Influence of the Upstream Parameters on the Thermal Limit for HV Gas-Blast Devices

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Increasing the intensity of the interaction between switching arc and gas flow can lead to increasing the HV gas-blast devices thermal interruption ability. The numerical investigations of the two-pressure monoflow arc-extinguishing chamber equip with open heating volume are discussed. Numerical simulation and experimental data have shown that this chamber changes the gas parameters in the upstream region, so the thermal interruption ability increases.

Keywords: interruption ability, upstream region, turbulence, numerical simulation

1 INTRODUCTION

One of the main problems in the gas-blast HV circuit breaker (CB) design consists in increasing the thermal interruption ability (SLF-mode in the absence of capacitors). The interaction between the switching arc and gas flow in the nozzle throat plays an important role for increasing the electric strength during the thermal phase of the breakdown. This section is very effective due to axial convection and radial turbulent heat conduction in the vicinity of the current zero. The axial pressure profile and turbulence level in the boundary layer inbetween the arc and gas in this region defines the interruption ability in the thermal phase.

The upstream region influences the thermal recovery, for some hot gas quantity remains in the stagnation zone nearby the upstream contact during the TRV wave. It is important to carry out investigations of the upstream region so that to increase the rated voltage and rated short-circuit breaking current per break HV CB without changing the rated pressure. Experimental and theoretical works [1, 2] give in detail various aspects of the arc behaviour during thermal interruption in the standard two pressure gas-blast arc-devices. Increasing the thermal interruption ability requires increase in upstream pressure, p_0, within the extinguishing chamber. Therefore, the problems of upstream parameters gas flow control in the HV arc-chamber demand further research.

The aim of this investigation is to study the upstream region influence by applying the open heating volume to increasing the thermal interruption ability.

In the present paper, results of a numerical analysis of the axial and radial gas flows nearby the upstream arc contact region and the pilot studies of the thermal mode within the two-pressure air monoflow arc-extinguishing chamber equip with open heating volume are presented.

2 GAS FLOW ANALYSIS IN THE UPSTREAM REGION

The arc-extinguishing chamber equip with open heating volume of the two pressure monoflow interrupter is discussed. Fig.1 shows the single nozzle system, where *1* is the upstream arc contact; *2* is the nozzle of critical section, S_*; V_{up} is the open heating volume of inlet gap section, S; p_0 is the upstream pressure; p_a is the downstream pressure.

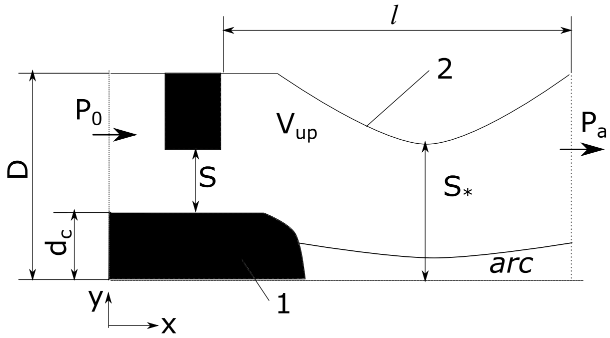

Fig.1: Geometry of the open heating volume arc-extinguishing chamber

The gas flow accelerates in the gap as in the nozzle throat (Fig.1). After the gap, the jet and stagnation region forms in the open heating volume, V_{up}. The radial pressure gradient in the open heating volume contributes to changing the flow parameters not only in the upstream region, but also in the throat and downstream region. The stagnation region destroys quickly under the action of the radial pressure gradient rather than in the standard geometry upstream region. Changes in the gas parameters involve changes in the turbulent viscosity. The coefficient of the turbulence viscosity increases and the turbulence heat transfer intensifies, which leads to bettering conditions for switching off the arc.

Turbulence model [3] for the turbulent arc simulation was presented. This model takes into account the turbulence in the shear layer between arc and gas flow produced by two type of instability, such as shear instability and Rayleigh–Taylor instability:

$$\mu_t \sim shear\ instability + \\ + Rayleigh - Taylor\ instability.$$

Accounting for Rayleigh–Taylor instability, the term being proportional to the radial gradient of the velocity radial component was inserted in the turbulent viscosity equation [3]:

$$Rayleigh - Taylor\ instability \sim \sigma_\delta^2 \frac{v_\Delta}{\Delta},$$

where Δ is the value of y, where y=1.5·$y_{0.15}$; v_Δ is value of velocity, v, at the point y = Δ; σ_δ is the middle arc radius on axis x. This term value is low in the supersonic nozzle, since the radial velocity is low and uniform. However, this term may be increased by increasing the radial velocity gradient in the upstream and throat regions of the nozzle.

