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DETERMINING THE FORCE OF IMPACT OF THE BRUSH ON THE COIL IN WIREWIRE POTENTIOMETERS

The research carried out by the authors established that a force of 4 g is required for a reliable contact of the PdW-20–AuCu-800 pair. At the same time, a dynamic equilibrium of the processes of creation and destruction of the oxide film at the level of the film of tunnel current conductivity is achieved. These are adhesive films that were studied by the English scientists Flom and Savage. They established that the thickness of such films at the level of $S \approx 10^{-6}$ *cm. For accurate installation of the conductive film for different contact pairs, it is necessary to have dependencies between contact force and contact resistance, and this dependence clearly shows the zone of optimal forces, as we have shown previously. The contact surface of the contact pair has roughness, and therefore the value of the contact resistance, although to a small extent, will be variable. Making a blow on such a surface imposes instability of the conduction process, which is dangerous for reliable contacting. The impact process itself, and even worse, its repetition at practically the same points, can cause plastic deformations at the contact points, which are accompanied by an intense connection with oxygen, which causes a change in the dynamic value of the contact resistance. This will lead to a loss of contact. The most dangerous thing is that for different contact pairs this value can be variable in amplitude and time. This is undesirable for control systems. Taking into account what has been said, the following must be taken into account: by solving the problem of determining the impact force of a contact brush on a winding strand, simple engineering formulas are obtained, which make it possible to select the design parameters of the contact pair at the stage of sensor design using graphic dependencies to ensure more reliable steam operation. The already mentioned graphical dependencies allow you to establish the contact force, which guarantees reliable operation of the pair.*

Key words: *impact force, contact force, reliable contact, speed of brush movement, wire potentiometer.*

Formulation of the problem. For more effective contact in potentiometers, it is necessary to conduct research on the formation of an adhesive film and on the establishment of contact force in the brush–winding pair. These studies make it possible to increase the reliability and durability of contact in wirewound potentiometers.

Analysis of recent research and publications. Adhesive films were studied by English scientists Flom and Savage [7, 12]. It has been established that the contact force that occurs during the operation of potentiometers has a significant influence on contacting [8, 10]. The methodology and some results of studying contact in wirewound potentiometers are presented in [1, 2, 8]. Due to the complexity of conducting experiments, research in this direction is insufficient. The authors also did not find engineering mechanical dependencies that would allow a quick theoretical study of the influence of various contact parameters on the contact force.

Task statement. The goal of the work is to obtain engineering mechanical dependencies to determine the contact force in wirewound potentiometers, and also to study the influence of various contact parameters on the specified force.

Outline of the main material of the study. Precision wire potentiometric sensors belong to low-current sliding contacts, in which processes caused by friction and wear of contact surfaces prevail over others, even over the phenomena of current flow. In this regard, it is of interest to determine the force of impact of the brush on the coil at the moment of its transition from coil to coil, which introduces significant changes in the contact process.

To determine the impact force, we find the deflection of the center of ring A (Fig. 1) relative to its highest position:
when lifting the ring:

$$\delta_r = R + r - \sqrt{(R+r)^2 - \left(r + \frac{a}{2} - S\right)^2},$$

when lowering the ring:

$$\delta_l = R + r - \sqrt{(R+r)^2 - \left(S - r - \frac{a}{2}\right)^2},$$

where R – is the radius of the slip ring,
r – winding wire radius,
a – winding gap,
S – arc coordinate of the slip ring center.

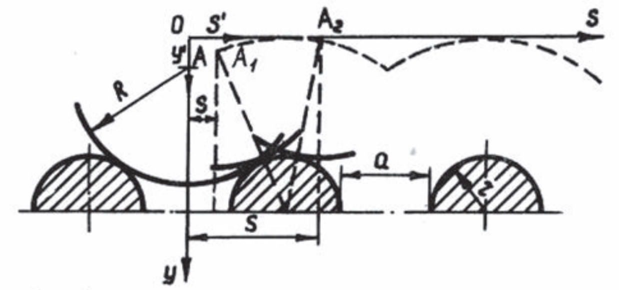

Fig. 1. Movement of the contact brush along the resistance winding

Then the speed of the center of the slip ring (projection of the speed of the center of the slip ring onto the y-axis)
when it rises:

$$V_r = \frac{d\delta_r}{dt} = \frac{-2\left(r+\frac{a}{2}-S\right)\left(-\frac{dS}{dt}\right)}{-2\sqrt{(R+r)^2-\left(r+\frac{a}{2}-S\right)^2}} = \frac{\left(S-r-\frac{a}{2}\right)\left(\frac{dS}{dt}\right)}{\sqrt{(R+r)^2-\left(r+\frac{a}{2}-S\right)^2}},$$

when lowering:

$$V_l = \frac{d\delta_l}{dt} = \frac{\left(S-r-\frac{a}{2}\right)\left(\frac{dS}{dt}\right)}{\sqrt{(R+r)^2-\left(-r-\frac{a}{2}+S\right)^2}}.$$

Slip ring center speed at the beginning of the climb ($S = 0$):

$$V_{l.r} = \frac{d\delta_r}{dt} = -\frac{\left(r+\frac{a}{2}\right)\left(\frac{dS}{dt}\right)_t}{\sqrt{(R+r)^2-\left(r+\frac{a}{2}\right)^2}}, \qquad (1)$$

at the end of lowering ($S = a + 2r$):

$$V_{e.l} = \frac{d\delta_l}{dt} = \frac{\left(r+\frac{a}{2}\right)\left(\frac{dS}{dt}\right)_t}{\sqrt{(R+r)^2-\left(r+\frac{a}{2}\right)^2}}.$$

Speed jump during transition from descent to ascent

$$\vartriangle V = V_{l.r} - V_{e.l} = \frac{-2\left(r+\frac{a}{2}\right)\left(\frac{dS}{dt}\right)_t}{\sqrt{(R+r)^2-\left(r+\frac{a}{2}\right)^2}},$$

where $\left(\frac{dS}{dt}\right)_t$ – value $\left(\frac{dS}{dt}\right)$ at the moment of transition.

Change in the projection of the momentum of the slip ring onto the y-axis during one collision with the resistance winding

$$m\vartriangle V = -\frac{2\left(r+\frac{a}{2}\right)\left(\frac{dS}{dt}\right)_t}{\sqrt{(R+r)^2-\left(r+\frac{a}{2}\right)^2}} m_{gv},$$

where m_{gv} – mass of the ring reduced to the point of contact.

Projection onto the y-axis of the impulses of all external forces acting on the contact ring during one collision with the resistance winding,

$$N_y = \frac{-2\left(r+\frac{a}{2}\right)\left(\frac{dS}{dt}\right)_t}{\sqrt{(R+r)^2-\left(r+\frac{a}{2}\right)^2}} m_{gv}. \qquad (2)$$

Neglecting friction, we assume that the impulse of the impact force (Fig. 2), with which the resistance winding acts on the slip ring during the collision with it, is equal to

$$N = -\frac{N_y}{\cos\alpha}. \qquad (3)$$

Taking into account dependence (2) and Fig. 2

$$\cos\alpha = \frac{\sqrt{(R+r)^2-\left(r+\frac{a}{2}\right)^2}}{(R+r)}.$$

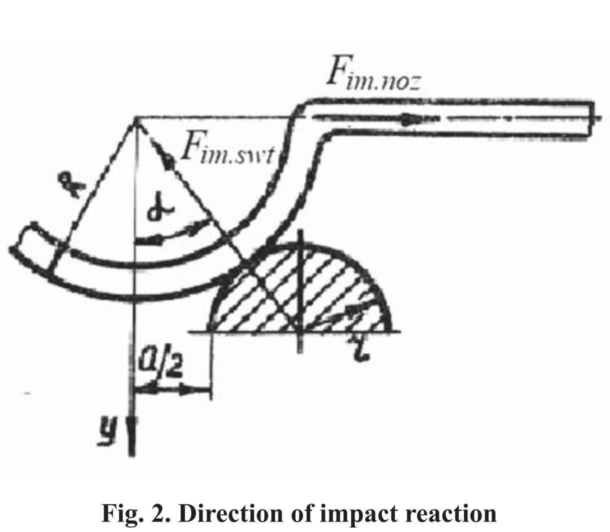

Fig. 2. Direction of impact reaction

Then expression (3) will take the form

$$N = \frac{2(R+r)\left(r+\frac{a}{2}\right)\left(\frac{dS}{dt}\right)_t}{(R+r)^2-\left(r+\frac{a}{2}\right)^2} m_{gv}. \qquad (4)$$

