ГАЛУЗЕВЕ МАШИНОБУДУВАННЯ

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STUDY OF THE CONTACT ZONE IN WIRE POTENTIOMETERS

The main topic of the article is the study of the behavior of contact resistance as the PdW-20–AuCu-800 pair wears out. The studies were carried out on 17 PTP-type potentiometers of the same nominal value – 1 kΩ with different contact forces – from 0.3 g to 5.0 g. The devices were installed on test stands. The running track of each potentiometer is regularly cleaned using the waterjet method. Each potentiometer has 12 conductivity control points assigned every 10 thousand running cycles (one cycle – forward and reverse stroke of the brush) at a speed of V=26 cycles/min. Tests were carried out up to 70 thousand cycles. The search for 12 control points was carried out using an optical dividing head. Based on the results of the study, the main dependence of the contact resistance on the number of cycles for each contact force was constructed. Analysis of the obtained dependencies shows a continuous process of destruction and restoration of the oxide film (secondary structures) for all contact forces. Confirmation was received for a pair: winding – nichrome, brush – ZlM-800. Of all the contact forces, the optimal values have been established – these are 4 g and 5 g. With these forces, the devices worked 70 thousand cycles without interrupting the conduction process. In addition, the dependence of the resistance of the oxide film on the contact force was constructed. The double amplitude of the oscillation of the contact resistance at a certain force was taken as the value of the film resistance. This gave us the opportunity to abandon R. Holm's method for determining the resistance of the oxide film. The constructed dependence of the contact resistance on the contact force according to the analytical expression and practical results of the study shows the identity of the curves, and most importantly, in the region of the optimal contact force (4 g) a bend in the dependence is visible, indicating the presence of a separating lubricating layer of oxide in the contact zone a film that creates a long-term service life of the device, and at the level of a tunnel conductivity film that maintains reliable conductivity of the contact pair. Further, after 70 thousand mileage cycles, the study of the wear of optimal contact pairs 4 g and 5 g was accompanied only by conductivity monitoring on a noise level-monitoring installation. This is the first attempt to create equipment for dynamic monitoring of the conductivity of low-current sliding contacts (LSC). The production of more advanced equipment that makes it possible to record the number of contact resistance values of a certain level in magnitude and duration will make it possible, using probabilistic characteristics, to arrange all contact pairs existing in operation in a row with their operational parameters and create an LSC information directory. The development of the research results obtained is the creation of a new type of LSC, where the technology for creating the old potentiometer of the PTP type has been changed. The research results gave good results. The presence of a high-resistance winding fastening agent (instead of epoxy resin) with low capillary forces will make it possible to create a new type of PTP with much higher performance.

Key words: *contact force, contact resistance, wear, oxide film, wirewound potentiometers.*

Formulation of the problem. Potentiometers are widely used in various automation systems, in computers and servo drive systems. For the most part, they serve to convert linear and angular movements into corresponding voltage values and are used as voltage dividers. In computers, these converters are used to perform various mathematical operations.

Wire-wound potentiometers, which are most widespread, are divided into single-rotating and multi-rotating. The law of change in the resistance of potentiometers can be set in three ways: using a shaped frame, using a winding with variable pitch and electrical shunting of individual sections of the winding.

There are two ways to arrange potentiometers in a structure [3, 8]:

– potentiometers used in radio equipment and computer technology are a separate device with a large number of parts placed in a housing with an external contact group;

– potentiometers used in gyroscopic devices, in precision mechanics devices, as a rule, consist of two main structural elements: a resistor (frame with winding) and a movable contact group (motor). The resistor element and the motor are mounted in different blocks and are joined only during the overall assembly of the product itself. The common elements in both groups are resistors and motors. The reliability, accuracy of function reproduction and the entire operation of the potentiometer depend on them.

Analysis of recent research and publications. Analysis of studies shows that the appearance of contact failures is observed after the sensor has worked out part of its service life [4, 7]. This indicates that in the contact zone there is a significant increase in contact resistance R_f. Therefore, the goal of the work was to study the change in R_f as the contact pair wears out. As the pair wears out, the contact resistance changes its value – it increases, then, after a certain period of time, it decreases. This leads to the conclusion that the oxide film grows in the contact zone, matures, as it were, and then collapses, while the contact resistance decreases. With increasing contact force, vibrations occur with a smaller amplitude, and with optimal contact force, the pair works with an oxide film, but of such a thickness that it easily breaks through the tunnel effect.

