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RESOURCE EVALUATION OF FRICTION PAIR "CONTACT WIRE – CONTACT STRIP"

Andrii V. Antonov[1], Víctor G. Sychenko[2]

[1,2] Dnepropetrovsk National University of Railway Transport named after Academician V. Lazarian, Dnipro, Ukraine

[1]e-mail: a.v.antonov91@gmail.com

Abstract: *Purpose. Investigate the impact of current collection system parameters and external factors on the resource of friction pair "contact wire – contact strip". Relevance. The level of electrified railways reliability depends on the reliability and durability of the individual objects of power supply system and the locomotive facilities, in turn, the current collection quality depends on design of contact network and pantographs, contact wires materials, contact strips and external influencing factors. The resource system "contact wire – contact strip" is an important technical and economic characteristics, and its average actual resource is much less established. It means that the actual resource does not reach the optimum value from an economic point. Increasing velocity of the electric rolling stock exacerbates the problem of improving the current collection quality, becomes an actual task of increasing the resource friction pair " contact wire – contact strip" for mainline railways. Scientific novelty. This work determined the influence structural parameters of the friction pair, the current collection system parameters and external factors on the wear rate of the friction pair "contact wire – contact strip". Proposed to create a predictive mathematical model that uses the dependence of the influencing parameters obtained in this work to assess the wear and resource of contact wire and contact strips. Practical importance. Developed the device for wear researching of friction pairs in laboratory conditions allows assessing the wear rate of the system "contact wire – contact strip" and their residual resource at different combinations of the friction pair and external factors. The obtained results allow us to construct a predictive mathematical model to evaluate wear rate of the elements of the friction pair "contact wire – contact strip" and identify their residual resource.*

Key words: *resource, reliability, current collection, wear rate, contact wire, contact strip, friction coefficient.*

1. Introduction

Global experience in operating high-speed electrified railways defines the requirements to ensure quality of current collection at speeds up to 200 km/h (Kuptsov, Yu. E., 2001; Frayfeld, A. V., & Brod, G. N., 1991; Berent, V. Ya., 2005; Miheev, V. P., 2003; Kaniewski M., & Głowacz M., 2016; Sitarz, M., et al., 2016; Da Hai He, et al., 1998; Kubo, S., & Tsuchiya, H., 2005; Kubota, Yo., et al., 2012; TU Chuan-jun, et al., 2008; Kiessling F., et al., 2009; Poetsch G., et al., 2001;):

- Ensuring the quality control of catenary system, using on the areas.
- Increasing the wires and catenary tension .
- Using modern pantographs for the electric rolling stock.
- Using new materials for contact wire and contact strips.

Increasing the speed of the electric rolling stock, the discrepancy of the electrified Railways infrastructure the above conditions leads to frequent catenary and pantographs breakdowns and to an increase in losses of the railway from stops of trains.

2. Relevance and purpose of the work

The import place in ensuring quality of current collection is the optimal choice and cost-effective parameters of the friction pair elements, which have to meet the specified conditions.

Nowadays a lot of different countries use such contact strip materials, on the pantographs of the electric rolling stock, as: copper and its alloys; aluminium alloys; low carbon and graphitized steel; powder materials and metal-carbon composites. Such variety of materials shows us the complexity of optimal variant contact strip choice that will effectively minimize the wear of the contact wire.

The level of electrified Railways reliability depends on the failsafety and durability of the individual objects of power supply system and the locomotive facilities, in turn, the current collection quality depends on contact network design and pantographs, materials from which are made contact wires and contact strips, external influencing factors. Resource of contact pair “contact wire – contact strip” is an important techno-economic characteristic and very often, the average actual resource is much less established. It means that the actual resource does not reach the optimum values from economic point. Increasing velocity of the electric rolling stock, exacerbates the problem of improving the current collection quality and becomes an actual task of increasing the resource friction pair “contact wire – contact strip” for mainline railways.

The aim of this work is to investigate the influence of parameters the current collection system and external factors on resource friction pair “contact wire – contact strip”.

