1. Dušan MEDVEĎ, 2. Ján ZBOJOVSKÝ

Technical University of Košice

ORCID: 1. 0000-0002-8386-0000; 2. 0000-0003-4383-3996

doi:10.15199/48.2021.12.48

Influence of the Position of the Electrical Contact on the Size of the Temperature Distribution

***Abstract**. This paper deals with the investigation of temperature field distribution around the high-current electric contact. The analyses of temperature field were realised in simulation environment ANSYS and provide better understanding why the electrical contact position influences the heat dissipation. Material of electrical contact was copper, aluminium, brass and non-standard material for power devices, silver. Results were compared and the conclusion with the recommendation were stated in the end of this paper.*

***Streszczenie.** Artykuł dotyczy badania rozkładu pola temperatury wokół wysokoprądowego styku elektrycznego. Analizy pola temperatury zostały przeprowadzone w środowisku symulacyjnym ANSYS i pozwalają lepiej zrozumieć, dlaczego położenie styku elektrycznego wpływa na rozpraszanie ciepła. Materiałem styku elektrycznego była miedź, aluminium, mosiądz oraz niestandardowy materiał do urządzeń zasilających, srebro. (**Wpływ położenia styku elektrycznego na wielkość rozkładu temperatury**).*

Keywords: temperature field distribution, electrical contact, ANSYS, heat transfer
Słowa kluczowe: rozkład pola temperatury, kontakt elektryczny, ANSYS, przenoszenie ciepła

Introduction

Electrical contacts are the most important part of electrical devices, because they are used for connecting or disconnecting electrical circuits. Contact faults can destroy electrical equipment that contains such contacts. Problems with these mechanisms can cause significant financial damage to capital equipment, not to mention injuries or loss of life. Maintaining well-functioning electrical contacts is an important element in ensuring the performance and safety of all electrical equipment and its components [1]. In order for current contacts to perform their function reliably, they must be made of a very hard but well-conducting material, they must be resistant to chemical influences and to opal arcs, which occur mainly during switching. The contacts are most often made of copper and are silver-plated or coated with a thin layer of brass. If the arc ignites during switching, then the arc is often moved to the tanning contacts, which have the shape of a plate or a strip and are made by powder metallurgy of tungsten and silver or tungsten and copper [2].

Foreign harmful layers are deposited on the contact and they increase the contact resistance (they are eliminated, for example, by friction of the contacts during contact). We know two types of foreign layers, chemical and mechanical. Chemicals act as oxides or sulphites and mechanical ones as greases and impurities [10].

Electrical devices must also reliably disconnect electrical circuits, i.e. the contacts must not be connected or welded when a nominal or short-circuit current passes [5]. When the rated current passes, the voltage drop between the contacts must not exceed the so-called material softening voltage and when the short-circuit current passes, the so-called welding voltage must not exceed. These values for individual materials are provided by the R-U diagram [1].

Electrical contacts are commonly used in electrical mechanical devices that operate on a wide range of voltages. We can find them in home appliances, motors, power plants, assembly lines, conveyors, cranes, special type converters [6–8] and the like [3, 12].

Thermal analysis of electrical contacts

In this part, we focused on the influence of electric current on the temperature of selected contacts, current coupling. When the current passes through the individual contacts, they may overheat, as a result of which the degradation of the contact or a failure of the device may occur. Therefore, it is important to choose the right dimensions and contact material when designing [9]. In terms of temperature, it is also necessary to observe the temperature classes, which indicate the values of temperatures that can be reached by the contacts.

Determining the temperature distribution on the individual contacts is too complicated by manual, numerical calculations. A more advantageous solution is the use of specialized software, which will allow numerical calculations to be performed in a very short time, based on which it calculate the temperature distribution [4, 11]. One of the many specialized software is ANSYS, which we used to determine the temperature distribution.

