ПРАКТИЧНА РОБОТА: ОФОРМЛЕННЯ НАУКОВОЇ СТАТТІ

Мета роботи: вивчення та освоєння ключових аспектів написання та оформлення міжнародної статті, огляд наукових журналів за професійним спрямуванням. В якості практичної частини для закріплення знань та навичок виступає написання невеликої статті за індивидуальними темами.

Теоретичні відомості:

В Україні за останні роки відбулися суттєві зміни у сфері вищої освіти. Одним з чинників, що зумовив модернізацію цієї сфери – це адаптація вітчизняної вищої школи до міжнародних стандартів у сфері освіти і науки.

Зокрема, йдеться про впровадження нових вимог до оформлення бібліографічного опису списку використаних джерел в дисертаціях та списку опублікованих робіт в авторефератах дисертацій; запровадження нового порядку присвоєння вчених звань науковим і науково-педагогічним працівника; зміни процесів підготовки здобувачів наукового ступеня «доктор філософії ” і «доктор наук” та присудження наукових ступенів.

Кожна поважаюча себе освічена людина повинна як мінімум знати вимоги для публікацій в мужнародних виданнях. А краще періодично публікувати наукові статті як результати своєї діяльності.

Пристатейна бібліографія (REFERENCES)

Список використаних джерел відповідно до ДСТУ можна оформити сьогодні відповідно до вимог ДАК України автоматично.

Для активного включення статей наукового фахового видання в обіг наукової інформації та коректного індексування публікацій наукометричними системами необхідно після наведення списку використаних джерел в кожній публікації наводити блок REFERENCES, який повторює список джерел з латинським алфавітом, та наводить список кириличних джерел у транслітерованому вигляді. Крім того цитування у блоці REFERENCES повинні бути оформлені за міжнародними стандартами.

Транслітерація здійснюється залежно від мови оригіналу відповідно до Постанови Кабінету Міністрів України № 55 від 27 січня 2010р. «Про впорядкування транслітерації українського алфавіту латиницею» (для української мови): Стандартна українська транслітерація.

Список інформаційних джерел у блоці REFERENCES повинен бути оформлений відповідно до міжнародних стандартів. Одним із найбільш популярних є стандарт APA (American Psychological Association (APA) Style), коли рік публікації наводиться у круглих дужках після імені автора. 59

Для оформлення кириличних цитувань необхідно транслітерувати імена авторів та назви видань (назви статей для кириличних видань транслітеруються або опускаються, можна навести авторський англійський варіант назви статі). Назви періодичних видань (журналів) наводяться відповідно до офіційного латинського написання за номером реєстрації ISSN (можна перевірити на сайті журналу або в науковій онлайн-базі, «Наукова періодика України» та багатьох інших).

В елементах опису не можна використовувати фігурні лапки (лише звичайні прямі (« «), не можна заміняти латинські літери на кириличні.

The Contactless Method of Diagnosing the State of the Sliding Power Contact of an Electric Transport Under Bench Tests Conditions

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Abstract: During the comprehensive study, a list of recommendations regarding the procedure and content of the program and methods of bench tests of the contact wire on the amount of wear was developed. The contactless method of diagnosing the state of the sliding power contact with the help of non-destructive temperature control at the point of current collection allows predicting the result of bench tests already at the initial stage of the tests. On the basis of scientifically substantiated results, it can be stated that the expansion of the program and methods of bench tests of the contact wire on the amount of wear by controlling the temperature of the contact zone will allow to reduce time, energy and other costs during mandatory bench tests of the latest samples of contact inserts of pantographs.

Keywords: Sliding Contact, Pantograph Insert, Wear, Contact Wire, Bench Tests.

1. Introduction

In rail transport systems, a sliding power contact formed by a contact wire and a special contact pantograph insert to transfer energy to the vehicle is very widely used. The efficiency of the entire transport system largely depends on the state of this unit and its efficiency. Taking into account the fact that the energy transmission unit is not redundant, maintaining its elements in the appropriate technical condition is an important and relevant task.

