

IMPACT OF ABLATION BASED SELF BLAST NOZZLES ON LOAD BREAK SWITCH CURRENT INTERRUPTION PERFORMANCE

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Abstract. In this contribution, SF₆ free ablation assisted medium voltage load break switchgear, has been investigated. In these switches, gases generated by the arc polymer interactions are trapped in expansion chambers and are released back onto the arc at the current zero crossing. This increases the current interruption capability of the switch without the use of additional mechanical parts, as opposed to using a puffer to blow on the arc. Existing self-blast research, in medium voltage load break switchgear, has focused on blowing axially or tangentially onto the arc in a cylindrical arcing channel. More geometries are possible. In this paper, alternative self-blast blow-position and the presence of obstructions in the arcing channel have been investigated experimentally and with cold flow simulation. It has been determined that blowing right onto the arc centre is not optimal for cooling the arc, and that the presence of an obstruction in the arc channel is beneficial to arc interruptions.

Keywords: Switchgear, ablation, self-blast.

1. Introduction

SF₆ has a high Global Warming Potential (GWP), at 25 200 times that of CO₂, currently the highest on record [1]. For this reason, research to develop technologies to replace it in high voltage equipment is currently being performed. In medium voltage (MV) AC switchgear, no gas has been able to replace it one to one [2, 3].

A solution proposed to help the new gases is to use ablation assisted self-blast nozzles to help extinguish the arc [4]. The working principle of these is the capture of some of the gasses produced by the arc nozzle interactions, a process called ablation. The gases are captured using holes in the walls of the nozzle leading to an expansion chamber. When the current zero approaches, the energy dissipated by the arc is reduced, stopping the ablation of the nozzle walls. The pressure in the arcing channel drops below the pressure in the expansion chamber, causing the trapped gases to flow back into the arcing channel, cooling the arc channel blowing the arc out.

Another proposed solution has been puffers to cool the arc [5]. This solution works, but it adds costs and mechanical parts, and it can be challenging to keep the same size as the SF₆ based device. Additional mechanical parts may also lead to more points of failure and can require more maintenance than alternative breakers. The advantage of ablation assisted self-blast breakers is the lack of additional moving parts. Both the capture of the ablated gases and their release back into the arc channel happen periodically, due to the alternating current.

The holes, being the channels through which the gases are captured and blown onto the arc, are an important part of the design aspect of the self-blast ablation assisted switchgear. Currently, the research

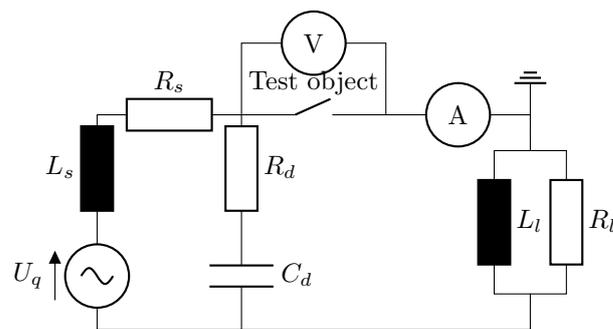


Figure 1. Test circuit used on the high voltage side of the high current breaker lab at NTNU

on ablation assisted self-blast switchgear has used holes blowing right onto the arc centre or along the arc length [6, 7]. This may not be the best way to cool the arc, as such, in this contribution, the positioning of these holes will be explored.

2. Method

2.1. Experimental setup

Experimental investigation of the different geometries were performed at the high current lab of NTNU. The setup used can be divided into three parts, the circuit, the measuring apparatus and the test object. In figure 1, the circuit used is illustrated. It is connected to the 12 kV grid through a transformer, that can be set to output 6.5 kV, 12 kV, 13 kV and 24 kV. The circuit is divided into the source branch, the load branch and a damping branch. These can be changed in discrete steps and are used to set the current, the rate of rise of recovery voltage (RRRV) and peak of the transient recovery voltage (TRV) the test object

