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RESEARCH OF CONTACT RESISTANCE IN HEAT-RESISTANT PRECISION POTENTIOMETERS

Theoretical and analytical studies of low-current sliding contacts (LSC) using the example of wire-wound potentiometers is a complex task associated with two main conflicting factors that determine success in research.

If in purely mechanical nodes studies are carried out on the contact of rubbing surfaces, then the durability of the assembly is the determining factor. When considering the SSC, this will not be enough. The second important factor is electrical conductivity, moreover, reliable, where this concept means acceptable rates of change in contact resistance both in magnitude and duration. These two norms can disable the tracking system, and it, in turn, can lead to disaster.

Thus, in LSK, two main factors determine the reliability of the node - this is the maximum durability and conductivity within the specified norms. These two factors are contradictory: to increase the service life in the rubbing surfaces, there must be a separator that does not allow the contact of juvenile surfaces, during which an unacceptable setting process occurs, leading to intense wear. The separator can be a natural oxide film or an artificial lubricant. Artificial lubrication is unacceptable, and if we talk about conductive, then due to the short circuit of the turns on the winding, it is also unacceptable. We can only talk about the natural oxide film.

In order to improve the conductivity in LSC, the industry was forced to move from unreliable contact pairs with the participation of nichromium to precious metals and their alloys. The researchers directed their efforts to the theoretical study of conductivity in the LSC, confirming their conclusions with the results of experiments.

Our theoretical studies are reduced to the presentation of a mathematical model of contact resistance, according to which an analytical expression is compiled that determines the dependence of contact resistance on force. The calculated data of the induced parameters for various contact forces are summarized in the table.

In addition, the dependence of the resistance of the oxide film on the force has been experimentally established. This dependence clearly indicates the zone of optimal effort for the pair in question, the zone where there is a separating medium for the contact pair, and studies have shown that this film breaks through the tunnel effect, maintaining reliable contact.

Key words: *contact resistance, contact force, reliability, friction, wear, potentiometer.*

Formulation of the problem. It is known that potentiometers, as a rule, mean resistors with a movable tap-off contact (motor). A feature of the potentiometer is that the electrical energy in it turns into thermal energy and dissipates. According to the constancy of the resistance value, potentiometers are divided into constant, variable and special ones. Permanent potentiometers (adjustment resistors) have a fixed resistance that is not regulated during operation. Variable potentiometers (variable resistors) are potentiometers whose resistance can be changed by mechanical action on the regulating body. The resistance of special potentiometers changes under the influence of external factors: flowing current or applied voltage (varistors), temperature (thermoresistors), illumination (photoresistors), etc. According to the type of resistive element, all potentiometers are divided into wire and non-wire. In wire potentiometers, the resistive element is a wire made of an alloy with a high specific resistance, wound on a special dielectric frame. Non-wire potentiometers can be membrane and volumetric. Film potentiometers have a resistive element in the form of a conductive film applied to the side surface of a ceramic dielectric base. Contact caps with wire leads welded to them are put on the end of the ceramic cylinder. Outside, the potentiometer is covered with a protective enamel coating.

When choosing a potentiometer, it should be borne in mind that the maximum voltage that can be applied to the resistor should not exceed the voltage determined by its thermal regime and calculated on the basis of the nominal dissipation power (for the nominal resistance and tolerance). To increase the resistance of the potentiometer, a resistive film is applied to the surface of the ceramic cylinder in the form of a spiral. In volumetric potentiometers, the resistive element is made in the form of a volumetric body made of a material with a high specific resistance, which is located inside a glass-ceramic tube with a rectangular section. The wire leads are pressed directly into the resistive element. Films of pyrolytic carbon (carbonaceous potentiometers), metals and their alloys (metal-film potentiometers), metal oxides (metal-oxide potentiometers) or a mixture of metallic and dielectric phases (metal-dielectric potentiometers) are used as the material of the resistive element in non-wire potentiometers), as well as films and volumetric bodies consisting of a mechanical mixture of a powdered conductor with its binding dielectric (composite potentiometers).

Heat-resistant precision potentiometers belong to low-current sliding contacts. It is known that in these contacts, the processes caused by friction and wear prevail over all other processes, even over the current flow processes [5, 7, 9].