3. Review of literature

Specialists are engaged in the issue of increasing the contact wire and contact strips resource from the beginning of the electrified Railways creation (Kuptsov, Yu. E., 2001; Frayfeld, A. V., & Brod, G. N., 1991; Kubo, S., & Tsuchiya, H., 2005; Berent, V. Ya., 2005; Kiessling F., et al., 2009; Poetsch G., et al., 2001; Cléon L.M., et al., 2006;).

The chief purpose of the works is to improve the quality of the current collection achieving maximum efficiency of current collection, while achieving a reasonably high durability of the contact wire and ensuring the necessary durability and reliability of the contact strip is (Kuptsov, Yu. E., 2001).

There are some work areas to improve the quality of the current collection:

- Improving catenary design.
- Improving pantographs design.
- Developing new contact wires and current collector elements.
- Mathematical modeling of the interaction catenary with the pantographs, the creation of physical models.

Anyway, all the research areas of the current collection process aimed at reducing capital and operating costs for repair and maintenance of the contact network and pantographs.

Generalized criterion of optimum current collection quality for contact network part which is designed or modernized the minimum discounted total costs of the contact network and pantographs (Kuptsov, Yu. E., 2001; Frayfeld, A. V., & Brod, G. N., 1991;) which ensure the specified modes of operation electric rolling stock, and determined by the total amount of the contact network and pantographs capital cost and annual operating costs for the contact network and pantographs. Also, as a generalized optimization criterion, characteristics and parameters of the contact network and pantograph can also be used at minimum reduced annual costs.

The main part of the costs associated with the process of current collection for the maintenance contact network and pantographs is the cost for substitution contact wires and contact strips (Bolshakov, Yu. L., & Antonov, A. V., 2015; Kubo, S., & Tsuchiya, H., 2005;), which are selected in accordance with the electric rolling stock type (current type), its power and climatic conditions operation.

4. The main material

Some parts of Railways, electrified with DC 3 kV is particularly acute issue of increasing the contact wire resource, the lifetime of which, on the main lines is 10 – 15 years. This situation is caused by using copper contact strips on the locomotives pantographs. Also on these plots are operated electric trains with pantographs, which are equipped with graphite contact strips, mileage that is 5 thousand km, more than 5 times less than the resource for this type of material.

Under the technical resource concept one should understand the lifetime object from the operation start until the occurrence of a limit state. The measure of the operation duration of the facility is selected the parameters that characterize the service time. For such contact wires the parameter are the passes number of the pantograph, but for contact strips – the mileage. What about the measure for determination the wear of contact wire and contact strips – cross-sectional area and height, accordingly. Physical and mathematical models of friction pairs are used for the wear processes research, conduct experiments in exploitation.

Such research can achieve the following objectives:

- To evaluate the combination of the contact pairs.
- To conduct comparison tests.
- To determine the optimal operating conditions.
- To predict the service life of the elements of the contact pairs.

Existing systems that simulate the interaction of pantographs with catenary, allow investigating the influence of design features on the current collection quality without conducting full-scale experiments. But even the leading companies in this field, which models partially covered in (Kiessling F., et al., 2009; Poetsch G., et al., 2001; Cléon L.M., et al., 2006;) do not take into account the influence parameters of friction pair “contact wire – contact strip” to the process of the wear.

From works (Kuptsov, Yu. E., 1972; Miheev, V. P., 2003) we know that the most objective criterion for assessing the quality of current collection is the value of friction pair wear.

The terms of the wear performance contact pair “contact wire – contact strips” can be represented by two components: mechanical and electrical wear. The wear rate of the friction pair can be characterized by their own parameters and parameters of the current collection system. In general, the impact of system parameters current collection on the wear rate of the friction pair is random, which depends mainly on the pressing force of the pantograph, speed, current consumption, external factors and parameters of the materials constituting the elements of the friction pair.

