POZNAN UNIVERSITY OF TECHNOLOGY ACADEMIC JOURNALS
No 74 Electrical Engineering 2013

Andrzej KSIĄŻKIEWICZ*
Ryszard BATURA*

THERMAL AND ELECTRODYNAMIC CHARACTERISTICS OF ELECTRICAL CONTACTS IN STEADY STATE

In this paper results of theoretical analysis of the thermal and electrodynamic characteristics of electrical contacts are presented. Influences of contact material on temperature changes are discussed. Real contact area impact on electrodynamics of electrical contacts is analysed

1. ELECTRICAL CONTACTS AND CONTACT MATERIALS

Electrical contacts are exposed to various hazards during their life cycle. Those hazardous phenomena include thermal and electro dynamical risks. In order for the electrical contacts to work properly for a long time it is necessary to calculate the influence of those phenomenons. To analytically present them many simplifying assumptions have to be made because of the complexity of considered issues.

Many different materials are used for electrical contacts. These materials include Ag, AgNi, $AgSnO_2$ and AgCdO. The first two of them are discussed in this paper. Both of them can be used in low power electromagnetic relays, but the dominant material is AgNi.

2. THERMAL CHARACTERISTICS OF ELECTRICAL CONTACTS

2.1. Thermal theoretical model

In order to analyse thermal characteristic of electrical contact in steady state a simple model will be used (Fig. 1). This model represents the contact spot between two connected conductors. In this model the presented temperatures are as follows: τ_p – steady temperature rise at $x = \infty$ (away from the contact spot), τ_z – steady temperature rise at $x = 0$, $\Delta\tau$ – additional temperature rise as result of higher current density in the contact spot. The additional temperature rise is a result of reduced cross section of the contact spot, which is many times smaller that the real contact size.

* Poznań University of Technology.

The temperature distribution in a conductor with a contact spot is described by [1]:

$$\tau(x) = \frac{1}{2} I^2 R_z \frac{1}{aS\lambda} \mathrm{e}^{-ax} + \tau_p \tag{1}$$

where: I – nominal current, R – contact resistance, λ - thermal conductivity, and a and τ_p are [1]:

$$a = \sqrt{\frac{k_{od} S_{p1}}{\lambda S}} \tag{2}$$

$$\tau_p = \frac{I^2 \rho}{S} \frac{1}{k_{od} S_{p1}} \tag{3}$$

where: k_{od} - heat transfer coefficient, S – contact spot cross-section, S_{p1} – lateral surface of a dx element of the conductor (in the discussed case is equal to 2πr), ρ – contact material electrical resistivity.

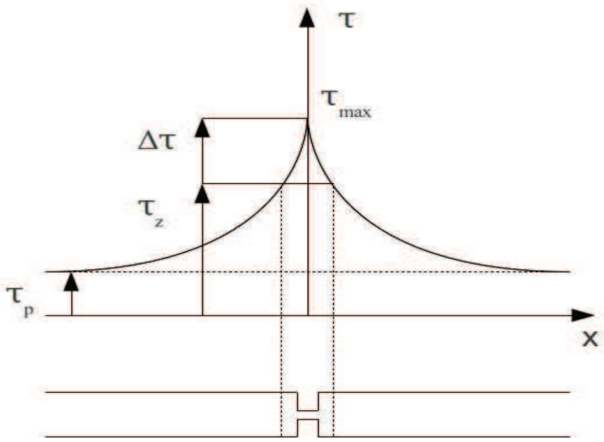

Fig. 1. Temperature distribution in electric conductor with contact spot: τ_p – steady temperature rise at $x = \infty$ (away from the contact spot), τ_z – steady temperature rise at $x = 0$, $\Delta\tau$ – additional temperature rise[1]

The additional temperature rise in steady state is described by [1]:

$$\Delta\tau \approx \frac{I^2 R^2}{8\lambda\rho_\vartheta} \tag{4}$$

The additional temperature rise should not be greater than 10 – 20 K [3].

