ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889,
2023-5.384 ResearchBib IF: 8.848 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-4, ISSUE-1

UDC 621.3.0481.

FUNCTIONAL DIAGNOSTICS OF TRACTION TRANSFORMER OF AC ELECTRIC LOCOMOTIVE USING SPECTRAL ANALYSIS METHOD

M.S. Yakubov., M.A. Sagatova, M.N. Tuychieva
Tashkent State Transport University

Abstract. The purpose of the study is to use spectral analysis for functional diagnostics of the traction transformer bushing of an AC electric locomotive, which is an important element of its asynchronous electric drive to ensure the reliability and continuity of the motion process and regenerative braking.

Methods. A new classification of methods for diagnosing and determining technical conditions of traction transformer bushing is presented, which makes it possible to determine the early stage of the appearance of partial discharges (PD) in them. An assessment of the numerical magnitude and sign of coefficients of the sine and cosine components of the Fourier series and, ultimately, the indication of partial discharges are performed.

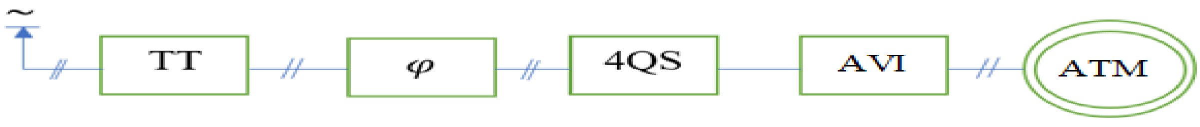
Practical significance. In the functional diagnostics of transformer bushing, the possibility of the issues of the principle of information content and invariance is noted.

Keywords: control, rolling stock, electric locomotive, traction transformer bushing, spectral analysis, diagnostics.

One of the most crucial elements of an AC electric locomotive is the traction transformer (TT). It is subject to the requirements of maximum use of active materials and high operational reliability; this eliminates additional preventive repairs between periodic maintenance. Traction transformers for electric locomotives differ from conventional transformers in a very wide regulation range of output voltage. The fundamental features of the TT are high dissipation of its windings, necessary for normal operation of the network part of the 4QS converter, a relatively large range of changes in the output voltage (19-31 kV or more), non-sinusoidal current and voltage, the permissibility of operation in over-excitation mode, latching current limitation at idle speed or when an electric locomotive passes a neutral section, the complex design of its bushing that causes the occurrence of partial discharges. Partial discharges increase the temperature of windings, insulation, and oil.

The failure of a traction transformer leads to a stop in the electric locomotive motion, significant losses, and emergencies, so an important task is its periodic functional diagnostics to determine its actual technical condition and prevent the damage of electrical technological equipment. To do this, it is necessary to identify the most common types of TT defects and select effective methods for detecting these faults [4, 8, 9].

AC electric locomotives use TTs with a voltage of 27.5 kW. The largest number of



ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2023-5.384 ResearchBib IF: 8.848 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-4, ISSUE-1

failures is associated with the failure of TT bushing [1, 2, 15]. Failure of this unit often leads to the triggering of the maximum current relay (MCR) (over-current relay) or is accompanied by a reduction in voltage in the contact network due to the shutdown of automatic protection at the traction substation. However, the protection can be triggered by failures of other elements of the electric locomotive. In this regard, in the depot, it is necessary to determine by simple and objective methods the conditions of traction transformers without disassembling them. The modern system of power circuit control for electric rolling stock (SCERS) has special technological equipment and a variable-frequency electric drive. In addition to the TT, this system includes other units (see Fig. 1).

Fig.1. Functional block diagram of AC SCERS.

The most common is the option with a four-quadrant 4QS converter, which allows for voltage and frequency regulation; it maintains a power factor close to unity and implements regenerative braking; a capacitive filter for voltage smoothing, an autonomous voltage inverter (AVI) using IGBTs controlled by a system of pulse-width modulation and self-diagnostics.

Variable frequency drive converters generate higher harmonics that distort current and voltage, leading to heating of the TT and its bushings.