Thermal analysis of a current coupling with insulation

High-current couplings are nowadays one of the most important innovations in the field of switchboard construction. They are used to connect individual electrical elements that are located inside high-current switchboards.

Fig.1. Ultraflexx high-current couplings with insulation [1]

For the analysis of the temperature distribution, we used the Ultraflexx current couple, the use of which in practice is shown in (Fig. 1). Ultraflexx are among the most flexible current couplings with insulation, as they are made of braided copper strips with a diameter of 0.15 mm. They are used for conductive interconnection, which absorbs oscillations and switching vibrations in all directions. The coupling ends are pressure welded, thanks to which they can be machined as one fixed end piece. The advantage of pressure welds is also the provision of excellent transient resistance and corrosion resistance, which ensures the stability of the transient resistance over time. It is thus possible to consider a lower power dissipation and a lower voltage drop.

The couplings are offered for electrical current loads up to 700 A and are made of high-quality electrolytic copper. The length of the current coupling for the manufacturer is specified by the customer, while sizes from 150 to 1000 mm are available. The coupling also includes black halogen-free electrical insulation made of PVC (polyvinyl chloride) material, which can withstand operating temperatures in the range from –55°C to +125°C [1].

Current coupling parameters

The length of the current coupling is not given in the table, as it is manufactured to measure from 150 mm to 1000 mm. The length of the coupling means the distance between the centers of the holes, while in Fig. 2 it is marked with the letter L. During the geometry design, we set the length L to 500 mm, i.e. the total length was 524 mm.

Table 1. Current coupling terminal parameters [1]

Cross section [mm^2]	Terminal dimensions [mm]					Current carrying capacity [A] at 65°C
	Width B	Width S	Length A	Diameter D_1,D_2	Hole spacing C	
25	20	1,5	35	8,5/10,5	9	120
50	20	4	35	8,5/10,5	9	200
100	20	6	35	8,5/10,5	9	320
120	32	4,5	35	10,5/12,5	12	355
240	32	9	35	10,5/12,5	12	560

Fig.2. Current coupling diagram with dimensions [1]

Fig. 3 shows a 3D model of a current coupler with set values of electric current and thermal convection. We selected the value of the current flowing through the coupling based on the current carrying capacity at 65°C. Our intention was for the flowing electric current to have the highest possible value, so we chose 560 A. The current corresponds to the cross-section of the 240 mm^2 coupling.

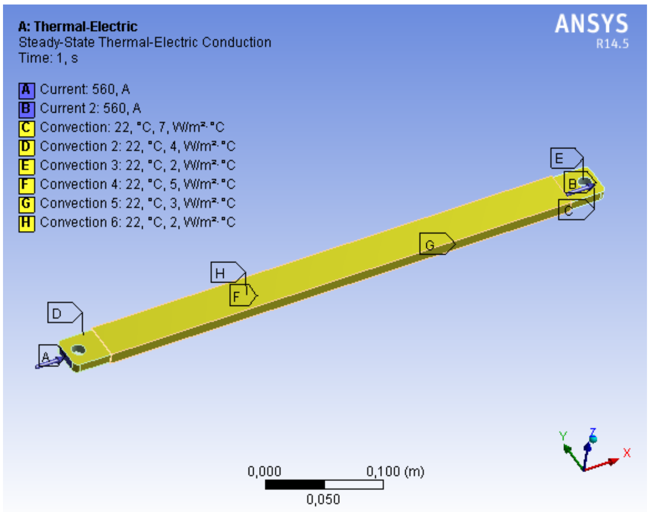

Fig.3. Current coupling model with indication of electro-thermal conditions (Points A, B represent electric current and points C-H represent thermal convection)

Even when simulating the current coupling, we considered free thermal convection, which arises as a result of gravity. We set the convections differently for the conductive part of the coupling and the insulation, because we took into account that the heat dissipation from the surface of the insulation is smaller than from the surface of the copper coupling.

