UDC 621.762

THE METHOD OF IDENTIFICATION AND EVALUATION HEATING DEPTH DETAILS CONTACT SWITCHING DEVICES

I. Radko[1], L. Chervinsky[1], I. Nazarenko[2]

[1]*National University of Life and Environmental Sciences of Ukraine,*
[2]*Taurian State Agro Technical University*

A method to identify and evaluate the depth of heating the contact details of switching devices based on a system of spherical coordinat. Determine the temperature distribution of the electric arc switching contacts energized.

The purpose of research - to improve the mathematical model of thermal processes switching devices.

Materials and methods research - arc parameters used and the method of thermal energy balance of the electric arc during switching power electric vehicles.

Research results - first calculated value of penetration depth, electrical erosion, lifetime contacts with research materials powder metallurgy and power electric arc.

$$P = a \cdot gradT_{ct} + \lambda G - GT_{ct}^4 ,$$

where: P – power released in the arc, Wt;
α – thermal diffusivity, m^2/s;
T_{ct} – limiting temperature of, ^{0}C;
λ – hidden heat of vaporization, ^{0}C;
G – constant Stefan-Boltzmann law.

The method to determine the depth of penetration contact details put the heat equation in spherical coordinates:

$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial^2 r} + \frac{2\partial T}{r\partial r}\right), \quad (1)$$

where: T – temperature mass contact details, which heats up, °C;
t – the duration of the arc energy, s;
α – the duration of the arc energy, m^2/s;
r – distance from the reference spots curves, m.

Since the size of the main arc is very small compared with the surface of the contact details of the calculation of the thermal regime of contact details is carried out using the methods of a point source. Solution of equation (1) we find so: we introduce the change of variables:

$$U = Tr \quad (2)$$

$$\frac{\partial U}{\partial t} = \frac{\partial Tr}{\partial t}; \quad \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial U}{\partial t}; \quad (3)$$

$$\frac{\partial T}{\partial r} = \frac{1}{r}\frac{\partial U}{\partial r} - \frac{T}{r}; \quad (4)$$

$$\frac{\partial^2 U}{\partial r^2} = \frac{\partial T}{\partial r} + \frac{\partial(r\partial T)}{\partial r^2} = \frac{\partial T}{\partial r} + \frac{\partial r\partial T}{\partial r^2} + \frac{\partial^2 Tr}{\partial r^2} = 2\frac{\partial T}{\partial r} + r\frac{\partial^2 T}{\partial r^2} \quad (5)$$

Substituting (3), (4), (5) in equation (1) we obtain:

$$\frac{\partial U}{\partial t} = r\frac{\partial T}{\partial t} \quad (3);$$

$$\frac{\partial T}{\partial r} = \frac{1}{r}\frac{\partial U}{\partial r} - \frac{T}{r} \quad (4)$$

$$\frac{\partial^2 T}{\partial r^2} = \frac{1}{r}\frac{\partial^2 U}{\partial r^2} - \frac{2}{r}\frac{\partial T}{\partial r} \quad (5)$$

$$\frac{1}{r}\frac{\partial U}{\partial t} = \alpha\left(\frac{1}{2}\frac{\partial^2 U}{\partial r^2} - \frac{2\partial T}{r\partial r} + \frac{2\partial T}{r\partial r}\right) = \frac{\alpha}{r}\frac{\partial^2 U}{\partial r^2}; \quad \frac{\partial U}{\partial t} = \alpha\frac{\partial^2 U}{\partial r^2}. \quad (6)$$

Supporting the arc spot we view as a ball of radius R, located inside the contact whose dimensions are much more times the radius R (unlimited environment). The initial temperature balls 0 <<R equal, and the temperature is zero. Thus, equation (6) is seen in the following boundary conditions:

– $U = T_0 r$, when $t = 0$ at $0 < r < R$;
– $U = 0$, when $t \neq 0$ at $r < R$;
– $U = 0$ when $t = 0$ at $r > R$.

