THERMAL ANALYSIS OF HIGH-CURRENT ELECTRIC CONTACT

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ABSTRACT

This paper deals with mathematical modelling of the temperature distribution in the vicinity of a direct electrical high-current contact under the action of a nominal current of 3000 A. High-current electrical contacts belong among the elements by which a large number of electrical devices are connected. They play an important role especially in the transmission and distribution system, where they have to withstand adverse weather conditions that have a significant impact on their degradation.

Keywords: *heat, temperature, electric current, electric contact, resistivity, heat transfer coefficient*

1. INTRODUCTION

Electrical contacts play a seemingly simple but important role in electrical systems. They provide the interface between the segments of the circuit, allowing the segments to connect and disconnect as needed. Although this may seem simple at first glance, the design of this type of connection (electrical contact) requires careful planning and consideration of all possible adverse effects. Improper design may result in excessive discoloration, welding wear, mechanical damage, or corrosive wear, which may result in incorrect connection [7–8]. The contacts must be designed to minimize the occurrence of these fault modes, all while maintaining low contact resistance, minimal electrical noise, and reliable connection and disconnection capabilities.

Most of the contacts are arced during tripping by the action of electric arcs, which arise on the contacts when the electrical circuit is interrupted. Electrical contacts belong therefore among the quite faulty parts of devices and circuits, so special materials are used for their production. There are hundreds of different contact materials that are successfully used in many different applications.

2. MATERIALS FOR ELECTRICAL CONTACTS

Electrical engineering uses a large number of materials that are produced in the metallurgical and chemical industries. Electrotechnical materials are much more expensive than conventional materials because they have significantly higher purity. That is why it is very important to manage them properly and then recycle them.

We recognize 5 types of electrotechnical materials [12]: electrically conductive (conductors), electrically non-conductive (insulators), semiconductive (semiconductors), magnetic and construction materials.

Electrically conductive materials used in electrical engineering are mostly solid (metals or non-metals), but liquids and gases also conduct electricity. In solid conductors, free electrons conduct current, and in liquids and gases, ions [1].

Electrical, mechanical and thermal requirements are placed on electrical contacts. No contact can transmit electricity without loss. Therefore, even in electrical contacts, undesirable phenomena are often generated, which are generated by the passage of current, such as material warming, material transfer and oxidation of the contacts. These phenomena, together with the transient resistance, are very important in the choice of material for electrical contact [5].

In terms of materials, the most demanding groups of contacts include switching circuits, switched during operation [9–11]. The materials for their production are various metals and alloys, and their main property is stiffness or elastic hardness. In many cases, bimetal contacts are used to make contacts, which are produced in the form of wires, strips and profiles [2].

3. INFLUENCE OF HIGH-CURRENT CONTACT IMPURITIES ON TEMPERATURE DISTRIBUTION

The influence of impurities on the temperature distribution was determined by adding an additional volume with a width of 1 mm to all contacts. This surface is characterized by slight wear, unevenness and especially oxidation of contacts, which occurs due to the negative impact of the environment, aging of the material and other factors. In fact, the thicknesses of such impurities are much smaller, of the order of 10^{-4} mm, but in order to simplify the calculation in the ANSYS environment [4], errors in the formation of crosslinks on the impurities could occur with such dimensions. In Fig. 1 the impurities are highlighted in green colour.

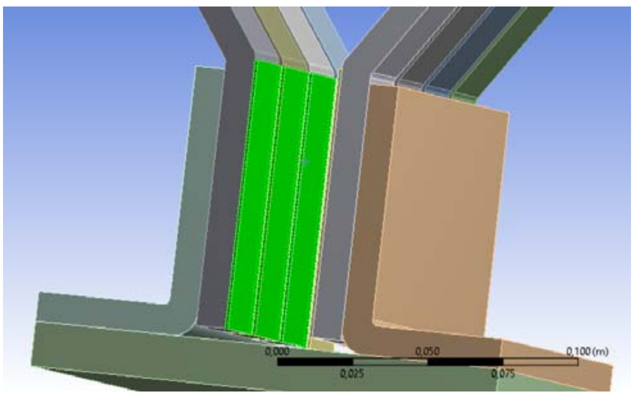

Fig. 1 Representation of impurities on contacts (green colour)

We used copper, as a material mostly used by the manufacturers, for the initial simulations of a given type of contact. Based on which we determined the importance of the entered parameters and values, for the most accurate calculation.

