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METROLOGICAL ASPECTS OF ENSURING MEASUREMENTS IN RAILWAY ROLLING STOCK PROJECTS

The problems of obtaining reliable information in online mode about the technical condition of rolling stock are considered. It was determined that obtaining such information is possible thanks to the use of a system for monitoring the parameters of the condition of the rolling stock using technical means that carry out measurements based on metrological support.

It is known that one of the main tasks of railway transport is the safety of traffic, which can be ensured by using a parameter monitoring system to maintain and restore the efficiency, reliability and reduce operational costs of rolling stock.

The paper presents the metrological aspects of providing measurements of rolling stock parameters by the statistical method of calculating verification intervals, which allows to determine control errors based on the available initial data in the form of specified error intervals of measuring devices.

A detailed description of the method and, accordingly, the results of using the method to determine the dependence of the average risk of verification and the dependence of the ratio of the value of the optimal control tolerance on the estimation of the error of the measuring device being verified to the limit of its permissible error on the ratio of losses due to false and undetected failures are presented, in a graphical form.

Keywords: *metrological support, system, monitoring, rolling stock, method, means of measurement.*

Introduction. One of the main tasks of railway transport is ensuring the safety of train traffic, which is faced by all divisions of railway transport. Improving the safety of train traffic and preventing accidents is possible through the use of measures to diagnose and control parameters of the technical conditions of both individual parts of the rolling stock and individual parts. To ensure the implementation of these measures in order to increase these measures, it is necessary to perform an analysis of technical capabilities and metrological characteristics.

Ensuring the reliability and safety of the means of railway transport, the economic efficiency of their use are important tasks, both at the stage of manufacture and in the conditions of operation. A large place in the production activity of railway transport is occupied by work related to the maintenance and restoration of the working capacity of rolling stock, which are accompanied by metrological support of parameter measurements. Thanks to the use of monitoring systems with the use of technical means and information-measuring systems, it is possible to ensure the process of measuring the parameters of the components of the rolling stock with their further processing to obtain results regarding taking further actions to ensure the trouble-free operation of the rolling stock [1].

In GOST 16263-70, at one time, an almost similar definition of measurement was regulated, namely as «finding the value of a physical quantity experimentally with the help of special technical means».

Organized multiple measurement, in our study, is used only as the basis of the concept of "monitoring". The measurement is carried out to compare the measured value with a measure that stores and reproduces a certain physical value of the given value.

Analysis of recent research and problem statement. The peculiarity of the monitoring measurement is that it requires not one measurement, but a certain set of measurements organized in a certain way. This makes it possible not only to obtain the value of the value of the monitoring indicator, but to conduct a certain observation of it. Registration of monitoring measurement results is particularly important for their ongoing use in on-line mode and often, in addition, also in real time. But, it is also important for retrospective analysis and forecasting [2-4]. Therefore, another feature of monitoring measurement is the mandatory storage of received and registered monitoring information for a given time. For purposeful and convenient use of the results of monitoring measurement, it is necessary to organize, in accordance with the purpose of the measurement, meaningful storage of the received information in a certain way - in the form of organized files, databases and knowledge bases.

The next, no less important, feature of the monitoring measurement is the presence in the monitoring system, along with the measurement subsystem, which allows direct measurement of the value, as well as the computing or analysis subsystem, which provides a large volume of indirect measurements, which allows not only to organize observations, but also to assess the state of monitoring object, which allows solving a number of monitoring tasks: control, diagnosis and others.

The purpose and tasks of the study. The purpose of the study is to improve the system of measuring the parameters of the rolling stock of railway transport by using the monitoring system in order to obtain reliable information about the technical condition of the rolling stock, ensuring the reliability of operation and the safety of transportation.

Research objectives: 1. To analyze the task of obtaining information on measurement parameters of the technical condition of rolling stock using the monitoring system. 2. Investigate metrological support of means of measuring the parameters of the technical condition of rolling stock. 3. To propose a method of metrological provision of measuring devices, which are a component of the monitoring system, with the help of which it is possible to reduce the interverification interval. 4. To present the results of the application of the method of metrological support for measuring devices..

Research materials and methods. The introduction of maintenance and repair of rolling stock, taking into account its actual technical condition, should be based on comprehensive and reliable information about the parameters of rolling stock equipment. The most effective way to obtain it is the use of a monitoring system using information measuring systems, microprocessor technology, personal computers and automated workplaces, which will necessarily lead to improved reliability indicators and lower operating costs.

According to its structure and functions, the process of monitoring rolling stock units can be conditionally divided into [5]: external, which is associated with telecommunication means of transmitting on-board data; internal (board).

