AERODYNAMIC CONDITIONS IN QUENCHING CHAMBER OF LV CIRCUIT BREAKER

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ABSTRACT

Problem of electric arc quenching accompanies designers from the very beginning to the final end. The whole construction of electric apparatus runs upon quenching chamber and quenching system at all. Requirement of minimization forces the designers to the better solutions of the quenching chamber design, current-carrying conductor from the electrodynamic forces or thermal field point of view. Problem arises during an electric arc switching, when extreme pressure and thermal conditions exist in the circuit breaker. Accumulated energy needs to be get off from the circuit breaker easily and quickly, due to the possibility of the apparatus destruction. Thats the reason why the aerodynamics is important inside circuit breaker.

1 INTRODUCTION

Construction of electric apparatus is related to the ability of an electric arc quenching. Engineers have for their disposal many subsidiary means like IT, numerical or diagnostic methods etc. Present requirements include integral use of the above mentioned resources in order to produce almost perfect part. These paper deals with one of many possibilities how to use modern calculation procedures for the construction of an electric apparatus. The paper is aimed to calculation of aerodynamics conditions in the circuit breaker during switching.

2 PROBLEM

During an electric arc switching, a big overpressure (of 500 kPa) due to high temperature (of 20 000 K) arises in the vicinity of the arc. A turbulent flow of hot air occurs inside the chamber, which can lead to the worse quenching ability. For that reason, one has to take into account the best air circulation in the chamber.

3 MODELING

3.1 BASIC PHILOSOPHY

In CFD (Computational Fluid Dynamics) modeling one always works with a model, i.e. certain phenomena are not solved in a full range. Instead of that, properties of the model are computed in a specific range of parameters and with simplified assumptions.

3.2 THEORY

Basic equations and physical laws used in CFD package ANSYS are as follows:

Mass conservation law In order to prevent an accumulation of a fluid in a volume V, the fluid input or output through unit area per unit time must be compensated by a temporal change of the fluid mass closed by the volume V. Using some modifications one gets common form of **the continuity equation** for unsteady and compressible fluids:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho w_i}{\partial x_i} = 0, \tag{1}$$

where ρ is density, w_i velocity and x_i position coordinates. For incompressible fluid $\rho = const.$ and equation (1) becomes

$$\frac{\partial w_i}{\partial x_i} = 0, \tag{2}$$

Momentum equation The conserved value in this case is a momentum $J = \rho w_i$. Te momentum flow generally consists of **convective** and **conductive** parts, which is result of an external force activity. Balancing equation for momentum is:

$$\int_V \frac{\partial \rho w_i}{\partial t} dV + \int_{\partial V} (\rho w_i) w_j n_j dS - \left(\int_{\partial V} \sigma_{ij} n_j dS + \int_V \rho f_i dV \right) = 0, \tag{3}$$

where n_i is normal vector. After modification, **Navier-Stokes equation** is obtained

$$\frac{\partial w_i}{\partial t} + w_j \frac{\partial w_i}{\partial t} = -\frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{1}{3} \nu \frac{\partial}{\partial x_i} \left(\frac{\partial w_j}{\partial x_j} \right) + \nu \frac{\partial^2 w_i}{\partial x_j \partial x_j} + f_i, \tag{4}$$

where σ_{ij} is a stress tensor, ν kinetic viscosity and f_i external force vector.

Law of energy conservation Conserved value is an energy. In the energy balance, another kinds of energy enter into the volume V. Work of external volume forces, work of surface forces (pressure and viscosity) and heat flow into the volume V. After substitution, a differential form is as follows

$$\frac{\partial}{\partial t} \rho E + \frac{\partial}{\partial x_i} \rho w_i E + \frac{\partial}{\partial x_i} (p w_i - \tau_{ij} w_j + qi) = \rho w_i f_i \tag{5}$$

4 CALCULATION

Calculation was done using CFD utility of ANSYS package. Mathematical approach is based on Finite Element Method (FEM).

4.1 CONDITIONS AND SIMPLIFICATIONS

Some presumptions and simplifications were taken into account in the model. The most important presumption is that the chamber is absolutely hermetic. Air is treated as an incompressible fluid (velocities up to 5 Mach do not exhibit compressibility of the air). Values of overpressure were of 20, 50, 100, 500, 1k, 5k, 10k, 50k, 100k, 150k, 200k, 250k, 300k, 350k, 400k, 450k a 500kPa. Calculation was made for steady-state, so it is obvious that some values are smaller due to inertia phenomenon.

4.2 MODEL

Fig. 1 represents side view of the chamber (arrows show direction of the air flow), view from behind and general view to chamber, respectively. It can be noted from the figure that outlet is realized only by 12 slots in a board (middle picture).

