EXTINGUISHING PROCESS IN LOW VOLTAGE CIRCUIT BREAKERS

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ABSTRACT

This contribution deals with the extinguishing process in low voltage circuit breakers. The main parameters that affect burning of an electric arc between contacts are described. The attention is focused on the first period of extinguishing process when the arc is moving along the contacts. One of the parameter - velocity of the contacts due to electrodynamic forces - is described in more details. The forces are computed using the finite element method.

1 INTRODUCTION

During the switching of a circuit breaker an electric arc is ignited between the contacts. The switching process is finished when the arc burns out in the quenching chamber. Low voltage circuit breakers are systems with a magnetic exhausting of the switching arc into the quenching chamber. They work with the highest arc voltage so they can also be used for direct currents switching.

The principle of the circuit breaker operation is based on the interaction between self-magnetic field of the electric arc and an external magnetic field, which is created by current-carrying conductors forming deep loop at fixed contact. This interaction generates electrodynamic forces, which force the arc into the quenching chamber.

Useful extinguishing of the electric arc is mainly affected by its movement. In case that the arc stops its movement there is a danger of the circuit breaker failure. The extinguishing process can be divided into two periods:

- arc ignition and its movement along the contacts
- arc entry into the quenching chamber and its moving in the chamber

The second part of extinguishing process depends on construction and technology used for the quenching chamber design. For the most application, the quenching chamber is composed from metal plates. They are mostly made of iron in order to increase the magnetic flux density in desired space. Next part will be focused on the first period.

2 ANALYSIS

When the contacts start to separate, the small contact areas are getting smaller which increases the current density and temperature. The small areas are melting and gradually converting into gas. The electric arc starts to burn in this medium. The melted parts of contacts are the sources of electron thermoemission for this moment. In this case, the electric arc can move badly. Ionization processes are based on thermoionization, which is characteristized by low voltage drop and small electric field intensity close to cathode. When the electric field intensity near cathode reaches the values sufficient for the electron emission the ionization process changes to autoemission. This ionization process is characteristized by relatively cold cathode and easy capability for arc moving.

So we can recognize three main phases of arc moving along contacts:

- phase of arc sticking on contacts when they start to separate
- phase of slow moving (thermoemission process)
- phase of high speed moving (autoemission process)

It is clear that the sticking phase should be as short as possible. The time of sticking is affected mainly by:

- material and surface of contacts
- velocity of contacts
- geometry of current-carrying conductors
- magnetic flux density values between contacts

The influence of magnetic field intensity and contact velocity can be seen from Figure 1 [1] - the higher intensity and velocity the smaller time of sticking.

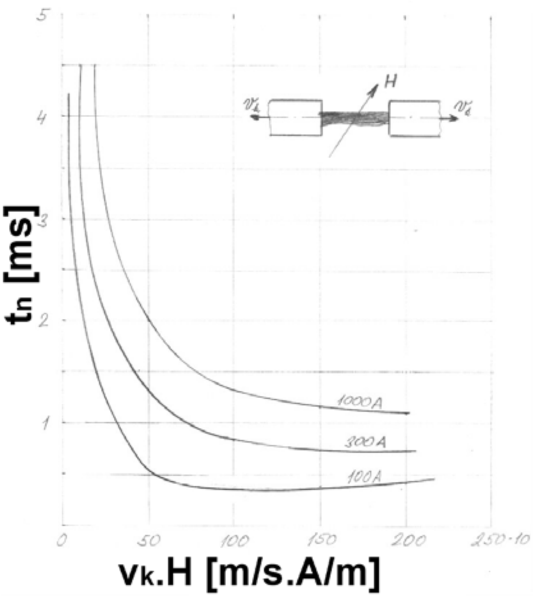


Fig. 1: *Time of sticking*

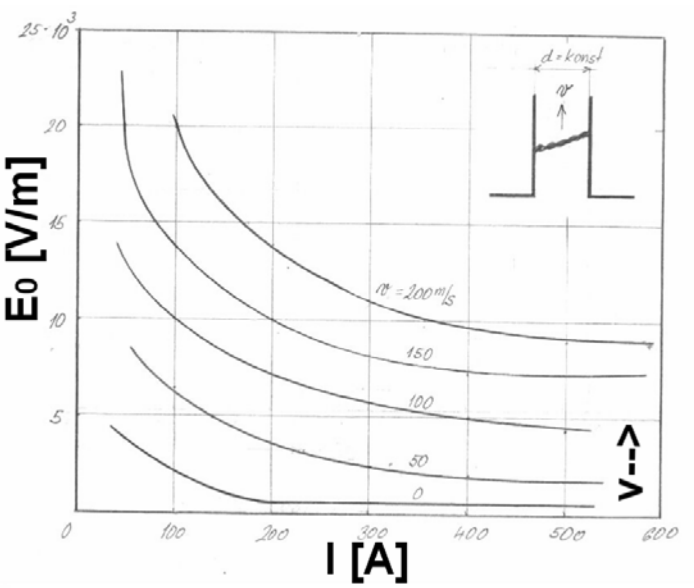


Fig. 2: *Volt-amps characteristic*

It is necessary to reach the relatively high speed of arc moving for the next phase of extinguishing. The Figure 2 [1] shows the influence of the arc velocity. The gradient of voltage rises with the higher arc velocity.