Assuming that design features, catenary and pantographs provide satisfactory current collection, the random parameters that affect the wear rate of the contact strips and contact wire can be obtained both experimentally and analytical. The functional dependency of mechanical and electrical wear of contact pairs is given in Holm, R. (1961), is offered to determine the average value of the wear taking into account such additional parameters as humidity, electrical resistivity and hardness of friction pairs by the following expression:

$$\overline{\Delta M}\left(P,V,I,\varphi,t,\rho,HB\right)= \Delta M\left(\overline{P},\overline{V},\overline{I},\overline{\varphi},\overline{t},\overline{\rho},\overline{HB}\right)+\frac{1}{2}\frac{\partial^2\cdot\overline{\Delta M}}{\partial P^2}\sigma^2\left(P\right)+ \frac{1}{2}\frac{\partial^2\cdot\overline{\Delta M}}{\partial V^2}\sigma^2\left(V\right)+\frac{1}{2}\frac{\partial^2\cdot\overline{\Delta M}}{\partial I^2}\sigma^2\left(I\right)+ \frac{1}{2}\frac{\partial^2\cdot\overline{\Delta M}}{\partial \varphi^2}\sigma^2\left(\varphi\right)+\frac{1}{2}\frac{\partial^2\cdot\overline{\Delta M}}{\partial t^2}\sigma^2\left(t\right)+ \frac{1}{2}\frac{\partial^2\cdot\overline{\Delta M}}{\partial \rho^2}\sigma^2\left(\rho\right)+\frac{1}{2}\frac{\partial^2\cdot\overline{\Delta M}}{\partial HB^2}\sigma^2\left(HB\right), \tag{1}$$

where:

σ^2 – variance of variable;

P,V,I,φ,t,ρ,HB – pressing force of the pantograph, the speed of electric rolling stock, current consumption, humidity level of the environment, the temperature in the contact zone, electrical resistivity, hardness of current collecting elements, respectively.

The decision of the achieving task the greatest current collection efficiency, while achieving a reasonably high contact wire durability and sufficient contact strips durability is reduced to the optimization solution problem the solution of which is necessary to determine the transfer function of the system, which depends on the number of input characteristics is non-linear.

The intensity of interacting surfaces wearing can be used as a comparative indicator for materials of contact pairs at different speeds of electric rolling stock, current consumption, the pressing force of the pantograph. Using the contact wire wear as an indicator of the current collection quality under operating conditions is difficult due to the need for the passage of a considerable period between measurements, at the same time, meteorological conditions and other factors will continue to change and determine the dominant influence factor on the wear rate is quite difficult. The solution of this problem can be creation of a physical model and using the received equalization data to build a mathematical model that would take into account the parameters of interacting systems.

Analyzing (Guangning, Wu., et al., 2016; Kubota, Yo., et al., 2012; TU Chuan-jun., et al., 2008) was established that the researches do not take into account possible changes in the external influencing factors on the wear rate of contact wire and contact strips. In order to research the influence on the intensity wear of contact wires and contact strips from changes humidity, current consumption and pressure, was developed device for the comparative research of friction pairs, which conducted the experimental study (Fig. 1).

This device allows to omitting through the sliding contact current up to 500 A, change the rotation speed of the disk with contact wires in a wide range, change the contact force of the contact strips to the contact wire, and in the contact zone can change the level of humidity.

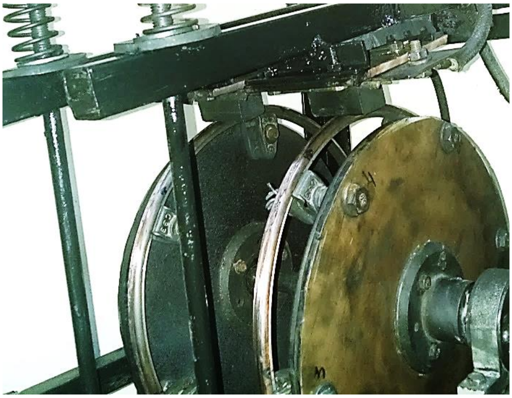


Fig. 1. Device for the comparative research of friction pairs

During the experiments, the displacement of the contact wire with a high linear velocity leads to oscillations of the elastic elements through the radial and angular displacement. Uneven contact pressure and ceases contact that take place during experiments, simulate the processes occurring in real conditions.

During the research, it was evaluated the intensity level of wear of the contact wire and contact strips (copper contact strips, coal and graphite contact strips type "A" and "B" accordingly), determined the friction coefficient depending on the contact force, the presence of moisture in contact and current omit via the sliding contact. Experiments with copper strips were carried out without supplying dry lubricant to the contact for simulated worst environments (Da Hai He, et al., 1998).