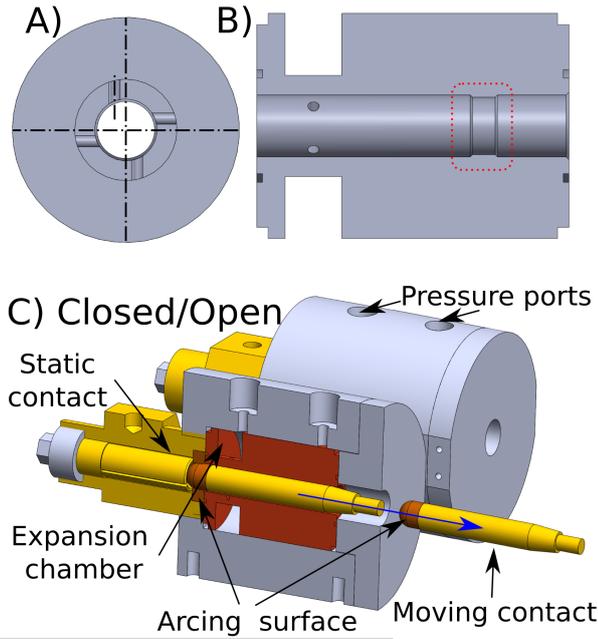


Figure 2. A) Nozzle cut along the hole plane. B) Nozzle cut along the arcing channel, with the obstruction framed in red. C) Nozzle in red without obstruction and with offset holes in test object. Both in the closed position and in the open position.

will be subjected to [8].

During each shot, a handful of variables can be recorded. Mainly, the current, the voltage, the contact travel and the pressure development in the test object. In addition to these measurements, the experiments are filmed using a high speed camera.

The experiments are performed in a tank where the dielectric medium can be controlled. In this paper, the dielectric medium was air at 1013 hPa. In the tank, a load break switch, driven by a spring compressed and held by a triggerable electromagnet, is placed. In figure 2C, the cross-section of the object of interest is illustrated both in closed and opened state. It consists of a fixed contact and a moving contact made out of brass with copper wolfram attachments as arcing surfaces. To test out different nozzle geometries, a polymer holder is made where the pressure sensor can be attached and into which the different nozzles can be inserted.

2.2. Nozzles

In figure 2C, the nozzle is represented in red. They are made from 40 mm PTFE cylinders, as this is a common nozzle material in ablation assisted switch gear [7]. In the nozzle, an 11 mm cylindrical channel is made where the 10 mm pin contact can move, this is the space where the arc is burning.

Close to the fixed contact, an expansion volume has been cut out of the nozzle. This volume is called the expansion chamber. It is connected to the arcing channel by four 2 mm² holes. The position of these holes is one of the two variables looked into in this paper. Four positions were chosen, the holes had an

offset of 0 mm, 0.5 mm, 1.25 mm and 2 mm. A cut of the nozzle along the plane of the holes is illustrated in figure 2A.

In addition, a second set of nozzles were tested. The same four hole positions were tested, but a slight obstruction was added along the arcing channel, as highlighted in figure 2B. This obstruction narrows the space between the nozzle wall and the moving contact along a small portion of the nozzle. This was added to increase the pressure early in the current interruption process by restricting the gas flow out of the nozzle, so more gas can be captured in the expansion chamber.

2.3. Simulations

Static turbulent cold flow simulations of the four hole positions were performed using COMSOL. The simulation was separated into two parts, first the gas capture and secondly the blast, which were calculated independently of one another. For both sets of simulations, the temperature of the gas was set to 293.15 K. To simplify the calculations, the gas flows were only calculated on a quarter of the nozzle, as each quarter are identical. The gases were, however, set to have cyclic properties along the borders of the quarter calculated on.

For the capture simulations, a 1300 hPa conical pressure source was used to simulate the arc. The output pressure was set to 1000 hPa at the end of the nozzle. The goal of the simulations was to obtain the pressure in the expansion chamber. For the blowing, a 1300 hPa pressure source at the holes was used for all hole positions, not the pressures calculated in the previous step, nor the experimentally measured values. This was done to better compare the quenching ability of each geometry without the interference of the gas capture. Experimentally, directly determining the speed of the blast is difficult. Fortunately, the energy dissipated by the arc can be assumed to be equal to the cooling of the arc.

$$p_{\text{cooling}} = u_{\text{arc}} \cdot i_{\text{arc}} \quad (1)$$

Where u_{arc} is the arc voltage, i_{arc} is the arc current and p_{arc} is the cooling power [9]. Since the current is the same for all nozzles, and they constrict the arc so that the arc length is almost the same, a higher voltage indicates a higher cooling power.

3. Results and Discussion

3.1. Simulation

The first simulations to be performed were for the gas capture and are illustrated in figure 3. The calculated pressures in the expansion chamber were 1326 hPa, 1343 hPa, 1295 hPa and 1304 hPa for the 0 mm, 0.5 mm, 1.125 mm and 2 mm nozzles, respectively. All in the vicinity of the filling pressure. According to the simulations, the best position for filling would be the hole offset by 0.5 mm, followed by the hole with no offset, the worst being 1.125 mm.