An electric drive of electric rolling stock (ERS) is characterized by severe operating conditions and the presence of dangerous voltages:

$$L_{III}\frac{di}{dt}, \qquad (1)$$

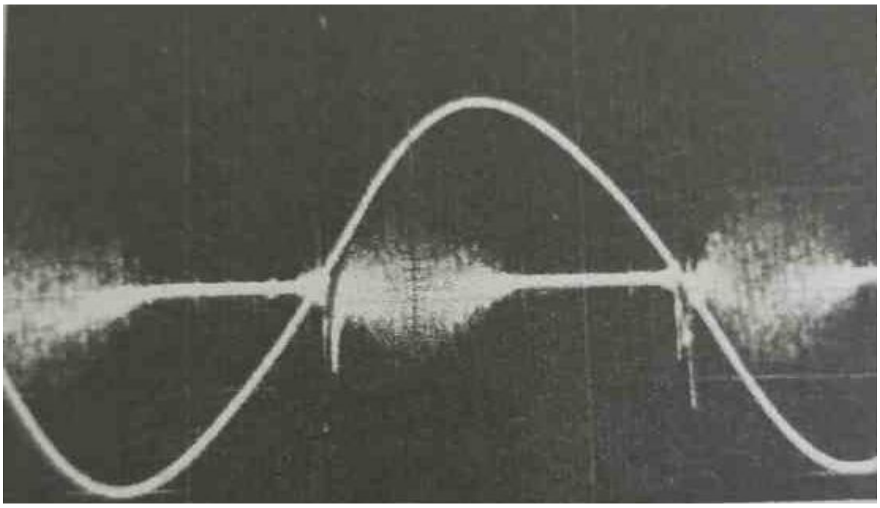
where L_{III} is the inductance, H; $\frac{di}{dt}$ is the change in current when switching IGBT and flows:

$$i = C_{IGBT}\frac{du}{dt} \quad , \qquad (2)$$

where C_{IGBT} is the capacitance of the IGBT terminals; $\frac{du}{dt}$ is the change in voltage when switching IGBT.

The above operating conditions of SCERS put higher demands on reliability and lead to an increase in wear.

Types of TT bushings for electric locomotives and their defects. There are TT bushings of the following designs [1]: bushings with oil insulation; oil retaining bushings and insulated rigid bushings.



ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2023-5.384 ResearchBib IF: 8.848 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-4, ISSUE-1

a)

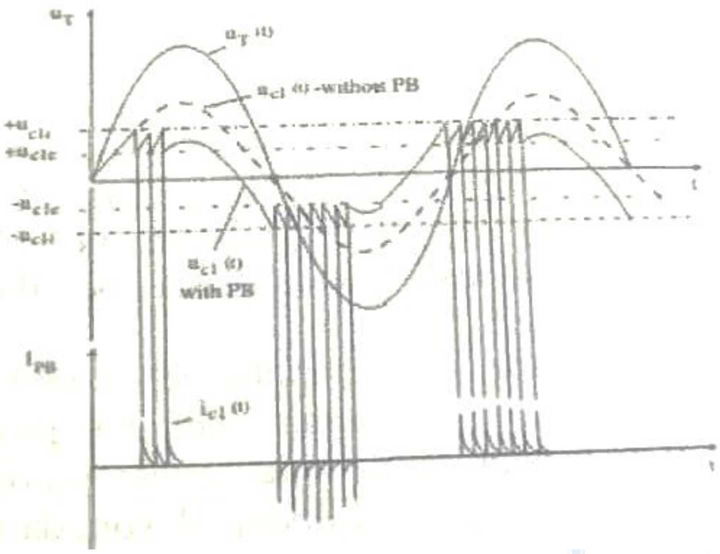
Fig. 2. a) oscillogram of discharges

The classification of the reasons for the deterioration of the technical condition of the TT bushing is shown in Fig. 2.

It is advisable to divide diagnostic properties (dielectric characteristics, chromatographic analysis of transformer oil, etc.) into integral parameters that characterize the phenomenon of aftereffect of a certain result that does not allow localizing a defect, for example, thermal imaging examination and PD measurement.

Diagnostic parameters must satisfy the principles of measurability, information content, and invariance. The informativeness of a parameter means that it carries significant information about defects, with the ability to quantify them. Invariance means that it should have an acceptable low sensitivity to noise. In experiments, one practically has to make a reasonable compromise on these requirements.

The complex design of TT bushings leads to an increase in electric intensity and the appearance of partial discharge, which destroys the internal insulation. The processes of appearance of PD of the TT bushings are shown in Figs. 2,a and 2,b.



b)

Fig. 2. b) time diagrams of the TT discharge occurrence.

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889,
2023-5.384 ResearchBib IF: 8.848 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-4, ISSUE-1

The classification of methods for diagnosing and monitoring the parameters of TT insulating bushings is shown in Fig. 3.