Researchers [1, 2, 5] believe that the fact of the transfer of electrons from one contact surface to another additional resistance, and the main conductivity mechanisms of electrical contacts are ohmic conductivity and conductivity through the tunnel effect. Ohmic resistance arises in the contact of metal surfaces as a result of a significant narrowing of the conductor at the point of contact and a decrease in the area of actual contact due to the roughness of the surface. At the same time, the current lines do not pass over the entire apparent surface of the contact spot, but are drawn to the contact spots. Tunnel conductivity is the conductivity of the oxide film. In this case, the general expression of the contact resistance is represented by the expression

$$R_{\mathrm{c}} = R_{\mathrm{f}} + R_{\mathrm{tr}},$$

where the first component is determined by the conductivity through the tunneling effect, the second – by the ohmic conductivity [2, 4].

Analysis of recent research and publications. Among a large number of theoretical representations of the nature of the transient resistance, the following works can be distinguished [3-5], in which the transient resistance is presented as a constriction resistance:

$$R_{\mathrm{up}} = \rho/(2\alpha),$$

where ρ – contact material resistivity, α – contact surface radius. In works [6-8], the transient resistance is presented as the resistance of microprotrusions:

$$R_{\mathrm{ld}} = 2\rho h/\sqrt{A \cdot A_{\mathrm{r}}},$$

where h – microprotrusion height, A – nominal contact area, A_{r} – actual contact area.

Setting the task. Combining both types of conductivities, we get a complete picture of the nature of the contact resistance of contacts.

Based on the latest theoretical concepts of the nature of the transient resistance, a model of electrical contact was compiled (Fig. 1).

The expression for the conductivity of an electrical contact can be represented as follows:

$$\frac{1}{R_{\mathrm{c}}} = \sum_{i=1}^{n}\left(\frac{1}{R_{1\,\mathrm{up}\,i}} + \frac{1}{R_{1\,\mathrm{ld}\,i}} + \frac{1}{R_{\mathrm{f}\,i}} + \frac{1}{R_{2\,\mathrm{ld}\,i}} + \frac{1}{R_{2\,\mathrm{up}\,i}}\right). \quad (1)$$

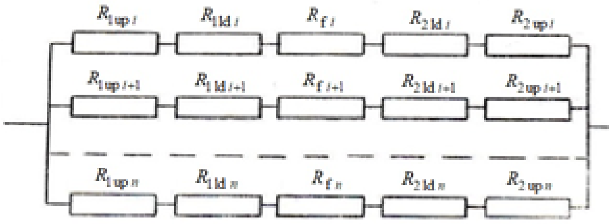

Fig. 1. Contact resistance model

Expression (1) takes into account the pulling resistance R_{up} and microprotrusions R_{ld} both surfaces, and the resistance of the film R_{f} – as the sum of the two surfaces.

Presentation of the main material. If we represent the resistance of microprotrusions as [6-8]

$$R_{\mathrm{ld}\,i} = R_{\mathrm{up}\,i}(r,h) + R_{\mathrm{up}\,i}(\infty,0),$$

where $R_{\mathrm{up}\,i}(r,h)$ – contraction resistance taking into account the influence of the microgeometry of the contact surfaces, characterized by the radius of curvature of the protrusions r and ledge height h, $R_{\mathrm{up}\,i}(\infty,0)$ – contraction resistance without taking into account the influence of the microgeometry of the contact surfaces, that is at $r \to \infty$ and $h \to 0$, then the resistance of the microprotrusions will be equal to

$$R_{\mathrm{ld}} = \frac{\rho\sqrt{h}}{4a\left(\sqrt{2r-h}-\sqrt{h}\right)}.$$

Then the contact resistance can be represented by the expression

$$R_{\text{ld}} = \frac{\rho n}{2a} + \frac{\rho\sqrt{h}}{4a\left(\sqrt{2-h}-\sqrt{h}\right)} + R_{\text{f}}, \qquad (2)$$

where n – number of contact areas, R_{f} – oxide film resistance.

