INFLUENCE OF SHORT-CIRCUIT CURRENT ON TEMPERATURE DISTRIBUTION IN FUSE-LINK

Petr Mazur
Doctoral Degree Programme (1), FEEC BUT
E-mail: xmazur02@stud.feec.vutbr.cz

Supervised by: Zdeněk Vávra
E-mail: vavra@feec.vutbr.cz

ABSTRACT

During a construction of electric machines or electric apparatuses, we have to take into account among others heat transfer caused by flowing current. That heat permeates to the surrounding and can affect degradation of insulation, in worse case destruction of machine. Heat calculation is one of the most important steps during construction. With the help of temperature rise we can design a current–carrying conductor and insulation of it. If we know the increase of temperature we can choose better materials or insulation or choose the best process to heat transport.

1. INTRODUCTION

Measurement and calculation were realized on fuse-link PN1 gG 100A and PN1 aM 100A. A melting effect is characteristic for fuses marked by gG (a metal with lower melting point is used on fusing conductor-overload spot). The most unfavourable cases in term of warming are investigate. Influence of melting effect on cutting off different values of short-circuit current is also investigated. A finite element model of fuse-link was build and computations were realized on the model.

2. ANALYSIS

2.1. TEMPERATURE DISTRIBUTION AND TRANSFER OF HEAT FROM FUSING CONDUCTOR

The PNx fuse-links are current limiting. A large short-circuit current will therefore not reach its full value. The value of breaking current, in which the current limitation occurs, is according to the producer around 15-times higher, than rated current. The breaking times are very short in these cases. The heat is concentrating in the fusing conductor during the short-circuit current and we consider the heating as an adiabatic process.

The thermal-time-constant τ determines when we can consider the process as adiabatic or non adiabatic. This constant depends on heat capacity of fusing conductor, its volume, its area contact with surrounding extinguishing medium (silicon sand) and heat-transfer coefficient between fusing conductor and extinguishing medium. The time must be shorter then

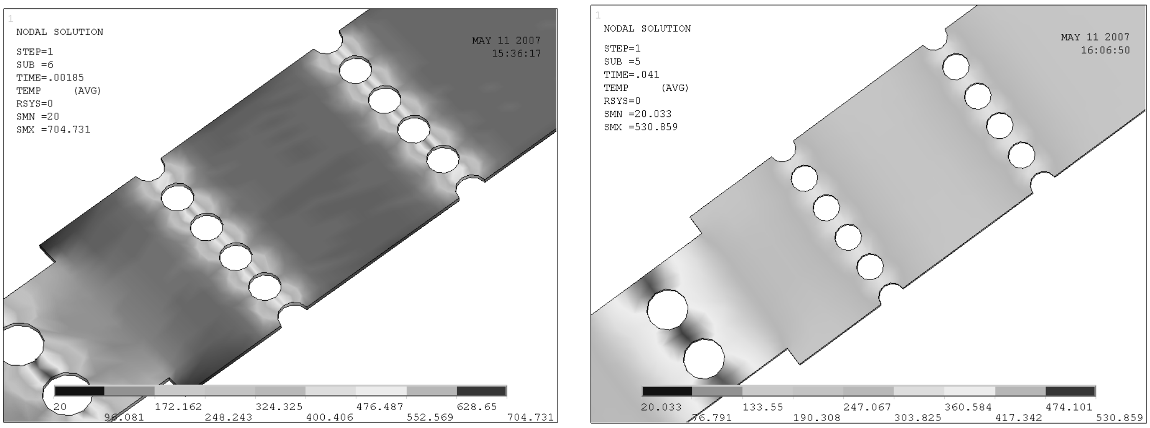
0.05τ. Then we can speak about adiabatic heating. The thermal-time-constant can be determined for fuse PN1 gG 100A according to the formula (1).

$$\tau = \frac{c_v \cdot V}{\alpha \cdot A} = \frac{385 \cdot 8900 \cdot 164 \cdot 10^{-9}}{20 \cdot 1{,}039 \cdot 10^{-6}} = 27s,\ 0{,}05\tau = 1{,}35s \qquad (1).$$

Where V is the volume and A is the area of the fusing conductor, from which the heat is transferred to extinguishing medium. If the transient process is shorter then 1s we can neglect transfer from fusing conductor to extinguishing medium.