Internal monitoring is provided by systems of collection, processing and application of on-board information to ensure effective management of rolling stock, without further use in logistics systems. External monitoring is the process of remote monitoring of the parameters and condition of the rolling stock, its direction of movement, speed and location, absence of emergency situations, etc. Internal monitoring is developing in several directions in a decentralized manner, gradually combining into a single on-board computer system. The use of monitoring systems makes it possible to move from preventive periodic diagnostics to constant control and analysis of the state of mechanisms and nodes, which, thanks to the timely elimination of malfunctions, allows you to save a lot of money, reduce the time and cost of repairs.

When developing (designing) a monitoring system, it is necessary to solve the problem of establishing inter-verification intervals for measuring devices [6-8], which are part of the system.

Let's consider the statistical method of calculating inter-verification intervals, which allows to determine control errors of the first and second kind based on the initial data available to the system developer in the form of specified error intervals of measuring devices [9, 18].

We assume that the error of a collection of the same type of measuring devices is a random function of time, and the errors are its realizations. Therefore, the verification of measurement tools from the point of view of statistical decision theory can be considered as testing a complex hypothesis against a complex alternative [10]. According to this approach, the quality of verification is characterized by an average risk, the expression for which, in the absence of losses with correct decisions, has the form:

$$R = C_1 P_{fr} + C_2 P_{uf}, \tag{1}$$

where P_{fr} and P_{uf} according to the probability of false and undetected failure; C_1 *and* C_2 – respectively, losses from erroneous and undetected failures.

Erroneous decisions made during verification are mainly due to two reasons: firstly, the final accuracy of the sample measuring devices and, secondly, the error of those recognized as suitable for use exceeding the permissible limit in the interverification period of operation. The error caused by the first cause can be called an instrumental error, and the second - a forecast error.

Next, we will determine the probabilities [11] of wrong decisionsP_{fr} and P_{uf}. We denote by G the event, which consists in the fact that the error of the measurement means during the inter-verification interval is within the permissible limits, by F - the event, which consists in the fact that at the moment of time the error estimate, as representing some function of the errors, is believed, and of the standard measuring instrument is within the control tolerance .

Then the probabilities of false and undetected failure:

$$P_{пв} = P\{G\bar{F}\} = P\{G\} - P\{GF\}, \tag{2}$$

$$P_{нв} = P\{\bar{G}F\} = P\{F\} - P\{GF\}. \tag{3}$$

Expressions for probabilities included in the right-hand side of Fq. (2) and Fq. (3) have the form:

$$P\{G\} = \int_{-\Delta}^{\Delta} W(T/\eta_0)\psi(\eta_0)d\eta_0, \tag{4}$$

$$P\{F\} = \int_{-\Delta}^{\Delta} \psi(\hat{\eta})d\hat{\eta}, \tag{5}$$

$$P\{GF\} = \int_{-\Delta}^{\Delta} W(T/\eta_0)\psi(\eta_0)d\eta_0 \left[\int_{-\Delta_k}^{\Delta_k} \psi(\hat{\eta}/\eta_0)d\hat{\eta}\right]d\eta_0. \tag{6}$$

where $\psi(\eta_0)$ – the density of the probability of error believed at the time of verification; $\psi(\hat{\eta})$– the probability density of the estimation of the error of the measuring means being verified at the time of verification; $\psi(\hat{\eta}/\eta_0)$ – conditional probability density of the error estimate at a fixed error, which are believed at the time of verification.

It is known [12, 13] that the best verification quality, i.e. the minimum average risk, can be achieved if the following solution rule is used: measuring means are considered suitable for use if the probability that the error of the verified measuring means will not exceed the permissible limits for time t, provided that the value of the error estimate obtained during verification is equal:

$$P\left\{\eta(t)\in\left[-\triangle,\triangle\right],t\in\left[0,T\right]/\hat{\eta}\right\}\geq\frac{C_2}{C_1+C_2}. \tag{7}$$

Using the Bayes formula and using Fq. (6), we get:

$$P\left\{\eta(t)\in\left[-\triangle,\triangle\right],t\in\left[0,T\right]/\eta\right\}=\int_{-\triangle}^{\triangle}W(T/\eta_0)\psi_1(\eta_0/\hat{\eta})d\eta_0, \tag{8}$$

where – $\psi(\eta_0/\hat{\eta})$ posterior probability density of the error probability of the measuring means to be believed at a fixed estimate at the time of verification.

