# ГАЛУЗЕВЕ МАШИНОБУДУВАННЯ

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# RELIABILITY OF WIRE POTENTIOMETRIC SENSORS USED IN THERMAL POWER INDUSTRY

*The article deals with general problems of contact reliability of low-current sliding contacts. Two methods of measuring the value of the contact resistance of a wire potentiometer are presented. According to one of the methods, the value of the contact resistance was measured and the measurement error was calculated.*

*The ability to measure contact resistance opens up wide opportunities for further research into the reliability of potentiometric sensors. One of the main directions in the research is the wear of the contact pair and how the contact resistance changes. This will make it possible to establish what processes occur in the contact zone, and after studying them, direct research on the management of these processes to achieve long-lasting operation and reliable current conduction in the contact pair. By conducting parallel theoretical studies, it will be known which main parameters affect the wear and conductivity of the friction pair. Similar studies can be carried out in different environments, in the cold, in a humid environment, with vibration, in an environment with different saturation of oxygen, hydrogen, various oils and other components. All these studies are carried out in static conditions after the sensor has worked out the set resource.*

*Of particular interest is the development of measuring equipment, which should decompose the received signals during one cycle of brush movement along the potentiometer winding, both by the set amplitudes and by time. Establishing information about the interruption of contact over time is of great importance, especially for tracking systems. The creation of such equipment opens up the opportunity to study potentiometric sensors in dynamics. And the probabilistic characteristics obtained at the same time will give a complete idea of the processes taking place in the contact zone.*

***Key words:*** *reliability, durability, plastic deformations, wear, sensor, contact.*

**Formulation of the problem.** The development of automatic control systems for aircraft largely depends on the reliability of the elements of these systems. In engineering, devices are widely used to measure the magnitude of the displacements of objects with their transformation into electrical signals. The potentiometric sensor in most designs is a rheostat and a sliding contact connected to the object, from which the signal is taken. The output parameter is the value of electrical resistance, depending on the angular or linear displacement of the moving element. The potentiometer converts linear or angular movements into the corresponding voltage, current or resistance values. Due to this, it is possible to work with many non-electrical quantities: pressure, level, flow, etc.

Potentiometric sensors, the principle of which is to measure the movement or location of the position, are connected by their moving contacts of a variable resistor to objects. These can be valves, antennas, cutting tools and much more. After power is supplied to the sensor, a signal is removed from it, depending on the position of the potentiometer slider, as from a voltage divider.

Wire-wound potentiometric displacement sensors are common in industry. They have high accuracy and stability, low temperature and transient resistance and low noise level. The disadvantages include: a small amount of resistance, low resolution, wear of moving parts and limited use when operating on alternating current.

Devices consist of three main elements:

– Frame. Made of heat-conducting insulating material or metal with a dielectric coating, does not change geometric dimensions when heated. The shape can be in the form of a ring, a curved plate, a rod.

– Insulated winding. It is carried out with precise laying of the wire, on the pitch of which the resolution of the device depends.

– Movable brush. In places of collision with the winding, the turns are cleaned of insulation. The moving contact in the devices can move translationally or rotationally. In the latter case, the devices can be single or multi-turn.

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The potentiometric position sensor is designed for the following purposes:

– control and measurement of movements of mechanisms, working bodies of machines and other objects;

– feedback link in robotics and automation systems;

– determination of distances to objects;

– testing in laboratories, control of the operation of mechanisms.

Thus, the potentiometric sensor is designed to issue an electrical signal depending on the mechanical movement of the current collector brush, and consists of an insulated frame with a winding, a high-resistance wire and a current collector brush.

The voltage taken from the potentiometer functionally depends on the movement of the current-collecting brush along the wire winding. This dependence can have laws: linear, sinusoidal, logarithmic, stepped, etc.

In the closed state, the work of a fixed contact does not differ from a movable one, therefore everything connected with the work of a fixed contact can be attributed to a sliding one.

The reliability of wire-wound potentiometric sensors (WPC) is little reflected in the literature, it is mainly quantitative and does not affect the causes of failures much. WPC are the last link in the signal output system of the device, and therefore the accuracy of the devices depends on the characteristics of the potentiometric sensors.