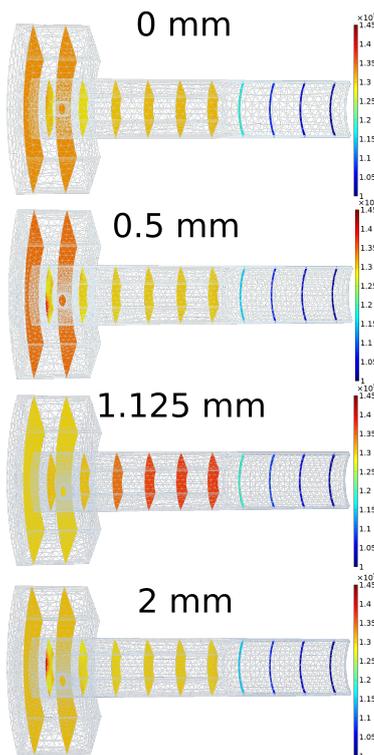


Figure 3. Computed pressure in the obstruction less nozzles for the four different hole positions, given a 1300 hPa source at the arc and a moving contact halfway through the nozzle.

Then the blast was simulated, here the maximum speed reached by the gas was 302 m s^{-1} , 461 m s^{-1} , 715 m s^{-1} and 553 m s^{-1} for the 0 mm, 0.5 mm, 1.125 mm and 2 mm nozzles respectively. All offsets gave a higher max speed than no offset, but the best was with an offset of 1.125 mm, slightly beyond the diameter of the opposite hole. This means they will in practice get a lower pressure than the smaller hole offsets and therefore have less gas to achieve the blowing speed calculated. There may therefore be a position between a large offset and a small offset where the combination of captured gas and effective blowing maximizes the cooling of the arc.

3.2. Measurements

To determine which of these four positions may be the best, 5 current interruptions were attempted for each hole offset with and without the nozzle obstruction. A 300 A RMS was used and the RRRV was set to $40\text{ V } \mu\text{s}^{-1}$ with a peak TRV of 11 kV. The speed of the moving contact was 2.4 m s^{-1} . An example of a measurement is plotted in figure 5.

The averaged measured pressures for nozzle without obstruction and voltage divided by the gap length are plotted in figure 6. There is only a slight pressure deviation between the 0 mm and 1.125 mm offsets, followed by the 0.5 mm offset, lastly the 2 mm offset. Different from the simulations, no offset was tied best experimentally, even though the simulation might have suggested it would be at a slight disadvantage. The

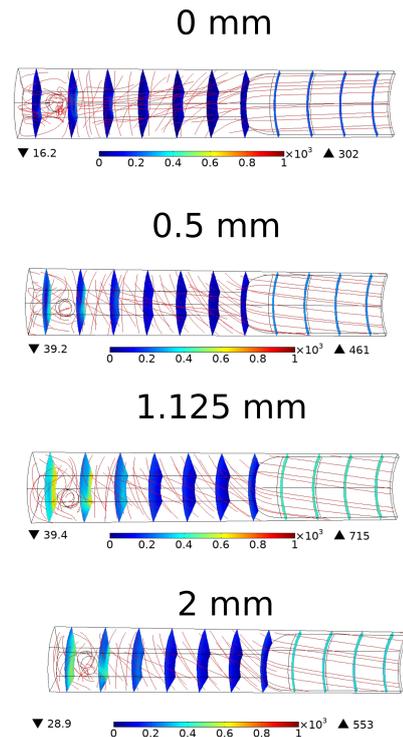


Figure 4. Computed velocities throughout the obstruction free nozzle for the four different hole positions, given a 1300 hPa source at the hole and a moving contact halfway through the nozzle.

