Development a Forecasting Method of Friction Pairs Wear of the Current Collection

Andriy V. ANTONOV[1], Yuriy L. BOLSHAKOV[2], Víctor G. SYCHENKO[3]

Summary
Purpose: Development a forecasting method of friction pairs wear of the current collection on electric rail transport.
Relevance: The most costly in the operation of the electrified railway transport are maintenance and repair of contact networks and pantographs. The costs magnitude depends of the catenary type, electric rolling stock, materials of the friction pair „contact wire – contact strip" and environment parameters. For today there is no consensus regarding the choice of the pantograph contact strips type for the specific operating conditions of the electric rolling stock. Therefore, the resource elements of the friction pair inefficiently used. A solution to this problem would be to a forecasting method of friction pairs wear of the current collection.
Scientific novelty: Developed a method forecasting wear of contact wires and contact strips basis on the of the neural network model. To build a neural network was used the experimental dependences and was taken into account the change pressing force of the pantograph along span of the catenary, current value, current collecting elements type and modify the parameters environment.
Practical importance: The proposed method allows to estimate the wear of the contact pair without the necessity for additional bench tests. This will significantly increase the effectiveness of the design new and modernization of already-exploited contact network sections.

Keywords: forecasting, neuron, current collector, contact strips, contact wire, wear

1. Introduction

To increase the trains speed on electrified sections of Railways it is necessary to toughen requirements to a contact networks and pantographs.

As noted in [1], to ensure high-quality current collection at high speeds it is necessary to provide the increased tension of the contact wires, use modern pantographs, choose the optimum types of contact wires and contact strips. Contact wire and contact strips must meet the requirements of electrical conductivity and mechanical strength and have high wear resistance in various modes.

It is known that the wear of the friction pair is characterized by mechanical and electrical component. Mechanical wear occurs in the form of surface layers destruction interacting elements by friction, and electric in the form of electroerosion wear at the contact loss [2, 3].

Therefore, all measures implemented as electric rolling stock and the contact network should be aimed at delivering the highest quality of current collection, if feasible and economically reasonable wear of the friction pair „contact wire – contact strip".

2. Relevance and purpose of the work

The most costly in the operation of the electrified railway transport are maintenance and repair of contact networks and pantographs. The costs magnitude depends of the catenary type, electric rolling stock, materials of the friction pair „contact wire – contact strip" and environment parameters. For today there is no consensus regarding the choice of the pantograph contact strips type for the specific operating conditions of the electric rolling stock. Therefore, the resource elements of the friction pair

[1] Postgraduate Student; Dnipropetrovsk National University of Railway Transport named after Academician V. Lazarian; e-mail: a.v.antonov91@gmail.com.
[2] Ph.D.; OOO Gloriya, Zaporizhia, Ukraine.
[3] Prof. Dr of Tech.Sci; Dnipropetrovsk National University of Railway Transport named after Academician V. Lazarian.

inefficiently used. A solution to this problem would be to a forecasting method of friction pairs wear in the current collection.

The purpose of this work is development a forecasting method of friction pairs wear of the current collection on electric rail transport.

3. Review of literature

A lot scientists were engaged in the research of the current collection process on railways [4-16], but the problem of determining the intensity wear of the friction pair and their resource at the design stage is still unresolved.

Existing systems dynamic interaction research of the contact network with pantographs [17] consider them as multi-level oscillating system with an infinite number degrees of freedom, without regard the current collection process and electrical and mechanical characteristics of the high-current contact „contact wire – contact strip". There are attempts to create systems that simulate the wear process of friction pairs in a high-current sliding contact [18] but proposed in this work method does not take into account a number of influencing factors and does not allow to accurately predict the friction pairs wear.

It is known that the wear process of friction pairs in high current sliding contact is influenced by number parameters: types of catenary and pantograph, materials from which made the friction pair elements, the influence environmental parameters, value of the current in contact and the number of pairs trains. Based on these influencing factors offered to justify a new approach to determine the quality of current collection through the intensity of the friction pair wear „contact wire – contact strip".

4. The main material

To achieve this purpose, was developed the device of Fig. 1 [19], allowing the laboratory to perform the comparative tests on wear of friction pairs.

The device has the following parameters: maximum rotational speed of the disk with the contact wire may be 1200 rpm; the length of the contact wire that is installed on the disk is 1 m; the pressure can vary between 1.5 and 8.5 daN; the current flowing through the sliding contact may be 500 A; the humidity in the contact zone may vary.