The speed V is determined from equation (4):

$$\vec{V} = \vec{V}_v + \vec{V}_h, \qquad (5)$$

where $\vec{V}_v$ – component of the slip ring velocity, parallel to the axis of rotation of the carrier and determined by dependence (1),
$\vec{V}_h$ – component of the slip ring velocity perpendicular to the axis of rotation of the carrier, the projection of which to the direction S is equal to

$$V_h = \left(\frac{dS}{dt}\right)_t. \qquad (6)$$

Based on (1), (5) and (6), the slip ring velocity component normal to the winding surface is equal to

$$V_1 = V_v \frac{\sqrt{(R+r)^2-\left(r+\frac{a}{2}\right)^2}}{(R+r)} + V_h \frac{\left(r+\frac{a}{2}\right)}{(R+r)}$$

or

$$V_1 = 2\left(\frac{dS}{dt}\right)_t \frac{\left(r+\frac{a}{2}\right)}{(R+r)}.$$

The time of collision of the slip ring with the resistance winding is determined by this component and can be estimated using the formula [3]

$$T = 2{,}977\frac{M^{\frac{2}{5}}K^{\frac{3}{5}}}{V_0^{\frac{1}{5}}},$$

where

$$M = \frac{M_1M_2}{M_1+M_2},$$

$$K = \sqrt[3]{\frac{9}{16R_w}\left(\frac{1-\nu_0^2}{E_0}+\frac{1-\nu^2}{E}\right)^2}.$$

Here M_1 and M_2 – masses of colliding balls 1 and 2,
K – coefficient taking into account the materials of colliding balls,
E_0 и E – elastic moduli of the brush and winding material, respectively,
ν_0 и ν – Poisson's ratios of the brush and winding material, respectively,
R_w – radius of the wire from which the brush is made.

At $M_1 = m_{gv}$, $M_2 = \infty$ and $V_0 = V_1$ brush impact time with winding

$$T = 2{,}977\frac{m_{gv}^{\frac{2}{5}}K^{\frac{3}{5}}}{\left[2\frac{r+a}{R+r}\left(\frac{dS}{dt}\right)_t\right]^{\frac{1}{5}}}. \qquad (7)$$

Then the average value of the impact force of the slip ring on the resistance winding can be represented by the expression

$$F = \frac{N}{T} = \frac{\dfrac{2(R+r)\left(r+\frac{a}{2}\right)\left(\frac{dS}{dt}\right)_t}{(R+r)^2-\left(r+\frac{a}{2}\right)^2} m_{gv}}{2{,}977\dfrac{m_{gv}^{\frac{2}{5}}K^{\frac{3}{5}}}{\left[2\frac{r+a}{R+r}\left(\frac{dS}{dt}\right)_t\right]^{\frac{1}{5}}}}. \qquad (8)$$

Impact force divided by actual contact area A_r, allows you to determine the stresses acting in the contact zone and, as a result, elastic or plastic deformations. Plastic deformations in the contact zone are accompanied by intense absorption of oxygen with the formation of an oxide film, causing catastrophic failures.

The study of expressions (8) and (7) makes it possible to trace the influence of operating parameters and mating surfaces on the impact force, namely:

– how does the impact force depend on the ratio of the radius of curvature of the contact part of the brush to the radius of the wound wire (R/r) at a constant winding pitch (Fig. 3);

– how does the resistor winding pitch affect the impact force at different brush speeds;

– how does the speed of movement of the brush affect the force of impact (Fig. 4);

– how does the impact time vary depending on the speed of movement of the brush (Fig. 5).

Analysis of the dependencies shows that the impact force depends on the speed almost linearly, and at the maximum operating speed of the potentiometers equal to 300 mm/s, an impact force of about $0{,}9\cdot10^{-5}$ N develops. Obviously, this value significantly affects the contacting process and the wear of contact pairs.

The magnitude of the impact force is added to the contact pressure at the moment of impact, resulting in deformation and hardening of the contact surface.