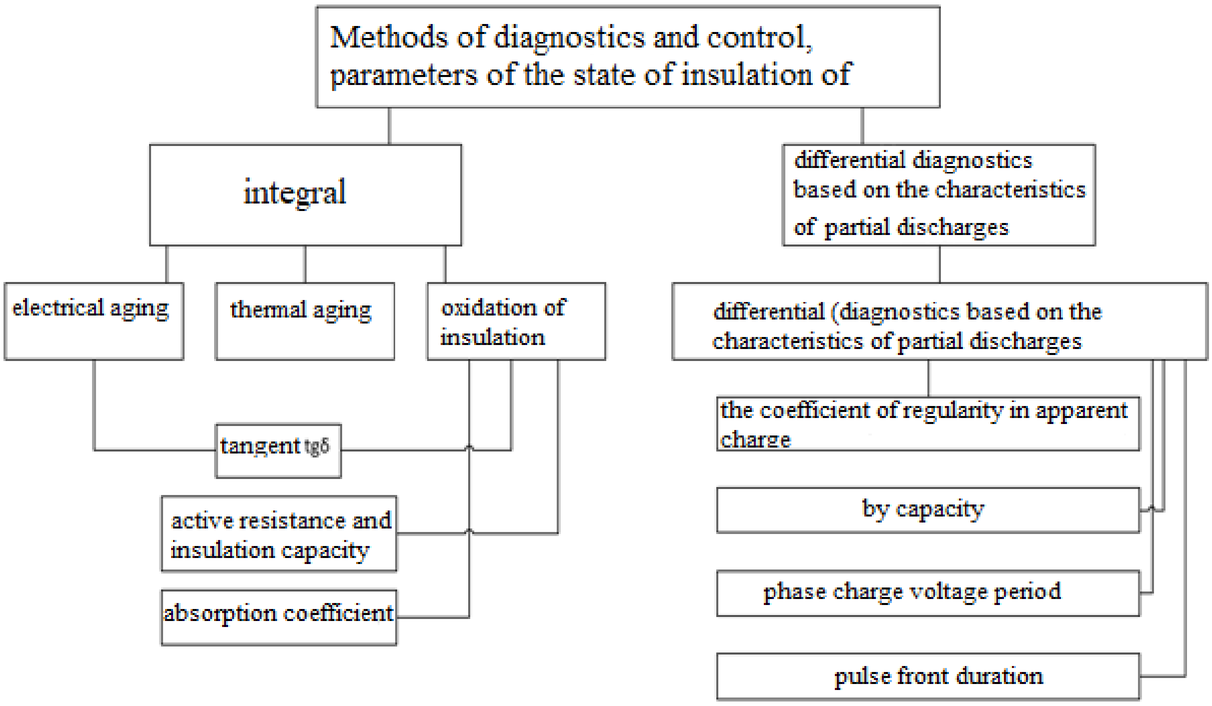


Fig.3. Classification of methods for diagnosing and monitoring the technical condition of TT bushings

Identification of spectral analysis of PD pulses is based on two identical forms of recording the Fourier series: through the coefficients of cosine and sinusoidal components [3, 6, 13]:

$$f(t) = C_0 + \sum_{k=1}^{N}(a_k cos\omega_1 t + b_k sin\omega_1 t)\ , \qquad (3)$$

and through the amplitudes and initial phases of harmonics:

$$f(t) = C_0 + \sum_{k=1}^{N} A_k \cos{(k\omega_1 t - \varphi_k)}\ , \qquad (4)$$

where $f(t)$ is the function of time; C_0 is the average value of the function over a given interval; k is the harmonic number; ω_1 is the circular frequency of the first harmonic; t is time; A_k is the amplitude of harmonic with number k; φ_k is the initial phase of the harmonic with number k.

If the experimental data are presented in the form of a table of values of the original function of time, then the numerical expansion of the Fourier series is found as the coefficients of the series using the following expressions [3, 12]:

$$a_k = \frac{2}{N}\sum_{t=1}^{N-1} f_1 cos\ \omega_1 ki\Delta t, \qquad (5)$$

$$b_k = \frac{2}{N}\sum_{t=1}^{N-1} f_1 \sin \omega_1 k i \Delta t, \qquad (6)$$

where i is the number of the point; N is the number of points in a given interval; f_1 is the value of the function at point number i; Δt is the time interval between points.

Amplitudes and phases are determined using the following analytical formulas [5, 14]:

$$A_k = \sqrt{a_k^2 + b_k^2}, \qquad (7)$$

$$\varphi_k = arctg\frac{b_k}{a_k}. \qquad (8)$$

When considering parameters (5) and (6) or (7) and (8), the time and spectral identification of the signal are equal, i.e., the signal spectrum contains complete information about the signal.

The criterion for the accuracy of spectral analysis is the comparison of the original signal with the function obtained during synthesis using the found coefficients a_k and b_k, to construct the amplitude spectrum A(f).