To obtain high-quality results of the friction pairs wear, the tests were carried out for different types of contact strips, the characteristics of which are given in Table 1.

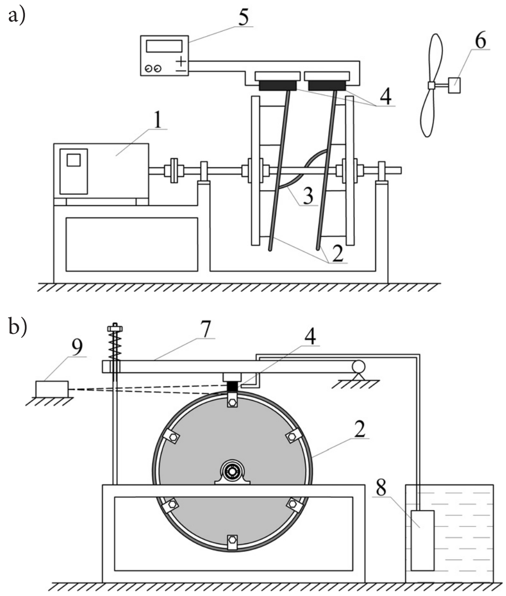

Fig. 1. Device for the comparative research of friction pairs: 1) variable frequency drive, 2) contact wires, mounted on the insulating disk, 3) the connecting conductor, 4) contact strips, 5) dc power supply, 6) air cooling system of the contact zone, 7) the pressing mechanism, 8) pump for water flow, 90 non-contact thermometer

Table 1

Parameters of the contact stripes

Parameter	Type «B» (graphite)	Type «A» (carbonite)	Copper
HB	19,5	32,8	93
ρ [μΩ·m]	18,0	27,5	0,018
***d* [g/cm³]**	1,74	1,65	8,85

Evaluation of wear contact wire and contact stripes carried out after 10 thousand passes contact strips by contact wire that corresponds to the current normative document [20]. To prevent outlying case, each test was conducted 6 times. To ensure steady-state friction and maintain a constant temperature in the contact, the device is equipped with air cooling system, which is associated with non-contact temperature meter.

The resulting test electromechanical wear of the sliding contact had a distinct U-shaped character, which is caused by the simulation real operating conditions. With the appearance condensate on the contact wire was caused by increased sparking and the separation caused a brief appearance an electric arc.

The analysis of the received dependences showed that for the contact wire and all types contact strip materials, was observed an increase wear with increase the pressing force and current strength in contact. It is established that the wear in a friction pair increases sharply with the appearance of moisture in contact and with current, regardless of pressure.

This is due to the appearance in the contact zone of low-conductivity film, which dramatically changes the interaction character of the friction pair and significantly increases the contact resistance between the contacting surfaces. Thus, the appearance of moisture in contact has a negative synergistic effect on the degree of contact strips wear. Especially it is noticeable on the electric transport DC. Widely known is the fact that the consumption of trolleybus inserts increases 3–5 times under rainy weather.

It should also be noted that when reducing the pressing force, the electric component wear prevailed over the mechanical. This conclusion applies both to the wear of contact wire and contact strips.

Experimental testing requires considerable time and material costs. To reduce the complexity of works on forecasting the friction pairs wear was proposed on the basis of the obtained experimental data to construct a predictive mathematical model, allowing to estimate the wear rate of the friction pair „contact wire – contact strip". One of the perspective directions time reduction and material costs for experimental research is the development predictive mathematical model that uses sets of known input and output characteristics to predict target values. One of such models is the artificial neural network, which is a modern, flexible and effective tool, designed for mining dependencies in complex systems. The most important advantage of neural networks is the ability to self-education.

To create an artificial neural network was used software package for statistical analysis STATISTICA Automated Neural Networks. As the neural network architecture it was decided to use a network of direct distribution, namely, multilayer perceptron, which has established itself as a neural network with a fairly simple structure and, at the same time, as a universal data processing means.

Determining the most appropriate type of neural network was carried out using the approach increasing [21], and the type most suitable activation function was determined using the method of iteration. When creating a neural network varied training, control and test readout to find the most optimal variant combination thereof. Scheme of a generalized neural network model is shown in Fig. 2.