Solving the problem of effective operation of the contact network and electric rolling stock requires further reduction of wear of the contact wire and cases of its destruction, increase of the service life of the skids of pantographs, reduction of electricity losses during current collection [1, 2].

Any measure aimed at reduction the wear of the elements that make up the sliding contact and improving the quality of its work must be based on knowledge of the amounts, nature and features of its wear, as well as on the correct understanding of the reasons that affect the quality of its work. One of the common approaches in solving this kind of problems is the use of statistical data obtained during the bench tests [3]. Bench tests are not only a tool for selecting and putting into operation the contact inserts of the pantograph that better meet the requirements of efficient and trouble-free operation; but also a basis for creating the advanced materials and technologies in the field of power sliding electrical contacts.

The main factors determining the level of wear of a high-current sliding contact are [4, 5, 6]:

- oxidation of the metal element of the friction pair;
- oxidation of the composite element of the friction pair and weakening of its strength;
- strengthening of adhesion due to dissociation of water films or organic substances under the action of electric current;
- the formation of shock thermal stresses in the dynamic contact due to the uneven distribution of the current density in it;
- electric sparking; arc formation, etc.

Usually, all of the named factors act simultaneously and are connected by heat generation on the transition contact resistance. Therefore, the temperature of the sliding contact zone can act as a kind of integral indicator that quite accurately reflects the quality of the current collection process, and accordingly, it can be used to compare different types of contact inserts of pantographs, as well as predict their resource and the resource of the contact wire [6]. This is facilitated by the development of instruments for temperature measurement and methods of their application. As part of non-destructive testing methods of surface temperatures, the thermovision technique of measuring friction temperatures is quite popular. The essence of this method is to register the infrared radiation of the research object and the subsequent transformation of the radiation into electrical signals or into a visible image. Only thin surface layers are involved in the process of radiant heat exchange, so thermal radiation for solid bodies can be considered as a surface phenomenon.

In [7, 8] attention is focused on the thermal state of the sliding contact in the conditions of bench tests, as the most informative factor, since the specific electrical resistance of the material, hardness, and friction coefficient directly depend on the temperature and affect the amount of wear of the material. The authors of [8] link the temperature of the contact zone with the amount of wear of carbon contact inserts, and also indicate a change in the microstructure of the contacting surfaces. The results of [8] are correlated with the results and conclusions obtained in [7] during the experimental study of the electrical sliding contact. It is logical to spread such an approach to the contact inserts of the pantograph made of composite materials that have enhanced self-lubricating properties.

2. FORMULATION OF THE PROBLEM

The purpose of the research is to develop scientifically justified recommendations for improving the standard method of bench tests of power sliding contact elements.

The relevance of research is caused by the need to reduce time, energy and other costs when conducting bench tests of power sliding contacts, due to the introduction of two-stage tests.

At the first stage, it is proposed to monitor the temperature state of the sliding contact and compare the obtained values with the indicators of the standard reference sample and the normative temperature value of the contact wire. The second (main, long-term) stage should be carried out only for samples that have successfully passed the first stage. In the standard methodology, the tests are carried out without division into stages, which leads to significant time, energy and other costs, without the possibility of predicting the final test results at the initial stage of the tests.

To achieve the goal, the following tasks were set:

1. To conduct experimental bench tests of the temperature regime of the sliding high-current contact using the non-destructive temperature control methods of the problem area.
2. To investigate the influence of the number of passes and the temperature in the contact zone on the wear value of the contact wire.
3. To provide recommendations for improvement/expansion of the bench test method.