Similar studies on changes in contact resistance were carried out and presented in works [1, 2, 7].

Task statement. The purpose of this study is to study how the contact resistance in the contact zone changes as the contact pair wears out.

Outline of the main material of the study. Research was carried out for a contact pair PdW-20–AuCu-800.

The study used the same type of wirewound potentiometers of the same rating with different contact forces P = 0.3 g – 2 pcs., P = 0.9 g – 2 pcs., P = 1.5 g – 3 pcs., P = 2.1 g – 3 pcs., P = 2.7 g – 3 pcs., P = 4.0 g – 3 pcs., P = 5.0 g – 3 pcs.

Each contact surface was processed according to a regulated waterjet method (Fig. 1).

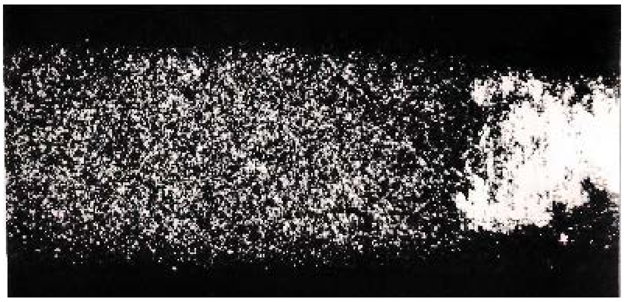

Fig. 1. View of the contact surface treated with waterjet

To implement the research program, we used: running stands, on which the reciprocating movement of the brush in a circle is ensured (Fig. 2), a specially equipped stand with an ODC (optical dividing head), on which, after the run, a potentiometer is installed and set the zero position is fixed, and then to measure R_f, according to the program, the ODG rotates the potentiometer axis to the required angle.

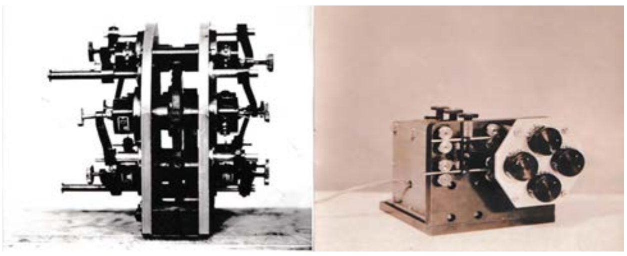

Fig. 2. Running stand

On each of the named potentiometers, 12 points were assigned on the treadmill, where after every 10 thousand cycles the contact resistance was measured, according to a well-known scheme and measurement technique [6].

Control points: from the zero point – 10 degrees, and then every 30 degrees, i.e.: 40; 70; 100; 130; 160; 190; 220; 250; 280; 310; 340 degrees. To find these points, after every ten-thousandth run, the potentiometer was removed from the testing stand, installed on a stand with an ODG, set to “0”, and then all control points were set.

Tests were carried out up to 70 thousand cycles.

The speed of movement of the brush along the resistance winding is selected V = 26 cycles/min.

From the family of obtained dependencies $R_f = f(P)$, curves of changes in contact resistance as the pair wears out were constructed from the average values for different values of the contact force.

As a result of the experiment, it was established that with an increase in contact force, the contact resistance decreases, however, at all contact pressures under study, there is an oscillation ("breathing") of the measured value of the contact resistance with a certain period. The obtained dependencies are shown in Fig. 3.

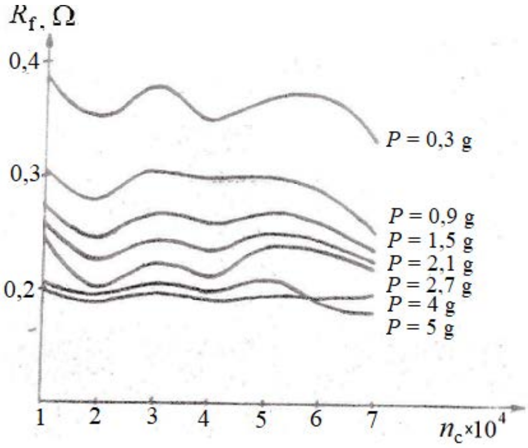

Fig. 3. Change in contact resistance as the pair wears out PdW-20–AuCu-800

Analysis of the fluctuation ("breathing") of contact resistance leads to the following conclusion. As the current-collecting brush slides along the resistance winding, complex physical and chemical processes occurring in the contact zone contribute to the intensive formation and growth of an oxide film, as evidenced by an increase in contact resistance.