**Analysis of recent research and publications.** The specificity of a sliding contact is a change in the contact area, and this is a change in the conditions for the passage of current. When sliding, plastic deformation of the surface layer occurs, the activation of physical and chemical processes on the contact surface increases, the quality of the layer changes, its interaction with the environment changes, its conductivity properties change [1]. According to the author of [5], the area increases according to the law

$$1+\alpha f^{2}\left(\frac{A}{A_0}\right)^{2},$$

where $A_0$ – fixed contact area,
$A$ – sliding contact area,
$f$ – coefficient of friction,
α – empirical coefficient.

There is no friting process in low current sliding contacts. The voltage must be sufficient to melt one or two conjugated metals - then the breakdown of the film and the retraction of the liquid metal into the formed channel. This is possible for fixed contacts, but in low-current sliding contacts with relative movement of the contact surfaces, this is unlikely.

**Setting the task.** In connection with the development of expensive aircraft, the failure of which is costly, the requirements for the reliability of potentiometric sensors have increased. This forced contact pairs to be made from noble metals such as gold, palladium, platinum, silver, as well as coatings based on these metals.

Detailed information about the properties of contact materials for potentiometric sensors has been considered by many authors. Several meetings on electrocontact materials were devoted to these issues.

**Presentation of the main material.** We carried out experiments on contact pairs: PdIr-10–AuCu-800, PdW-20–AuCu-800; palladium-iridium and palladium-tungsten windings, gold-copper brush.

These contact materials practically do not oxidize under static conditions at normal temperature.

When studying the sliding contacts of these pairs, it was found that there is a dynamic oxidation with the formation of a film that prevents the passage of current. The presence of this film is controlled by the contact resistance.

After winding a high-resistance wire on an insulating frame, the process of attaching this wire to the frame follows, for which the frame with the wire is impregnated by immersing the frame with the wire in insulating varnish or heated epoxy to a certain depth. Capillary forces also impregnate the rest of the height of the frame, fill the interturn space in the area of the treadmill, falling on the treadmill itself, which causes the inevitability of stripping the treadmill from the insulator.

In potentiometers, the processing of the contact track is most often carried out by the hydroabrasive method or with a felt washer with GOI paste. Surface treatment in one way or another should take into account not only obtaining a high class of surface cleanliness [1], but, more importantly, to establish how the treatment method affects the physical properties of the surface layer. Polishing of the contact surface is accompanied by an intensive process of absorption of the atoms of the environment, and most of all oxygen.

When the surface is polished, plastic deformation of the upper layers of the wire occurs, which at some stage of polishing makes the surface loose and then smooth due to roughness, and during this period the surface is activated to interact with oxygen.

The surface, thus, being polished, is saturated with oxygen, and when working with dynamic oxidation, the contact zone is double saturated with oxygen - from the environment and from the metal structure. The metal gives off previously saturated oxygen.

Therefore, a conclusion arises.

Any machining of the contact zone for potentiometric transducers is detrimental to current flow.

It is known [2, 3, 4] that to increase the service life of potentiometers in the contact zone of the brush with the winding in secondary structures, the presence of an oxide film is necessary. It is a separating medium in the contact pair, prevents the process of setting of juvenile surfaces, while increasing the service life, however, this service must be reliable in terms of the absence of contact losses (up to 2 milliseconds).

The main characteristic of contact reliability is the contact resistance $R_c$.

In potentiometric sensors, this is the resistance between the high-ohm winding wire and the contact brush. There is a need to measure the contact resistance.

This is dictated by the ever-increasing requirements for improving the reliability of potentiometers. The value of contact resistance can be represented as the sum of two resistances [1]:

$$R_c = R_f + R_{tr}.$$

First component $R_f$ caused by surface films, the second component $R_{tr}$ – the presence of irregularities on the metal surface.

The value of the contact resistance makes it possible to establish the relationship between the physical properties of the contacted materials, the geometric shape of the contact surface and the contact force. The measurement of the contact resistance of two conductors, for example, between the contacts of a relay and the contacts of other electrical devices, is usually carried out using bridges or compensators and does not present significant difficulties [7].