When a contact brush of the "flycatcher" type moves along the resistance winding, the contact geometry can be represented as a contact of intersecting cylinders, for which the radius of the contact spot, according to Hertz's theory, is expressed by the dependence

$$a = \alpha\sqrt[3]{\frac{PD_1D_2}{D_1+D_2}\left(\frac{1-\mu_1^2}{E_1}+\frac{1-\mu_2^2}{E_2}\right)},$$

where P – contact force, α – coefficient depending on the ratio of the contacting diameters D_1/D_2 [3].

We consider the contact of surfaces in one area, that is $n = 1$, then $a = r$.

For the case of intersecting cylinders, the actual contact area can be represented as $A_{\text{r}} = \pi ab$, where a and b – semi-axes of the ellipse formed by the contact of the contact surfaces, related by the coefficient β how $b = \beta a$, β – coefficient that takes into account the deviation of the actual area from the circumference, its values depend on the ratio D_1/D_2 and are presented in the handbook [4-6].

The currently existing method for determining the resistance of the oxide film is not applicable in this case, since it 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 for the materials under study (palladium-tungsten windings, gold-copper brush).

We have found a way out of this situation by determining the dependence of the resistance of the oxide film on the force $R_{\text{f}} = f(P)$ (experimental) (Fig. 2).

Using expression (2), we will calculate the dependence of the contact resistance R_{c} from effort in contact P and compare it with the dependence obtained experimentally (Fig. 3).

The calculated data are given in Table. 1.

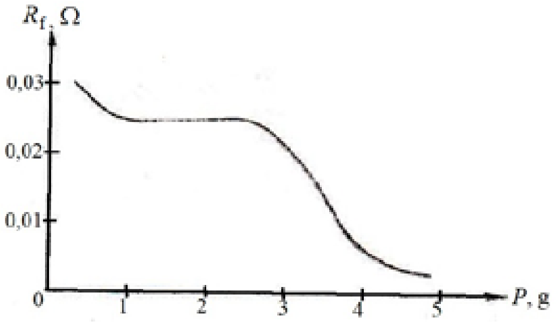

Fig. 2. The dependence of the resistance of the oxide film on contact force

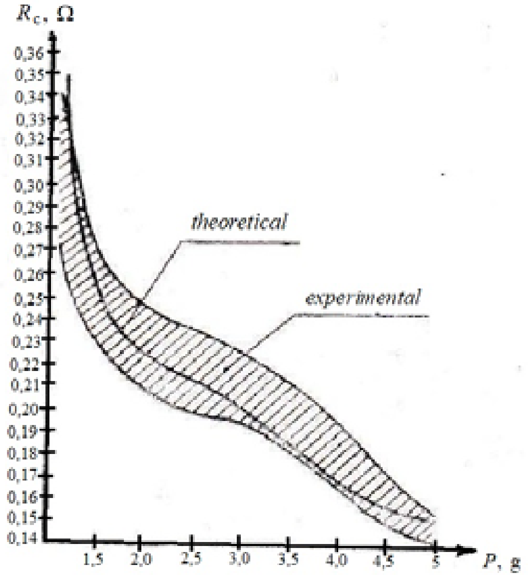

Fig. 3. Dependence of contact resistance on force in contact

Table 1

Estimated data

An effort P, g	**a, mm**	**b, mm**	R_{exp}, Ω	R_{theor}, Ω	R_{f}, Ω	A_{r}, mm^2
0,5	$0{,}162\cdot10^{-2}$	$0{,}124\cdot10^{-2}$	0,26–0,33	0,3506	0,028	$0{,}06\cdot10^{-4}$
1,0	$0{,}205\cdot10^{-2}$	$0{,}150\cdot10^{-2}$	0,24–0,30	0,28	0,025	$0{,}1\cdot10^{-4}$
1,5	$0{,}234\cdot10^{-2}$	$0{,}179\cdot10^{-2}$	0,22–0,27	0,25	0,025	$0{,}13\cdot10^{-4}$
2,0	$0{,}258\cdot10^{-2}$	$0{,}197\cdot10^{-2}$	0,21–0,24	0,23	0,025	$0{,}159\cdot10^{-4}$
2,5	$0{,}287\cdot10^{-2}$	$0{,}220\cdot10^{-2}$	0,20–0,23	0,208	0,025	$0{,}195\cdot10^{-4}$
3,0	$0{,}299\cdot10^{-2}$	$0{,}225\cdot10^{-2}$	0,19–0,22	0,2	0,0225	$0{,}208\cdot10^{-4}$
3,5	$0{,}310\cdot10^{-2}$	$0{,}237\cdot10^{-2}$	0,17–0,21	0,1826	0,014	$0{,}23\cdot10^{-4}$
4,0	$0{,}320\cdot10^{-2}$	$0{,}245\cdot10^{-2}$	0,16–0,19	0,168	0,005	$0{,}246\cdot10^{-4}$
4,5	$0{,}340\cdot10^{-2}$	$0{,}258\cdot10^{-2}$	0,15–0,17	0,159	0,004	$0{,}274\cdot10^{-4}$
5,0	$0{,}349\cdot10^{-2}$	$0{,}267\cdot10^{-2}$	0,14–0,16	0,153	0,004	$0{,}293\cdot10^{-4}$