Solution of equation (6) in this case will be the:

$$T = \frac{T_0}{2r\sqrt{\pi at}}\int_0^R r'[l^{-\frac{(r-r')^2}{4at}} + l^{-\frac{(r-r')^2}{4at}}]\partial r' =$$
$$= \frac{T_0}{2r\sqrt{\pi at}}\int_0^R r' l^{-\frac{(r')^2}{4at}}(l^{-\frac{rr'}{2at}} + l^{-\frac{rr'}{2at}})\partial r' . \quad (7)$$

Using smallness, we expand the integrand in a series in powers and limit first by (3) members schedule:

$$l^{-\frac{(r')^2}{4at}} = 1 - \frac{(r')^2}{4at} \pm \frac{(r')^4}{32a^2t^2}; \quad (7')$$

$$l^{-\frac{rr'}{2at}} = 1 + \frac{rr'}{2at} + \frac{r^2(r')^2}{8a^2t^2}; \quad (7'')$$

$$l^{-\frac{rr'}{2at}} = 1 - \frac{rr'}{2at} + \frac{r^2(r')^2}{8a^2t^2}. \quad (7''')$$

After substituting (7'), (7''), (7'') in (7) we obtain:

$$T = \frac{T_0 l^{-\frac{(r')^2}{4at}}}{2r\sqrt{\pi at}}\int_0^R (r' - \frac{(r')^3}{4at} + \frac{(r')^5}{32a^2t^2})(2 + \frac{r^2(r')^2}{4a^2t^2})\partial r' =$$
$$= \frac{T_0 l^{-\frac{(r')^2}{4at}}}{2r\sqrt{\pi at}}\int_0^R [2r' + \frac{(r')^3}{4at}(-1 + \frac{r^2}{2at}) + \frac{(r')^5}{16a^2t^2}(1 - \frac{r^2}{2at})]\partial r' \quad (8)$$

After integration (8) takes the form:

$$T = \frac{T_0 l^{-\frac{(r')^2}{4at}}}{2r\sqrt{\pi at}}[R^2 + \frac{R^4}{8at}(-1+\frac{r^2}{2at}) + \frac{R^6}{96a^2t^2}(1-\frac{r^2}{2at})] \quad ; (9)$$

$$T = \frac{T_0 l^{-\frac{(r')^2}{4at}}}{2r\sqrt{\pi at}} R^2[1+\frac{R^2}{8at}(-1+\frac{r^2}{2at})] \quad . \qquad (10)$$

Find the temperature distribution of the source in the case of an end time. For this we use the known ratio:

$$mcdT = qIUdt \qquad (11)$$

where: m– supply source (spots), г;
c – specific heat, $\frac{J}{\kappa g \cdot grad}$;
I– current arc, A;
U – voltage drop in the arc, V;
q – electrothermal equivalent, $\kappa al/j$.

Define here E, whose value we substitute in (10) and integrating over from 0 to obtain:

$$T = \frac{3qIUR^2}{2r\sqrt{\pi a \pi R^3}\gamma c}\int_0^t \frac{l^{-\frac{r^2}{4a(t-t_1)}}}{\sqrt{t-t_1}}[1+\frac{R^2}{8at}(-1+\frac{r^2}{2at})]\partial t =$$

$$= \frac{3qIU}{8rR\gamma\pi c\sqrt{\pi a}}[\int_0^t \frac{l^{-\frac{r^2}{4a(t-t_1)}}}{\sqrt{t-t_1}}\partial t' -$$

$$\frac{R^2}{8a}\int_0^t \frac{l^{-\frac{r^2}{4a(t-t_1)}}}{\sqrt{t-t_1}}\partial t' + \frac{R^2 r^2}{16a^2}\int_0^t \frac{l^{-\frac{r^2}{4a(t-t_1)}}}{\frac{5}{2}(t-t_1)}\partial t' \quad . \qquad (12)$$

Using the change of variables:

$$\frac{1}{\frac{1}{2}(t-t_1)} = \sigma \quad ; \qquad \partial\sigma = \frac{\partial t'}{2(t-t_1)^{\frac{3}{2}}} \quad ;$$

$$t = 0 \qquad \sigma = t^{-\frac{1}{2}};$$
$$t = t \qquad \sigma = \infty,$$

we have:

$$2\int_{\frac{1}{\sqrt{t}}}^{\infty} \frac{l^{-\frac{r^2}{4at}\sigma^2}}{\sigma^2}\partial t = 2\sqrt{t}l^{-\frac{r^2}{4at}} - \frac{r^2}{a}\int_{\frac{1}{\sqrt{t}}}^{\infty} l^{-\frac{r^2}{4at}\sigma^2}\partial t =$$

$$= 2\sqrt{t}l^{-\frac{r^2}{4at}} - \sqrt{\frac{\pi a}{r^2}}\frac{r^2}{a}\left[1-\phi\left(\sqrt{\frac{r^2}{4at}}\right)\right] . \qquad (13)$$