3. MATERIALS AND RESEARCH METHODS

Standard of Ukraine DSTU GOST 32680:2016 "Head current collection elements of pantographs of electric vehicle. General specification" [9] regulates the procedure for acceptance and standard tests for pantograph contact inserts. The program of such tests includes checks of contact inserts and contact wire wear. The mileage of the contact inserts till they reach limit wear is determined based on the results of operational tests. Inserts are considered to have passed the test if they have an estimated replacement forecast based on ultimate wear not less than: for light-type pantographs $60 \cdot 10^3$ km or more; for heavy type pantographs $25 \cdot 10^3$ km or more, as indicated in clause 5.1.5 of DSTU GOST 32680:2016 [9]. The amount of contact wire wear is checked on a special bench. Clause 8.3.13 of DSTU GOST 32680:2016 [9] sets the following requirements for the test bench: a segment of the MF-100 (copper shaped wire with cross-section of 100 mm^2) contact wire is fixed in the form of a closed curve on a rotating device, which ensures the required linear speed of any point of the wire, and the point of contact of the contact wire should ensure smooth sliding of insert on it. Two identical pieces of the contact insert are installed on the test bench, facing each other. They are pressed against the contact wire with a force of (40±8) N. The amount of wear of the contact wire is considered acceptable if, after 500,000 revolutions of the rotating device, it does not exceed 2 mm (or 40 μm per 10,000 revolutions) [9].

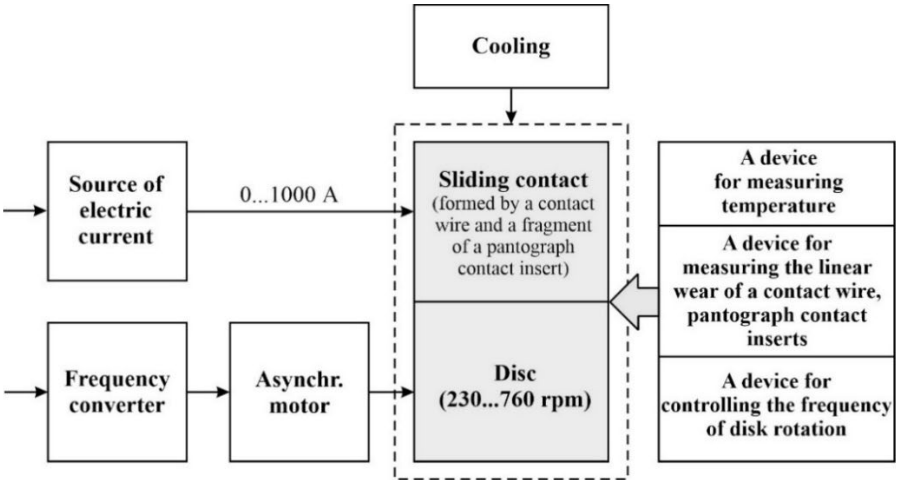

Fig. 1. Block diagram of a laboratory test bench for studying the wear of elements of power sliding contact

In its turn, GOST 2584-86 " Copper and copper alloys trolley wires" establishes the permissible temperature of the contact wire, so for the MF-100 wire, the permissible temperature is 95ºC, taking into account possible heating during the entire service life [10]. Industrial research laboratory (IRL) "Reliability and unification of rolling stock electrical equipment" of the Ukrainian State University of Science and Technologies is equipped with a specialized bench for determining the amount of contact wire wear. The block diagram of the bench is shown in Fig. 1. Similar benches are used by many laboratories of the world when studying the properties of not only sliding, but also removable contacts and contacts of electrical devices [3, 4, 11]. In most cases they include measuring equipment for monitoring the temperature of the contact zone.

During bench tests, the authors used a Testo 875 thermal imager with the IrSoft software package to control the temperature of the sliding contact zone (Fig. 2).

The thermal imager allows us to perform remote and contactless measurement of the temperature of the sliding contact zone during the tests at a certain time interval and have a heating curve of the specified zone at the end of the cycle.

The authors' studies [3, 12] show the results of mathematical modeling of the wear of contact pairs taking into account the temperature. The analysis shows that wear is largely determined by the temperature of the friction bodies, which affects the hardness of the elements of the contact pair and the actual contact area. The dominant role of the electrical component of wear in increasing of the friction pair temperature is shown in [13].