Measuring the contact resistance between the brush and the turns of the potentiometer winding presents significant difficulties, since the total resistance of the potentiometer can be tens or more ohms.

To measure the contact resistance in this case, sometimes they resort to taps from a coil or a group of turns, and then measure the resistance between the brush and the taps using bridges or ohmmeters [6]. Naturally, such a measurement method is laborious and cannot provide high measurement accuracy.

In this paper, we propose two methods for measuring contact resistance in contacts on a finished potentiometer using a DC compensator. The scheme of measurements according to the first method is shown in Fig. 1.

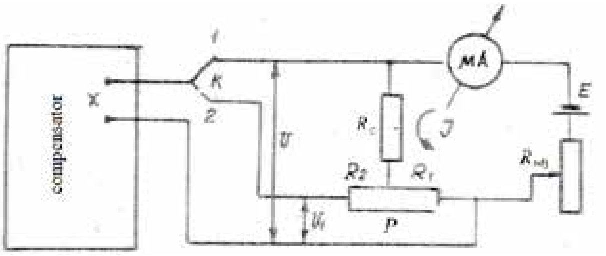

**Fig. 1. Schematic diagram of the installation:**
***P*** **– potentiometer,** $R_{adj}$ **– resistor to adjust the current in the circuit,** ***mA*** **– milliammeter,** ***E*** **– DC source,** $R_c$ **– contact resistance between brush and potentiometer winding**

Since the resistance values $R_c$ and $R_1$ for a given measurement and a certain position of the brush on the potentiometer winding are constant, then the accuracy of determining the value of the contact resistance will depend on the constancy and accurate determination of the current *I*.

The principle of determining the contact resistance according to the first method is as follows. First key position «*K*» voltage drop is measured *U* on resistance $R_c$ and $R_1$:

$$U = I\left(R_c + R_1\right).$$

Current $I$ set by adjusting resistance $R_{adj}$. In the second position of the key «*K*» voltage drop is measured $U_1$ on resistance $R_1$:

$$U_1 = IR_1.$$

In this case, the contact resistance

$$R_c = (U - U_1)/I.$$

The current in the circuit is set taking into account the permissible current value for a given wire potentiometer.

On Fig. 2 shows a diagram for measuring the contact resistance between the brush and the turns of the potentiometer winding according to the second method.

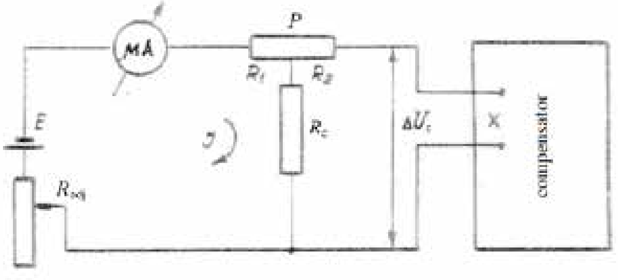

**Fig. 2. Scheme for measuring contact resistance according to the second method**

Contact resistance value $R_c$ according to the proposed method is determined by the magnitude of the voltage drop $\Delta U_c = IR_c$, which is measured by the DC compensator. The current strength is set by milliammeter «*mA*» depending on requirements.

Thus, the value of the contact resistance

$$R_c = \Delta U_c / I .$$

Resistance value $R_1$ and $R_2$ does not affect the measurement of contact resistance, since $R_1$ enters the contact circuit, and on $R_2$ practically no voltage drop. To show by example the use of this circuit, the contact resistance between the brush and the winding was determined «rough» potentiometer (outside accuracy class) with total resistance $R_1 + R_2 = 480\ \Omega$.

The measurement data for an arbitrary value of the current strength in the contact circuit at various points of the potentiometer are given in Table 1.