2nd integral:

$$\int_0^t \frac{l^{-\frac{(r')^2}{4a(t-t_1)}}}{\frac{3}{2}(t-t')}\partial t' \quad .$$

We introduce the change of variables:

$$\frac{1}{\frac{1}{2}(t-t')} = \sigma \quad ; \qquad \partial\sigma = \frac{\partial t'}{2(t-t_1)^{\frac{3}{2}}} \quad ;$$

$$t = 0 \qquad \sigma = t^{-\frac{1}{2}};$$
$$t = t \qquad \sigma = \infty,$$

$$2\int_{\frac{1}{\sqrt{t}}}^{\infty} l^{-\frac{r^2}{4at}\sigma^2}\partial t' = 2\sqrt{\frac{\pi a}{r^2}}\left[1-\phi\left(\sqrt{\frac{r^2}{4at}}\right)\right] . \qquad (14)$$

3rd integral:

$$\int_0^t \frac{l^{-\frac{(r')^2}{4a(t-t_1)}}}{\frac{3}{2}(t-t')}\partial t' \quad .$$

$$\frac{1}{\frac{1}{2}(t-t')} = \sigma \quad ; \qquad \partial\sigma = \frac{\partial t'}{2(t-t_1)^{\frac{3}{2}}} \quad ;$$

$$t = 0 \qquad \sigma = t^{-\frac{1}{2}};$$
$$t = t \qquad \sigma = \infty,$$

$$2\int_0^t \sigma^2 l^{-\frac{r^2}{4at}\sigma^2}\partial\sigma = 2\frac{1}{2}\int_{\frac{1}{t}}^{\infty} \sigma l^{-\frac{r^2}{4at}\sigma^2}\partial\sigma^2 = \int_{\frac{1}{t}}^{\infty}\sqrt{x}l^{-\frac{r^2}{4at}x}\partial x$$

change of variables

$$\sigma^2 = x \; ; \quad \sigma = \frac{1}{\sqrt{t}} \; ; \quad \sqrt{x} = \frac{1}{\sqrt{t}} \; ; \quad x = \frac{1}{t}$$

Substituting the values of the integrals (13) and (14) in (12), we have:

$$T = \frac{3qIU}{8\pi\sqrt{\pi a}R\gamma c}(2\sqrt{t}l^{-\frac{r^2}{4at}} + \frac{r^2}{a}\sqrt{\frac{\pi a}{r^2}}[1-\phi] -$$

$$-\frac{2R^2}{4a}\sqrt{\frac{\pi a}{r^2}[1-\phi]}) + \frac{4aR^2r^2}{16a^2r^2}\frac{1}{\sqrt{t}}l^{-\frac{r^2}{4at}}$$

$$+\frac{4a}{r^2}\sqrt{\frac{\pi a}{r^2}}\frac{R^2r^2}{16a^2}[1-\phi] =$$

$$= \frac{3qIUR^2}{8\pi\sqrt{\pi a R^2}\gamma c}\{\left(2\sqrt{t}+\frac{R^2}{4a\sqrt{t}}\right)l^{-\frac{r^2}{4at}} -$$

$$-[1-\phi]\left(\frac{r^2\sqrt{\pi a}}{4ar}\frac{a^2\sqrt{\pi a}}{4ar}\right)\}$$

$$T=\frac{3qIU}{8\pi\sqrt{\pi a}R^2\gamma c}[\frac{1}{r}l^{-\frac{r^2}{4at}}\left(2\sqrt{t}+\frac{R^2}{4at}\right)-\sqrt{\frac{\pi}{a}}\left(1-\phi\sqrt{\frac{r^2}{4at}}\right)] \quad (16)$$

This shows that the temperature of contact can not exceed a certain maximum. The maximum surface temperature of the electrodes we determined the thermal energy balance equations at the electrode by the formula:

$$P=a\cdot gradT_{ct}+\lambda G+GT_{ct}^4, \quad (17)$$

where: P – power released in the arc, Wt;
α – thermal diffusivity, m^2/s;
T_{ct} – limiting temperature of, ^0C;
λ – hidden heat of vaporization, ^0C;
G – constant Stefan-Boltzmann law.

