 Simulation of the process of current distribution in a traction rail network

A G Isaicheva¹, M V Basharkin¹, A L Zolkin², V N Malikov³ and O V Saradzheva⁴

¹ Department “Automation, telemechanics and communication on railway transport”, Samara State Transport University (SSTU), 2V, Svobody Street, Samara, 443066, Russia
² Computer and Information Sciences Department, Povolzhskiy State University of Telecommunications and Informatics, 23, L. Tolstogo Street, Samara, 443010, Russia
³ Department of General and Experimental Physics, Altai State University, 61, Lenina Street, Barnaul 656057, Russia
⁴ Economic security, controlling and audit department, Russian State University named after A.N. Kosygin, 33, Sadovnicheskaya Street, Moscow, 115035, Russia

E-mail: aspirantsamiit@rambler.ru; aspirantsamiit@rambler.ru; alzolkin@list.ru; mirotnas@gmail.com; olgasaradjeva@icloud.com

Abstract. The article synthesizes a simulation model of a section of a traction rail network, analyzes the norms of permissible asymmetry current, at which a choke-transformer is able to function with a set quality. The simulation of the current distribution process that occurs in the traction rail network during the movement of trains of increased weight and length has been carried out. The graphs of the dependence of the asymmetry current on the traction current consumed by the electric rolling stock have been obtained, and the simulation of the dynamics of changes in the traction current in each of the rail lines has been carried out when the train was moving along a section of the traction rail network. Conclusions about the need to monitor the state of traction rail network elements, the service life of which in heavy traffic conditions is significantly reduced both due to dynamic loads and due to overheating due to the passage of increased traction currents have been made.

1. Rationale
The main component of the program for the development of heavy traffic on the training ground of the Russian Railways network is trains of increased weight and length. During they pass, there are significant loads on infrastructure facilities. In addition to the increase in axle load from 23 to 27 tf, the current consumed by the traction electric rolling stock also increases. The combination of these factors leads to premature failure of traction rail network elements with inadequate quality control over their condition, the strengthening of which is necessary in conditions of heavy traffic [1,2,3].

Due to the wearing of the elements, their resistance to the traction current increases and, as a consequence, an inequality of resistance of one rail thread appears relative to the other, which leads to the appearance of longitudinal asymmetry of the traction current. The asymmetry current is determined by the formula:
\[ I_a = |I_{rl1} - I_{rl2}|, \]  

where \( I_{rl1} \) is the value of the traction current flowing in the first rail line (A), \( I_{rl2} \) is the value of the traction current flowing in the second rail line (A).

The asymmetry current magnetizes the magnetic system of the choke-transformer and at a certain value the signal current in the secondary winding becomes less than the trip relay operating current. It results an armature release [4,5]. The consequence of this is the appearance of a failure of the track chain "false occupied". The movement of trains on the section stops until identification and elimination of the cause of this failure. Due to train downtime, the Russian Railways company suffers financial and image losses.

2. Simulation model synthesis

To analyse the process of current distribution that occurs in the traction rail network during trains passing, it is necessary to develop its mathematical model. The traction electric rolling stock is replaced by the current source \( J \), and the elements of the traction rail network with the corresponding resistances \( (R_{btj}, R_{hc}, R_{lt}, R_{et}, R_{wl}, R_{fl}) \). It is also necessary to determine the maximum permissible values of the asymmetry current at which the choke-transformer stops converting the signal current and voltage with a set quality.

The document [3] defines the following maximum permissible rates of asymmetry current (see table 1).

| Traction type       | Impedance bond type | Permissible asymmetry current (A) |
|---------------------|--------------------|----------------------------------|
| DC electric traction| Impedance bond DT-0.2-500, Impedance bond DT-0.6-500 | 60                               |
|                     | Impedance bond DT-0.2-1000, Impedance bond DT-0.6-1000 | 120                              |
|                     | Impedance bond DT-0.2-1500, Impedance bond DT-0.4-1500 | 180                              |

It shall be noted that the presented standard values are selected in such a way that even if they are slightly exceeded, stable operation of the choke-transformer is ensured.