The method of finding the probability *P*, by Fq. (6) – (8), with arbitrary probabilistic characteristics of a random function leads to very complex and therefore unacceptable calculations in engineering practice. However, the problem is significantly simplified if the apparatus of the theory of Markov processes is applied to it. The problem [14] of determining the probability is solved for a normal stationary random function that has a correlation function and a mathematical expectation. With constant coefficients, the expression obtained in it has the form:

$$W(T/\eta_0)=\left\{2_{\sigma}^{\triangle}\sum_{j=1}^{\infty}a_je^{-\lambda_j\alpha T}F_1\left(-\lambda_j/2;1/2;\eta_0^2/2\sigma^2\right)\right\}\ if\ \left|\eta_0\right|\leq 0\ \ if\ \left|\eta_0\right|>0 \tag{9}$$

where $2_{\sigma}^{\triangle}\sum_{j=1}^{\infty}a_je^{-\lambda_j\alpha T}F_1\left(-\lambda_j/2;1/2;\eta_0^2/2\sigma^2\right)$ degenerate hypergeometric function. Fq. (9) converges quickly and for practical calculations it is sufficient to use one or two of its terms.

Fq. (7) boils down to establishing the optimal control [15-17] (warning) tolerance for the estimation of the error that are believed, then the value is defined as the root of the equation:

$$\int_{-\triangle}^{\triangle}W(T/\eta_0)\psi_1(\eta_0/\triangle_{KO})d\eta_0=\frac{C_2}{C_1+C_2}. \tag{10}$$

Next, the problem of finding such a maximum confidence interval for a measuring instrument is solved, for which the average risk minimized according to rule by Fq. (7) would not exceed the permissible value, that is, it is necessary to determine T_0:

$$T_0=\max T\quad if\quad \min_{\triangle_K}R\left(\triangle_K,T\right)\leq R_D. \tag{11}$$

The initial data for the calculation are the values themselves, which are the probabilistic characteristics of the means to be believed. Since the analysis of the analysis of the function shows that it is increasing. From this it follows that the task is reduced to solving a system of transcendental equations, one of which is Eq. (10), and the second is the following equation:

$$C_1P_{fr}(T_0,\triangle_{KO})+C_2P_{uf}(T_0,\triangle_{KO})=R_D. \tag{12}$$

For the convenience of calculations, we introduce dimensionless quantities:

$$\theta = \alpha T_0, \quad r = \frac{\triangle}{\sigma}; \quad z = \frac{\sigma_1}{\sigma}, \quad k = \frac{\triangle_{KO}}{\triangle}, \quad q = \frac{C_1}{C_2}.$$

Then:

$$R_Y = \left\{ \begin{aligned} &\frac{R_D}{C_2} = qP_{rf} + P_{uf} \quad if \quad q \le 1, \\ &\frac{R_D}{C_1} = P_{rf} + \frac{P_{uf}}{q} \quad if \quad q > 1, \end{aligned} \right\}. \tag{13}$$

The value can be called the specific average risk. Then, under the accepted assumptions, the system of transcendental Eq. (10) - (11) takes the form:

$$\begin{cases} r\sqrt{\dfrac{2}{\pi}\left(1+\dfrac{1}{z^2}\right)}\displaystyle\int_{-r}^{r} W(\theta, x) e^{-\frac{\left[x(1+z^2)-rk\right]^2}{2z^2\left(1+z^2\right)}} dx - \dfrac{1}{1+q} = 0, \\ r\sqrt{\dfrac{2}{\pi}}\displaystyle\int_{-r}^{r} W(\theta, x) e^{-\frac{x^2}{2}} dx + 2\Phi_0\left(\dfrac{rk}{\sqrt{1+z^2}}\right) - \\ -2r\sqrt{\dfrac{2}{\pi}}\displaystyle\int_{-r}^{r} W(\theta, x) e^{-\frac{x^2}{2}} \left[\Phi_0\left(\dfrac{rk+x}{z}\right) + \Phi_0\left(\dfrac{rk-x}{z}\right)\right] dx - R_Y = 0 \end{cases} \tag{14}$$

where – $2\Phi_0\left(\dfrac{rk}{\sqrt{1+z^2}}\right)$ normalized Laplace function**.**

Eq. (14) meets the requirements of most metrological standards in the range of specified values. As a result of the calculations, graphs were constructed (fig. 1 and fig. 2), which allow to determine the dependence of the average verification risk on the ratio of losses due to erroneous and undetected failures for different values of the maximum interverification interval and the dependence of the ratio of the value of the optimal control tolerance on the error estimate based on the specified values of the instrument being verified, to the limit of its permissible error from the ratio of losses under erroneous and undetected failure for different values of the maximum interverification interval.