On the input layer of multilayer perceptron during the training was use value of input signals corresponding to the received at tests of the target values. The best model was determined on the basis of the productivity readout, and also on the basis of the errors. We analyzed the histogram of the residuals and dispersion of the target and output values for each network were also constructed the response surface on the test set. The parameters of the selected models are given in table 2.

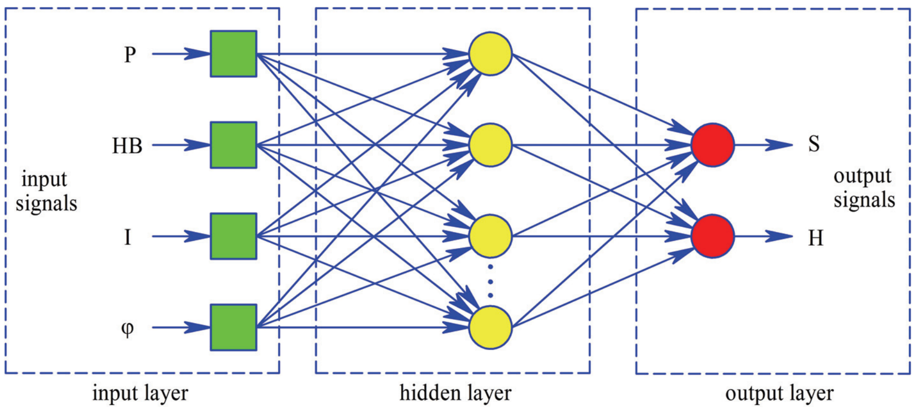

Fig. 2. Scheme of the neural network model

Table 2

Parameters of the best models

No. network	Structure	Test productivity	Training algorithm	Activation function	
				hidden neurons	output neurons
1	MLP 4-17-2	0,996578	BFGS 234	Hyperbolic	Logistics
6	MLP 4-15-2	0,997133	BFGS 568	Logistics	Exhibitor
18	MLP 4-25-2	0,996521	BFGS 201	Hyperbolic	Logistics
21	MLP 4-29-2	0,996300	BFGS 195	Logistics	Identical
25	MLP 4-22-2	0,996529	BFGS 174	Hyperbolic	Sinus

For further use were selected No. 6 which showed the best performance on the training, control and test samples. Histogram of the residuals and the response surface on the test set for which is shown in Fig. 3 and 4, respectively.

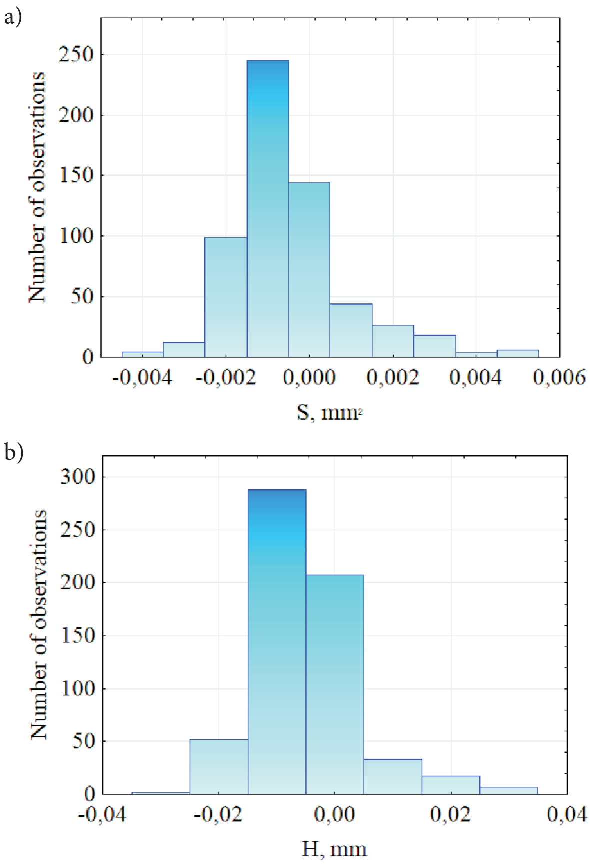

Fig. 3. Histograms of the residuals for model No. 6: a) wear of the contact wire, b) wear of the contact strip

The quality of the selected model was tested on the test sample. It was found that the average value of the relative errors of wear predicting of the contact strip is 1,64%, and wear prediction of the contact wire – 7,98%.