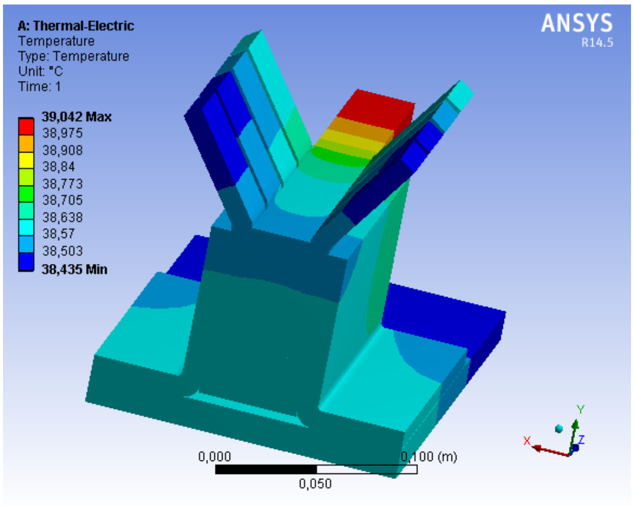

Fig. 2 Temperature distribution of high-current copper contact (without impurities)

From the temperature distribution in Fig. 2, it can be seen that the highest temperature is at the beginning of the contact knife, with a maximum value of 39,042°C. The lowest temperatures are at the part of the base above which the contact holders are not located and at the same time at the ends of the contacts placed at the end of the knife, where the minimum temperature value reaches 38,435°C.

The contact model in Fig. 2 was modelled without the mentioned impurities, i.e. it shows the so-called ideal operating condition during which the contacts do not overheat due to impurity. In this case, overheating could occur, for example, with an increased value of the electric current flowing through the direct contact.

Using the stated range of resistivity (Table 1) [2–3], the deteriorating electrical conductivity, which represented the contamination between the contacts and the knife, was subsequently adjusted. The value of 10^{-8} Ω·m represented small impurities and the value of 10^{-4} Ω·m characterized a very large contamination of areas of the same considered added volume (with width of 1 mm).

The given contacts can be loaded with an electric current from 500 A to 4000 A, while in the analysis, we considered the value of 3000 A. The magnitude of the passing electric current depends on the number of contacts to which the contact knife is attached [6].

Because electrical contact is considered in real operation (with gravitation), the free convection was considered according to assignment of correspondent heat transfer coefficient to particular surfaces (Fig. 3). The ambient temperature, and the initial temperature of the overall contact, was considered 22 °C.

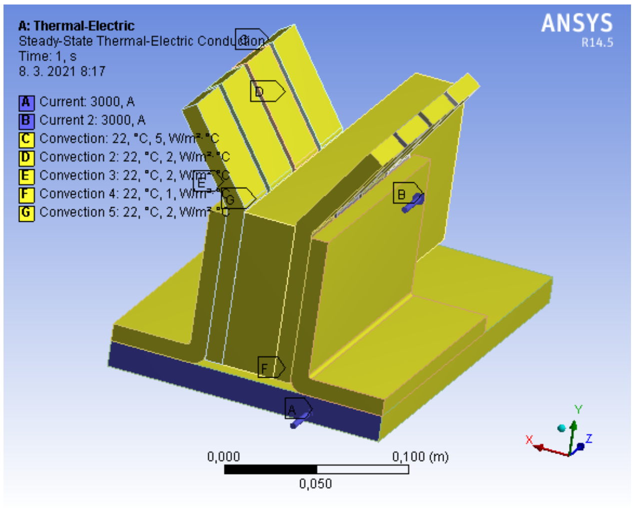

Fig. 3 Model of contact with indication of electro-thermal conditions (Points A, B represent electric current and points C-G represent thermal convection)

Table 1 Measured values of temperatures (high-current copper contact)

Material	λ [W/(m·°C)]	ρ [Ω·m]
Copper	390	$1{,}72 \cdot 10^{-8}$
Aluminum	237	$2{,}65 \cdot 10^{-8}$
Brass	111	$6{,}3 \cdot 10^{-8}$
Silver	428	$1{,}59 \cdot 10^{-8}$
Impurity	30	$10^{-8} \div 10^{-4}$

Fig. 4 shows a contact with a resistivity of 10^{-8} Ω·m. This value was considered to reflect the real operating state at initial start-up.