Until this time, we do not consider the thermodynamic (temperature and pressure due to arc heating) of plasma that also affects the arc moving. This makes the prediction of the arc moving much more complicated. The problem can be numerically solved by computer using magnetohydrodynamic equations. These equations are based on laws of conservation and Maxwell's equations. The general computational scheme is shown in Figure 3.

We can generally say that the arc velocity decreases with the distance between contacts. This is caused by length of arc and its easy deformation, which increases the aerodynamic resistance.

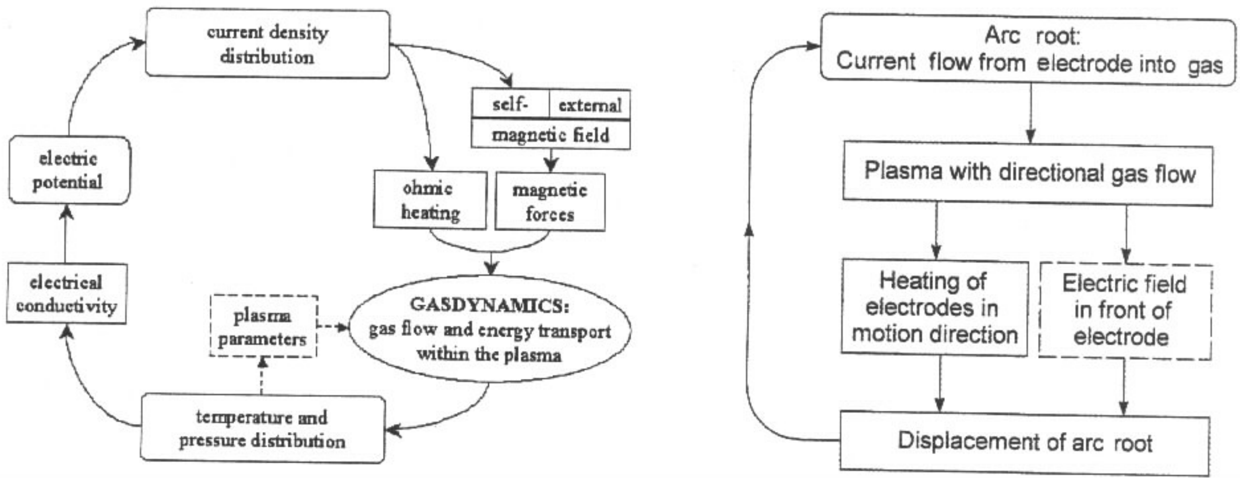


Fig. 3: *Interaction of processes in arc column and near electrodes*

3 CONTACT MOVEMENT AND ELECTRODYNAMIC FORCES

3.1 ANALYSIS

As it was said, the velocity of contact has the great influence on sticking time of electric arc. Analysed circuit breakers are constructed for heavy nominal currents so they have quite big and mass contacts as well as breaking mechanism, which must be accelerated. The tripping by a release of a circuit breaker always means some delay and in addition, the opening spring does not provide enough force for acceleration. But we can use electrodynamic forces caused by electromagnetic field to disconnect the contacts fast enough.

For the force calculation on contacts, we can consider the undeformed arc, since the arc forces are quite small at the first phase. The following influences affect the forces. There is an interaction between parallel parts of conductor plus influence of two loops. Other contribution to the forces is caused by current strait between contacts. Finally, we have to consider ferromagnetic material of sheets in the quenching chamber. These sheets cause growth of both magnetic flux density and force – this is also used for higher arc velocity.

3.2 PROCEEDING AND CONDITIONS OF CALCULATION

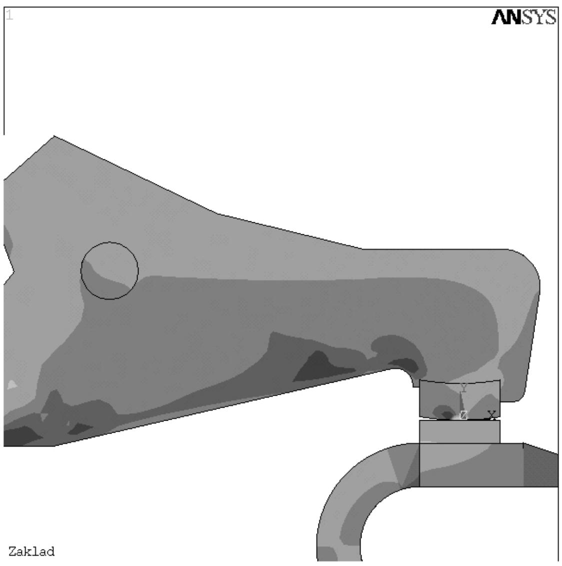
The **steady-state** problem is assumed for calculating the forces. It means that direct current (which creates steady-state electric and magnetic field) is considered. The real problem is quasi-static so the skin-effect in current-carrying conductor and eddy currents in sheets of quenching chamber are neglected. These presumptions can be done since the skin depth is much bigger for copper material (current-carrying conductor) in comparison with iron material, which is not involved in the current conduction. The geometry is not symmetrical so that **3D model has to be used**.