Fig. 2. General view of the test facility

The influence of different types of contact inserts (more than 10 types in total) [14] on the amount of wear of the contact wire was investigated in laboratory conditions. During these tests, the heating of the contact wire was controlled, especially – the maximum temperature according to GOST 2584-86 (95°C) [10].

The manufacturers of the contact wire MF-100 guarantee its quality indicators in case of not exceeding the specified value of 95°C. If this value is exceeded, the physical and mechanical properties of the contact wire deteriorate, in particular the density of the working surface of the sliding contact, which can lead to increased wear of the contact wire. Therefore, if this value is exceeded during the tests, the test results of this sample were considered unsuccessful.

From the researched types of contact inserts of the pantograph, experimental samples were made, which are hereinafter referred to as "Sample 1", "Sample 2", etc.

Before the start of the bench tests, photos of both the test samples of the contact inserts and the contact wire were taken. Fig. 3 shows the photo of the surface of the MF-100 contact wire. An elliptical ring was made of this wire and mounted on the rotating part of the test bench.

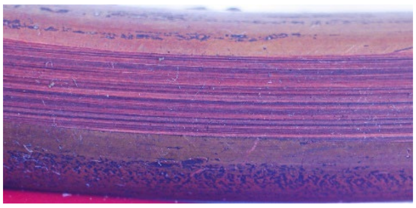

Fig. 3. The photo of the surface of the MF-100 contact wire before the start of the bench tests

Fig. 4 shows the photo of the surface of the experimental sample "Sample 1" before the start of the bench tests.

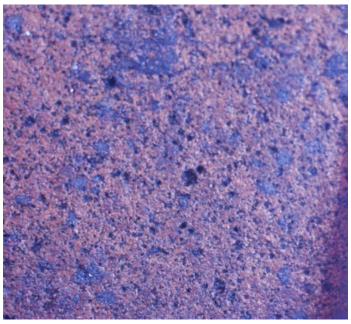

Fig. 4. The photo of the surface of the experimental sample "Sample 1" before the start of the bench tests

The first stage of the tests consisted of 10,000 revolutions of the disk of the test bench, while the temperature in the contact zone was recorded every minute, which made it possible to assess the dynamic change in temperature over time, from the initial value to the steady state. The duration of the first stage of testing was 50 minutes. The rotation frequency of the bench disk was 205 rpm, and the current flowing through the sliding contact was 300 A.

After the first stage of the tests, photos of the surface of the contact wire in the places of measurements of its geometry (Fig. 5) and of the test sample (Fig. 6) in the place of contact with the ring were taken.

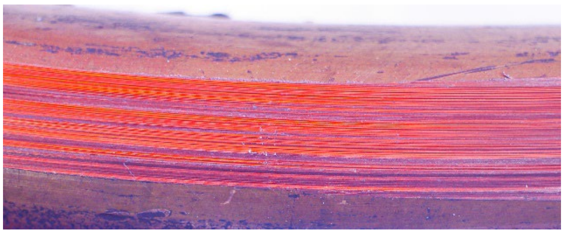

Fig. 5. The photo of the surface of the MF-100 contact wire after the first stage of the tests

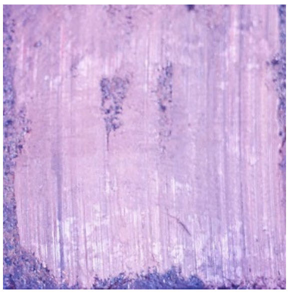

Fig. 6. The photo of the surface of “Sample 1” after the first stage of the tests

Fig. 7 shows one of the thermograms obtained during tests of a fragment of the contact insert "Sample 1" using a thermal imager Testo 875. The established temperature of the sliding contact zone for "Sample 1" does not exceed the value of 45 °C. The process of reaching a fixed value is relatively long and depends on the properties of this contact, and therefore can be used as a kind of "passport".