3 ANALYSIS OF THE THERMAL INTERRUPTION MODE

The interruption ability investigations have been carried out for the two-pressure air open heating volume extinguishing chamber of critical diameter d=11 mm (Fig.1) [4]. Pressure ratio, P_0/P_a, is equal to 0.8 MPa /0.1MPa. Geometry is as follows: l=31 mm, D=34 mm, d_c =18mm. The area of internal section S is variable. The normalized limit current is equal to $I_* = I/I_s$, where I is the thermal interruption limit for the open heating volume extinguishing chamber, I_s is the thermal interruption limit for the standard upstream region in the extinguishing chamber. The direct single-frequency test used, and the 50% performance level was determined. Arc-chamber was tested according to the “up-and-down” procedure. Current peak values varied between 1.5 to 2.5kA, the voltage source in 8 – 12 kV, frequency was equal to 250Hz. The RRRV characteristics were determined using RC-circuit unit and 2.4 kV/μs constant.

Fig. 2 shows the dependence of the normalized current, I_*, for two-pressure air open heating volume extinguishing chamber as the function of the section area ratio, S/S*, (curve 1 is for volume V_{up1}, according to the l =31 mm; curve 2 is for volume V_{up2}; V_{up1}<V_{up2}) [4]. The vertical lines in Fig.2 show the scattering in the experimental data. The optimum section area ratio being equal to 1.5÷2, the increase in the thermal limit may be equal to 27÷30%.

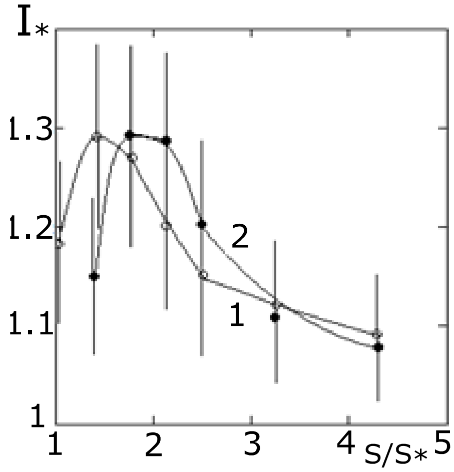

Fig. 2: The experimental dependence of the normalized current, I, as the function of the section area ratio, S/S* (1–V_{up1}, 2–V_{up2}, V_{up1}<V_{up2})*

4 NUMERICAL ANALYSIS OF SWITCHING ARC NEARBY THE UPSTREAM CONTACT

For the switching arc numerical analysis, the Reynolds-averaged Navier-Stokes equations were used. The source term in the energy equation includes the Ohmic heating and radiation loss. The electrical field strength is calculated according to the Ohm’s law. The current in the arc changes in time under synthetic test.

The geometry of the channel was assumed to be the same as in the experiment [4]. The channel is axisymmetric; its walls are impenetrable and adiabatic.

The turbulence model takes into account two versions of instability, namely: shear and Rayleigh–Taylor. For steady state, the turbulent viscosity coefficient model was used described in [3]. For unsteady state, according to the [3], the "freeze" theory of the kinematic turbulent viscosity was used. It means that at all moments of time when the current decreases rapidly, the kinematic turbulent viscosity is defined as constant and its numerical value is equal to its stationary value. For the radiation transfer, the "radiation conductivity" approximation presented in [3] was used. All equations were solved using the special software.

Fig.3 shows the calculated turbulent and molecular viscosity ratio in the nozzle throat at different section area ratios, S/S*.

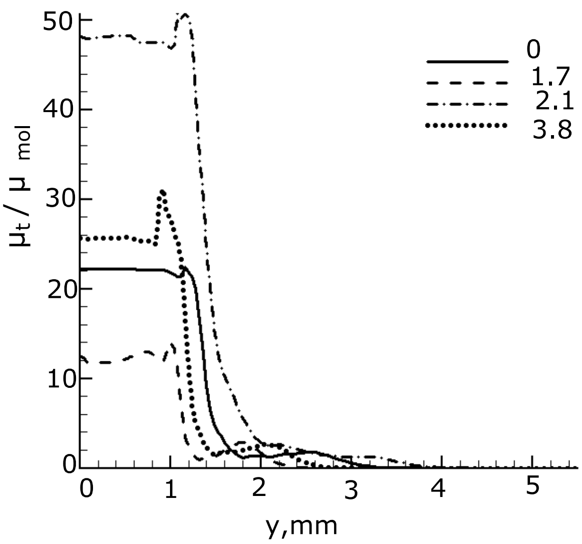

*Fig.3: The turbulent and molecule viscosity ratio in the nozzle throat at different values of the section area ratios, S/S**

