INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS

ISSN(print): 2643-9840, ISSN(online): 2643-9875

Volume 05 Issue 06 June 2022

DOI: 10.47191/ijmra/v5-i6-21, Impact Factor: 6.261

Page No. 1341-1345

Mathematical Modeling of the Reliability of Ferromagnetic Current Converters with Adjustable Range for Traction Power Supply Devices

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ABSTRACT: The factors affecting the operational reliability of primary measuring transducers (PMT) developed on the basis of ferromagnetic current transducers with adjustable range (FMCT RD) are highlighted. An assessment and analysis of the system of basic quantitative indicators of reliability for each of the proposed three current converters, which differ in the principles of operation and the number of assembly units, is made. A maintenance and repair strategy is indicated, combined with the use of methods and tools of a modern diagnostic system that ensures the reliability of these converters, using a combination of three groups of stages: during design, during their operation and repair.

KEYWORDS: ferromagnetic current converters, operational reliability, assessment of point indicators of reliability, gamma resource, diagnostics, maintenance and repair strategy.

INTRODUCTION

The development of new, operation and improvement of existing systems of high-speed traction power supply requires a change in the methods of analysis and calculation of structural and parametric reliability, taking into account operating experience, a set of initial data of the results of the experiment, and the calculation of general reliability indicators, analysis of options for ensuring reliability, forecasting gamma resources, the end result of which is to provide optimal maintenance schedules for power supply facilities [1,2].

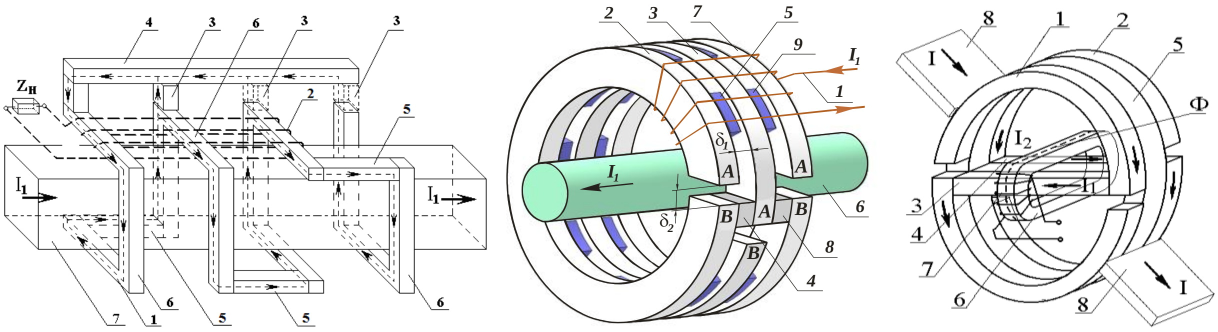
Research aimed at improving methods for improving the design, manufacture and operational reliability of technical facilities with enhanced functionality and dynamic range, as well as ensuring accuracy and reliability through the use of a new maintenance and repair system, combined with functional diagnostics for high-speed power supply facilities at the present time is important and relevant.

To ensure the principle of compliance with the operation process of the developed ferromagnetic current transducers with an adjustable range (FMCT AR) [3], used for systems of energy-intensive traction power supply systems, a systematic approach is required with a separate assessment of the reliability of each design, taking into account their operating principle.

The task is to analyze the options for ensuring reliability, taking into account the analysis of test results and the assessment of reliability indicators that allow objectively taking into account the experience of their operation, data of experiments, to justify their increased metrological and adjustment characteristics while significantly reducing material and financial costs.

THE MAIN FINDINGS AND RESULTS

Let us give examples of the calculation and comparative evaluation of the reliability indicators of the three ferromagnetic current converters proposed by us with an adjustable range [4,5,6].



a) b) c)

Fig.1. Designs of ferromagnetic current transducers with adjustable range

a) a device for non-contact measurement of currents; b) a device for converting direct current into alternating current; c) adjustable current transformer

Experimental studies on the calculation of reliability indicators and analysis of their results were carried out in agreement with the parent organization represented by the Power Supply Center "O'zbekiston temir yo'llari" during 2020-2021. In accordance with GOST 17510-72 and GOST 17509-72.