Convection values for current coupling:

- Upward: 7 W/(m^2·°C)
- On the sides: 4 W/(m^2·°C)
- Bottom: 2 W/(m^2·°C)

Convection values for insulation:

- Upward: 5 W/(m^2·°C)
- On the sides: 3 W/(m^2·°C)
- Bottom: 1 W/(m^2·°C)

Despite the fact that the coupling is made of knitted copper strips with a diameter of 0.15 mm, when creating the geometry, we considered a full core (solid) of the coupling.

Influence of materials and current coupling position on thermal distribution

When analyzing the current coupling, we no longer dealt with the influence of impurities or dirt on the temperature distribution, but we focused on the influence of deposition. By deposition, we meant the position of the coupling, whether it is in a vertical or horizontal position, whether it is aligned or bent at an angle. The idea of dealing with the effect of mounting has been prompted by the fact that in most switchboards in which these couplings are mounted, they are mounted in all possible positions. An exemplary location of the current couplings is shown in (Fig. 4).

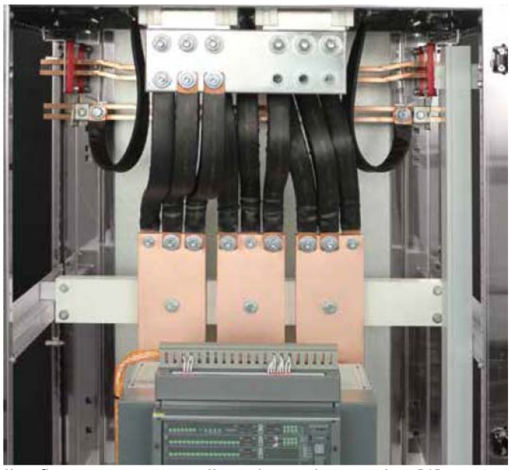

Fig.4. Ultraflexx current coupling shown in practice [1]

We changed the placement of a given current coupler using the values of thermal convection, taking into account the theory of free convection, which describes the fact that heat dissipation from the surface of the object is highest at the top, lower at the side and lowest at the bottom [11]. Thus, in this case, the main role is not played by resistivity, but by thermal convection on certain walls of the model.

We have selected 5 simplified positions in which current couplings can be operated. Admittedly, these positions represent ideal shapes. Models with different positions applied in the simulation are shown in the following figures.

Fig.5. Horizontal position, vertical position, position at 45°, position at 90°, position “sideways”

Effects of positions on the thermal distribution of a current coupling made of copper material

We performed the initial simulation of the thermal distribution of the current coupling with a material with a conductive part made of copper and with PVC insulation.

Since the coupling is also installed in switchboards with insulation, we assumed that the current load at 65°C with a current of 560 A in (Tab. 1) applies to the model with insulation. The use of insulation was therefore very important, as the insulator can reduce the heat dissipation from the surface of thermally conductive metals and thus increase the temperature in certain parts of the coupling.

The basic position we used in the initial simulation was horizontal. We have identified it as a basic one, despite the fact that in practice we do not encounter this storage so often. The temperature distribution for said condition is visible in the following figure.

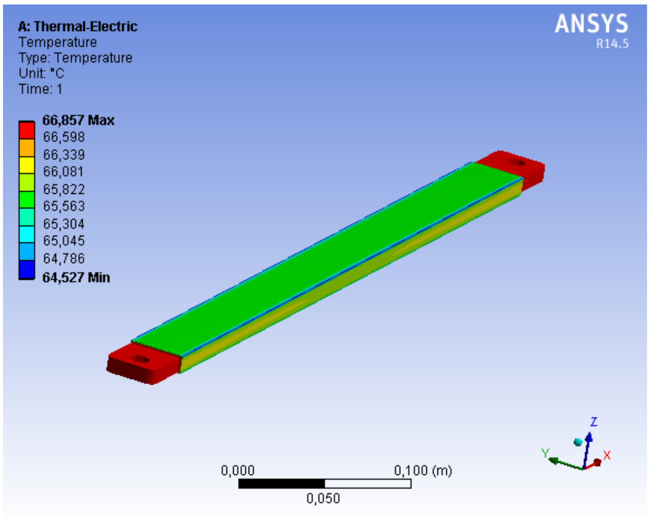

Fig.6. Temperature distribution on the copper current coupling, in horizontal position and seen from above