Forecasting method of friction pairs wear allows to take into account the schedule of consumption electric current, type catenary and characteristics of the susceptor, the environment parameters and the number trains pairs.

This article describes an example of modeling the contact wire wear along the span length, after 10 thousand passes contact strips by contact wire, and the wear magnitude of the contact strip is calculated after a distance of 600 km. In calculation were used the curve pressing the pantograph TŁ-13U with static pressing of 100 N along the span of the catenary KC-160 DC with two copper contact wires MF-100 (Fig. 5). To calculate the average current was taken as 300 A, the trains were simulated in the forward and backward movement on the section line, the value of air humidity was assumed at 60%. The simulation results shown in Fig. 6–7.

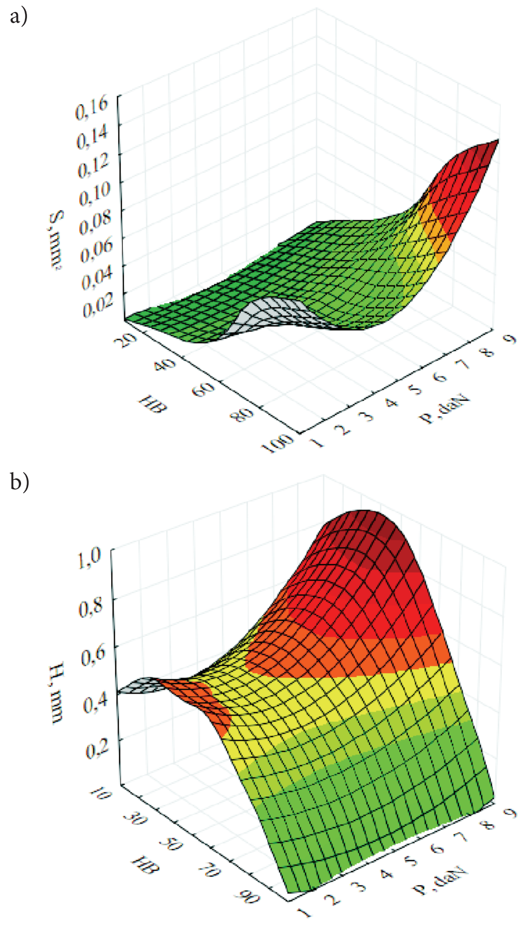

Fig. 4. The response surface on the test set: a) wear of the contact wire, b) wear of the contact strip

The curves of contact strip wear type „B" in Fig. 7 obtained by simulation and operational test, as can be seen, the obtained curves have similar appearance and differ slightly in size.

The proposed forecasting method of friction pairs wear in the current collection on electric rail transport allows to estimate the wear of the contact pair „contact wire – contact strip" without conducting additional operational test that will significantly increase efficiency design new and modernization already-exploited sections of the contact network. To improve the accuracy of the forecast model by adding additional influencing factors, for example, electrical resistivity of the contact strip and the transitional resistance of „contact strip – pantograph slide".

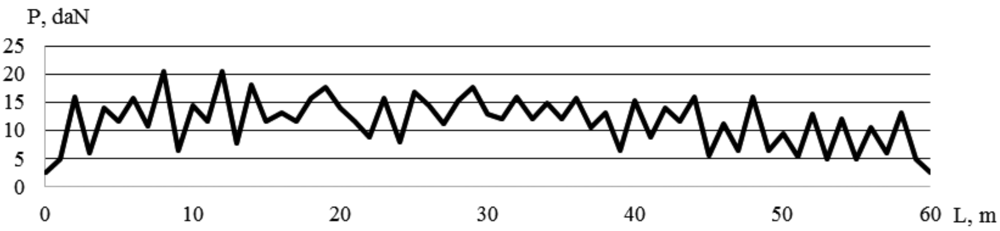

Fig. 5. Curve pressure of the TŁ-13U pantograph type along the span of the catenary M-120+2MF-100

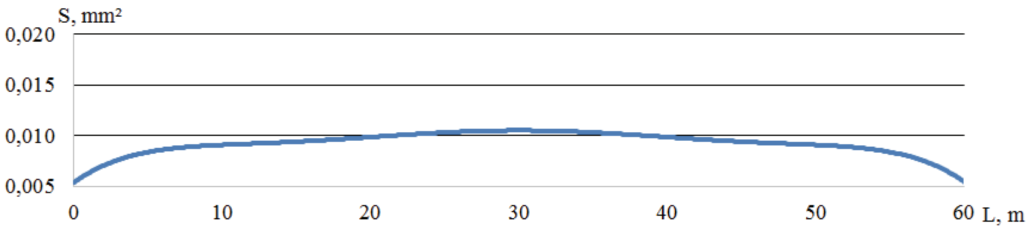

Fig. 6. Curve showing contact wire wear along the span of the catenary M-120+2MF-100