When we look at geometry of fusing conductor, it is obvious that the most of heat will be generated in current bridge. With respect to the high heat conductivity of fusing conductor (made from copper) the heat generated in current bridge will be conduct much faster to other parts of copper then to extinguishing medium. If we suppose the current bridges as very short conductor with constant cross-section and the other parts of fusing conductor as well, we can calculate the temperature of individual copper parts for given short-circuit current [1].

From finite element model depicted on picture 2.1, it is obvious the influence of transient process to heat conducting in fusing conductor. At the picture 2.1 a), it is depicted transient process in time 1.85ms and short-circuit current 5kA. The whole heat generated in current bridges heats up only these bridges and is not able to conduct to colder part of copper. In the second case depicted at picture 2.1b), the current is 2kA and time is 41ms. The heat is able to conduct to other parts of copper with lower temperature, despite short time.



a) b)

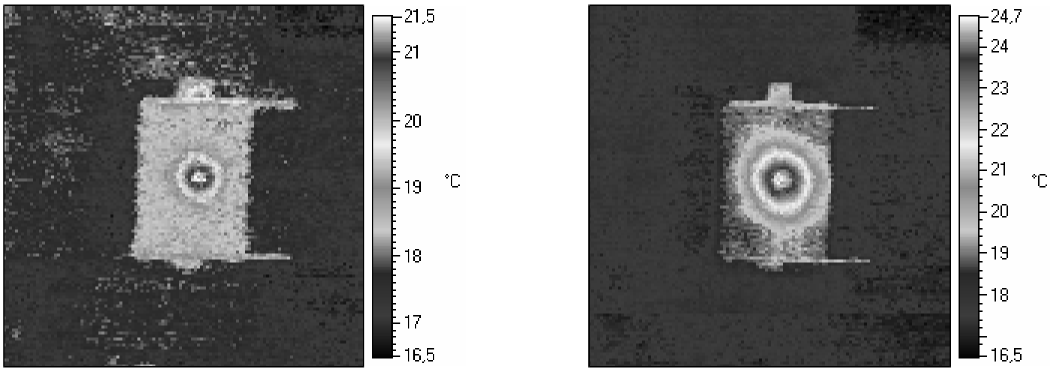
Figure 2.1a,b Temperature distribution a) I=5kA, t=1,85ms, b) I=2kA, t=41ms

2.2. WARMING BY DIFFERENT SHORT-CIRCUIT CURRENT

The short-circuit current and arc created inside of a fuse affect the temperature nearby fusing conductor and after some time a whole body of fuse. The most unfavourable state for gG fuse is connected with the current nearly under breaking current. The generated heat is not so intensive but time of breaking is long (over 1 hour). The fuse temperature rises for about 110°C. Double value of rated current is broken within 5 minutes and max. temperature is 85°C. The heat and warming generated by short-circuit current is lower then by long term overload.

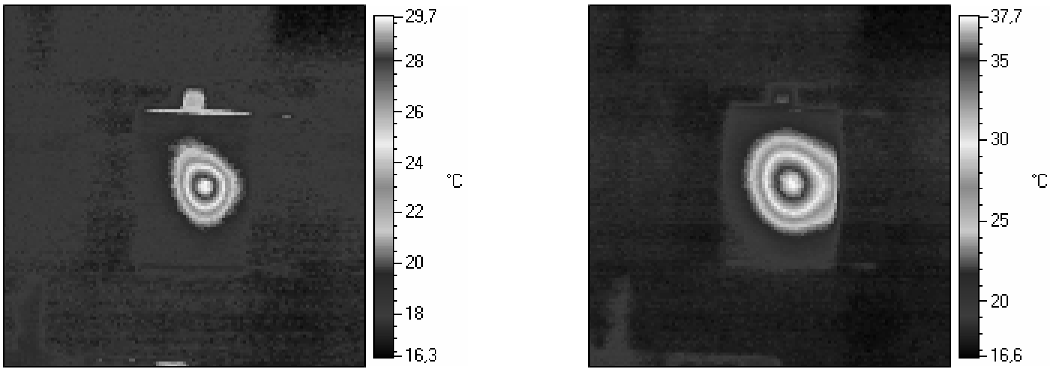
In the figure 2.2 you can observe the spread of heat after short-circuit current of 2kA. The highest temperature was reached on ceramic body in 50 s after short-circuit. The temperature increased about 8°C and reached 24.7°C. Then the surface cooled down and heat flow to surrounding air. In figure 2.3 is the same process just with different short-circuit current of 3kA.Warming is around 20°C and max. temperature after short-circuit reached almost 38°C.