After a certain period of time, the film "ripens" and acquires a set of properties, as a result of which it is destroyed by the brush, and the contact resistance drops.

The amount of resistance drop depends on the contact force. As the contact force increases, the vibration level and amplitude decrease. Thus, the "breathing" of the measured value indicates a constant process of destruction and restoration of secondary structures in the contact zone. Consequently, the double amplitude of the contact resistance fluctuation characterizes the destroyed layer of the oxide film of such a thickness, the resistance of which is equal to the double amplitude.

To confirm this phenomenon, the same experiment was carried out, where a nichrome winding was taken as a contact pair, and the contact brush material was taken as before – AuCu-800. Nichrome was used because its main disadvantage is a stable oxide film that prevents reliable contact.

The dependence $R_f = f(n_c)$ was plotted for one contact force $P = 2.5$ g and is shown in Fig. 4.

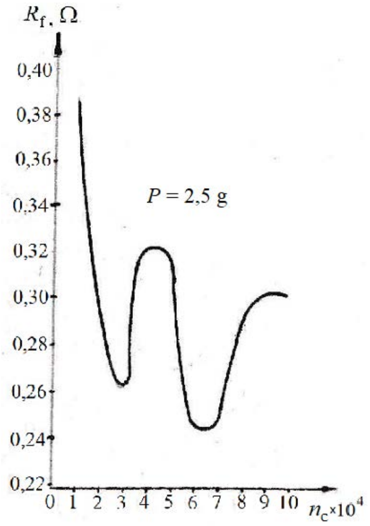

Fig. 4. Change in contact resistance as a pair of nichrome wears out–AuCu-800

Our judgments about the vibration ("breathing") of the oxide film were confirmed. As can be seen from the dependence, the level of oscillation, its amplitude and period differ from the previously studied contact pair.

Thus, it was found that the fluctuation of the measured value occurs due to the destruction and growth of the oxide film.

Obviously, the parameters for changing the contact resistance as the contact pair wears out will be different for different pairs.

Based on our research, we determined the dependence of the change in the resistance of the oxide film on the contact force (Fig. 5 and 6) [1].

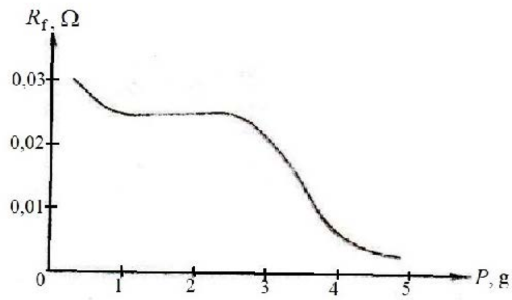

Fig. 5. Dependence of oxide film resistance on contact force

In this case, the double amplitude of the oscillation of the contact resistance at a certain force was taken as the resistance value of the oxide film.

This gave us the opportunity to abandon the existing method of R. Holm [4], which has the complexity of analytical calculations and the absence in the literature of the values of a number of parameters included in the calculation formulas.

The resulting graphical dependence practically does not give large errors relative to the actual value of the resistance of the oxide film, since although after its destruction a small layer of film remained, it did not affect the conductivity of the contact pairs, but served as a separating layer.