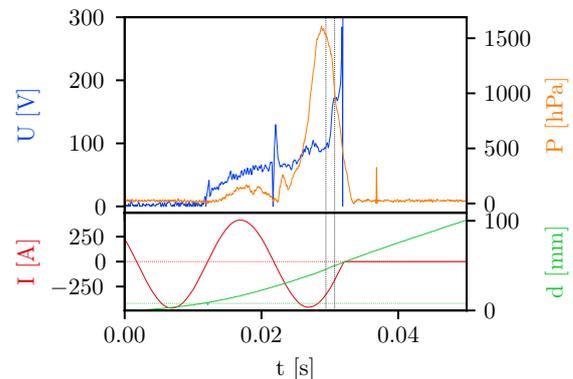


Figure 5. Voltage, pressure, current and travel curve measurements for a nozzle with obstruction. Two vertical lines delimit the obstruction.

pressure of the 1.125 mm offset was the best nozzle, considerably different from the simulations. And the interruption attempt for the 0.5 mm offset was lower than the 0 mm offset nozzle. Notably, even though the pressures are similar between 0 mm and 1.125 mm, the voltage is higher with the offset, suggesting the cooling is more efficient for it. And a 0.5 mm offset has about the same cooling as the nozzle with no offset, even though it had a lower pressure build up. None did successfully interrupt the current. However, at higher pressures, 1300 hPa, the obstruction free nozzles with no offset has successfully interrupted the current.

In figure 7 are the average pressures measured for the nozzles with obstructions and electric field in the

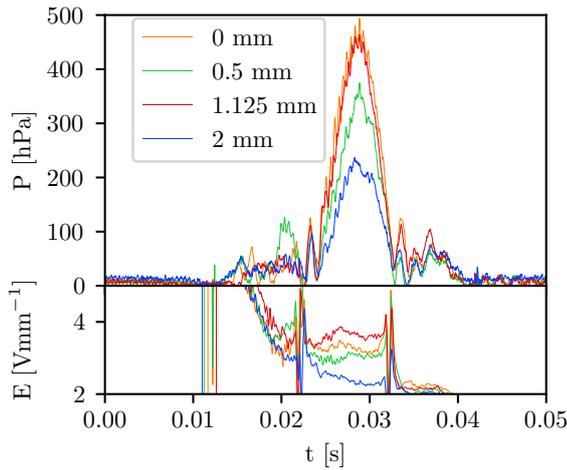


Figure 6. Average measured pressures and electric fields at 300 A RMS, in obstruction free nozzles.

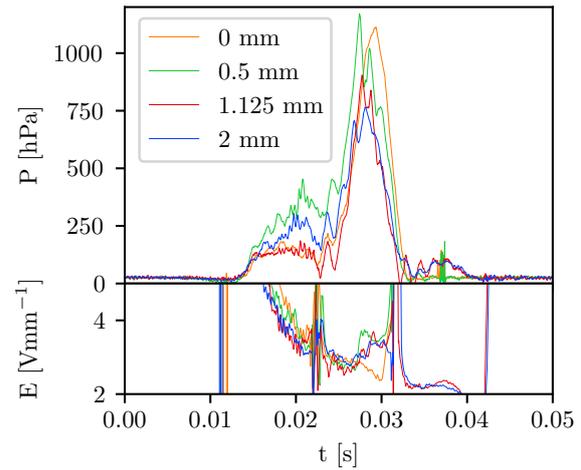


Figure 7. Average measured pressures and electric fields at 300 A RMS, in obstructed nozzles.

arc plotted. The pressure in the self-blast chamber is notably higher than without obstruction for all configurations. The order has changed and are closer to the simulated order. This time, all interruption attempts of the 0 mm offset were successful, four out of five attempts of the 0.5 mm were successful and none of the two others were successful. It should be noted that the timing of the switch heavily influences the current interruption ability, as cooling during peak current does not help, only cooling and blowing close to the current zero does. The voltages early on, before the pin contact passes the obstruction, are similar for all hole positions, suggesting the same or little arc cooling. When the pin moves past the obstruction, there is a jump in arc voltage as more cooling is applied. The arc voltages for all off-centre holes are higher than for the no offset nozzle. But they do not all break the current, suggesting that cooling is not the single key for a successful breaker.

4. Conclusion

It was computed and verified experimentally that offsetting the holes connecting the expansion chamber to the arcing chamber increases the cooling power of the nozzle, but offsetting them too much will reduce the quantity of gas captured in the expansion chambers. The effect of an obstruction in the nozzle was not computed, but as expected, it leads to a higher pressure build up in all configurations. Both the 0 mm and 0.5 mm offset nozzles were able to interrupt a 300 A current with the obstruction. No offset was tied with the highest pressure levels, both with and without the obstruction. 1.125 mm being best with no obstruction and 0.5 mm with one. In conclusion, offsetting the holes increases the cooling, but reduces the interruption capability if the offset is too large. The presence of an obstruction does increase the interruption capability of the breaker. Further investigation on the impact of hole offset at different pressures and in different gases will be performed.

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