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ELECTRICAL CONTACT TEMPERATURE CHANGE AFTER SHORT-CIRCUIT CURRENT

Theoretical analysis is preformed concerning temperature rise of electrical contacts exposed to short-circuit current. This temperature is calculated for three different contact materials: AgNi, AgCdO and $AgSnO_2$, used in low voltage electromagnetic relays. An assumption is made that the heat process is adiabatic. Amount of heat is calculated based on let-through energy (Joules heat) of miniature circuit breaker and on real electrical contact resistance. A simplified model of electrical contact heating is proposed.

KEYWORDS: contact materials, contact resistance, Joule's heat

1. CONTACT MATERIALS USED IN ELECTROMAGNETIC RELAYS

Electrical contacts are exposed to various hazards during their life cycle. To analytically present them many simplifying assumptions have to be made because of the complexity of considered issues. Those hazardous phenomena include thermal risks. One of them is high short-circuit current that leads to high temperature rise of contact spot and may cause contact welding or may reduce relay life time.

Many different materials are used for electrical contacts, and most commonly utilized in low voltage relays are AgNi, $AgSnO_2$ and AgCdO. Few selected physical and electrical properties are presented in Table 1.

Table 1. Selected contact materials properties

Material	Density	Melting point temperature	Hardness	Thermal conductivity at 20 ºC	Electrical conductivity
	[g/cm^3]	[ºC]	[HB]	[W/(K m)]	[m/(Ωmm^2)]
AgNi10	10,3	961	50	350	54
AgCdO10	10,2	961	70	313	48
$AgSnO_2$10	9,9	961	70	307	49

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2. POINT HEAT SOURCE AS A CONTACT SPOT

Electromagnetic relays are often used as parts of actuators used in building automation systems such as KNX, LCN or any other Building Management System (BMS). These systems include traditional electrical installations. This installations and electrical devices used in them have to be properly protected against short-circuit currents. For this purpose the Miniature Circuit Breakers (MCBs) are used. Important parameter of MCBs is let-through energy, that defines the amount of energy which electrical circuit and devices in it have to withstand. This factor will be used in later calculations of contact spot temperature.

Real contact spot of electrical contacts is significantly smaller than contact rivet [1, 2, 3, 4, 5]. Electrical current is conducted through this spots, called a-spots [3, 4, 5]. Because these a-spots are so small in diameter there is a high temperature rise on them [6]. A short-circuit current, which reaches a lot higher values than nominal current of the relay, can generate so much heat that the contact material in that a-spot can be melted and create a weld [7]. In order to calculate rise of a-spot temperature a model is proposed based on this presumptions:

- electric contacts are closed, no electrical arc influence,
- real contact area is represented as a single a-spot,
- this a-spot is treated as a point heat source (PHS) in an infinite space.

Figure 1 shows the heat source in infinite space [8]. Assuming that inner radius r_w – 0 we can treat this heat source as a single point that generates energy Q.

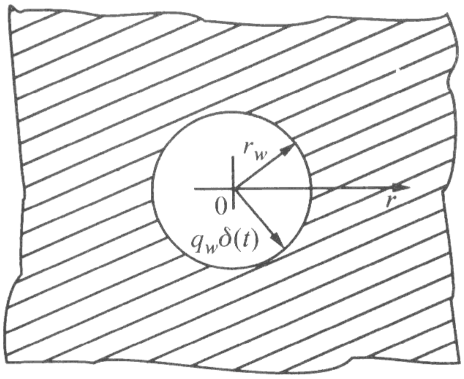


Fig. 1. Heat Source in infinite space [8]

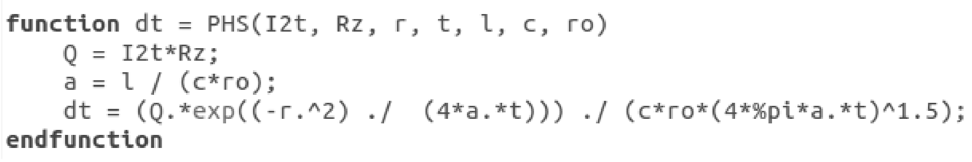
Temperature rise created by this PHS can be calculated using eq. 1, where: Q – amount of energy generated in heat source, c – specific heat, ρ – density, a – temperature compensation coefficient $a = \frac{\lambda}{c \cdot \rho}$, t – time, r – radius, distance from PHS.

$$\Theta = \frac{Q}{c \cdot \rho \cdot (4 \cdot \pi \cdot a \cdot t)^{\frac{3}{2}}} \cdot e^{\frac{-r^2}{4 \cdot a \cdot t}} \tag{1}$$

Important issue was to bind the energy Q with let-through energy of MCB. Using know electrical contact resistance R_k and the let-through energy amount of energy generated by a short-circuit current can be calculated using eq. 2.

$$Q = \int i^2 dt \cdot R_k \left[\mathrm{J}\right] \tag{2}$$

A script was written using Scilab scientific program for numerical calculations (Fig. 2).