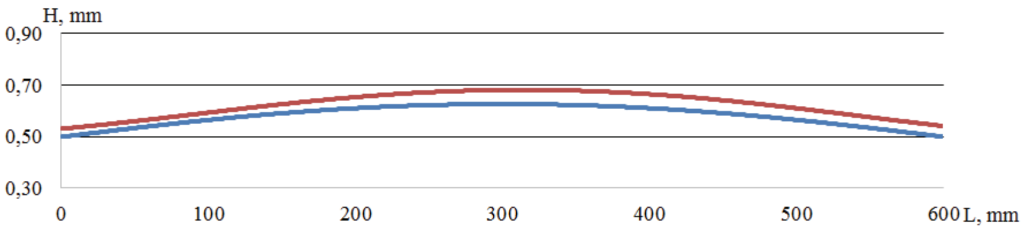

Fig. 7. Curve of contact strip wear type „B" along the length of a pantograph: 1) simulation, 2) the result obtained during operational test

5. Conclusions

1. Developed a forecasting method of friction pairs wear in the current collection on electric rail transport based on a neural network of direct distribution.
2. The proposed forecasting method of friction pairs wear in the current collection on electric rail transport allows to estimate the wear of the contact pair „contact wire – contact strip" without conducting additional operational test that will significantly increase efficiency design new and modernization already-exploited sections of the contact network.
3. To improve the accuracy of the forecast model by adding additional influencing factors, for example, electrical resistivity of the contact strip and the transitional resistance of „contact strip – pantograph slide".

Literature

1. Yandovich V.M., Sychenko V.G., Antonov A.V.: The comparative analysis of the catenaries in the European Union and Ukraine: the organization of a reliable current collection, Electrification of transport, 2014/7, pp. 67–77.
2. Kuptsov YU.E.: (2001) Conversations about the current collection and its reliability, efficiency and on ways to improve, Moscow: Modern.
3. Bolshakov YU.L., Antonov A.V.: Increase the resource of current collector elements of the electrified high-speed transport in operating conditions, Science and Transport Progress, Bulletin of Dnipropetrovsk National University of Railway Transport, 2015/4, p. 57–70.
4. Frayfeld, A.V., & Brod G.N.: (1991) Design of a contact network (3th ed.). Moscow: Transport.
5. Berent V.YA.: (2015) Materials and properties of the electrical contacts in the devices of railway transport, Moscow: Intext.
6. Holm R.: (1961) Electrical contacts, Moscow: Foreign literature.
7. Gershman I.S., Bolshakov YU.L., Sychenko V.G.: The compatibility of the various current collector materials on the same part of the contact wire, Railway transport of Ukraine, 2008/5, pp. 56–59.
8. Kuptsov YU.: Research of some physico-technical characteristics and service properties of coal inserts, Proceedings of the Central scientific research Institute the Ministry of transport and communications,1962/233, pp. 67–84.

9. Kuptsov YU.E.: The increase resource of a contact wire, Moscow: Marshrut 1972.
10. Kiessling F., Puschmann R., Schmieder A., Schneider E.: (2009) Contact Lines for Electric Railways: Planning, Design, Implementation, Maintenance, Second Edition, Wiley, John & Sons.
11. Sitarz M., Adamiec A., Manka A.: (2016) Uszkodzenia węglowych nakładek stykowych pantografów kolejowych stosowanych w Polsce, Technika transportu szynowego, 1–2, 70–74.
12. Da Hai He, Manory R., Grady N.: (1998) Wear of railway contact wires against current collector materials, Elsevier, Wear 215, pp. 146–155.
13. Kubo S., Tsuchiya H.: (2005) Wear properties of metal-impregnated carbon fiber-reinforced carbon composite sliding against a copper plate under an electric current, World Tribology Congress III.
14. Bucca G., Collina A.: (2009) A procedure for the wear prediction of collector strip and contact wire in pantograph – catenary system, Elsevier, Wear 266, 46–59.
15. Guangning WU. et al.: (2016) Evolution of the electrical contact of dynamic pantograph–catenary system, Transport, 24 (2), 132–138.
16. Shang F. et al.: (2016) Research Status and Development Trend of Pantograph Contact Strip Materials. SMAE, 67, 163–167.
17. Kudryashov E.V. et al.: (2013) Modelling of the dynamic interaction between pantographs and catenary, using the finite element method, Proceedings of the sixth international Symposium „Eltrans-2013", pp. 215–226.
18. Mikheev V.P., Sidorov O.A.: (2003) New method of predicting wear, Locomotive, 8, pp. 41–42.
19. Antonov A.V. et. al.: A device for determining the friction coefficient and wear rate of friction pair, Patent UA, no. 116437, 2017.
20. State Standard 32680 – 2014, 2015 Contact elements of current collectors of electric rolling stock, Standartinform.
21. Khaikin S.: (2006) Neural networks, Full course 2nd ed. Moscov: Publishing house „Williams".