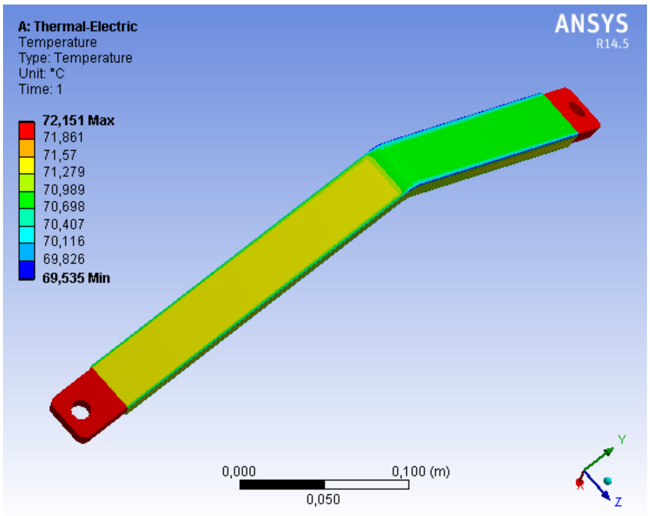

Fig.7. Temperature distribution of the copper current coupling at 45° and top view

Table 2. Measured values by temperature probes, with copper coupling material

Coupling position	Coupling center ϑ [°C]	PVC bellow ϑ [°C]	PVC side 1 ϑ [°C]	PVC side 2 ϑ [°C]	PVC top ϑ [°C]	Terminal surface ϑ [°C]
1 – horizontal	66,78	66,546	66,421	66,421	66,204	66,836
2 – vertical	72,056	71,666	71,656	71,656	71,666	72,123
3 – 90°	68,172	68,008	67,776	67,862	67,38	68,519
4 – 45°	72,049	71,842	71,658	71,662	71,38	72,131
5 – on the side	71,893	71,504	71,237	71,757	71,504	71,927

The temperature values that we wrote down in the previous table were divided into two parts based on the placement of the temperature probes. In one part, there were three places with temperature probes. The given division thus enabled the creation of two clear graphical dependencies (another one is in [1]), each of which contained three waveforms. To simplify the marking on the *x*-axis, we have assigned numbers to the individual positions of the current coupling.

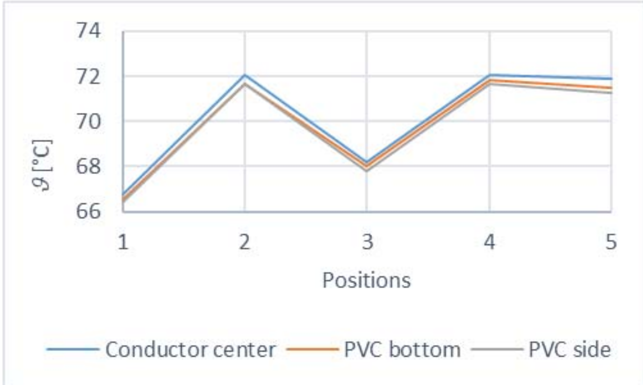

Fig.8. Temperature dependence on the position of the copper current coupling (Positions: 1 – horizontal, 2 – vertical, 3 – 90°, 4 – 45°, 5 – on the side)

From the graphical dependences on Fig. 8 temperature fluctuations can be observed at different positions, while the increase between positions is linear. The largest increase of more than 5°C occurred between the horizontal and vertical position, where there was a minimal difference between the temperatures at the vertical, 45° position and the side position, in the order of tenths of °C. There was no big difference between the horizontal and 90° positions.