Conclusions. Comparing the theoretical dependence with the experimental one, we can say that the theoretically calculated contact resistance is in the range of experimental values.

The initial part of the curve calculated by formula (2) is in worse agreement with the experimental data. This can be explained by the fact that when deriving the basic equation, all factors affecting the conductivity of the electrical contact were not taken into account, and the current density providing a point breakdown of the oxide film was not taken into account.

By the value of contact resistance, in addition, it is possible to determine the height of microprotrusions *h*, thereby determining the class of surface cleanliness.

With a steady contact resistance, the height of the microprotrusions corresponds to the 9-th class of surface cleanliness, which is optimal for heat-resistant precision potentiometers.

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Петрик В.О., Трубачев С.І., Колодежний В.А. ДОСЛІДЖЕННЯ КОНТАКТНОГО ОПОРУ В ПОТЕНЦІОМЕТРАХ ТЕПЛОСТІЙКИХ ПРЕЦИЗІЙНИХ

Теоретичні та аналітичні дослідження слаботочних ковзних контактів (ССК) на прикладі дротяних потенціометрів є складним завданням, пов'язаним з двома основними суперечливими факторами, що визначають успіх у дослідженнях.

Якщо в суто механічних вузлах проводять дослідження по контактному зіткненню тертьових поверхонь, то довговічність вузла є визначальним фактором. При розгляді ССК цього буде недостатньо. Другим важливим фактором є електрична провідність, причому надійна, де під цим поняттям мають на увазі допустимі норми зміни контактного опору як за величиною, так і за тривалістю. Ці дві норми можуть вивести з ладу систему, що слідкує, а це, у свою чергу, може призвести до катастрофи.

Таким чином, в ССК два основних фактори визначають надійність вузла - це максимальна довговічність і провідність у межах заданих норм. Ці два фактори суперечливі: для збільшення терміну служби в тертьових поверхнях повинен бути роздільник, що не допускає зіткнення ювенільних поверхонь, при якому відбувається неприпустимий процес схоплювання, що призводить до інтенсивного зносу. Розділювачем може бути природна окісна плівка або штучне мастило. Штучне змащення неприпустиме, і якщо говорити про струмопровідність, то через замикання витків на обмотці - теж недопустиме. Мову можна вести тільки про природну окисну плівку.

Для підвищення показників провідності ССК промисловість змушена була перейти від ненадійних контактних пар за участю ніхрому до дорогоцінних металів та їх сплавів. Дослідники направили свої зусилля на теоретичне вивчення провідності ССК, підтверджуючи свої висновки результатами експериментів.

Наші теоретичні дослідження зводяться до представлення математичної моделі контактного опору, за якою складено аналітичний вираз, що визначає залежність контактного опору від зусилля. Розрахункові дані наведених параметрів при різних зусиллях контакту зведені в таблицю..

Крім того, експериментально встановлена залежність опору окисної плівки від зусилля. Ця залежність наочно вказує зону оптимального зусилля для аналізованої пари, зону, де є роздільне середовище контактної пари, а дослідження показали, що ця плівка пробивається тунельним ефектом, зберігаючи надійний контакт.

Ключові слова: *контактний опір, контактне зусилля, надійність, тертя, зношення, потенціометр.*