2.2. Results of thermal characteristics calculations

The presented calculations were made for two different contact materials: Ag and AgNi, and two different contact resistance R_z. The parameters used: $I = 10\ A$, $k_{od} = 1$, $r = 1{,}5\ mm$ (for the S and S_{p1}). Contact material electrical resistivity equals:

ρ_{Ag} = 1,65·10^{-8} Ωm [4] and ρ_{AgNi} = 1,88·10^{-8} Ωm [2], thermal conductivity: λ_{Ag} = 4,18·10^{-2} $W/m{\cdot}K$, λ_{AgNi} = 3,83·10^{-2} $W/m{\cdot}K$. Electric contact resistance R_z was taken as the minimum and maximum described in [5] (R_{zmin} = 2,07 $m\Omega$, R_{zmax} = 7,88 $m\Omega$). Results of the calculations are presented in Table 1.

Table 1. Temperature value depending on contact material and contact resistance

Contact resistance R = 2,07 mΩ				
Material	τ_p	τ_z	$\Delta\tau$	τ_{max}
	[ºC]	[ºC]	[ºC]	[ºC]
Ag	24,77	44,35	6,93	51,28
AgNi	28,22	46,97	6,57	53,54
Contact resistance R = 7,88 mΩ				
Ag	24,77	99,40	88,89	188,29
AgNi	28,22	99,68	84,61	184,29

The steady temperature rise τ_p is equal for both of the contact resistances as it is only dependent on current and electrical resistivity of the material. The AgNi has a slightly higher resistivity than pure Ag (around 14%) thus τ_p has a higher value. Because of different thermal conductivity λ of the two materials the temperature rise τ_z and $\Delta\tau$ of AgNi is slightly smaller that Ag.

The greatest influence on the temperature rise comes from the change in electrical contact resistance R_z. Higher the contact spot resistance the real contact area gets smaller, which leads to higher current density and greater generation of heat. With the rise of the resistance by a factor of 3,81 the maximum temperature for the Ag and AgNi rose by 3,67 and 3,44 respectively. The additional temperature rise factor is even greater and is equal to 12,83 and 12,88 respectively.

However use of AgNi as a contact material gave a slightly lower maximum temperature than Ag which is a better result as the contact spot shouldn't generate too much heat. In both cases with the higher contact resistance the additional temperature rise exceeded the maximum proposed rise of 20 K mentioned earlier. This may be the result of a higher that required contact resistance and by the imperfection of the theoretical model. The maximum temperature is not the only criteria based on which a material is chosen, amongst those criteria are the resistance against welding and electric wear.

3. ELECTRODYNAMIC CHARACTERISTIC OF ELECTRICAL CONTACT

3.1. Electrodynamic simplified theoretical model

Reduction of the electrical contact cross area generates an electrodynamic force F_y which is repealing the contacts apart [3]:

$$F_y = \frac{\mu_0}{4\pi} i^2 \ln \frac{r_1}{r_2} \tag{5}$$

where: r_1 – radius of cylindrical contact, r_2 – real contact area radius.

A simplified model representing the two radius values is presented on figure 2.

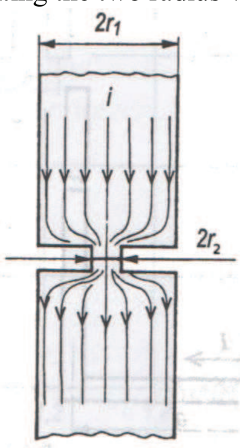

Fig. 2. Simplified model of single point electric contact [1]

To calculate this force the radius r_2 has to be known. It is almost impossible to determinate its value, and for single contact point only an approximation can be made based on the contact closing force and contact material properties and is described by [3]:

$$r_2 = \sqrt{\frac{F_s}{\pi \sigma_0}} \tag{6}$$

where: F_s – contact closing force, σ_0 – yield strength of contact material.

Another way to determinate the real contact radius can be based on electric contact resistance and the elliptical contact surface model [4]:

$$R = \frac{\rho}{2r_2} \tag{7}$$

With known contact resistance and the resistivity of contact material the value of r_2 can be calculated.