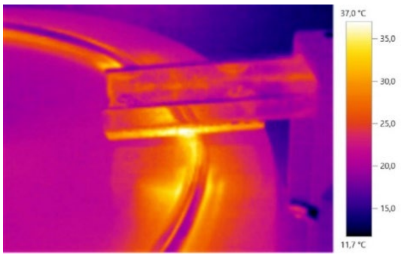

Fig. 7. The thermogram during tests of a fragment of the contact insert "Sample 1" (right fragment)

Fig. 8 shows the graph of the change in temperature of the sliding contact zone heating during the tests of the fragment of the contact insert "Sample 1". Graphs for the left (red color) and right (black color) fragment of the contact insert on the bench are presented separately.

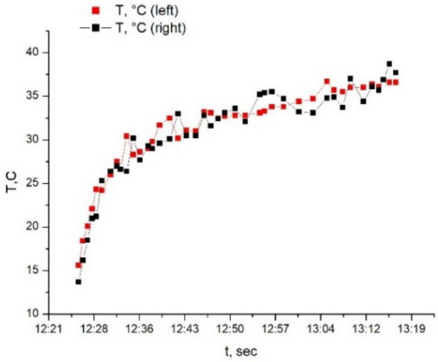

Fig. 8. The graph of the heating temperature change of the sliding contact over time during the testing of the fragment of the contact insert "Sample 1"

Fig. 8 shows that the heating process is aperiodic, therefore the heating time constant for sliding contact elements can be determined graphically. The results of determining the heating time constant of power sliding contact zone are collected in Table 1. Table 1 also shows the established temperature values for each sample. Since two fragments of the same sample are simultaneously tested on the bench, the values in the Table 1 are given for each of them separately.

For the sliding contact that is formed by the contact wire MF-100 and the fragment of the contact insert "Sample 4", it is impossible to determine the time constant, since the tests were stopped after 3 minutes. The reason was a significant increase in the temperature of the contact zone (more than 95ºC) and "jamming" of the bench – the disk stopped rotating and the gripping of elements of the sliding contact was observed. Fig. 9 shows the photo of "Sample 4" after jamming of the bench.

Table 1. The values of the established temperature and heating time constants of sliding contact zone

Sample number		1	2	3	4
Heating time constant of the contact zone, min	Left holder	9	9	10	-
	Right holder	9	9	10	-
Established temperature, ºC	Left holder	47	41	47	-
	Right holder	35	39	43	-

Fig. 9. The photo of "Sample 4" after jamming of the bench

Fig. 10. The photo of the surface of the MF-100 contact wire after working in pair with the sample "Sample 4"

The photo of the contact wire surface after working in pair with the sample "Sample 4" is presented in Fig. 10. In general, the surface of the contact wire had damage and burrs and was not suitable for further use after the tests. "Sample 4" was not allowed to proceed with the second stage of tests.

It should be noted that there is a temperature difference during the operation of the left and right fragments of the sample, which is caused by a gradual decrease in the contact pressure of the right holder of the fragment to the contact wire, due to the design features of its elastic elements.

Thus, if the obtained heating time constant of the elements of the sliding contact is approximately equal to 9 min, and the temperature of the contact wire did not exceed the maximum permissible value (95ºC for a contact wire of the MF-100 type), then the contact insert is allowed to the second stage of testing (full cycle – 500,000 disk revolutions).

During bench tests, every 10,000 passes of the disk, wear values of the contact wire were recorded. The results of these records are presented in the Table 2.

Table 2. Results of wear measurement along the height of the contact wire after 10,000 passes

Sample number	Average value of wear along the height of the contact wire, mm
1	0.015
2	0.016
3	0.023
4	-

The analysis of wear measurements along the height of the contact wire of all samples during bench tests indicates that they have an uneven, stochastic, probabilistic nature. Therefore, it is necessary to investigate the dependence of contact wire wear on the number of revolutions (passes) of the disk of the test stand, or other indicators by using the methods of mathematical statistics.