The observation plan is selected [N, U, T], where N is the number of installations, determined by the formula $\delta + 1 = {2N}/{\chi^2_{(1-\beta);2N}}$; δ - relative error; $\chi^2_{(1-\beta);2N}$ - quintile distribution of the number of χ -chi squared at the number of degrees of freedom. N=50 FMCT AR were placed under observation; T - observation time. After the failure, the current transducers were not replaced with new ones. Total testing time$T_0 = 200 \times 10^3$hour During the specified time of testing, the winding insulation, their input and output terminals failed, the working positions of the converters changed. The output voltage readings were corrected taking into account the mathematical expectations M [u(t)] and the dispersion D [u(t)].

In total, failures of elements of the PMT were observed. FMCT AR was made according to the scheme No. 1, No. 2 and No. 3, respectively, of the first and second types. The developments on the assembly units of the converters are given in the table №1.

Table No. 1

Operating hours of the converter according to scheme No. 1, hour	80;82;94;98;101;140,3;142;170,4; 181,7;	$\sum t_i = 1472$
Operating hours of the converter according to schemes No. 2,3, hour	51;78;93;101;103;111;121;127;130; 131;132;148;151;157;163;171;174; 178;180;182;193;195;197	$\sum t_i = 3267$

Considering that the time to failure is subject to the exponential law of distribution of failures in the insulation of the PMT windings, we will determine according to GOST 17509-72 [7,8] separately for the assembly elements of the FMCT AR according to the scheme of Fig. 1. T_{mt}- Mean time to failure; P(t)-probability of no-failure operation at$t = 400 \times 10^3$ hour; failure rate "λ" and gamma resources for $\gamma = 90$.

Let us find an estimate of the distribution parameter$\widehat{\lambda_1}$. Since for the exponential law "λ'ʳ=λ=const, we will determine the failure rate calculated according to Table 9, given in accordance with GOST 175-72 [7], for the plan [N, U, T]:

$$\widehat{\lambda_1} = \frac{d}{\sum_{i=1}^{d} t_i + (N-d)T_0} = \frac{2}{1472 + (50-2)\cdot 200\cdot 10^3} = 0{,}21 \cdot 10^{-6}\ {}^{1}/_{\text{hour}}.$$

Let's define two-sided confidence limits for "λ'ʳ with confidence probability β=0.9. For the plan [N, U, T] according to Table 1 of Appendix 1 to GOST 17509-72 we have:

Calculation of the lower bound:

$$\lambda_{1\text{н}} = \frac{\hat{\lambda} N T \chi^2_{\frac{1+\beta}{2},2d}}{d\left(2N - d + \frac{1}{2}\chi^2{}_{\frac{1-\beta}{2},2d}\right)} = \frac{0{,}21\times 10^{-6}\cdot 50\cdot 54{,}5}{2\left(2\cdot 50 - 2 + \frac{1}{2}5{,}45\right)} = 0{,}105\cdot 10^{-6}\ {}^{1}/_{\text{hour}},$$

along the upper border:

$$\widehat{\lambda_{1\text{в}}} = \frac{\hat{\lambda} N T \chi_{\frac{1+\beta}{2},2d}}{d\left(2N - d + \frac{1}{2}\chi^2{}_{\frac{1+\beta}{2},2d}\right)} = \frac{0{,}21\cdot 10^{-6}\times 50\times 15{,}7}{2\left(2\cdot 50 - 2 + \frac{1}{2}\cdot 15{,}7\right)} = 0{,}780\cdot 10^{-6}\ {}^{1}/_{\text{hour}},$$

where values are $\chi^2_{\frac{1-\beta}{2},2d} = 5{,}45$ и $\chi^2_{\frac{1+\beta}{2},2d} = 15{,}7$ Are found according to the tables [10]. distribution quintiles χ squared.

