PROBABILISTIC METHOD FOR RATIONING OF EMC OF RAILWAY AUTOMATICS

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ABSTRACT

The scientific and technical problem of rationing of noise immunity level and rigidity of tests of railway automation and telemechanics is considered. The problem remains topical in connection with the widespread introduction of microprocessor and computer automation systems that ensure train traffic safety. The task is to find the norms of noise immunity on the basis of taking into account the probabilistic nature of the level of interference and the level of noise immunity of the hardware element base. The «load-stability» method was used to obtain equations for determining the normalized value of noise immunity. The norms calculated by the proposed method allow optimizing rigidity of tests and associated design solutions.

Keywords: *railway, automation and telemechanics systems, electromagnetic compatibility, rationing, probabilistic approach, test methods, probability of failure, train traffic safety.*

Background. *Microelectronic and microprocessor systems of railway automation and telemechanics (RATS) perform the responsible functions of ensuring the safety of train traffic. Therefore, they have to meet high requirements for electromagnetic compatibility (EMC), reflected in the regulatory and technical documentation.*

In this documentation, EMC standards are chosen based on the worst-case conditions, the test stiffness class is determined by a set of qualitative characteristics of the surrounding electromagnetic environment (EME), and rigidity of tests is taken to reproduce the maximum level of interference. The main standardized values for the description of EMC are «the level of electromagnetic compatibility», that is, the maximum level of interference in operating conditions and the «immunity level». For such quantities, the normative and technical documentation sets fixed values. Therefore, this approach to establishment of norms on EMC based on the construction principle is deterministic.

Objective. *The objective of the authors is to consider probabilistic method for rationing of EMC of railway automation.*

Methods. *The authors use general scientific and engineering methods, probabilistic methods, comparative analysis.*

Results. *On the other hand, in the modern theory of RATS [1–3], the level of safety and electromagnetic compatibility is expressed by the probability of failure of equipment during its operation.*

Consequently, the problem of rationing EMC of such systems should be solved from the standpoint of ensuring the required probability of equipment failure in EME and taking into account the probabilistic properties of the interference and noise immunity levels. At the same time, it is necessary to pay attention to the peculiarities of construction of microelectronic and microprocessor RATS. To ensure the required level of security, they are built on the principle of «two of two» or «two of three» and include, in addition to the actual computational channels, blocks of comparison schemes and blocks of shutdown schemes. The first perform the function of detecting failures, the second – the function of blocking the computational channel in the protective state when a failure is detected. According to [2], the probability of a hardware failure P_{mlf} *is determined by the probability of failure of the computational channel* P_{mfch}*, the probability of detection of this failure* P_{dt} *and the probability of the channel transfer to the protective state* P_{dsch}*:* $P_{mlf} = P_{mfch}(1 - P_{dt} P_{dsch})$*.*

Since the blocks of the comparison circuits and the blocks of the shutdown circuits have a significant effect on the security of the system and work on the principle of self-checking, it is logical to assume the probabilities P_{dt} *and* P_{dsch} *along with* P_{mfch}*. And the probabilities* P_{dt} *and* P_{dsch} *should be very high and are the probabilities of failure-free operation of the corresponding blocks in this EME. Then, for rationing, the failure probability of its computational channel is used:* $Q_{dt} = 1 - P_{dt}$*,* $Q_{dsch} = 1 - P_{dsch}$*,* $P_{mfch} = P_{mlf} / (1 - P_{dt} P_{dsch})$*.*

Since the electromagnetic situation at the place of operation of RATS is often specified, the problem of EMC rationing can be put in the following form: for a given failure probability, to determine the normalized value of the noise immunity level of the system equipment block with known parameters of the law of distribution of the probability density of the interference level and the specified limits on standard deviations of noise immunity.

The solution of this problem gives an answer to the question, what should be the characteristics of the noise immunity levels of the equipment, so that it works with a given probability of failure in EME at the site of its operation.