The effect of the ratio of the radius of curvature of the contact brush to the radius of the wound wire on the impact force is shown in Fig. 3. This dependence shows that more favorable conditions for pair operation occur with a minimum thickness of the wound wire, that is, with R/r = 22,5.

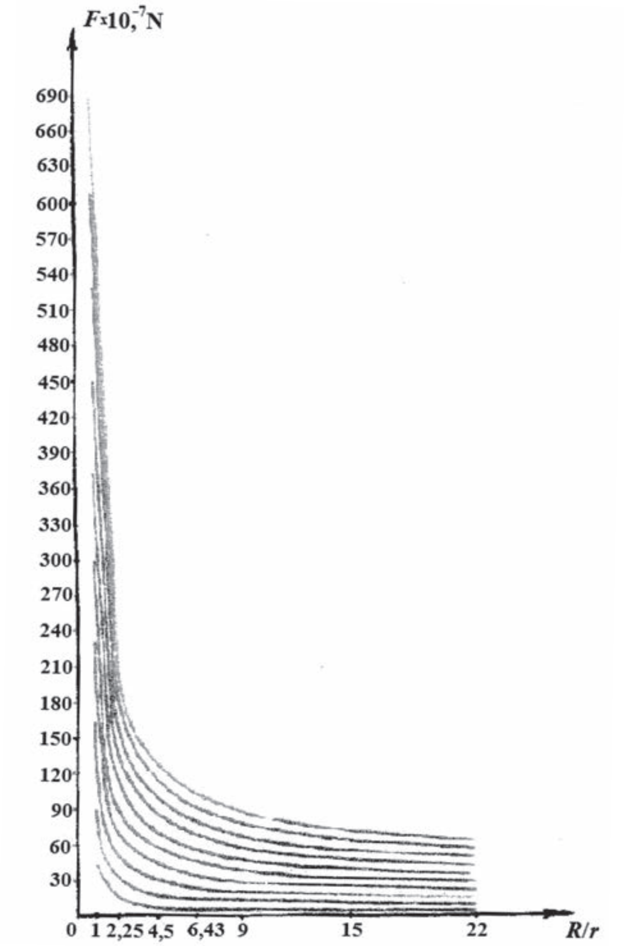

Fig. 3. Dependence of impact force on ratio *R*/*r*

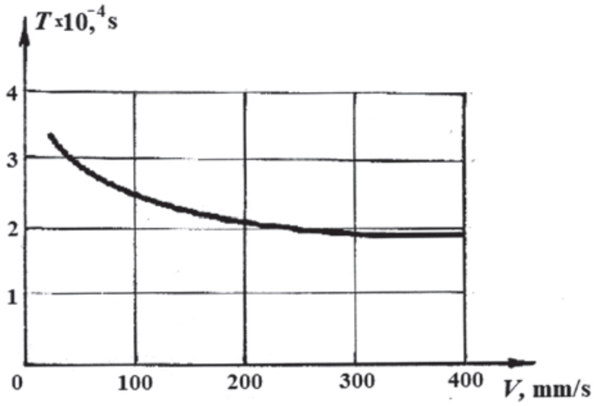

Fig. 5. Dependence of impact time on the speed of movement of the contact brush

At *R*/*r* = 1, the impact force reaches $7\cdot10^{-5}$ N. With increasing *R*/*r*, the impact force drops sharply, even at *V* = 400 mm/s it is only $0.6\cdot10^{-5}$ N. This is confirmed by practice, since at *R*/*r* = 4,5 the operating life of the device is designed for 50000 cycles, and at *R*/*r* = 22,5 (r = 0,02 mm) it is 25000 cycles [7].

The graphical dependence presented in Fig. 4 indicates the influence of the speed of movement of the contact brush on the impact force at different ratios *R*/*r*.

The curve corresponding to the case of *R*/*r* = 0.1 clearly shows that even at minimum speed the impact force reaches a significant value.