This phenomenon is confirmed by the fact that the lowest overheating on the surface of the current coupling occurs in the horizontal position, followed by the position with 90° characteristics and in the other three positions the highest overheating occurred. Admittedly, these three positions do not have the same temperatures, but the deviations between them are minimal.

Despite the resulting temperature difference, it is possible to use the current coupling in all simulated positions. Since there were no multiple fluctuations between the temperatures at the positions.

Temperature difference between individual materials

The graphical dependence on Fig. 9 showed that the temperatures measured by the temperature probes in the middle of the coupling were highest for the brass current coupling and the lowest for the silver current coupling. Low temperatures were also achieved with the copper material. From these positions, the lowest temperatures were measured at the horizontal and 90° positions.

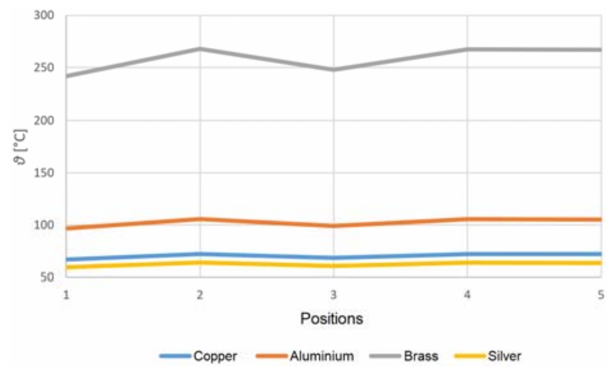

Fig.9. Temperature dependence of current coupling positions for considered materials in the middle of the coupling (Positions: 1 – horizontal, 2 – vertical, 3 – 90°, 4 – 45°, 5 – on the side)

No symmetry of the waveforms can be observed on the given dependence (Fig. 9), because there is a large spacing between temperatures. Moreover, most importantly, it is caused by small deviations at low temperatures and large temperature variations between positions at high temperatures.

Simulations performed on four different materials proved that the most suitable material for the production of a current coupling is silver, followed by copper, then aluminium and brass. One of the most suitable mounting is in a horizontal position. Of course, these statements apply only in terms of temperature distribution.

In Fig. 9 one can see, that the highest temperatures occurred with brass. Such a high temperature would immediately reduce the mechanical strength of the material and could even burn it. At such a temperature, the current coupling would burn much sooner than direct contact, as it is made of braided wires that have a small diameter. In direct contact, the contacts and the knife would be tanned.

From the point of view of thermal distribution, silver proved to be the most suitable material for the production of direct contact as well as a current coupling. However, this priority belongs to its mainly due to its high thermal conductivity, but not for the price.

Conclusion

The results from this paper present fact, that the high thermal conductivity does not guarantee the best temperature resistance of the material. The proof is the values of melting temperatures, which belong to the physical properties of materials. By comparing these values for individual materials, we found that copper has the highest melting point, followed by silver, brass and aluminium. From the four materials used in the simulation, copper has the highest heat resistance. In operation, this feature will provide the electrical components with resistance to transients or short circuits, which can lead to multiple temperature rises. At such high temperatures, for example, opals are formed, which first appear at the point of collision of the two elements and thus reduce their mechanical strength. It is precisely because of these phenomena that the use of copper has a great advantage, since it has the largest heat reserve. By thermal reserve, we meant the difference between the operating temperature of 65°C and the melting point. Compared to the three mentioned materials, copper also has the best mechanical strength, which is a big plus for the current coupling. Thanks to this mechanical property, it is possible to bend the coupling at an acute angle without damaging it.

Mechanical properties are attributed to the primacy of copper. From the point of view of temperature distribution, copper occurred in second place. Thus, in the end, in terms of mechanical strength and thermal distribution, this material is suitable for the production of a current coupling as well as direct contact.