Metoda prognozowania zużycia par ciernych w urządzeniach odbierających prąd

Streszczenie
Cel: Opracowanie metody prognozowania zużycia par ciernych urządzeń odbierających prąd w kolejowej trakcji elektrycznej.
Znaczenie: Utrzymanie i naprawa systemu sieci trakcyjnej i pantografów są najbardziej kosztowne w eksploatacji elektrycznego taboru kolejowego. Wielkość kosztów zależy od typu sieci trakcyjnej, elektrycznego taboru kolejowego, materiałów, z których są wykonane pary cierne, tzn. przewodu jezdnego i nakładki stykowej oraz parametrów środowiska. Do dzisiaj nie dokonano wyboru typu nakładki stykowej pantografu dla konkretnych warunków eksploatacji elektrycznego taboru kolejowego. W związku z tym, właściwości elementów par ciernych nie są efektywnie wykorzystywane. Rozwiązaniem tego problemu może być metoda prognozowania zużycia par ciernych urządzeń odbierania prądu.
Innowacja naukowa: Opracowana metoda prognozowania zużycia par ciernych przewodu jezdnego i nakładki stykowej jest oparta na modelu sieci neuronowej. W celu zbudowania sieci neuronowej wykorzystano zależności eksperymentalne i wzięto pod uwagę zmianę sił nacisku na pantograf wzdłuż przewodu trakcyjnego, wartość prądu, typy elementów urządzeń odbierania prądu i zmiany parametrów środowiska.
Znaczenie praktyczne: Zaproponowana metoda pozwala ocenić zużycie pary ciernej przewodu bez konieczności przeprowadzenia dodatkowych badań stanowiskowych, co znacznie zwiększy efektywność projektowania nowych i modernizacji już istniejących odcinków sieci trakcyjnej.

Słowa kluczowe: prognozowanie, neuron, odbierak prądu, nakładka stykowa, przewód jezdny, zużycie

Разработка метода предусмотрения износа фрикционных пар токоприемников

Резюме
Цель: Разработка метода предусмотрения износа фрикционных пар токоприемников в тяговом железнодорожном транспорте
Значение: Содержание и ремонт системы электрической тяги и пантографов являются найболее дорогими в эксплуатации электрического железнодорожного транспорта. Стоимость зависит от типа тяговой сети, электрического подвижного состава, материалов, из которых сделаны фрикционные пары, т.е. контактный провод и контактная вставка а также параметров окружающей среды. До сих пор нет согласия по вопросу выбора конкретного типа контактной вставки пантографа для конкретных эксплуатационных условий электрического подвижного состава.
В связи с этим ресурсы элементов фрикционных пар нееффективно использованы. Решением этой проблемы может быть метод предусмотрения износа фрикционных пар токоприемников.
Научная инновация: Разработанный метод предусмотрения износа фрикционных пар контактного провода и контактной вставки основана на модели нейронной сети. Для постройки нейронной сети были использованы экспериментальные зависимости и учтены изменение силы давления на пантограф вдоль контактного провода, значение тока, типы элементов токоприемников и изменений параметров окружающей среды.
Практическое значение: Предложен метод позваляет оценить износ фрикционной пары провода без необходимости проведения дополнительных стендовых испытаний, что значительно увеличит эффективность проектирования новых и модернизации существующих участков тяговой сети.

Ключевые слова: предусмотрение, нейрон, токоприемник, контактная вставка, контактной провод