In both cases the temperature of fuse and ambient air was the same - around 18°C. In other words, fuse was not flown by rated current before measuring. Results from experiment point to fact that heat generated by short-circuit almost does not affect overall warming after short-circuit.



a) b)

Figure 2.2a,b Temperature of fuse gG 100A short-circuit current 2kA, a) 18s after short-circuit, b) 50s after s-c



a) b)

Figure 2.3a,b Temperature of fuse gG 100A short-circuit current 3kA, a) 20s after short-circuit, b) 60s after s-c

2.3. BREAKING OF SHORT-CIRCUIT CURRENT

At the moment of short-circuit and closely after short-circuit the heat is conducted only to nearby surrounding of fusing conductor. Very tiny layer with similar temperature is created in very near surrounding around fusing conductor. So-called cooling channel is created in this layer, which intensively cools down the arc discharge. The pressure is sharply increased by arc discharge in the cooling channel. The vapors of copper condensate on sand particles in sufficient distance from arc discharge. Intensive cooling causes very fast increase of resistance and subsequently the arc extinction. Residual resistance of melting silicon sand and copper vapors have positive effect to over-voltage.

Results of temperature calculation in cooling channel are in figure 4.4 for 2kA short-circuit current. The lower short-circuit creates arc discharge only in a weaker parts of fusing conductor (in current bridges) and high short-circuit current causes evaporating of entire fusing conductor.

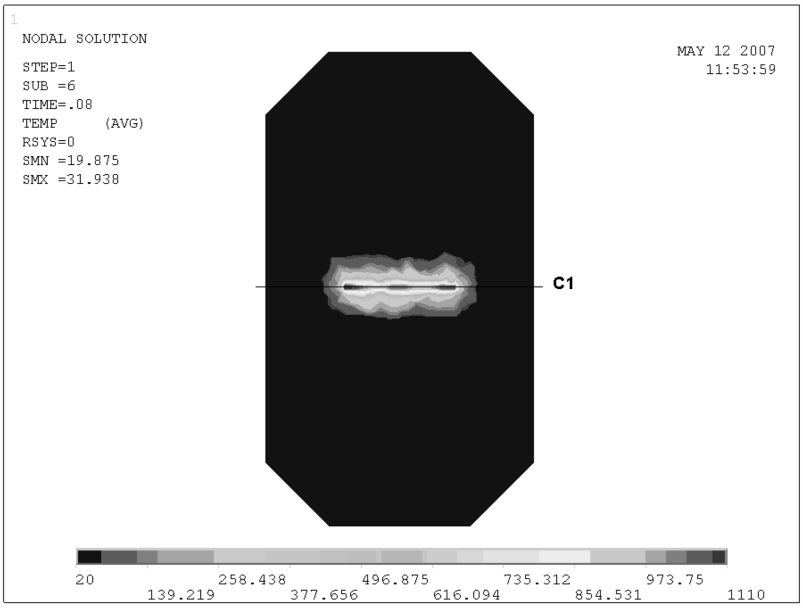


Figure 2.4 Thermal distribution in cross-section (gG), short-circuit current 2kA, time 80ms

A sharp rise of arc voltage drop on fuse terminals is a consequence of high current limitation and fast breaking. A value of arc-drop voltage can reach voltage which could be dangerous for electric insulation in assumed circuit. In two pictures below are depicted curves of short-circuit current and arc-drop voltage, short-circuit current of 2kA and 3kA. The current in picture 2.5 gradually grows from zero value, in time 5ms it reaches its max. value of 2.8kA (RMS 2kA). The fuse conductor is warmed by current, its temperature and resistance grows and arc-drop voltage reaches approximately 10V. The temperature reaches melting point and arc-discharge is generated inside of the fuse. The arc-discharge causes sharp increase of voltage drop (150V) and decrease of current. During the arc the voltage-drop and the current fall and the arc is quenched.