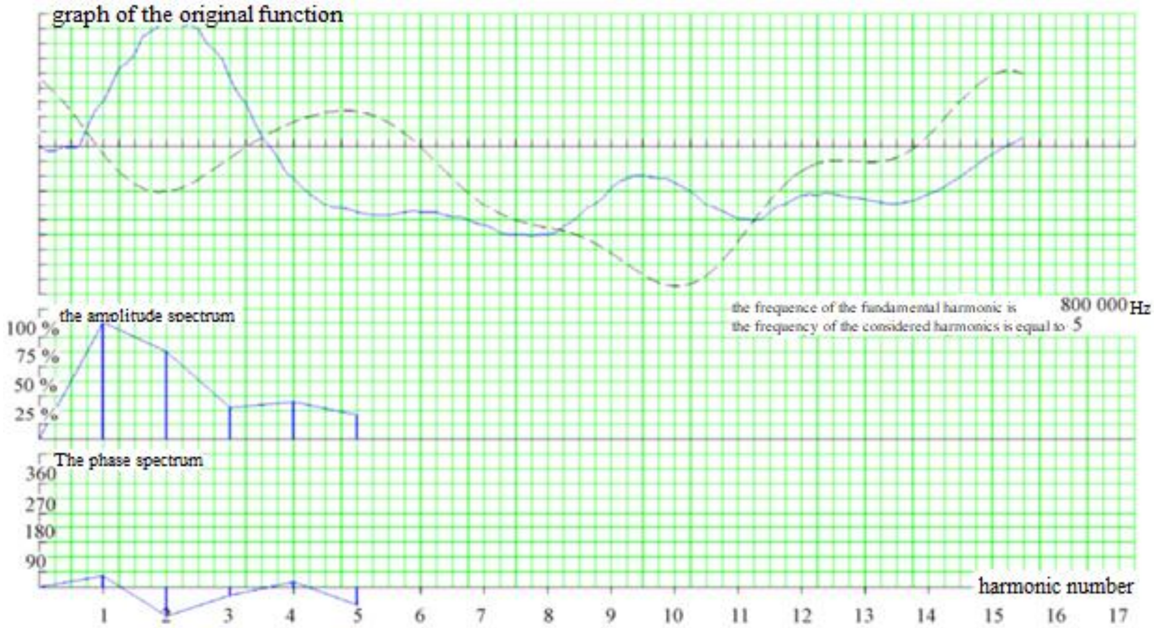


Fig.4. Synthesis of a PD pulse using expression (2) without considering the signs of coefficients *a* and *b* when determining the initial phases

When constructing the phase spectrum of a PD pulse, it is necessary to pay attention to determining the initial phase of each harmonic. This means that it is necessary to consider not only the values of $\varphi_k = arctg\frac{b_k}{a_k}$, but also the signs of coefficients a_k and b_k, i.e.,

if $a_k \geq 0$, then $\varphi_k = arctg\frac{b_k}{a_k}$,

if $a < 0$, then $\varphi_k = \pi - arctg\frac{b_k}{a_k}$, (10)

if $b_k < 0$, then $\varphi_k = 2\pi + \varphi_k$. (11)

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2023-5.384 ResearchBib IF: 8.848 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-4, ISSUE-1

Without considering expressions (9), (10), and (11), the signal waveform is distorted, and diagnostic information loses its meaning (Fig. 4). To avoid distortion

of the signal, it is necessary to expand the PD pulse interval by adding zero values.

A measuring transducer connected to the measuring terminals of high-voltage bushings or the ground circuit of the CT tank could be used to conduct experiments of spectral analysis to diagnose TT bushings. To obtain the above invariant principle when measuring PD parameters, it is necessary to have low sensitivity to electromagnetic discharges inside the CT and discharges from the external circuit [4, 5, 10, 11]. With a simple scheme for connecting a measuring transducer to the grounded circuit, it is necessary to use technical means and methods for shielding negative environmental factors.

When measuring PD parameters of the TT and processing their results for spectral analysis, it is necessary to keep in mind that the spectra of these pulses have minimal attenuation: they have a maximum upper limit of the frequency band compared to other (external) PD pulses:

$$E = E_0 e^{-\alpha_k x - j\beta_k x}, \qquad (11)$$

where E_0 is the initial and current intensity of the PD signal, respectively; α_k is the attenuation coefficient; β_k is the phase attenuation coefficient.

Expression (11) shows that PD in TT bushings differ in the width of the frequency spectrum of the external pulse [6, 7, 9].