It makes no sense to determine the distribution law of the studied amount of wear of the contact wire, because in the end, only numerical characteristics which describe the most essential properties of this distribution are needed. In our case, a mathematical expectation can be such a characteristic.

It is known that with a sufficient number of measurements, the average value of a random variable approaches to its mathematical expectation (m) in probability, and therefore, in practical calculations, it can be accepted as an estimated value.

To ensure the compliance with the basic provisions about the normal probability distribution, the confidence interval must be 68% (standard), this condition will be ensured in the case of an approximate number of experimental points at the level of 20. In our case, the number of controlled points on the experimental ring of the bench is six, so it is necessary to perform three measurements of contact wire wear in each of these points. This will allow the number of experimental points to be obtained in the amount of 18, which is close to the desired value.

Thus, in the experimental studies, 18 measurements of wear along the height of the contact wire are recorded. In the Table 3 summary measurements of wear along the height of the contact wire under the condition of working in pair with "Sample 1", the measurement interval is 10,000 revolutions of the bench disc. The amount of wear is determined in relation to the previous 10,000 revolutions, that is, the value of wear is actually determined for every 10,000 revolutions of the bench.

Table 3. Results of wear measurement along the height of the contact wire under the condition of working in pair with "Sample 1"

Control point	Wear value along the height of the contact wire, mm			
	20,000 revolutions	30,000 revolutions	40,000 revolutions	50,000 revolutions
1	0.021	0.023	0.015	0.014
	0.022	0.023	0.016	0.0135
	0.022	0.025	0.016	0.0125
2	0.015	0.018	0.021	0.019
	0.016	0.0185	0.021	0.0185
	0.015	0.018	0.023	0.02
3	0.03	0.0195	0.025	0.027
	0.028	0.02	0.025	0.028
	0.029	0.02	0.0245	0.029
4	0.006	0.015	0.012	0.013
	0.006	0.0165	0.0123	0.0125
	0.005	0.0155	0.0123	0.012
5	0.012	0.0055	0.007	0.0085
	0.015	0.0065	0.0075	0.0085
	0.016	0.0065	0.008	0.008
6	0.002	0.0015	0.0018	0.0019
	0.001	0.001	0.0019	0.0019
	0.001	0.001	0.002	0.002

The χ^2 criterion was used to check the hypothesis:

$$\chi^2 = \sum_{i=1}^{k} \frac{(M_i - np_i)^2}{np_i}, \tag{1}$$

where M_i is the number of samples in the grouping interval; np_i is he expected number of samples in the grouping interval.

For clarity of checking the χ^2 criterion, we will present the calculations in the Table 4.

Table 4. The results of checking the distribution hypothesis of the random value of contact wire wear according to the χ2 criterion ("Sample 1" after 20,000 revolutions)

i	M_i	np_i	M_i- np_i	$\frac{(M_i - np_i)^2}{np_i}$
1	4	3	1	0,33
2	2	3	-1	0,33
3	4	3	1	0,33
4	2	3	-1	0,33
5	3	3	0	0
6	3	3	0	0
Σ	18	18	0	1,33
1,61>1,33				

The table value of the χ^2 criterion at the number of degrees of freedom at the level $m = k - 1 = 6 - 1 = 5$ equals 11.1 (with probability of α=0.05), which exceeds the calculated 1.33 (Table 4), this means that the hypothesis of a normal distribution is valid.

For further research, the wear value along the height of the contact wire is taken to be equal to the mathematical expectation, i.e. 14.6 μm per 10,000 revolutions, for the interval from 10,000 to 20,000 revolutions of the test bench disk.

Similar calculations for the following intervals of bench operation are presented in the Table 5.