To obtain a solution it is necessary to have a mathematical expression connecting the statistical parameters of the law of distribution of the probability density of interference, the fixed value of the standard deviation of noise immunity, the unknown mathematical expectation of the level of noise immunity, which is normalized, and the probability of failure. Such an expression, like [4], is called the coupling function and has the form $P_{mfch} = f(\mu_R, \sigma_R, \mu_N, \sigma_N)$. In this ratio μ_R is the mathematical expectation of noise immunity of electronic equipment, σ_R is the standard deviation of its noise immunity, μ_N is the mathematical expectation of the interference level in the EME at the site of operation, σ_N is the standard deviation of the interference level.

The coupling functions are obtained by the known «load-stability» method [5]. In [3] the results of applying the method for the normal distribution of noise immunity are presented, which corresponds to the conclusions of the central limit theorem and the most widespread laws of interference distribution [6].

When the interference is distributed according to the normal law, the coupling function has the form

$$P_{mlf} = \frac{1}{2} - \Phi\left(\frac{\mu_R - \mu_N}{\sqrt{\sigma_R^2 + \sigma_N^2}}\right), \quad (1)$$

where Φ is probability integral.

In the distribution of interference according to the Rayleigh law

$$P_{mlf} = exp\left(-\frac{\mu_R^2}{2\left(\sigma_R^2 + \sigma_N^2\right)}\right)\frac{\sigma_N}{\sqrt{\sigma_R^2 + \sigma_N^2}} \bullet \left[\frac{1}{2} + \Phi\left(\frac{\mu_R \sigma_N}{\sigma_R\sqrt{\sigma_R^2 + \sigma_N^2}}\right)\right]. \quad (2)$$

With an exponential distribution of interference with the exponent λ

$$P_{mlf} = exp\left(-\frac{1}{2}\left(2\mu_R\lambda - \lambda^2\sigma_R^2\right)\right) \bullet \left[\frac{1}{2} + \Phi\left(\frac{\mu_R - \lambda\sigma_R^2}{\sigma_R}\right)\right]. \quad (3)$$

With the lognormal distribution of interference

$$P_{mlf} = \frac{1}{2} - \Phi\left(\frac{\mu_R - ln\mu_N}{\sqrt{\sigma_R^2 + \sigma_{lnN}^2}}\right). \quad (4)$$

In practice, the possible values of the interference level and the level of interference immunity are limited from above and from below. Therefore, the case where the interference and noise immunity levels are distributed according to the truncated normal law with parameters a, b, c, d is of interest. For this case, the coupling function has the form

$$P_{mlf} = 1 - \frac{\Phi\left(\frac{b - c - \left(\mu_R - \mu_N\right)}{\sigma_R^2 + \sigma_N^2}\right) - \Phi\left(\frac{-\left(\mu_R - \mu_N\right)}{\sigma_R^2 + \sigma_N^2}\right)}{\Phi\left(\frac{b - c - \left(\mu_R - \mu_N\right)}{\sigma_R^2 + \sigma_N^2}\right) - \Phi\left(\frac{a - d - \left(\mu_R - \mu_N\right)}{\sigma_R^2 + \sigma_N^2}\right)}. \quad (5)$$

In this case, the unknown mathematical expectation of the noise level enters into the argument of the probability integral function, that is, is within the limits of integration of the indefinite integral. Therefore, to simplify the calculation relationships in the coupling function, the variable is replaced.

For (1), the new variable $z = \frac{\mu_R - \mu_N}{\sqrt{\sigma_R^2 + \sigma_N^2}}$.

In (2), the new variable $z = \frac{\mu_R}{\sqrt{\sigma_R^2 + \sigma_N^2}}$.

In (3), the new variable $z = \mu_R - \lambda\sigma_R^2$.

In (4) respectively $z = \frac{\mu_R - ln\mu_N}{\sqrt{\sigma_R^2 + \sigma_{lnN}^2}}$.

And in (5) $z = \frac{\mu_R - \mu_N}{\sigma_R^2 + \sigma_N^2}$.

Then to find the unknown variable z it is necessary to solve transcendental equations.