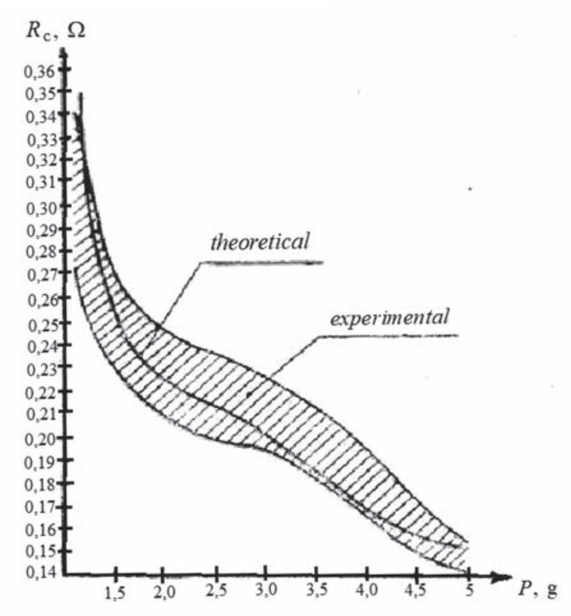

Fig. 6. Dependence of contact resistance on contact force

However, the dependence we obtained can be considered approximate, since all measurements were made statically, in laboratory conditions. The values of the previously indicated parameters in dynamics, when the brush moves along the winding of a high-resistance wire, will be more accurate. Unfortunately, these studies have not yet been carried out.

Analysis of the dependencies presented in Fig. 5 and 6, makes it possible to recommend contact forces of 4 g and 5 g as optimal for a given contact pair, since after a run of 70 thousand cycles these sensors did not disturb the process of current conduction, compared to other potentiometers, which tested for wear. With these contact forces, the potentiometers were left for further mileage, followed by checking, every 10 thousand mileage, for loss of contact.

What should be understood by the concept of loss of contact?

Low-current sliding contacts operate under friction conditions, in which activation of the contact surface, excited by dynamic loading, can be realized either due to frictional oxidation with an increase in the oxide film – then a violation of the contact will occur, or due to more intense destruction of secondary structures leading to the process of seizure of contacting surfaces due to nose – this is the nature of failures of low-current sliding contacts.

Thus, failure should be understood as exceeding established limits in amplitude, duration of these values and frequency of occurrence of these limits of contact resistance.

The introduction of such criteria for the failure of low-current sliding contacts facilitates the development of equipment for recording failures.

Often, when measuring the number of failures at increased speeds of movement of the current-collecting brush, it is more convenient and no less important to measure not the number of failures, but their duration, which is more important for control systems.

To register failures in potentiometers, we established the following parameter, which we took as a threshold, the excess of which was considered a failure – this is contact resistance $R_f = 60\ \Omega$.

We recorded this value using the NLC-1 installation (noise level control). Registration was carried out when the brush moved along the potentiometer winding. We called the change in contact resistance when the brush moves noise.

The experiments carried out to identify the optimal contact force for the pair under study lead to the conclusion that the most optimal contact forces for the PdW-20–AuCu-800 pair are 4 g and 5 g. Further running of the potentiometers (6 pieces) with these forces of the contact brushes showed that after running 110 thousand cycles at a contact force of 5 g, the process of setting the rubbing surfaces was observed, during which the contact resistance dropped almost to zero and the stability of its values was disrupted. This picture was observed in all three potentiometers with a mileage difference of two to three thousand cycles.

The optimal contact force for this pair should be considered $P = 4$ g. With it, the process of friction and wear is steady and has the property of self-regulation, in which the rate of destruction of oxide films is equal to the rate of their formation, i.e. $V_{fd} = V_{ff}$. This equilibrium occurs at a minimum thickness of the oxide film, which serves as a separating, lubricating layer that prevents the process of surface setting and does not interfere with the conduction process.

Conducted studies on the wear of contact pairs and their conductivity reveal requirements for eliminating deficiencies for wirewound potentiometers.

We consider the main disadvantage to be any mechanical impact on the contact track. It is accompanied, to a greater or lesser extent, by plastic deformation, which means increased activation of the metal to the environment, which is realized by intense saturation with oxygen and its release into the contact zone with the formation of oxide films that interfere with the process of current conduction.

Conclusions. Analyzing this phenomenon, the conclusion suggests itself about the creation of a potentiometer with a modified technology of its component parts. We have partially traveled this path and obtained good results.

1. The toroidal frame, made slightly barrel-shaped, is not completely dried. It is dried until the moment when high-resistance wire can be wound on it.

2. Winding is carried out with high-resistance bare wire. Winding is carried out with preload, of course, within the limits of elastic deformations. Winding is carried out on machines with a certain pitch, guaranteeing a gap between the turns, and, consequently, with the absence of interturn closure. Checking the resistance of the wire, wound and in the form of a straight wire, confirms this.