The above assessment showed that the maximum surface temperature of contact details is 2400º K, which is close to the temperature of the evaporation of silver.

The depth of penetration of the material contact parts depends on the energy of the arc, physical and mechanical properties of the contact material arcing time is determined by the expression:

$$r=0{,}17\sqrt{\frac{U_0I_0\omega\sqrt{t_0}}{bT}}, \quad (18)$$

where: U_0 – voltage power supply, V;
I_0 – load current, A;
t_0 – time breaking contact details, s;
$b\sqrt{\pi\lambda\gamma c}$ – ratio, defined thermophysical properties of the contact material, $J/(m^2Ks^{1/2})$;
T – estimated melting temperature, K.

As can be seen from equation (18), to a depth of penetration of the contact material affects the time of the arc during switching current. Therefore, we can determine the optimal time breaking contact details, where the depth of penetration and erosion will be minimal:

$$t_{опт}=\frac{\pi\lambda\gamma S^2T^2}{P_{сер}^2}, \quad (19)$$

where: S – evaluation contact, which operates an electric arc energy, *mm*;
$P_{сер}$ – the average value of the power curves, *Wt*.

Evaluation maximum depth proplavlena the formula (18) shows that its value is 0.5. Considering the microstructure of a longitudinal section of the electrodes can be seen that the depth of penetration is on average 0.6.

Thus, the coincidence data and experimental data is satisfactory, given the estimated calculation.

Conclusions. The depth of penetration of the material of contacts depends on the energy of the arc, spark material properties contact time burning arc and is given by:

$$h=\sqrt{\frac{U_0I_0\omega\sqrt{t_0}}{2\psi T_pl_0}}, \quad (20)$$

where ω – coefficient characterizing the type of load, depending on the ratio of active resistance to the consumer R_0 and its inductance L, and time-dependent release contact t_0:

$$\omega=\frac{R_0t_0}{L}, \quad (21)$$

where: ψ – factor for the ratio between the sizes of contacts;
T_p – calculated melting point of contact material, K;
$b\sqrt{\pi\lambda\gamma c}$ – ratio, defined physical and mechanical characteristics of the material contacts, $J/(m^2Ks^{1/2})$;
U_0 – voltage current source, V;
I_0 – amperage consumer, A;
t_0– time breaking contact details, s. As a result of the calculations was the dependence of the lifetime of the contacts on the amount of electricity transferred in the arc.

References

1. G. V. Butkevych. Processes at commutations in electric chains / Butkevych G. V.:- M.: Energy 1973. - 172 p.
2. G. V. Butkevych. Questions erasing the contact electric switching devices Action arch / G. V. Butkevych - M.: MEI, 1965.
3. Dekabrun N. E. Contacts switching devices to rough voltage / N.E. Dekabrun: M.: Energy, 1970.- 327 p.
4. Koblenz M. G. Study of electrical contactors erasing. / M. G. Koblenz. // Elektrotehnyka. 1966. - 277 p.
5. A. V. Lykov. Theory thermal conductivity / A. V. Lykov - M.: 1967. - 250 p.
6. R. Holm. Elektrics contacts / R. Holm - M.: 1961. - 464 p.

Аннотация

МЕТОД ОПРЕДЕЛЕНИЯ И ОЦЕНКИ ГЛУБИНЫ ПОВРЕЖДЕНИЯ ДЕТАЛИ КОНТАКТА КОММУТАЦИОННЫХ УСТРОЙСТВ

Радько И. П., Червинский Л. С., Назаренко И. П.

Рассмотрен метод определения и оценки глубины нагрева контактов коммутирующих аппаратов, основанный на использовании системы сферических координат. Что позволяет определить распределение температуры электрической дуги переключения вглубь контактов.

Анотація

МЕТОД ВИЗНАЧЕННЯ І ОЦІНКИ ГЛИБИНИ ПОШКОДЖЕННЯ ДЕТАЛІ КОНТАКТУ КОМУТАЦІЙНИХ ПРИСТРОЇВ

Радько І. П., Червінський Л. С.,
Назаренко І. П.

Розглянуто метод визначення та оцінки глибини нагрівання контактів комутуючих апаратів, основа ний на використанні системи сферичних координат. Що дозволяє визначити розподілення температури. електричної дуги перемикання в глиб контактів.