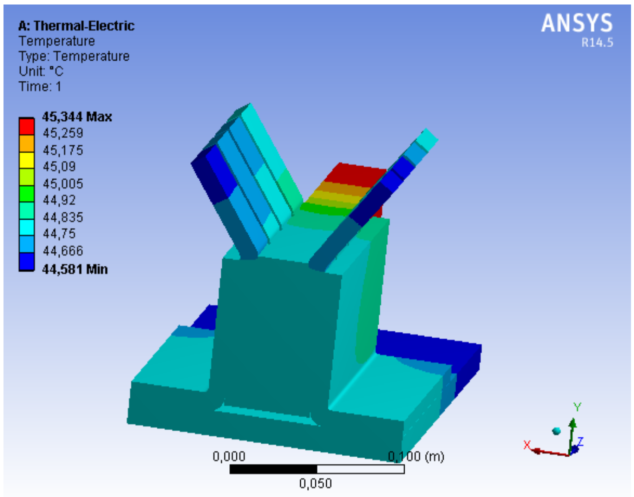

Fig. 4 Temperature distribution characteristics of high-current copper contact, with resistivity of impurity 10^{-8} Ω·m

The given temperature distribution confirms the higher maximum and minimum temperature value compared to the previous state (without impurities), while there was an increase of approximately 6°C. The highest and lowest temperatures are located in the same places as in Fig. 2, with the difference that there was a slight increase in some areas. These facts express the difference between the ideal and real state of direct contact.

The following figure shows direct contact with an impurity with a considered resistivity of 10^{-4} Ω·m, which represents the condition after long-term use (the worst-case scenario). Of course, it is very difficult to declare that after such a long period of use, the surface of the contacts can become so dirty to such an extent. Because no object made of the same material has exactly the same contamination, degradation or damage, this was considered as the worst-case scenario.

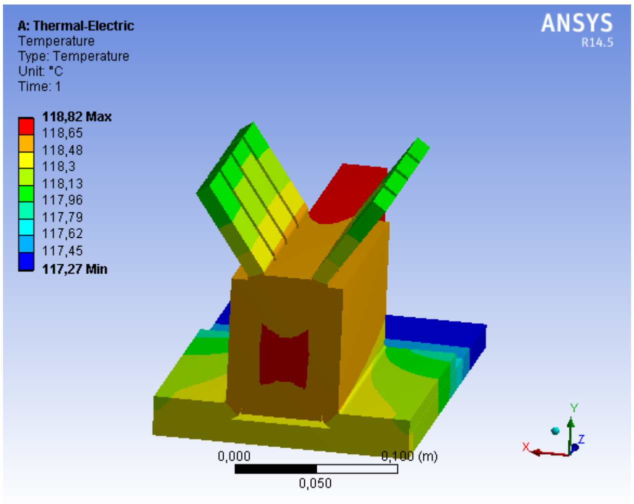

Fig. 5 Temperature distribution characteristics of high-current copper contact, with resistivity of impurity 10^{-4} Ω·m

The maximum temperature value in the presented temperature distribution reached 118,82°C, while the minimum temperature has a value of 117,27°C. Comparison of these temperatures with those ones found in the previous two conditions showed a more than doubled increase in values. Compared to the previous, real operating state, the highest temperature increased by 73,476°C and compared to the ideal operating state, the highest temperature increased by 79,778°C.

Significant changes also occurred in terms of the distribution of individual temperature zones. In the actual state, areas with a higher temperature (areas with orange and red colour in the picture) predominate, which prove that the parts in the immediate vicinity of the knife overheat the most. Thus, contamination of the contacts can greatly affect the temperature of the electrical connections. Therefore, it is important to perform contact checks at regular intervals.

It was further considered that the largest distribution of the maximum temperature area is located in the middle of the contact assembly. Therefore, a cross-sectional view was chosen for a more thorough analysis of the selected contact. The cross section was applied to the center of the simulated object.

After the realising the cross section through the center of high-current contact, temperature probes were placed on specific places of the model. These probes allow the measurement of the temperature (discrete element) at any point. A total of 6 temperature probes were used at different locations. In Fig. 7 shows their arrangement, being located in the same places as the coordinate systems. Individual names of probes were entered and names were based on their positions [6].