Table 1

**Measurement results**

| Current strength *I*, A | $\Delta U_c$, V | $R_c$, Ω |
|---|---|---|
| $15{\cdot}10^{-2}$ | $8{,}1{\cdot}10^{-4}$ | $5{,}34{\cdot}10^{-3}$ |
| $14{\cdot}10^{-2}$ | $6{,}0{\cdot}10^{-4}$ | $4{,}28{\cdot}10^{-3}$ |
| $13{\cdot}10^{-2}$ | $5{,}0{\cdot}10^{-4}$ | $3{,}84{\cdot}10^{-3}$ |
| $11{\cdot}10^{-2}$ | $4{,}0{\cdot}10^{-4}$ | $3{,}65{\cdot}10^{-3}$ |
| $8{,}0{\cdot}10^{-2}$ | $2{,}0{\cdot}10^{-4}$ | $2{,}5{\cdot}10^{-3}$ |

In this method, the measurement error is determined by the accuracy class of the milliammeter and the errors of the compensator. So, for the fifth measurement (Table 1), the error in measuring the current strength is

$$\gamma_a = \pm 0{,}1 \cdot \left(15 \cdot 10^{-2}\right) / \left(8 \cdot 10^{-2}\right) \approx \pm 0{,}2\% ,$$

absolute error of determination $\Delta U_c$ compensator is determined by the formula

$$\Delta U = \pm (150U + 0{,}5m) \cdot 10^{-6} ,\ \text{V},$$

where $U \approx \Delta U_c$ – instrument reading,
m – number of decades, whose reading is not equal to zero,

$$\Delta U = \pm \left(150 \cdot 2 \cdot 10^{-4} + 0{,}5 \cdot 1\right) \cdot 10^{-6} = \pm 0{,}53 \cdot 10^{-6}\ \text{V}.$$

Relative error

$$\gamma_r = \pm \left(\Delta U / \Delta U_c\right) \cdot 100\% = 0{,}2\% .$$

Total error in determining $R_c$

$$\gamma = \gamma_a + \gamma_r \le \pm 0{,}4\% .$$

**Conclusions.** Knowing the schemes for measuring contact resistance, it is possible to study the physical properties of contact surfaces for various materials, observe the geometric shape of the contact surface and, most importantly, how these parameters change with a change in contact force.

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**Петрик В.О., Трубачев С.І., Колодежний В.А. НАДІЙНІСТЬ ДРОТЯНИХ ПОТЕНЦІОМЕТРИЧНИХ ДАТЧИКІВ, ЩО ВИКОРИСТОВУЮТЬСЯ В ЕНЕРГОМАШИНОБУДУВАННІ**

*У статті розглядаються загальні проблеми надійності контактування слаботочних ковзних контактів. Наведено два методи вимірювання величини контактного опору дротяного потенціометра.*

*За одним з методів проведено вимірювання величини контактного опору і підраховано похибку вимірювання.*

*Уміння вимірювати контактний опір відкриває широкі можливості подальшого дослідження питань надійності потенціометричних датчиків. Одним з основних напрямків у дослідженні є зношення контактної пари і як при цьому змінюється контактний опір. Це дозволить встановити, які процеси відбуваються в зоні контакту, а вивчивши їх, направляти дослідження з управління цими процесами для досягнення довговічного в роботі і надійного в провідності струму в контактній парі. Проводячи паралельно теоретичні дослідження, буде відомо, які основні параметри впливають на зношення і провідність пари, що треться. Подібні дослідження можна проводити в різних середовищах, в холоді, у вологому середовищі, при вібрації, у середовищі з різною насиченістю кисню, водню, різних олій та інших компонентів. Всі ці дослідження проводять у статичних умовах після відпрацювання датчиком встановленого ресурсу.*

*Особливий інтерес представляє розробка вимірювальної апаратури, яка повинна розкласти отримані сигнали за один цикл руху щітки по обмотці потенціометра як за встановленими амплітудами, так і за часом. Встановлення інформації про переривання контакту за часом має велике значення, особливо для слідкуючих систем. Створення такої апаратури відкриває можливість досліджувати потенціометричні датчики в динаміці. А отримані при цьому імовірнісні характеристики дадуть повне уявлення про процеси, що відбуваються в зоні контактування.*

***Ключові слова:*** *надійність, довговічність, пластичні деформації, зношення, датчик, контакт.*