Table 5. The results of checking the distribution hypothesis of the random value of contact wire wear according to the χ2 criterion ("Sample 1")

i	$\frac{(M_i - np_i)^2}{np_i}$		
	30,000 revolutions	40,000 revolutions	50,000 revolutions
1	0	0	0
2	0	0	0
3	3	0	3
4	0	0	0,33
5	3	0.33	1,33
6	0	0.33	0
Σ	6	0.67	4.67
	11.1>6	11.1>0,67	11.1>4,67

Contact wire wear measurements for samples "Sample 1", "Sample 2" and "Sample 3" were made every 10,000 revolutions up to 50,000 passes (included). After that only one measurement was made after 500,000 passes, as a control one to verify the predicted wear value of the contact wire during bench tests only for the sample "Sample 1".

As a result of tests conducted to investigate the amount of wear of the contact wire when working with the type of contact insert "Sample 1", a relationship between the average amount of wear of the contact wire by height and the temperature in the contact zone was obtained (Table 6).

Table 6. Results of wear measurement along the height of the contact wire with the corresponding temperatures of the sliding contact zone

Number of disk revolutions, thousand		10	20	30	40	50
Wear value, μm		15	29.6	43.7	57.7	71,6
Temperature of the contact zone, °C	Left holder	47	48	48	49	48
	Right holder	36	37	38	38	39

Based on the data in the Table 6 we can say that in case of successful tests (according to temperature indicators) at the initial stage of the tests (the first 10,000 passes) – the temperature indicators will remain unchanged during the following stages.

Experimental points are shown in Fig. 8 in blue; the proposed approximation dependence in the form of equation like $y(x)=c+k(x)$ is shown in red.

In our case, the following approximation equation is proposed:

$$\Delta_{\mathrm{КП}}(n_{\mathrm{DISK}}) = 1{,}13 + 1{,}413 \cdot n_{\mathrm{DISK}}, \qquad (2)$$

where: n_{DISK} is the number of revolutions of the test bench disc (in thousands).

The resulting ratio (2) is a model of contact wire wear during bench tests.

The adequacy of the ratio obtained by the method of approximation of the analytical expression and the original experimental data was proved by the method of least squares – the coefficient of least squares at the level of 0.999 (complete conformity).

Using expression (2), it is possible to estimate standard indicators, for example, the amount of wear per 500,000 passes of the disc.

So, in the case of using contact inserts of the first type ("Sample 1"), the wear of the contact wire after the end of the full test cycle (500,000 revolutions) will be estimated at the level of:

$$\Delta_{\mathrm{КП}}(n_{\mathrm{DISK}}) = 1{,}13 + 1{,}413 \cdot 500 = 707\ \mu\mathrm{m}.$$

In order to check the adequacy of the obtained contact wire wear model, a full volume of tests with a volume of 500,000 revolutions was conducted for a fragment of the contact insert "Sample 1". The obtained experimental value of the wear was 723 μm.

The difference between the amount of contact wire wear expected by model (2) and its experimental value will be equal to 2.3%, that indicates the adequacy of the mathematical model of contact wire wear.

Similarly, approximations of the experimental values of contact wire wear values $\Delta_{\mathrm{КП}}$ were made by linear expressions, respectively, for contact inserts of the second and third types:

$$\Delta_{\mathrm{КП2}}(n_{\mathrm{DISK}}) = -2{,}01 + 1{,}803 \cdot n_{\mathrm{DISK}} \qquad (3)$$

$$\Delta_{\mathrm{КП3}}(n_{\mathrm{DISK}}) = -3{,}27 + 2{,}653 \cdot n_{\mathrm{DISK}} \qquad (4)$$

Then, in the case of using contact inserts of the second type ("Sample 2"), the wear of the contact wire at the end of the full test cycle (500,000 revolutions) will be estimated at the level:

$$\Delta_{\mathrm{КП2}}(n_{\mathrm{DISK}}) = -2{,}1 + 1{,}803 \cdot 500 = 899\ \mu\mathrm{m},$$

And for inserts of the third type ("Sample 3"):

$$\Delta_{\mathrm{КП2}}(n_{\mathrm{DISK}}) = -3{,}27 + 2{,}653 \cdot 500 = 1{,}323\ \mu\mathrm{m}$$

This means that "Sample 2" will have a smaller resource than "Sample 1" by almost 27%.