The friction coefficient determined by the friction moment:

$$\mu = \frac{M_{fs} - M_{fm}}{d_o \cdot P}, \tag{2}$$

where:

M_{fs} – the friction moment of the system, N/m;

M_{fm} – the friction moment of the motor, N/m;

d_o – the diameter of the counterbody, м;

P – the force of pressure, N.

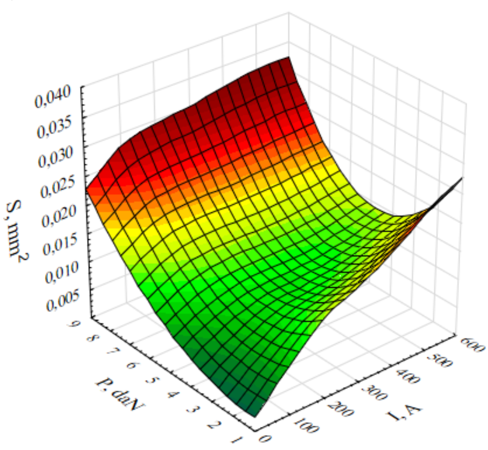
During the calculation of the friction coefficient the interaction between the contact wire and contact strip occurs under conditions of plastic deformation in multi-point contact (Kuptsov, Yu. E., 1962;).

Evaluation of wearing the contact wire and contact strips was carried out after 10 thousand passes contact strips at contact wire.

The external parameters influence on the wear of contact pair is random, therefore at carrying out of the repeated experiments, the results had some discrepancy.

The results of these experiments is shown in Fig. 2 – 4.

a)



b)

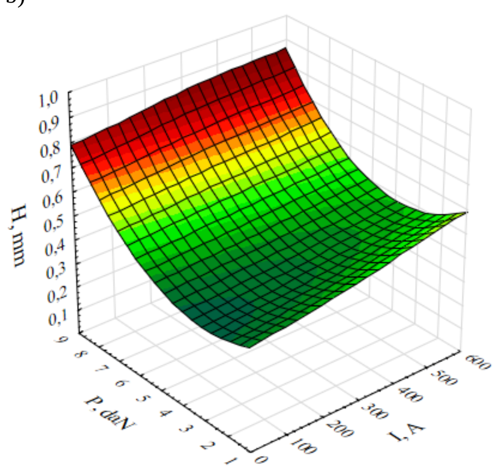


Fig. 2. Surface changes in wear rate on the value of the pressure at the contact point and current for: a) contact wire; b) contact strip

a) b)

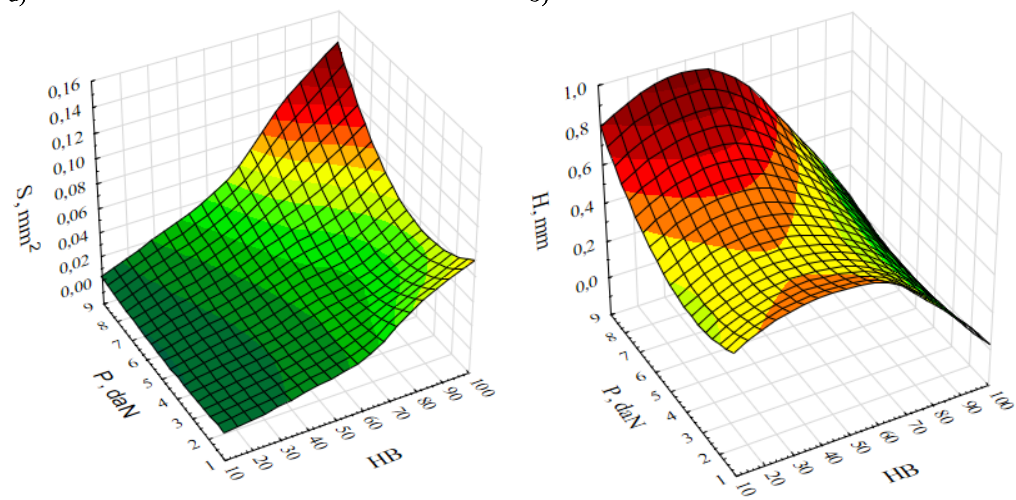


Fig. 3. Surface changes in wear rate on the value of the pressure at the point of contact and the hardness of contact strip for: a) contact wire; b) contact strip

a) b)