The calculated values of the lower and upper limits of the distribution parameter, respectively $\widehat{\lambda_{1н}} = 0{,}105 \cdot 10^{-6}$ and $\widehat{\lambda_{1в}} = 0{,}780 \cdot 10^{-6}\ {}^{1}/_{\text{hour}}$, with a probability of 0.9 on the interval $(0{,}105 \cdot 10^{-6};\ 0{,}780 \cdot 10^{-6}\ {}^{1}/_{\text{hour}}$ cover the true values of the parameter $\hat{\lambda}$.

Calculation of a point estimate of the mean time to failure (according to table 8): $T_{1m} = \frac{1}{\hat{\lambda}} = \frac{1}{0{,}21 \cdot 10^{-6}} = 4{,}760 \cdot 10^6$ hour.

Lower and Upper Confidence Limits for Mean Time to Failure:

$$T_{1m.d} = \frac{1}{\widehat{\lambda_в}} = \frac{1}{0{,}780 \cdot 10^{-6}} = 1{,}28 \cdot 10^6 \text{ hour;}$$

$$T_{1m.t} = \frac{1}{\widehat{\lambda_н}} = \frac{1}{0{,}105 \cdot 10^{-6}} = 9{,}52 \cdot 10^6 \text{ hour.}$$

Let us determine the probability of failure-free operation of 1-FMCT $t = 400 \cdot 10^3$ hour according to table No. 8 GOST 17509-72:

$$P(t)_в = e^{-\hat{\lambda}t} = e^{-0{,}21 \times 10^{-6} \cdot 400 \cdot 10^3} = 0{,}919\,.$$

Bilateral confidence limits for P(t) can be determined using the found values $\lambda_в$ and $\lambda_н$:

$P(t)_в = e^{-\lambda_н t} = e^{-0{,}105 \cdot 10^{-6} \cdot 400 \cdot 10^3} = 0{,}958;$

$P(t)_н = e^{-\lambda_в t} = e^{-0{,}780 \cdot 10^{-6} \cdot 400 \cdot 10^3} = 0{,}730.$

Let's define 90% resource (γ=90%), for 1-FMCT according to the formula of Table No. 8 GOST 17509-72:

$$T_{1\gamma} = \frac{1}{\hat{\lambda}}\left(-\ln\frac{\gamma}{100}\right) = \frac{1}{0{,}21 \cdot 10^{-6}}\left(-\ln\frac{90}{100}\right) = 0{,}501 \cdot 10^6 \text{ час}$$

т.е. 90%total elements of the FMCT has a resource of less $0{,}501 \cdot 10^6$ hour.

Bilateral 90% Resource Confidence Bounds:

$$T_{1\gamma н} = \frac{1}{\lambda_в}(-\ln 0{,}9) = \frac{1}{0{,}78 \cdot 10^{-6}}(-\ln 0{,}9) = 0{,}135 \cdot 10^{-6} \text{ hour}$$

$$T_{1\gamma в} = \frac{1}{\lambda_н}(-\ln 0{,}9) = \frac{1}{0{,}105 \cdot 10^{-6}}(-\ln 0{,}9) = 1{,}003 \cdot 10^{-6} \text{hour}$$

Calculation and evaluation of the reliability indicators of the PMT of the second and third versions of the FMCT AR.

Failure rates:

$$\hat{\lambda}"_{2,3} = \frac{d"}{\sum_{i=1}^{d} l_i + (N-d")L_0} = \frac{2}{3267+(50-2)200 \cdot 10^3} = 0{,}15 \cdot 10^{-6} \text{ 1/hour,}$$

Bilateral confidence limits for (λ")̂_2.3 with confidence probability β=0.9 according to the second and third versions of the FMCT AR:

Calculation of the lower bound:

$$\hat{\lambda}"_{2,3н} = \frac{\hat{\lambda}" N \chi^2_{\frac{1-\beta}{2},2d}}{d(2N-d"+\frac{1}{2}\chi^2_{\frac{1-\beta}{2},2d}} = \frac{0{,}15 \cdot 10^{-6} \times 50 \cdot 5{,}45}{2(2 \cdot 50 - 2 + \frac{1}{2} \cdot 5{,}45)} = 0{,}083 \times 10^{-6} \text{ 1/hour}$$

upper bound calculation:

$$\hat{\lambda}"_{2,3в} = \frac{\hat{\lambda}" N \chi^2_{\frac{1\pm\beta}{2},2d}}{d(2N - d" + \frac{1}{2}\chi^2_{\frac{1+\beta}{2},2d})} = \frac{0{,}150 \cdot 10^{-6} \cdot 50 \cdot 15{,}70}{2(2 \cdot 50 - 2 + \frac{1}{2} \cdot 15{,}70)} = 0{,}556 \times 10^{-6} \text{1/hour}$$

Calculation of $\hat{\lambda}"_{2,3н} = 0{,}083 \cdot 10^{-6}$ and $\hat{\lambda}"_{2,3в} = 0{,}556 \cdot 10^{-6}$ cover the true values of the parameters (λ")̂_2,3 with probability γ=0,9.

Point estimate of the average value of the operating time of the PMT of the second and third variants of the FMCT AR to failure according to table 8 (GOST 17509-72):

$$T_{avg} = \frac{1}{0{,}150 \cdot 10^{-6}} = 6{,}667 \cdot 10^6 \text{ hour.}$$

Confidence limits of the average operating time, respectively, for the lower and upper limits:

$$T"_{2,3avg\,u} = \frac{1}{\hat{\lambda}"_u} = \frac{1}{0{,}556 \cdot 10^{-6}} = 1{,}798 \cdot 10^6 \text{ hour;}$$

$$T"_{2,3avg\,l} = \frac{1}{\hat{\lambda}"_l} = \frac{1}{0{,}083 \cdot 10^{-6}} = 12{,}048 \cdot 10^6 \text{ hour.}$$

Probability of failure-free operation of the PMT of the second and third variants of the FMCT AR $l = 400 \cdot 10^3$ hour is determined according to table 8 GOST 17509-72:

$$P\,"_{2,3}(l) = e^{-\widehat{\lambda"_{2,3}} l} = e^{-0{,}150 \cdot 10^{-6} \cdot 400 \cdot 10^3} = 0{,}941$$

According to the above values $\widehat{\lambda}"_{2,3l}$, $\widehat{\lambda}"_{2,3u}$ find, respectively, bilateral confidence bounds for $P"_{2,3}(l)$:

$$P"_{2,3}(l)_u = e^{-\widehat{\lambda}"_{2,3l} l} = e^{-0{,}083\cdot10^{-6}\cdot400\cdot10^{3}} = 0{,}967;$$

$$P"_{2,3}(l)_l = e^{-\widehat{\lambda}"_{2,3u} l} = e^{-0{,}556\cdot10^{-6}\cdot400\cdot10^{3}} = 0{,}800.$$

According to the calculated options, we determine 90% resource (γ = 90%) according to the formula 8 GOST 17509-72:

$$T"_{2,3\gamma} = \frac{1}{\widehat{\lambda}"_{2,3}}\left(-\ln\frac{\gamma}{100}\right) = \frac{1}{-0{,}150\cdot10^{-6}}\left(-\ln\frac{90}{100}\right) = 0{,}702\cdot10^{6}\ \text{hour}.$$

Bilateral Confidence Bounds of 90% Resource.

$$T"_{2,3\gamma} = \frac{1}{\widehat{\lambda}"_{2,3u}}\left(-\ln\frac{\gamma}{100}\right) = \frac{1}{0{,}083\cdot10^{-6}}\left(-\ln\frac{90}{100}\right) = 1{,}269\cdot10^{6}\ \text{hour};$$

$$T"_{2,3\gamma} = \frac{1}{\widehat{\lambda}"_{2,3l}}\left(-\ln\frac{\gamma}{100}\right) = \frac{1}{0{,}556\cdot10^{-6}}\left(-\ln\frac{90}{100}\right) = 0{,}189\cdot10^{6}\ \text{hour}$$

Comparative assessment and analysis of the reliability indicators of the PMT FMCT AR for the first option, as well as for the second and third options, shows that their difference is due to different technical resources, properties of the materials used and their operating conditions. Therefore, it is expedient in order to reduce costs, it is necessary to carry out maintenance and repair (MR) by conducting a more advanced diagnostic system according to Fig. 2, which accordingly shows the scheme of the MR strategy according to the real state of the FMCT PMT. It improves the reliability of the instrument, the safety during maintenance, and the real economic efficiency.