When distributing interference according to the normal law

$$\Phi(z) = \frac{1}{2} - P_{mlf}. \quad (6)$$

In the distribution of interference according to the Rayleigh law

$$P_{mlf} = exp\left(-\frac{z^2}{2}\right)\frac{\sigma_N}{\sqrt{\sigma_R^2 + \sigma_N^2}}\left[\frac{1}{2} + \Phi\left(\frac{\sigma_N z}{\sigma_R}\right)\right]. \quad (7)$$

When distributing noise according to an exponential law

$$P_{mlf} = exp\left(-\frac{1}{2}\lambda\left(2z - \lambda\sigma_R^2\right)\right) \bullet \left[\frac{1}{2} + \Phi\left(\frac{z}{\sigma_R}\right)\right]. \quad (8)$$

In the distribution of noise by the lognormal law, the equation for z is analogous to (6).

In the distribution of noise levels and noise immunity, according to the normal truncated law, the equation for z

$$1 - P_{mlf} = \frac{\Phi\left(\frac{b - c}{\sigma_R^2 + \sigma_N^2} - z\right) - \Phi(-z)}{\Phi\left(\frac{b - c}{\sigma_R^2 + \sigma_N^2} - z\right) - \Phi\left(\frac{a - d}{\sigma_R^2 + \sigma_N^2} - z\right)}. \quad (9)$$

To solve the equations, it is expedient to apply the method of successive approximations. The expansion of the probability integral in a series is incorrect, since the argument of the probability integral in EMC tasks is of the order of 10^2 [3]. The application of asymptotic approximations leads to higher-order algebraic equations for an unknown quantity [7]. Such equations can be solved only by numerical methods. Thus, an uncontrolled accumulation of error occurs, the solution obtained is rendered unsuitable for RATS. Therefore, the method of successive approximations is used to solve the above transcendental equations, which was implemented in the EMCPar program developed in the laboratory

«Safety and EMC» of NIIZHT at Belarusian State University of Transport.

The relations deducted in the article allow us to calculate the required levels of noise immunity of the electronic apparatus of RAT according to the given probability of a system failure and the probabilities of failure-free operation of control circuits in the composition of this system. After that, it is possible to select the element base of the circuit and design solutions that provide the required level. At the same time, the indicators of the level of security of both individual circuits and units within the RATS equipment and the entire system will be included, taking into account the security effect of individual circuits and blocks on the security level of the system as a whole.

Conclusion. *Received by the proposed methodology, the norms for the interference immunity of the RATS equipment are consistent, and compliance control helps to maintain a specified level of reliability of the microelectronic and microprocessor-based RATS in EME. The application of the probabilistic method of rationing makes it possible to optimize the design activities and rigidity of tests aimed at ensuring EMC and the safety of the operation of RATS. This gives an optimization of the costs of such provision and the economic effect of the introduction of modern automation and telemechanics systems on the railways of Russia and the CIS.*

An illustration of this conclusion is the following example. Let $P_{mfch} = 10^{-6}$, $\mu_N = 1000$ *V*, $\sigma_N = 100$ *V*, $\sigma_R = 10$ *V. The levels of noise immunity and interference are distributed according to the normal law. Then* $\Phi(Z) = 0{,}5 – 10^{-6} = 0{,}499999$. *According to the table of the Laplace function,* $Z = 4{,}76$. *Taking into account the change of variable, the value of* $\mu_R = 1478{,}37$ *V.*

According to the existing regulations, the test rigidity of 1000 V or 2000 V would be assigned in this case. The first value is underestimated and will lead to unsatisfactory results of testing or operation of the automation and telemechanics device. The second value is significantly overestimated. It follows from the example that overstating the requirements for EMC parameters leads to an unjustified increase in the cost of the equipment due to additional constructive measures to ensure noise immunity. Underestimation of these requirements is unacceptable for reasons of security.

The advantage of the proposed probabilistic approach is that it uses the numerical characteristics of interference in EME at the site of operation of the system, obtained by collecting statistical information and its subsequent processing. In this case, the developed norms of noise immunity as much as possible correspond to the operating conditions.

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Article received 23.12.2016, accepted 21.01.2017.