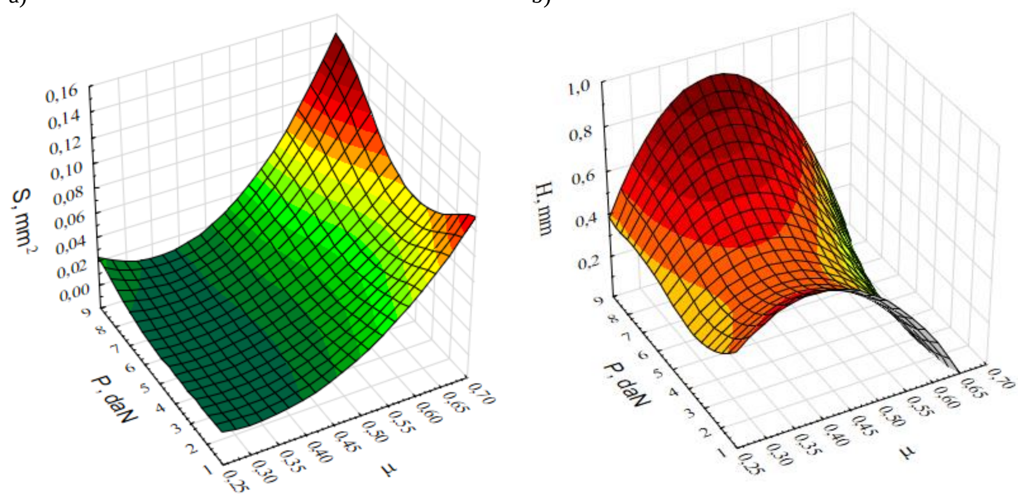


Fig. 4. Surface changes in wear rate on the value of the pressure at the point of contact and friction coefficient for: a) contact wire; b) contact strip

The resulting surface of the electromechanical wear of the contact wire and contact strips have a pronounced U-shaped character, which is caused by the simulation of real operating conditions. This is reflected in the degraded current collection through the appearance condensate of the contact wire that causing increased sparking and arcing.

In the friction process, in the area of long interaction coal and graphite contact strips creates a wear-inhibiting film which reduces the wear of the friction pair elements (Fig. 5, a). The appearance of moisture in contact the wear-inhibiting film is disappears and the intensity of contact strips and contact wire wear is increased (Fig. 5, b).

In the interaction of the contact wire with copper contact strips without supplying dry lubricant appear scuffing, seizure surfaces and, as a result, the contact wire wears out much more intensively (Fig. 5, c).

The joint exploitation of the copper contact strip and graphite contact strip leads to increased wear the latest (to 6 times) (Fig. 6). The results of the experiments in exploitation (Gershman, I. S., et al., 2008, Bucca, G., & Collina, A., 2009) confirm the results of research and testify the impossibility use on one section the copper contact strips and graphite contact strips – it leads to a sharp reduction in the actual resource graphite contact strips and intensive wear of the contact wire.

During the experiments without omitting current through elements of the friction pair and at a humidity of 100% the wear rate of contact wire, in contrast to the coal and graphite contact strip, somewhat reduced. Under similar conditions, with electric current in the contact zone, wear rate of the contact wire and contact strip is considerably increased (see Fig. 2). From (Kubo, S., & Tsuchiya, H., 2005; Guangning, Wu., et al., 2016;) we know that the increase of temperature in the contact zone leads to rapid wear of the contact pair elements.

