$\omega_1 = \int_0^T [1 - F(t)]\, dt \qquad (5)$$

Using expression (3) in formulas (4) and (5) and due to the fact that the probability of a malfunction in the blocks of the assembly group is negligibly small, we obtain

$$K_\Gamma = \frac{m - 3\sigma + \int\limits_{m-3\sigma}^{T} \left\{ 0.5 - \frac{1}{\sigma\sqrt{2\pi}} \int\limits_{m}^{t} \exp\left[ -\frac{(t-m)^2}{2\sigma^2} \right] dt \right\} dt}{T + 0.5(\tau_B + \tau_Д) + \frac{(\tau_B - \tau_Д)}{\sigma\sqrt{2\pi}} \int\limits_{m}^{T} \exp\left[ -\frac{(t-m)^2}{2\sigma^2} \right] dt} \qquad (6)$$

Expression (6) reflects the dependence $K_\Gamma$on the indicators of testability $\tau_Д$; maintainability $\tau_B$; failure-free operation $m$, $\sigma$and diagnostic frequency $T$.

The approximate value of the optimal diagnostic period, at which the maximum is achieved $K_\Gamma$, can be calculated using the formula

$$T_{ОПТ} = -x + \sqrt{(x+m)^2 + \sqrt{2\pi}\sigma(x-m) - 1.5\sigma^2},$$

Where

$$x = \frac{\sqrt{2\pi\sigma(\tau_Д + \tau_B) - 2m(\tau_B - \tau_Д)}}{2(\sqrt{2\pi}\sigma + \tau_B - \tau_Д)}$$

## 3. Conclusion

The study proposes the method of analysis, organization and construction of the diagnostic system of the railway automation and telemechanics dialing group units taking into account the use of an individual programmable microcontroller in each unit. The introduction of additional diagnostic functions into the controller software required a change in the principles of construction of maintenance of these devices by signaling and communication distance workers. The application of the diagnostic procedure assumes the use of an automatic system, since it excludes the functions performed by specialists, the known criteria for assessing the diagnostic system based on the use of known statistical characteristics of the dialing block devices are considered. As a result of the analysis of the functioning of the block route centralization system, mathematical expressions were obtained to determine the criteria for assessing the diagnostic process. A transition graph of the diagnostic system of the starting point unit of the dialing group was developed and analyzed to determine the readiness indicator. The method for obtaining the readiness coefficient $K_\Gamma$ and its mathematical expression using the apparatus of semi-Markov processes under the law of distribution of time before failures (Gaussian) is of a general nature and therefore can be used with other initial data. The above method allows one to calculate the maximum value with sufficient reliability$K_\Gamma$ and the corresponding optimal diagnostic period for different values of statistical indicators. Analysis of the results obtained for $K_\Gamma$ expression allows us to determine the dependence of this indicator on the variables $\tau_Д$, $\tau_B$, reliability and diagnostic frequency.

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