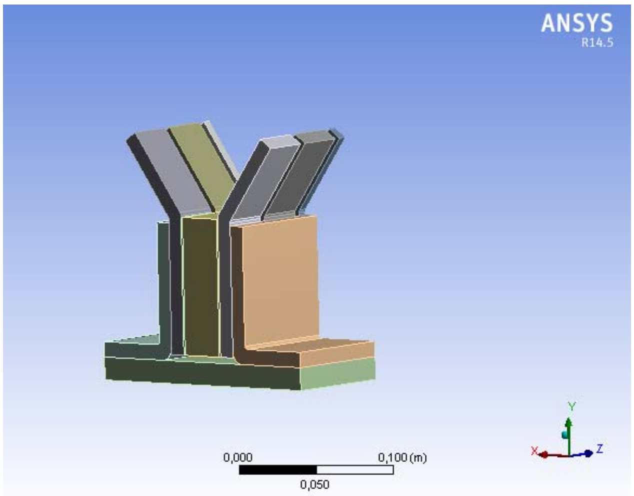

Fig. 6 Visualisation of the cross section through the center of high-current contact

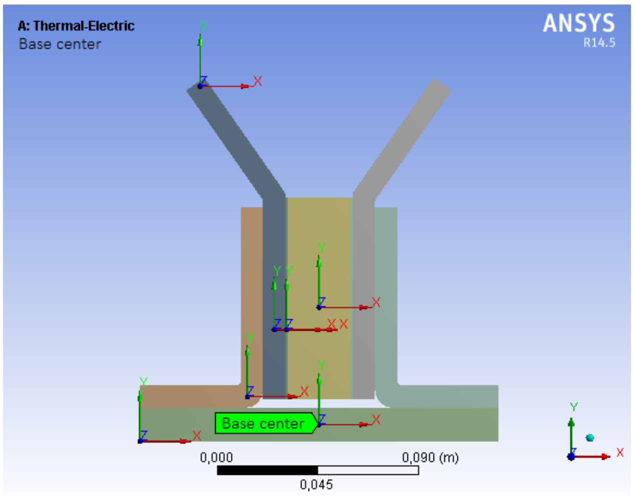

Fig. 7 Visualisation of the location of the temperature probes in the middle of the high-current contact

The temperature values measured by temperature probes were registered in the tables. Graphical dependences were created from the measured values, which indicate how the temperature changes at certain points in the center of contact, under the influence of individual types of impurities.

Table 2 Measured values of temperatures (high-current copper contact)

ρ [Ω·m]	Base center ϑ [°C]	Fold ϑ [°C]	Contact center ϑ [°C]	Knife center ϑ [°C]	Impurity center ϑ [°C]	Contact top ϑ [°C]
$1\cdot10^{-4}$	118,21	118,37	118,62	118,66	118,67	118,11

$1\cdot10^{-5}$	54,133	54,175	54,236	54,246	54,243	54,066
$1\cdot10^{-6}$	46,632	46,659	46,696	46,7	46,698	46,564
$1\cdot10^{-7}$	45,215	45,239	45,272	45,276	45,274	45,147
$1\cdot10^{-8}$	44,79	44,813	44,845	44,849	44,847	44,723

Measured temperatures by probes, shown in Table 2 do not have significantly different values, in some cases it is a maximum difference of 0,5°C. The highest temperatures are in the middle of the knife or impurity, with the highest temperature reached 118,67°C and the lowest 44,79°C observed at the top of the contact.

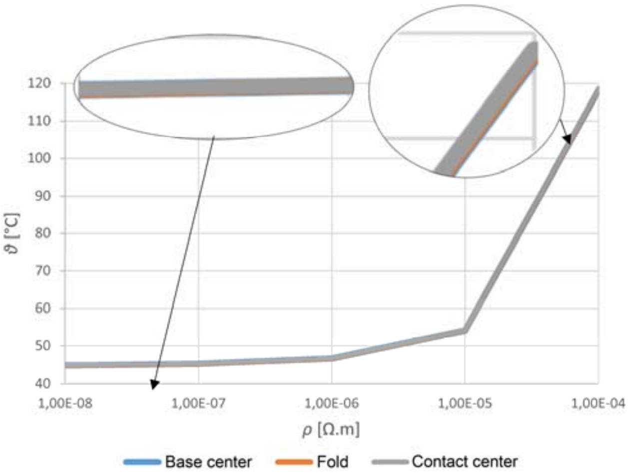

Fig. 8 Temperature dependence on the resistivity of impurities in high-current copper contact

For better clarity of graphical dependencies, two graphs were constructed, with 3 curves placed in both. Note: If six curves were stored in one graph, the characteristics would overlap even more and the temperature difference would not be visible.