Since 1990, the manufacturing plants have established the standards of the permissible asymmetry current, presented in table 2 [4].

| Traction type       | Impedance bond type | Permissible asymmetry current (A) |
|---------------------|--------------------|----------------------------------|
| DC electric traction| Impedance bond DT-0.2-500, Impedance bond DT-0.6-500 | 320                              |
|                     | Impedance bond DT-0.2-1000, Impedance bond DT-0.6-1000 | 320                              |
|                     | Impedance bond DT-0.2-1500, Impedance bond DT-0.4-1500 | 400                              |

In paper[5], the maximum permissible values of the asymmetry current for choke transformers of various types have obtained practically (see table 3).
Table 3. The maximum permissible level of asymmetry for different types of choke-transformers.

| Traction type          | Impedance bond type                  | Permissible asymmetry current (A) |
|------------------------|-------------------------------------|----------------------------------|
| DC electric traction   | Impedance bond DT-0.2-500,          | 360                              |
|                        | Impedance bond DT-0.6-500           |                                  |
|                        | Impedance bond DT-0.2-1000,         | 360                              |
|                        | Impedance bond DT-0.6-1000          |                                  |
|                        | Impedance bond DT-0.2-1500,         | 560                              |
|                        | Impedance bond DT-0.4-1500          |                                  |

Thus, in order to obtain the most accurate results during the simulation of the current distribution process in the traction rail network, the values given in Table 3 shall be used.

3. Simulation in MATLAB-Simulink

The model of a traction rail network section, implemented in the MATLAB-Simulink environment, consists of resistances, the values of which are determined in the paper [6,7,8]. The resistance of the half-winding of the choke-transformer of the DT-0.2-1500 type is \( R_{hc1} = R_{hc2} = 250 \pm 25 \, \mu\Omega \). The resistance of the half-winding of the choke-transformer of the DT-0.4-1500 type is assumed to be as follows \( R_{hc1} = R_{hc2} = 400 \pm 40 \, \mu\Omega \). The resistance of the choke jumpers is \( R_{ij1} = R_{ij2} = R_{ij3} = R_{ij4} = 523.8 \, \mu\Omega \). In the developed model, a section 800 meters long is considered. Within the boundaries of this section there are 32 rails, 25 meters long each, interconnected by 31 prefabricated conductive rail joints. It is assumed that 90% of the rails are in good working order and the resistance of each of them is \( R_{wr} = 635.2 \, \mu\Omega \), then \( R_{wr1} = R_{wr2} = \sum_{rr=1}^{29} R_{wrr} = 18420.8 \, \mu\Omega \), and the total resistance of 10% of the rails, the sole wear of which is within the acceptable limits, will be \( R_{fr1} = R_{fr2} = \sum_{jrr=1}^{5} R_{frr} = 2001 \, \mu\Omega \). The resistance of the prefabricated conductive rail joint under the best operating conditions is \( R_{wj} = 30 \, \mu\Omega \). The maximum allowable value of the joint resistance established by document [3] is \( R_{wj} = 200 \, \mu\Omega \). In paper [7,9] it is noted that the value of the joint resistance can reach values of \( R_{ij1} = 750 \, \mu\Omega \). \( R_{wj1} \) is defined as the sum of the resistances of 28 working connectors, and \( R_{ij1} = \sum_{ij=1}^{3} R_{ijr} = 630 \, \mu\Omega \). Then \( R_{wj1} = \sum_{wj=1}^{28} R_{wjr} = 840 \, \mu\Omega \). In this case, the value of \( R_{ij2} \) is set as 199 \( \mu\Omega \), \( R_{wj2} = \sum_{wj=1}^{26} R_{wjr} = 5174 \, \mu\Omega \). \( R_{ij2} = \sum_{fjr=1}^{5} R_{fjr} = 3750 \, \mu\Omega \). The resistance of the choke jumpers \( R_{hij} = R_{hij2} = 81.9 \, \mu\Omega \), however, in the considered case, these values can be ignored during the simulation.

Figure 1 shows a block diagram of a simulation model of a traction rail network section.
Figure 1. Block diagram of a simulation model of a traction rail network section.

The Ramp block allows to change the set level of the current consumed by the electric rolling stock. Formula (1) is implemented in the Subtract block. Comparing the obtained values, a graph of the dependence of the asymmetry current on the traction current consumed by the electric rolling stock is built for the given values of the resistances of the elements of the traction rail network (see figure 2).

Figure 2. Dependence of the asymmetry current on the traction current consumed by the electric rolling stock.

With a traction current $I > 3500$ A, the asymmetry current $I_a$ will exceed 520 A, which becomes critical for all types of choke transformers.

The MATLAB-Simulink environment also allows simulating the dynamics of changes in the traction current flowing in each of the rail lines and the asymmetry current when the train is moving (figures 3-6).
Figure 3. Dynamics of changes in traction current consumed by electric rolling stock.

Figure 4. Dynamics of changes in asymmetry current.

Figure 5. Dynamics of changes in the traction current in the first rail line.
Figure 6. Dynamics of changes in traction current in the second rail line.

The obtained values allow to say that under the given conditions the value of the asymmetry current is more than 435 A, which will cause the failure of DT-0.2 (0.6) -500, DT-0.2 (0.6) -1000 type choke-transformers. An increase in the traction current consumed by the electric rolling stock, or a deterioration in the state of the traction rail network elements, will lead to an increase in the asymmetry current to values at which choke-transformers, DT-0.2 (0.4) -1500 that is the most resistant to asymmetry of the traction current will fail.