3.2. Results of electrodynamic characteristics calculations

Based on equation 5 electrodynamic force was calculated for to contact resistances 2 *mΩ* (Fig. 3) and 7 *mΩ* (Fig. 4).

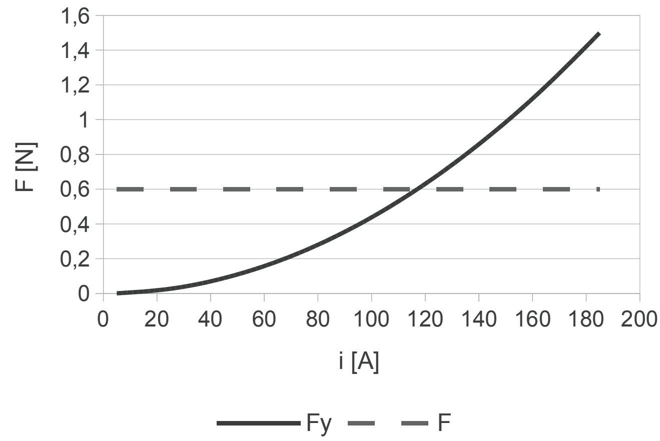

Fig. 3. Repelling contact force F_y dependent on current (R = 2 $m\Omega$), F – relay nominal contact force

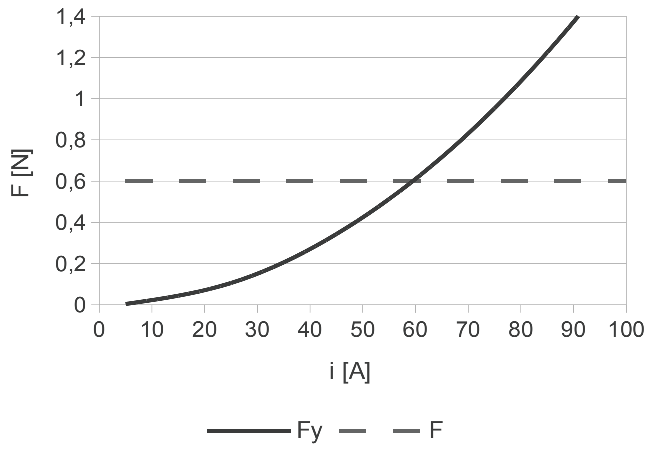

Fig. 4. Repelling contact force F_y dependent on current (R = 7 $m\Omega$), F – relay nominal contact force

As mentioned earlier the contact resistance determinates real contact area radius r_2. Greater electrical contact resistance leads to smaller contact spot area. That strengthens the effect generated by higher current density in the contact spot, which results in greater repelling force acting on the contacts. Relay nominal contact force was measured and it was not greater than 0,6 N.

The calculated repelling force for both cases in the steady state is insignificant. However in case of a short circuit current there exists theoretical possibility that the contacts could open if the current value will be greater than 120 A and 60 A respectively.

4. CONCLUSION

Influence of electric contact material on thermal and electrodynamic characteristics of electrical contact was discussed. Based on the results presented concerning temperature rise on contact spot a minimal influence of contact material can be observed. A much greater influence on thermal characteristics had electric contact resistance. The same relationship was found concerning the electrodynamic force. Higher value of contact resistance leads to lower tolerance for force generated by a greater current value but in relation to steady state its impact can be omitted.

REFERENCES

[1] Markiewicz H., Urządzenia elektroenergetyczne, WNT, Warszawa, 2006 (in Polish).
[2] http://www.gljg.com.cn/en/lvc_sn.html
[3] Au A., Maksymiuk J., Pochanke Z., Podstawy obliczeń aparatów elektroenergetycznych, WNT, Warszawa, 1976 (in Polish).
[4] Ciok Z., Procesy łączeniowe w ukłądach elektroenergetycznych, WNT, Warszawa, 1983 (in Polish).
[5] A. Książkiewicz: Change of electric contact resistance of an electromagnetic relay during switching operations without electric load, 5th International Interdisciplinary Technical Conference of Young Scientists, 16-18 May 2012, p. 257 - 260, Poznan.