During the friction pair “contact wire – coal contact strip” research sparking was yellow-red color, and using copper contact strip sparking was white-blue, indicating the emergence the contactless electric arc erosion as the contact wire and copper contact strip (Fig. 7). Along the contact wire there were the characteristic traces of arson.

a) b) c)

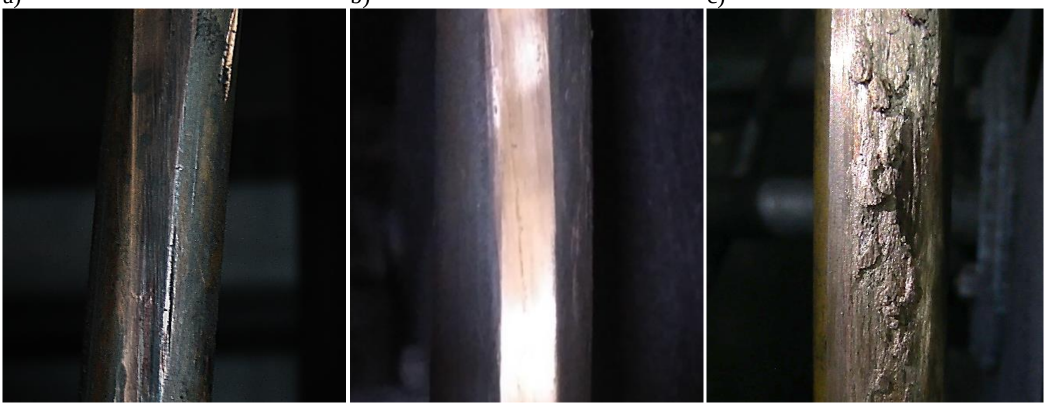


Fig. 5. Friction surface of contact wire: a) after the interaction with coal and graphite contact strips under dry friction; b) after the interaction with coal and graphite contact strips with moisture in contact ; c) after interaction with copper strips

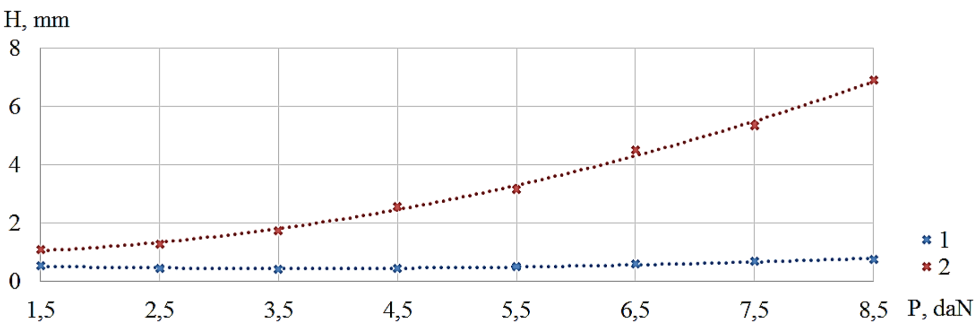


Fig. 6. Curves wear graphite contact strip type “B”: 1 – before interaction contact wire with copper contact strip; 2 – after interaction with copper contact strip

Fig. 7. Sparking in the contact zone when the omit current 500 A: a) contact strip type "A" – yellow red sparks; b) contact strip type "B" – yellow red sparks; c) copper contact strip – blue and white sparks

Analysis of these dependences show that for all types materials can be traced to the increasing wear with increasing the contact force of the contact strip to the contact wire, increasing current and moisture in contact.

In real conditions the increase of moisture environment is accompanied by a sharp deterioration in the quality of current collection – there is intense sparking. When icing and long ceases contact appears electric arc, which lead to a sharp reduction in resource contact strips and surface friction damage of the contact wire.

5. Conclusions

1. Developed device and methodology for the wear researching of friction pairs, which allow simulating the influence of external random factors on the intensity of wear of contact wires and contacting strip.
2. Analysis of the findings shows that the determinants of the increase intensity wear of contact wire and contact strips is the pressing force of the pantograph, the current in the contact and the contact strips characteristics.
3. In the work dependences of the influence of structural parameters friction pair, the parameters of the current collection system and external factors on the wear rate of the friction pair "contact wire – contact strip".
4. It was established experimentally that the joint exploitation the copper contact strip and graphite contact strip was unacceptable – it leads to increased wear the latest (to 6 times).
5. Conducting bench research requires considerable time and cash costs.
6. The purpose of the authors in further research is constructing a predictive mathematical model that uses the dependence of the influencing parameters obtained in this work to assess the wear and resource of frictional pairs.

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