Around values of short-circuit current of 2kA we still have to respect influence of melting effect. The evidence is fusing conductor after short-circuit. Fusing conductor was interrupted only in overload spot [1].

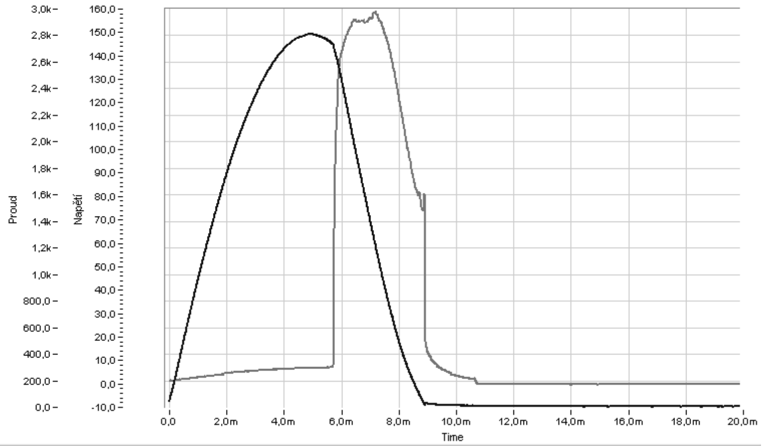


Figure 2.5 Behavior of current and voltage drop, short-circuit current is 2kA

Curves of current and voltage drop at short-circuit current 2kA and 3kA are similar. Arc-drop voltage reaches 4 times higher value then in the case above and breaking time is shorter. The heat generated by this short-circuit is depicted in figure 2.3. Around 3kA, the melting effect stops influencing the breaking process and fusing conductor melt in all current bridges.

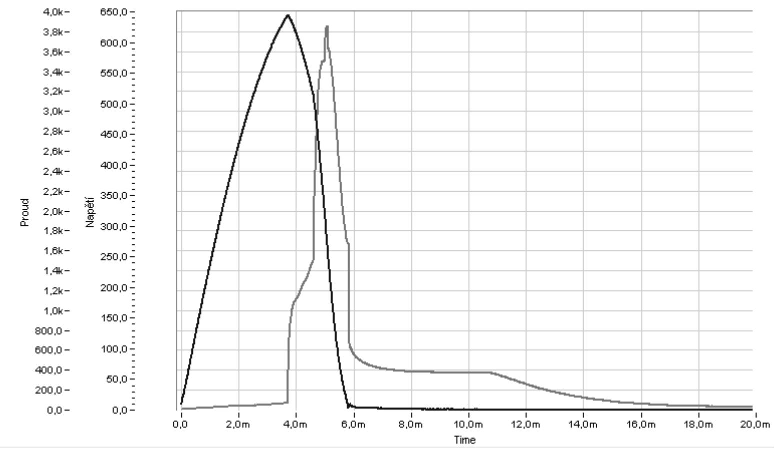


Figure 2.6 Behavior of current and voltage drop, short-circuit current is 3kA

3. CONCLUSION

Short-circuit currents are characterized by intensively generated heat, however, at very short time. Short-circuit does not pose considerable problems with warming. On the contrary, long overload closely under breaking current does. Over-voltage appears on fuse terminal when breaking a short-circuit, which depends on amplitude of current, on speed of breaking and parameters of the circuit. This must be taken into consideration too. The volt-ampere characteristic was calculated from finite element model. Computed characteristic and characteristic given by the producer had some differences especially in overloaded area. It is causes by neglect of overload spot in finite element model.

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