If the section area ratio is in the range between 1 and 1.5 (1 < S/S* < 1.5), the gap is small, and the stagnation region after the gap is great and takes up almost the whole volume V_{up}. The intense radial gas flow is nearby the contact edge, which leads to rapid destruction of the stagnation region. The turbulence viscosity is approximately two times lower than in the standard case (Fig. 3).

When section area ratio, S/S*, changes in the range from 1.5 to 2.5, the open heating volume influence on the interruption ability is maximum. In this case, the stagnation region is part of the volume V_{up}. The intensive radial convection due to the pressure gradient in the upstream region and intense turbulent mixing (Fig.3) provides favourable conditions for switching off the arc. The thermal interruption ability increase is approximately 30% in this case and is comparable to an asymmetrical double-flow HV gas-blast device, where ratio of the two nozzles critical diameters is as follows 1:0.25.

For large values of the gap size (S/S* > 2.5), the latter has a little influence on the gas parameters in the open heating volume. The pressure gradient tends to zero, the radial gas flow is weak and its influence on the stagnation region destruction is almost absent.

Fig. 4 shows the pressure field in (a) the standard extinguishing chamber and (b) arc-extinguishing chamber equip with open heating volume of the section area ratio S/S* =2.5.

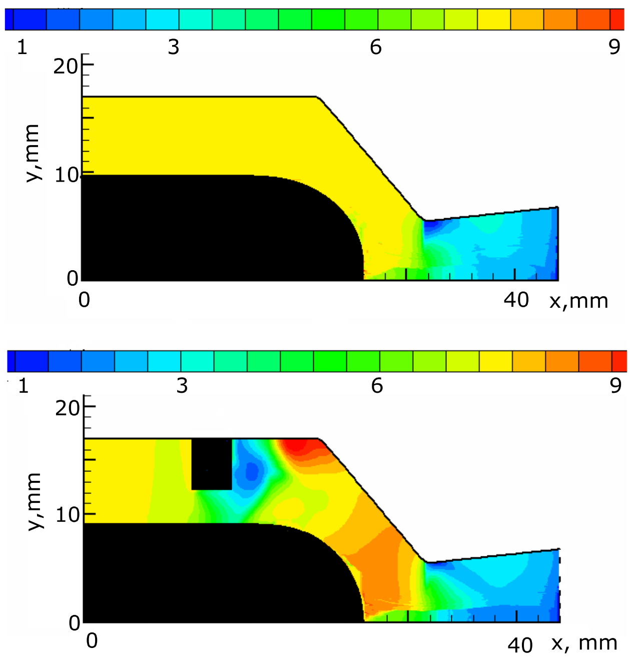

Fig.4: The pressure field in (a) the standard extinguishing chamber and (b) arc-extinguishing chamber equip with open heating volume of the section area ratio S/S =2.5*

In the Fig. 4a, the pressure field in the upstream region is uniform; there are no pressure gradients in this region. As seen in Fig.4b, the pressure gradient in the gap is small. However, the pressure gradient is large and the radial flow forms within the open heating volume, which helps destroy the stagnation region.

5 CONCLUSIONS

Based on the experimental and numerical data, one can make the following conclusions:

- The open heating volume arc-extinguishing chamber changes the gas flow parameters in the upstream region and increases the thermal interruption ability of the HV gas-blast devices. The maximum effect (up to 30%) is achieved provided that section area ratio, S/S_*, is in the range of 1.5 ÷ 2.5.
- Numerical simulations have shown that the pressure gradient generated in the open heating volume result in the more rapid destruction of the stagnation region nearby the upstream contact rather than in the standard case.

REFERENCES

[1] Briggs A C, 7th Int. Conf. "Gas Discharges", London (1982) 28-31.

[2] Current interruption in HV Networks (edited by K. Pagaller), Plenum Press, New York, 1978.

[3] Averianova S, Akatnov N, Tonkonogov E, XV Symposium on Physics of Switching Arc. – Brno (Czech Republic) (2003) 3-6.

[4] Ugriumov E, et al., XIII Symposium on Physics of Switching Arc. – Brno (Czech Republic) (1998) 359-361.