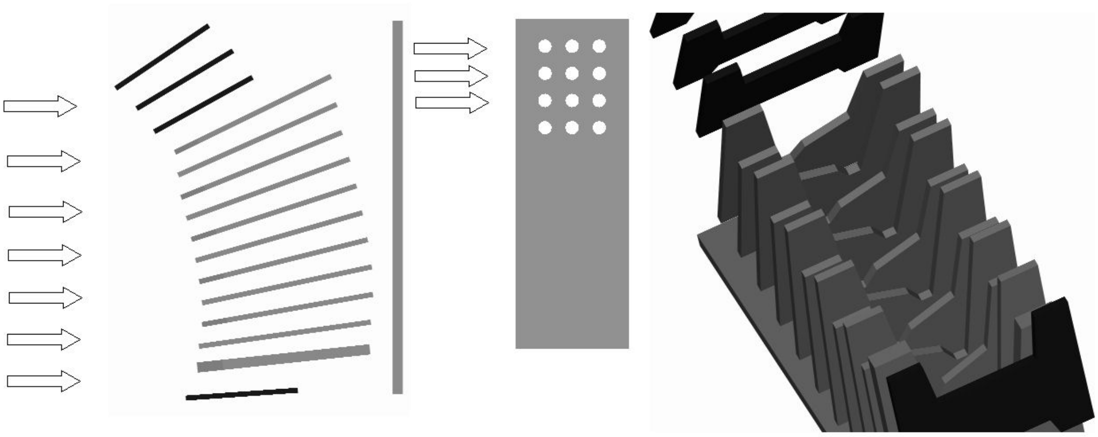

Figure 1: View on chamber

5 CONCLUSION

In the table bellow, maximal velocities and corresponding pressures in the chamber are presented.

Overpressure [Pa]	20	100	500	1000	2000	5000	10000
Velocity [$m \cdot s^{-1}$]	4.08	4.32	19.44	28.00	61.2	86.4	119.52
Overpressure [Pa]	50000	100000	200000	300000	400000	500000	
Velocity [$m \cdot s^{-1}$]	180.00	234.00	295.00	320.00	336.00	349.00	

Table 1: Overpressures and corresponding velocities

It can be seen from the table that maximal velocity is of 349 $m \cdot s^{-1}$.

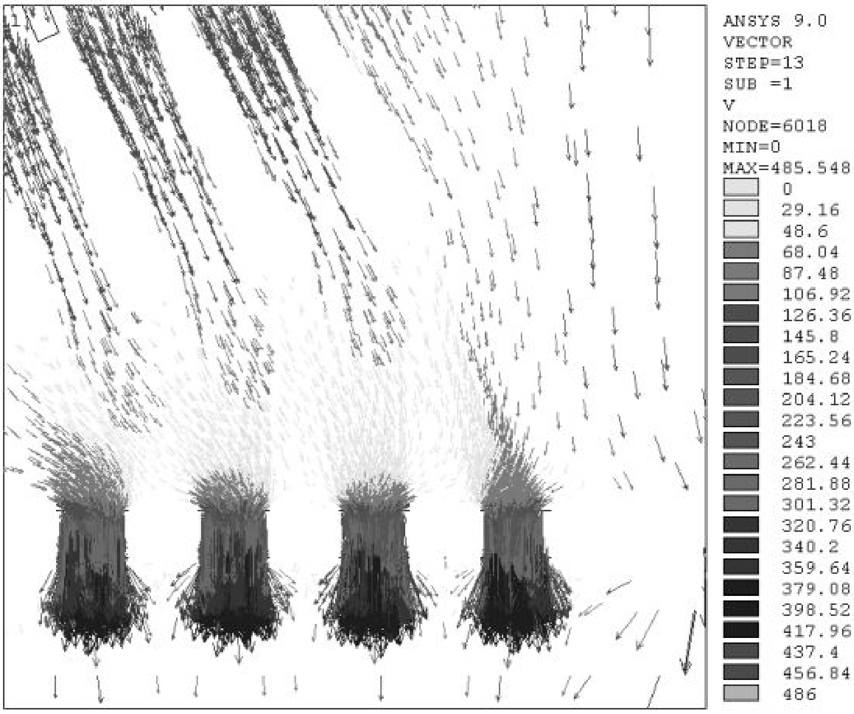

Figure 2: Visualisation of velocities using vector field in a side view

From calculated results we have obtained maximal velocities and pressure distribution in quenching chamber during switching process. Efflux velocity of air is around 320 $m \cdot s^{-1}$ at overpressure of 500kPa. Obtained results can be used as the first step for an experimental verification of the pressure distribution in quenching chamber of air circuit breaker. Modified model will be used for thermodynamic conditions prediction in the quenching chamber.

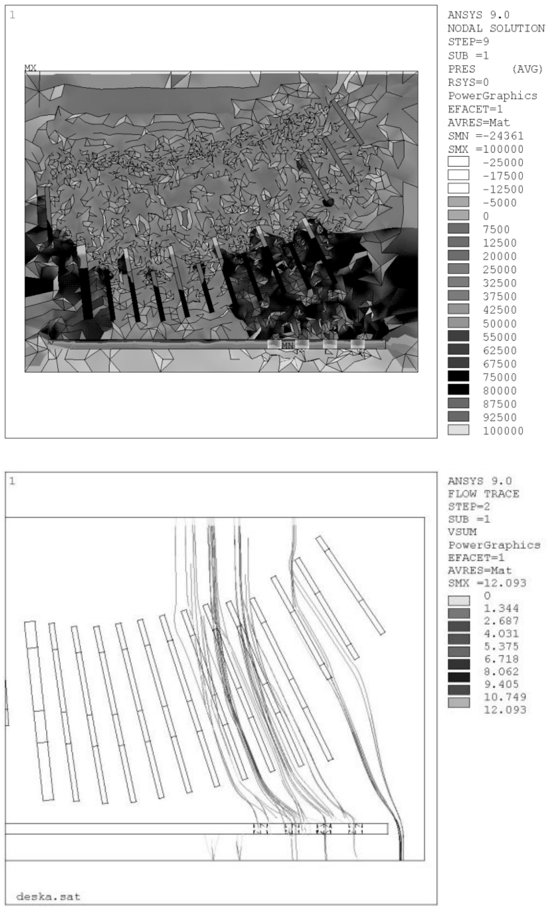

Figure 3: Visualisation of pressure distribution in lengthwise section (left) and streamlines (right)

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