The relationships indicated in fig. 2. Must be guaranteed primarily by the operational manufacturability, implemented by fulfilling conditions 8-12, ensuring higher simplicity and safety of work performed under high voltage in cramped conditions and time pressure.

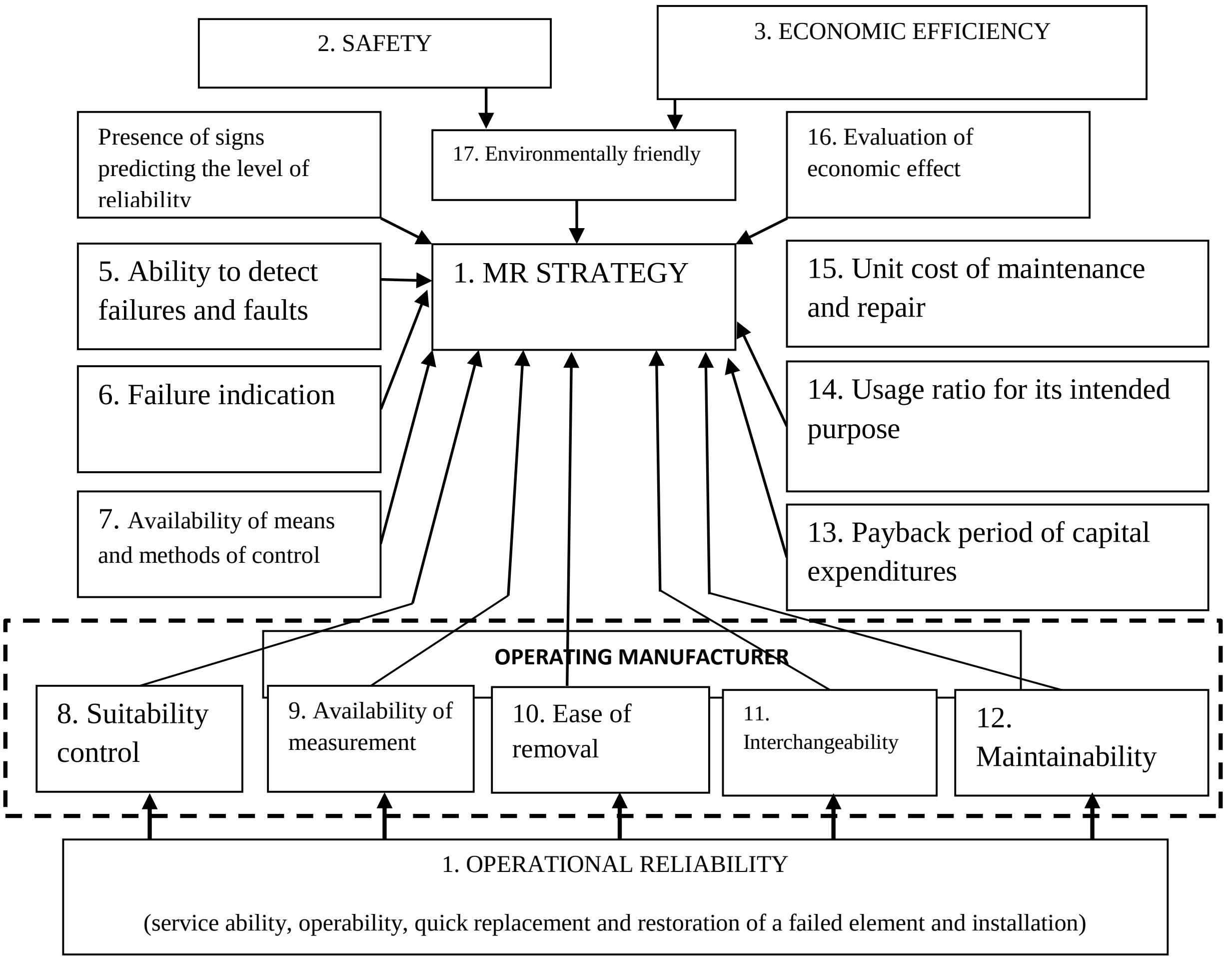


Fig.2. Conditions for the implementation of the strategy for the maintenance and repair of elements of the PMT of traction power supply systems, taking into account the normal indicators of reliability and the real state.

Naturally, the proposed strategy is easier to implement in the maintenance and repair of power supply facilities, which provides for the fulfillment of conditions 4-12 at the design stage, prefabrication, as well as during operation and reconstruction.
The implementation of indicators 13-16 will provide an economic effect associated with the optimal frequency of preventive examinations using a technical diagnostic system.

CONCLUSION

An analysis of the calculated reliability indicators of the considered ferromagnetic current converters with adjustable ranges, taking into account the implementation of maintenance and repair, shows that the two-sided confidence probability of their failure-free operation is more than 0.9, which meets the requirements of automatic control systems for traction power supply of an electrified railway. Differences in the reliability indicators of each device are explained by the difference in materials, as well as their electrical and magnetic properties.
It can be said that individual elements of diagnostics have long been used to monitor the state of the most vulnerable elements of the PMT. But long-term operation and the existing system of maintenance and repair (MR) shows the need for the use of methods and means of technical diagnostics, which is embedded in almost every control scheme with adjustable traction power supply.
The widespread introduction of diagnostic methods and tools will make it possible, instead of scheduling the MR, to apply the planning of diagnostic checks according to the real state.