Conclusions. Failure of a traction transformer of an AC electric locomotive is one of the most severe cases of malfunction, often leading to defects. In each of them, it is necessary to identify the failed unit, find the reason that led to the damage to this element, and determine the guilty party for assigning the costs of eliminating the malfunction: the manufacturer, operational or repair department. High costs of traction transformers lead to high costs for their repair. One of the effective methods of functional diagnostics of electrical machines (power transformers, induction motors, converters, etc.) is spectral analysis based on fast Fourier transform. This method allows for timely diagnostics to locate defects, the presence and development of partial discharges in transformer bushings, short circuits of turns, and other faults. The use of spectral analysis reduces the accident rate of traction transformers, and increases the reliability and uninterrupted motion of electric locomotives. The use of such monitoring systems would significantly reduce the number of failures of traction transformers, preventing the development of faults to an irreversible state.

The study reveals the technical capabilities of the spectral analysis method, its schematic features, based on the ability to measure partial discharges, the availability of information content, and invariant solutions when diagnosing traction transformers.

References

1. Guidelines for increasing the reliability and safety of operation of electrical equipment of nuclear power plants by providing the necessary regulatory documentation. // OJSC Rosenergoatom Concern. Moscow No. 126 – uk, 01.12.2009. (1.4 Diagnostics of power transformers, autotransformers, reactors and their bushings 1.33.99.0038-2009 (Appendix 4).

2. U. T. Berdiev, I. K. Kolesnikov, M. N. Tuychieva, F. F. Khasanov and U. B. Sulaymonov. Methods of new technological developments of electric motors based on soft

magnetic materials. E3S Web of Conf., 401 (2023) 03038. DOI: https://doi.org/10.1051/e3sconf/202340103038

3. Abitkhodja Burkhankhodjaev, Malika Tuychieva, Elena Iksar, Kholjan Kholbutayeva, Bakhtiyor Nurmatov; Investigation of the energy performance of electric locomotives in asymmetric modes. AIP Conf. Proc. 5 January 2023; 2552 (1): 030024. https://doi.org/10.1063/5.0133920

4. Usan Berdiev, Abitkhodja Burkhankhodzhaev, Malika Tuychieva, Elena Iksar, Komil Usmonov; Investigation of energy indicators with asymmetry of the voltage of the power source of mainline electric locomotives of alternating current. AIP Conference Proceedings 5 January 2023; 2552 (1): 030018. https://doi.org/10.1063/5.0131839

5. GOST 20074-83-Method for measuring the characteristics of partial discharges.

6. I.N. Bronstein, K.A. Semendyaev. Handbook of higher mathematics for higher educational institutions. Moscow: VSh, 1968, 364 p.

7. Grafakos L. Classical and Modern Fourier Analysis.- Prentice – Hall. 2004.-359p.

8. Ravinda Aroca, Wolfgan Mosch. High Voltage and Electrical Insulation Engineering. Quebec, Canada, 371 p. John and Sons, Inc, 2011.pp 340-341, pp 343-345.

9. 10. Demarchan K.S., Neiman L.R., Korovkin N.V., Chechurin V.P. Theoretical foundations of electrical engineering. SPB, "VSh".

10. Sergey Goolak, Viktor Tkachenko, Gintautas Bureika, Gediminas Vaiciunas, “Method of spectral analysis of traction current of AC electric locomotives.” Dept. of traction Rolling Stock, State University of Infrastructure and Technologies, Kyiv, Ukraine. TRANSPORT, 2020, pp. 659-668.

11. Yakubov M.S., Nazirkhonov T.M., Sagatova M.A. “Assessing the reliability of control systems for asynchronous electric drives of AC electric locomotives in various operating modes using regression and correlation analysis.” Unversum 2023 No. 6(111).

12. Capolino, G.; Antonino-Daviu, J.; Riera-Guasp, M. (2015). Modern Diagnostics Techniques for Electrical Machines, Power Electronics, and Drives. IEEE Transactions on Industrial Electronics, vol 62(3):1738-1745. doi:10.1109/TIE.2015.2391186.

13. Zavidey V.I., Putilova I.V., Starshinov V.A. “Modern methods of monitoring and technical diagnostics of electrical machines.” Energy, pp. 38-43.

14. Yakubov M.S., Sagatova M.A. “System analysis and classification of typical defects and malfunctions of AC electric drives with three-phase asynchronous motors in high-speed motion, focused on their diagnostics.” Scientific and technical journal MECHANICAL ENGINEERING. No. 1, 2023, pp. 107-103.

15. M. S. Yakubov, K. Kh. Turdibekov, S. A. Norzhigitov, and M. A. Sagatova. Improving maintenance system for controlled asynchronous electric drives of electric locomotives based on their diagnosis. E3S Web of Conferences 401, 05019 (2023) CONMECHYDRO – 2023.