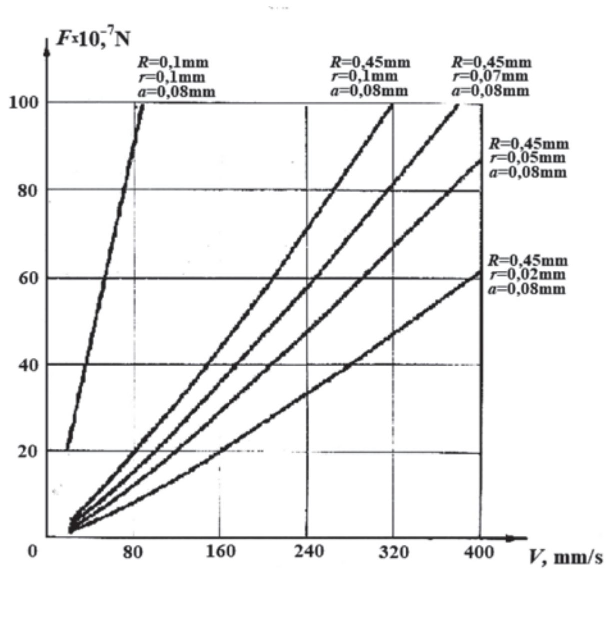

Fig. 4. Dependence of impact force on the speed of movement of the contact brush

Conclusions. The presence of impact force complicates the contact process. It causes a distribution of stresses and strains in the contact zone, as evidenced by different hardnesses on the contact surface.

The impact force contributes to the formation of an additional easily moving surface layer and, as a result, increased wear.

To reduce the impact and create more favorable conditions for the movement of the brushes, an additional technological operation is introduced – running in the contact surface with a ball and lapping the treadmill on micron sandpaper (for low-resistance potentiometers) [6].

1. By solving the problem of determining the force of impact of the brush on the coil, fairly simple engineering formulas were obtained that allow, at the design stage of the device, using graphical dependencies, to select the design parameters of the pair such that they guarantee that the brush does not bounce off the contact surface and provide more favorable working conditions couples.

2. The given graphical dependencies determine the minimum required contact force to guarantee reliable mechanical contact between the pairs.

3. The main parameters influencing the process of mechanical contact of a pair are: the ratio of the radius of curvature of the brush to the radius of the wound wire, contact force, rigidity of the contact brush and the speed of its movement.

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Петрик В.О., Трубачев С.І., Колодежний В.А. ВИЗНАЧЕННЯ СИЛИ УДАРУ ЩІТКИ ПО ВИТКУ У ДРОТЯНИХ ПОТЕНЦІОМЕТРАХ

Проведені авторами дослідження встановили, що для надійного контакту пари ПдВ-20–ЗлМ-800 необхідне зусилля 4 г. При цьому досягається динамічна рівновага процесів створення і руйнування окисної плівки на рівні плівки тунельної проводимості току. Це адгезіонні плівки, які досліджувались англійськими вченими Фломом і Савіджем. Ними установлено, що товщина таких плівок на рівні $S \approx 10^{-6}$ см. Для точного встановлення плівки проводимості для різних контактних пар необхідно мати залежності між контактним зусиллям і контактним опором, і по цій залежності наглядно видно зону оптимальних зусиль, як це показано нами попередньо. Поверхня дотику контактної пари має шорсткість, а тому і значення контактного опору, хоча і в незначній мірі, але буде змінним. Здійснення удару по такій поверхні накладає нестабільність процесу проводимості, що небезпечно для надійного контактування. Сам процес удару, а ще гірше його повторність в тих же практично точках, може визвати в точках контакту пластичні деформації, які супроводжуються інтенсивним з'єднанням з киснем, що визиває зміну динамічного значення контактного опору. Це приведе до розриву контакту. Самим небезпечним є те , що для різних контактних пар ця величина може бути змінною за амплітудою і часом. Для систем управління це небажано. Враховуючи сказане, необхідно враховувати наступне: розв'язанням задачі з визначення сили удару контактної щітки по вітку обмотки отримані прості інженерні формули, які дають можливість ще на стадії проєктування датчика за допомогою графічних залежностей підібрати конструктивні параметри контактної пари такими, які забезпечать більш надійну роботу пари. Уже названі графічні залежності дозволяють встановити контактне зусилля, що гарантує надійну роботу пари.

Ключові слова: *сила удару, контактне зусилля, надійне контактування, швидкість переміщення щітки, дротяний потенціометр.*