The above material can serve as a methodological basis for drawing up plans for improving design and operational work. It is possible to ensure the reliable functioning of the PMT FMCT in the power supply system using a combination of three groups of proposed PMT: ensuring reliability during design, operation and during repairs.

REFERENCES

1) GOST 28001-83. The system of maintenance and repair of equipment. Basic provisions M: Publishing House Standards, 1983, 23 p.
2) GOST 27518-87. Product diagnostics. General requirements. -M: Publishing House of Standards, 1988.43 p.
3) Amirov S.F., Shoyimov Y.Yu., El-Amin Mohammed // Magnetic systems with multi-turn cores for measuring transducers. Uzbek journal "Problems of Informatics and Energy", Tashkent, 2000, No. 3. p. 23-26.
4) Patent of the Republic of Uzbekistan. No. 03591. Device for converting current into voltage / Amirov S.F., Khalikov A.A., Shoyimov Y.Yu. , Khushbokov B.Kh., Balgaev N.E. // Official Bulletin. – 2008. – №2.
5) Patent of the Republic of Uzbekistan. No. 03617. Device for non-contact measurement of currents / Amirov S.F., Khalikov A.A., Khushbokov B.Kh., Shoyimov Y.Yu., Balgaev N.E.. // Official bulletin. – 2008. – №3.
6) Patent of the Republic of Uzbekistan. No. 03858. Current transformer / Amirov S.F., Khalikov A.A., Shoyimov Y.Yu., Khushbokov B.Kh., Balgaev N.E.. Official bulletin. – 2009. – №1.
7) GOST 17509-72. Reliability of engineering products. System for collecting and processing information, methods for determining point estimates of reliability indicators based on the results of observation, 53 p.
8) GOST 27002-89. Reliability in technology. Basic concepts. Terms and Definitions. -M: Publishing House of Standards.
9) Collection of methodological manuals for monitoring the state of electrical equipment. / JSC Firm ORGRES, edited by F.L. Kogan 1999, 428p.
10) Bronstein I. N., Semendyaev K. A. B 88. Handbook of mathematics for engineers and students of higher educational institutions: Textbook. - St. Petersburg: Publishing house "Lan», 2010.