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-19-0576 and by the Ministry of Education, Science, Research and Sport of the Slovak Republic and the Slovak Academy of Sciences under the contract VEGA 1/0757/21 and VEGA 1/0435/19 and project FEI-2021-74.

***Authors**: doc. Ing. Dušan Medveď, PhD., Technical University of Košice, Mäsiarska 74, 04201 Košice, Slovak Republic, E-mail: Dusan.Medved@tuke.sk; Ing. Ján Zbojovský, PhD., Technical University of Košice, Mäsiarska 74, 04201 Košice, Slovak Republic, E-mail: Jan.Zbojovsky@tuke.sk.*

REFERENCES

[1] Presada J., Medveď D., Tepelná analýza priameho kontaktu, In: *Electrical Engineering and Informatics XII*. Košice: FEI TU, 2021, pp 82-87, ISBN: 978-80-553-3940-5.
[2] Okrajni J., Twardawa M., Wacławiak K., Impact of Heat Transfer on Transient Stress Fields in Power Plant Boiler Components, In: *Energies*, 2021, 14(4), 862; Doi: 10.3390/en14040862.
[3] Lotiya J., Thermal analysis and optimization of temperature rise in busbar joints configuration by FEM, *6th IEEE Power India International Conference* (PIICON), 2014, pp. 1-5, doi: 10.1109/POWERI.2014.7117684.
[4] Szulborski M., Łapczyński S., Kolimas Ł., Thermal Analysis of Heat Distribution in Busbars during Rated Current Flow in Low-Voltage Industrial Switchgear. In: *Energies*, 2021, 14, 2427. Doi: 10.3390/en14092427.
[5] Kanálik M., Kolcun M., Pavlík M, The impact of multi-system overhead lines operation with different voltage levels to voltage unbalance, In: *Elektroenergetika 2015*. Košice, TU, 2015, pp. 73-76. ISBN 978-80-553-2187-5.
[6] Pavlík M: Compare of shielding effectiveness for building materials, In: *Przegląd Elektrotechniczny = Electrotechnical Review*. Varsaw: Stowarzyszenie Elektrykow Polskich, 1919 Vol. 95, No. 5 (2019), pp. 137-140 [print]. ISSN 0033-2097.
[7] Bereš M., et al., Efficiency Enhancement of Non-Isolated DC-DC Interleaved Buck Converter for Renewable Energy Sources. *Energies*, 2021, 14.14: 4127. Doi: 10.3390/en14144127.
[8] Beláň A., et. al., Measurement of Static Frequency Characteristics of Home Appliances in Smart Grid Systems. *Energies*, 2021, 14, 1739. Doi: 10.3390/en14061739.
[9] Deželak K., Bracinik P., Sredenšek K., Seme S., Proportional-Integral Controllers Performance of a Grid-Connected Solar PV System with Particle Swarm Optimization and Ziegler–Nichols Tuning Method. *Energies*, 2021, 14, 2516. Doi: 10.3390/en14092516.
[10] Hajek J., Rot D., Jirinec J., Distortion in Induction-Hardened Cylindrical Part, In: *Defect and Diffusion Forum*, Vol. 395, Aug. 2019, pp 30-44, Doi: 10.4028/www.scientific.net/DDF.395.30, ISSN: 1662-9507.
[11] Rot D., Kozeny J., Jirinec S., Jirinec J., Podhrazky A., Poznyak I., Induction melting of aluminium oxide in the cold crucible, In: *18th International Scientific Conference on Electric Power Engineering* (EPE) 2017, pp 1-4, Doi: 10.1109/EPE.2017.7967281.
[12] Kanalik M., Margitova M., Bena L., Temperature calculation of overhead power line conductors based on CIGRE Technical Brochure 601 in Slovakia, In: *Electrical Engineering*, Volume 101, Issue 3, 1 September 2019, pp 921-933, Doi: 10.1007/s00202-019-00831-8.