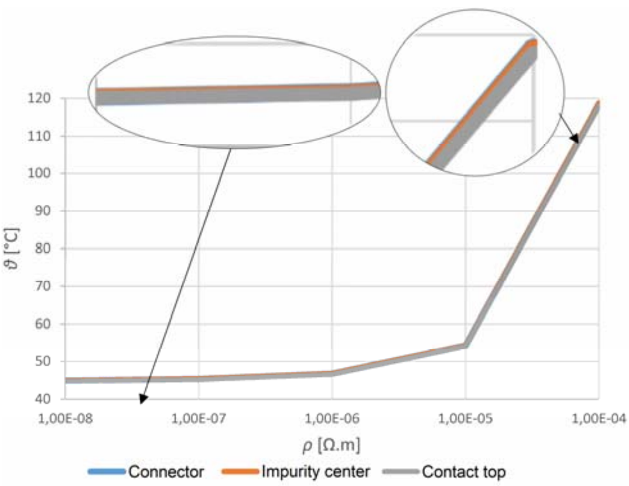

Fig. 9 Temperature dependence on the resistivity of impurities in high-current copper contact

From the graphical dependencies on the figures Fig. 8 and Fig. 9 is an observable non-linear increase in temperature. With impurity resistivity from 10^{-8} Ω·m to value of 10^{-6} Ω·m, the temperature increased a small step along the linear curve. The change began to occur at an impurity resistivity of 10^{-6} Ω·m to 10^{-5} Ω·m, with the largest temperature step being between 10^{-5} Ω·m to value 10^{-4} Ω·m.

If one can consider higher permissible current (in this electric contact up to 4000 A), the obtained temperatures will be higher, but still in the allowable value, that is prescribed by the electric contact producer.

This fact confirms the fact that there is a considerable temperature difference between medium and large contact surface contamination. Of course, the increase in temperature also depends on other factors, including influencing the heat dissipation from the surface of the building. The temperature can be affected, for example, by a fan that cools the electrical assembly of the contact (so-called cabinet) or a fan that serves to circulate the air in the room and is located near the high-current contact. Nevertheless, it is important to clean and treat the individual contacts at regular intervals.

4. CONCLUSIONS

The aim of this paper was to present the results of the temperature distribution on the surface of the high-current contact under the operation of the nominal value of the current 3000 A (the permissible current values for this type of contact was in the range of 500 A to 4 000 A). The paper presents the outputs from the ANSYS Workbench program, which was used to assess the temperature distribution around the contact. Simulations have shown an increase in temperature with increasing values of impurity resistivities. These resistivities represented individual degrees of pollution, where the largest pollutants corresponded to resistivities with values of 10^{-4} Ω·m and the smallest pollutants to the values of resistivities of 10^{-8} Ω·m. The increase in temperatures was also confirmed by the values measured by temperature probes, which were located in different locationss in the middle of the high-current contact. Graphical dependences constructed from the measured values subsequently visualized the nonlinear increase of temperatures with increasing resistivities of impurities. These results show that it is very important to pay attention to the cleanliness of electrical contacts, perform regular inspections and treat the surface of electrical contacts.

From the results and simulations is visible, that improper design may result in excessive discoloration, , mechanical damage, or corrosive wear, which may result in incorrect connection. The contacts must be designed to minimize the occurrence of these fault modes, all while maintaining low contact resistance, minimal electrical noise, and reliable connection and disconnection capabilities. The simulation of temperature field of the electrical contact could be the first choice to identify the bottlenecks of the connections and to design the more effective contacts.

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Ján Presada was born on 25.01.1997. In 2019 he graduated (B.Sc.) and in 2021 he graduated (MSc.) at the Department of Electrical Power Engineering of the Faculty of Electrical Engineering and Informatics at Technical University in Košice. He defended his B.Sc. in the field of numerical modelling of electromagnetic fields in 2019, and in the field of temperature modelling of high-current devices in 2021.