4. RESULTS

Practical scientific work on improving the method of diagnosing the state of the sliding contact formed by the contact wire and contact insert of the pantograph under the conditions of bench tests showed the following results:

Within the framework of the experimental part of the sliding contact on the amount of wear of its elements; the relationship between the amount of wear along the height of the contact wire and the temperature in the area of the sliding contact was established.

Statistical data on the amount of wear and temperature of sliding contact elements, processed with the help of generally known methods of mathematical statistics, formed the basis of the analytical dependence between the temperature regime in the contact zone and the amount of wear of the contact wire.

Based on the dependences of the contact wire wear and the number of passes of the disk of the test bench, a simplified resource model of the sliding contact of the electric vehicle, when using a specific type of pantograph inserts.

The contactless method of diagnosing the temperature of the sliding contact during the first stage of the test allows us to obtain a heating time constant. The comparison of this constant with the same indicator for the reference sample allows us to conclude that it is appropriate to conduct a full test cycle for the contact insert of the pantograph that was tested.

Thus, it is proposed to add the following to the standard methodology of bench tests of elements of sliding contact for wear value:

To divide the testing process into two stages (preliminary and main);

To make an assessment of feasibility of conducting a full cycle of tests at the first stage, based on monitoring the thermal state of the sliding contact and the resource model for this type of contact insert;

The proposed changes to the standard method of conducting bench tests do not require significant additional financial costs, increase in time and complication of the procedure. It will allow to speed up the tests, reduce the consumption of electrical energy. It will also allow the manufacturers of contact inserts to improve quality due to accelerated initial control, which should be supplemented by a bench test procedure for determining the wear of sliding contact elements in the amount of 10,000 passes of the test bench disk with contactless monitoring of the thermal state of the contact.

5. CONCLUSION

The result of a comprehensive study of the process of wear of the contact wire during bench tests of contact inserts of electric transport pantograph is the following scientifically substantiated recommendations.

1 . It is suggested to monitor the temperature value at the point of contact using non-destructive methods. In particular, use a thermal imager or pyrometer.

2. It is advisable to conduct the tests in two stages. The first – preliminary tests, the second – main tests. During the preliminary tests, it is recommended to constantly monitor the temperature in the contact zone at regular intervals. As a recommendation, to set such an interval as one minute. According to the temperature monitoring data, determine the heating time constant and compare it with a similar indicator of the reference sample of the contact insert. As a reference sample, it is proposed to use “Sample №1”, as the one that has shown the smallest wear of the contact wire and did not lead to exceeding the permissible value of the temperature of the contact wire. Samples during the tests of which temperature excess was not recorded, are allowed to undergo the second stage of tests.

3. The duration of the first stage of testing is recommended to be set at 10,000 revolutions, and for the second – from 10,000 to the normative 500,000 revolutions of the bench disc.

4. According to the results of statistical data processing, when measuring contact wire wear, it is recommended to set up the number of measurements to at least three, for each of the experimental points where measurements are made. Further determination of the average value should be made and compared with the normative one. The expediency of such an approach is justified by the conformity of the wear process of the contact wire with the normal law, which was proven during research.

Implementation of these recommendations will increase the effectiveness of bench tests – first of all due to a possible reduction of test time.

For example, if at the first stage of testing (10,000 disk passes) it is established that further testing of the insert samples in full (500,000 disk passes) is impractical due to temperature excess or increased wear of the contact wire, then the savings of time to test fund will be almost 98%.

Thus, the use of the proposed recommendations will increase the efficiency by eliminating unnecessary costs, when conducting potentially unsuccessful tests, the feasibility of which in full is questionable.

The second factor that improves the efficiency of bench tests is contactless temperature control in the high-current contact zone in combination with a predictive wear model (2). This feature is particularly valuable for manufacturers of contact inserts of pantographs, as it will allow, already at the first stage of testing, to determine those samples that allow obtaining minimal wear of the contact wire.

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