The proceeding of calculation is as follows:

- creating the geometry, choosing the proper finite elements, associating material properties, ...
- calculation of current density **J** in current-carrying conductor
- calculation of magnetic flux density **B** using the magnetic vector potential (**A**) approach
- calculation of distribution of electrodynamic forces using **J** and **B**

3.3 RESULTS

Figure 4 shows distribution of *y* component of electrodynamic forces in movable and partly fixed contact. The force acts in *y* and *x* direction can be seen in Figure 5, which represents vectors of forces. But the movable component is only in *y* direction. The z component of force is zero, which is caused by the symmetry. X component is significant for forcing the electric arc inside the quenching chamber. It can be seen that the force tries to move contacts asunder.



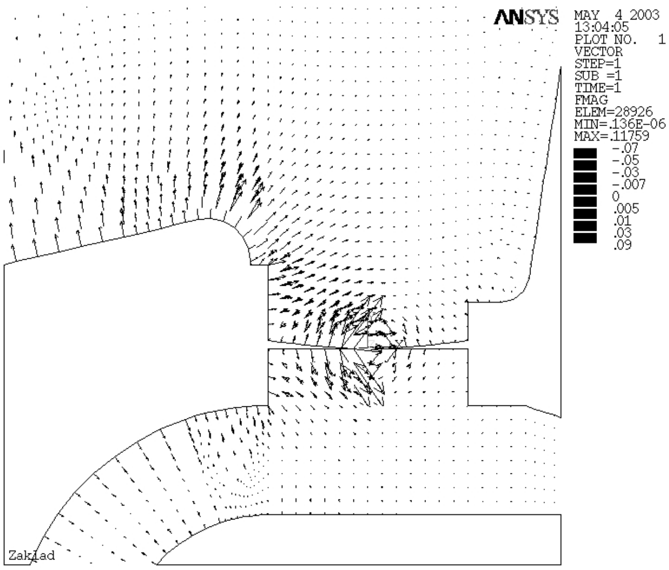


Fig. 4: *y component of force*

Fig. 5: *Vectors of forces*

I also analysed the influence of current value on the electrodynamic forces acting on moving contact. If permeable materials are neglected, the force should be ascending according to the square power of current (dashed curve in figure 6). But when the permeable material saturates, the force is smaller (solid curve in Figure 6).

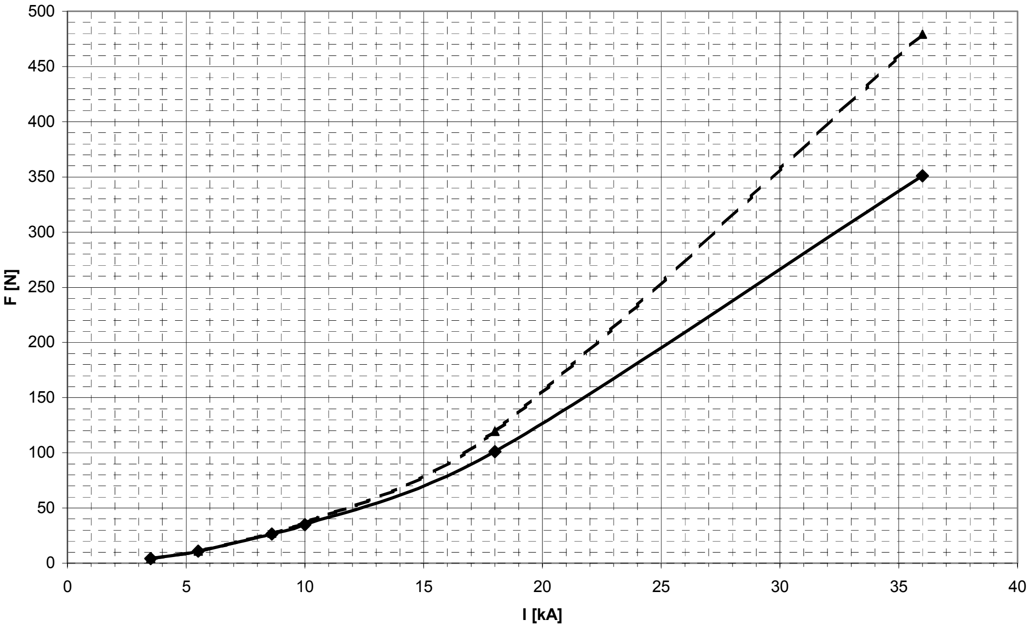


Fig. 6: *Electrodynamic force on moving contact as a function of current*

4 CONCLUSION

In this paper, only the influence of contact velocity was analysed. Next, the other influences (material of contact, magnetic flux density, geometry of quenching chamber, etc.) on arc sticking time and arc moving will be studied. Theoretical results will be validated with experimental results. The experimental results will be obtained using the digital high-speed camera system (available frame speed: 33 000fps) and voltage and current curves.

ACKNOWLEDGEMENTS

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