3. The wire, wound with pretension after about two weeks, presses the track on the frame with incomplete polymerization under it.

4. Drying the frame with the wire until the frame coating is completely polymerized. The wire was not further secured to the frame, as usual, with heated epoxy resin.

5. Next – according to the usual assembly technology until the contact track is prepared.

6. The contact path was washed only with gasoline.

7. The contact group is installed with an optimal force of 4 g.

Such potentiometers were manufactured. Their studies were carried out for maximum service life with testing of contact reliability. When backed up with two brushes, the potentiometers went through 2·106 cycles. This is several times greater than the resource established by the technical specifications.

These devices have not been tested according to the program: vibration, shock, cold, heat, etc. Obviously, to be completely sure of passing the tests, it is necessary to additionally fasten the coils. Epoxy resin in the form in which it is used is not suitable, since, having significant capillary properties, it will close the treadmill, and this will lead to an unnecessary operation – stripping.

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Петрик В.О., Трубачев С.І., Колодежний В.А. ДОСЛІДЖЕННЯ ЗОНИ КОНТАКТУВАННЯ У ДРОТЯНИХ ПОТЕНЦІОМЕТРАХ

Основна тема статті – це вивчення поведінки контактного опору в міру зносу пари ПДВ-20–ЗлМ-800. Дослідження проводилися на 17 потенціометрах типу ПТП одного номіналу – 1 кОм з різним контактним зусиллям – від 0,3 г до 5,0 г. Прилади були встановлені на прогонних стендах. Бігова доріжка кожного потенціометра зачищена регламентно гідроабразивним методом. На кожному потенціометрі призначено 12 точок контролю провідності через кожні 10 тисяч циклів пробігу (один цикл – прямий і зворотний хід щітки) при швидкості V = 26 цикл/хв. Випробування проводили до 70 тисяч циклів. Знаходження 12 точок контролю здійснювали за допомогою оптичної ділильної головки. За отриманими результатами дослідження побудована основна залежність контактного опору від числа циклів для кожного контактного зусилля. Аналіз отриманих залежностей показує безперервний процес руйнування та відновлення окисної плівки (вторинних структур) для всіх контактних *зусиль. Підтвердження отримано для пари: обмотка – ніхром, щітка – ЗлМ-800. З усіх контактних зусиль встановлені оптимальні значення – це 4 г і 5 г. За цих зусиль прилади відпрацювали 70 тисяч циклів, не перериваючи провідності. Крім того, побудована залежність опору окисної плівки від контактного зусилля. За величину опору плівки брали подвійну амплітуду коливання контактного опору при певному зусиллі. Це дало нам можливість відмовитися від методики Р. Хольма щодо визначення опору окисної плівки. Побудована залежність контактного опору від контактного зусилля за аналітичним виразом і практичними результатами дослідження показує ідентичність кривих, а головне, в районі оптимального контактного зусилля (4 г) видно вигин залежності, що вказує на наявність в зоні контактування роздільного змащувального шару окисної плівки, що створює довговічну службу приладу, причому на рівні плівки тунельної провідності, що підтримує надійну провідність контактної пари. Надалі, після 70 тисяч циклів пробігу, дослідження зносу оптимальних контактних пар 4 г і 5 г супроводжувалося лише контролем провідності на установці, що контролює рівень шуму. Це перша спроба створення апаратури динамічного контролю провідності слаботочних ковзаючих контактів (СКК). Виготовлення більш досконалої апаратури, що дозволяє фіксувати кількість значень контактного опору певного рівня за величиною і тривалістю, дасть можливість, використовуючи ймовірнісні характеристики, розставити всі існуючі в експлуатації контактні пари в ряд зі своїми експлуатаційними параметрами і створити інформаційний цінний довідник СКК. Розвитком отриманих результатів досліджень є створення нового типу СКК, де змінена технологія створення старого потенціометра типу ПТП. Результати досліджень дали непогані результати. Наявність скріплювальної речовини високоомної обмотки (замість епоксидної смоли) з малими капілярними силами дозволить створити новий тип ПТП з набагато вищими показниками.*

Ключові слова: *контактне зусилля, контактний опір, знос, оксидна плівка, дротяні потенціометри.*