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function dt = PHS(I2t, Rz, r, t, l, c, ro)
    Q = I2t*Rz;
    a = l / (c*ro);
    dt = (Q.*exp((-r.^2) ./  (4*a.*t))) ./ (c*ro*(4*%pi*a.*t)^1.5);
endfunction
```

Fig. 2. Point Heat Source (PHS) function realization in Scilab

The PHS function calculates temperature rise based on equation 1. Its parameters are: *I2t* – let-through energy, *Rz* – contact resistance, *r* – distance form point heat source, *t* – time, *l* - thermal conductivity, *c* – specific heat, *ro* – density of the material.

3. RESULT OF CALCULATIONS

With help of this program calculations were made for three contact materials (table 1) and two different let-through energy values: 2 kA^{2}s and 15 kA^{2}s. These values were take from data sheet of a typical MCB for two prospective short-circut current values of 1 kA and 6 kA respectively.

Radius r was calculated using eq. 3. It defines the a-spot radius assuming that the contact spot is a singe sphere. This radius is a function of contact force F and contact material hardness HB. The ξ coefficient was assumed equal to one. Contact force was measured on electromagnetic relays under question.

$$r_Z = \sqrt{\frac{F}{\pi \cdot \xi \cdot HB}} \tag{3}$$

Contact resistance R_Z was measured on the same relays as contact force. Presented value is a median from 10 measurements of contact resistance. Resulting values of contact resistance and a-spot radius are presented in Table 2. Time t was equal to 10 ms, which is a typical short-circuit time for a circuit with high power factor cos φ ≈ 0,998 and protected by a MCB.

Table 2. Contact resistance and contact spot size

Material	R_Z	r_Z
	[mΩ]	[μm]
AgNi	1,445	11,95
AgCdO	4,745	9,63
$AgSnO_2$	8,876	10,77

Based on data presented earlier in Table 1 and 2 contact spot temperature rise *Θ* was calculated using the Scilab script and the results are presented in Table 3.

Table 3. Contact spot temperature rise depending on contact material and let-through energy

Let-through energy $\int i^2 dt$ = 2000 A^2s		
Material	Q	θ_{max}
	[J]	[K]
AgNi	2,89	15,70
AgCdO	9,49	62,61
$AgSnO_2$	17,75	112,78
Let-through energy $\int i^2 dt$ = 15000 A^2s		
AgNi	21,68	117,77
AgCdO	71,18	466,59
$AgSnO_2$	133,14	845,88

For the three analysed contact materials with the rise of contact resistance the temperature rise increases. This rise is only around 16 degrees Kelvin for the AgNi contact material up to 113 degrees Kelvin for $AgSnO_2$ with AgCdO in the middle for the let-through energy of 2 kA^2s. Although high, these temperatures are way below melting point temperature of contact materials used in this relays. We can assume that they do not present real threat for the normal operation of relays under tests. The same situation is with energy level *Q* for three three contact materials.

For the 15 kA^{2}s let-through energy the temperature rise for AgSnO$_2$ reaches a value high enough that may result in contact spot material melting temperature. For the two remaining materials the temperature rise reaches high values, but below the melting point.

For this calculations the radius r was equal to the contact spot diameter r_Z as defined by eq. 3 and shown in table 2. If the heat penetration was greater, that is radius r had higher values, the temperature rise would have been less significant. Figure 3 shows the temperature rise for three contact materials and two let-through energy values in question.

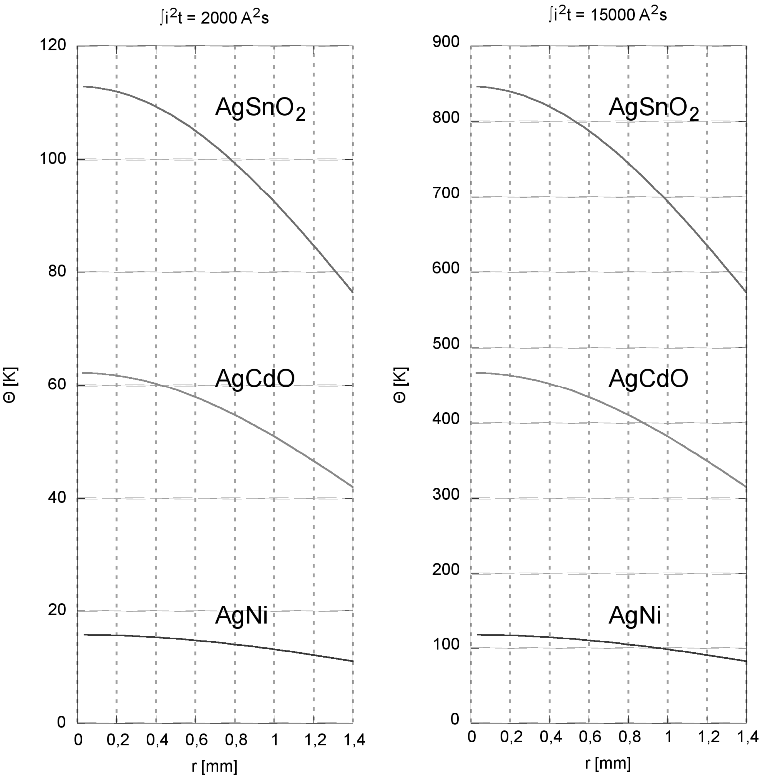

Fig. 3. Contact spot temperature as a function of penetration depth radius for two considered letthrough energy values

Radius r can not be grater than the real dimensions of contact rivet. It is clear that with greater penetration depth the temperature rise is smaller, as more material absorbs the energy.

Change in temperature rise in function of r is negligible for AgNi contact, as it had the lowest contact resistance. As for AgSnO$_2$ and AgCdO contact materials temperature decreases with higher r values. However with low r, less than 0,2 mm, the difference between the temperature rise is insignificant. It can lead to a conclusion that if the real a-spot radius would be higher, for example with higher contact force *F*, the temperature rise wouldn't change drastically.

4. CONCLUSION

Presented model of contact spot heating with point heat source has to be verified practically. First results appear to be probable for the presented conditions. Model itself can be improved by taking into account that the temperature is not conducted in every direction the same way. Instead of a single point heat source a small surface heat source can be used.

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