4. Findings

In course of the study, a simulation model of a traction rail network section has been prepared. This model allows to simulate the process of current distribution by network elements. The values of the traction current at which the choke transformers installed on the traction rail network sections containing faulty elements will fail are determined. Analysis of the permissible asymmetry currents when the choke-transformer is capable of performing the function of converting the signal current and voltage with a set quality has been carried out [10,11].

At the next stage of the work, the model shall be supplemented with the possibility of analyzing the behaviour of the asymmetry current when the resistance of each of the elements of the traction rail network changes.

The results of the work allow to say that the failure of even several elements of the traction rail network can lead to disruption of the stable operation of the choke transformers and, as a result, to the failure of the rail circuits, which will negatively affect the carrying capacity of the railway.

In the conditions of heavy traffic, special control over the state of the elements of the traction rail network is necessary. In order to do it, it is necessary to develop an automated control systems, a feature of which, shall be the possibility of predictive analytics of ongoing processes (taking into account modern trends in the development of railway transport) [12,13,14]. This will require the creation of a multi-parameter mathematical model, on the basis of which it will be possible to train the system in order to obtain high-precision forecasts of the state of the elements of the traction rail network.

References

[1] Isaycheva A G, Volik V G, Basharkin M V and Mitrofanov A N 2020 Method for monitoring of asymmetry of traction currents in the rail line Volga region transport periodical 5(83) (Samara: Samara State Transport University) 29-34

[2] Bushuev A V, Bushuev V I and Bushuev S V 2014 Rail circuits: Theoretical foundations and operation: monograph (Yekaterinburg: Publishing house of the Ural State University of Railway Transport) 311

[3] 2012 Devices and elements of rail lines and traction rail network. Technical requirements and standards of content (Moscow: Russian Railways JSC) 40
[4] Soroko V I and Fotkina Zh V 2013 Apparatus of railway automation and telemetry in 4 books 1 (Moscow: Planeta) 1060

[5] Naumov A V and Naumov A A 2006 Selection of parameters and rules for construction of a reverse traction rail network on electrified railways with high-speed and heavy traffic (Moscow: Intekst) 143

[6] Basharkin M V and Isaycheva A G 2021 Features of current distribution in traction rail network during heavy traffic Transport Urala 3(70) (Yekaterinburg: Ural State University of Railway Transport)

[7] Grigorev V L and Teplyakova N V 2005 Study of currents flowing through choke transformers Current problems of development of transport networks in the Russian Federation: Collection of scientific papers 54-6

[8] Isaycheva A G, Basharkin M V, Nadezhkin V A and Pokhoday S N 2020 On the possibility of use of predictive analytics to determine pre-failure states in track circuits caused by the asymmetry of the traction current Science and education to transport 1 (Samara: Samara State Transport University) 293-5

[9] Yumashev A and Mikhailov A 2020 Development of polymer film coatings with high adhesion to steel alloys and high wear resistance Polymer Composites 41(7) 2875-80 doi: 10.1002/pc.25583

[10] Cao Y, Farouk N, Taheri M, Yumashev A V, Bozorg S F K, Ojo O O 2021 Evolution of solidification and microstructure in laser-clad IN625 superalloy powder on GTD-111 superalloy Surface and Coatings Technology 412 127010

[11] Vlasova Natalya V, Kuznetsov Dmitry V, Mehdiev Shamsaddin Z, Timofeeva Ekaterina S, Chistyakov Maxim S 2019 Information Technologies in the Context of Forming the Synergy of Post-industrial Consciousness and Digital Economy ISC 2019: Modern Global Economic System: Evolutional Development vs. Revolutionary Leap 1241-7 DOI: 10.1007/978-3-030-69415-9_135

[12] Zolkin A L, Domracheva E A, Losev A N and Avdeev Yu M 2021 Use of the modern information technologies for continuous monitoring of transport infrastructure IOP Conference Series: Materials Science and Engineering (Krasnoyarsk Science and Technology City Hall Krasnoyarsk Russian Federation) 12094 DOI: 10.1088/1757-899X/1047/1/012094

[13] Tormozov V S, Zolkin A L and Vasilenko K A 2020 Optimization of neural network parameters based on a genetic algorithm for prediction of time series International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2020 9271536 DOI: 10.1109/FarEastCon50210.2020.9271536

[14] Lavrov E A, Paderno P I, Volosiuq A A, Pasko N B and Kyzenko V I 2019 Automation of Functional Reliability Evaluation for Critical Human-Machine Control Systems In Proceedings of 2019 3rd International Conference on Control in Technical Systems CTS 2019 144-7 Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/CTS48763.2019.8973294