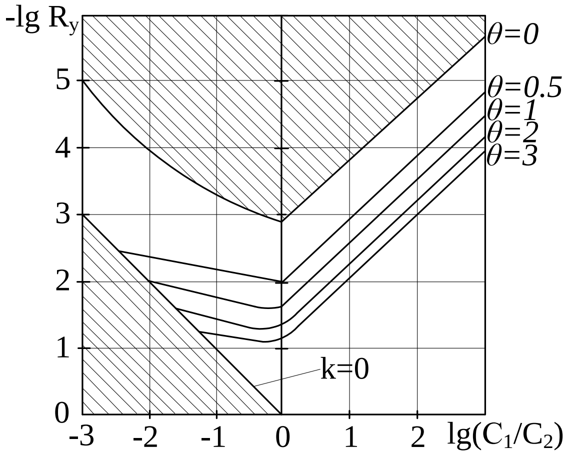

Fig. 1. **Dependence of the average verification risk on the ratio of losses due to false and undetected failures for different values of the maximum interverification interval**

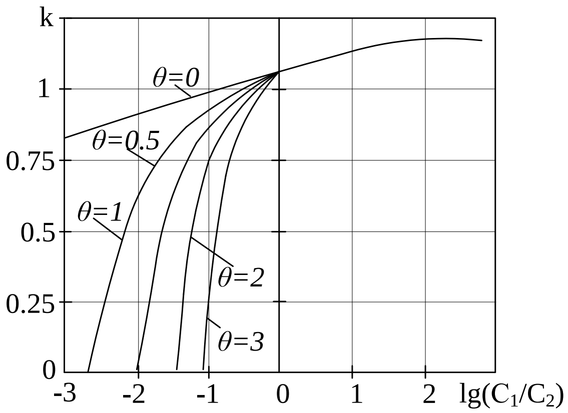

Fig. 2. **Dependence of the ratio of the value of the optimal control tolerance for the estimation of the error of the measuring instrument being verified to the limit of its permissible error on the ratio of losses due to erroneous and undetected failures for different values of the maximum interverification interval**

In the shaded areas in fig. 1 solution of system Eq. (14) is missing. The lack of a solution in the area located above the curve is due to the finite accuracy of the sample means, and the curve itself corresponds to the minimum possible average risk. The shaded area in the lower left corner is bounded by the curve. This means that when entering this area, the a priori risk corresponding to the recognition of the unsuitability of measuring tools without verification will be minimal:

$$R_{\min} = R_{apr} = C_1 \int_{-\Delta}^{\Delta} \varphi(\eta_0) d\eta_0 \tag{15}$$

The statistical method for estimating the inter-verification intervals of measuring instruments considered in the work is the basis for establishing and optimizing [19] the inter-verification interval for the monitoring system of rolling stock parameters of railway transport.

Conclusion. The problem of obtaining information on measuring the technical condition of rolling stock was analyzed. It has been studied that obtaining information is provided thanks to the means of measurement, which are a component of the rolling stock parameters monitoring system. Since it is necessary to receive information in real time, metrological support of measuring instruments is necessary. To improve the system, we used a static method of calculating inter-verification intervals, which allows, based on the available initial data in the form of specified error intervals of measuring instruments, to determine control errors, which will allow to reduce the inter-verification interval.

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МЕТРОЛОГІЧНІ АСПЕКТИ ЗАБЕЗПЕЧЕННЯ ВИМІРЮВАНЬ В ПРОЄКТАХ РУХОМОГО СКЛАДУ ЗАЛІЗНИЧНОГО ТРАНСПОРТУ

Розглянуто проблеми отримання достовірної інформації в on-line режимі про технічний стан рухомого складу. Визначено, що отримання такої інформації можливо завдяки використанню системи моніторингу параметрів стану рухомого складу з використання технічних засобів, які проводять вимірювання на основі метрологічного забезпечення.

Відомо, що однієї з головних задач залізничного транспорту є безпека руху, що можливо забезпечити, використовуючи систему моніторингу параметрів для підтриманням і відновлення працездатності, надійності та зменшення експлуатаційних витрат рухомого складу.

В роботі наведені метрологічні аспекти забезпечення вимірювань параметрів рухомого складу статистичним методом розрахунку міжповірочних інтервалів, що дозволяє за наявними вихідними даними у вигляді заданих інтервалів помилок вимірювальних засобів визначити помилки контролю.

Представлено детальний опис методу та відповідно результати використання методу для визначення залежності середнього ризику повірки та залежності співвідношення значення оптимального контрольного допуску на оцінку похибки засобу вимірювання, що повіряється, до межі його допустимої похибки від співвідношення втрат за помилкової та невиявленої відмов, в графічному вигляді.

Ключові слова: *метрологічне забезпечення, система, моніторинг, рухомий склад, метод, засоби вимірювання.*