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EXPERIMENTAL STUDIES OF ARC MOTION BETWEEN TWO PARALLEL RUNNERS WITH SPLITTER PLATES

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Abstract. In this paper, we present an experimental study on the influence of vent aperture on arc motion and the influence of splitter plates on arc voltage drop and arc motion in simplified arc chamber geometry of Low-Voltage Circuit Breaker (LVCB). The arc chamber is composed by two parallel arc runners and following the configuration chosen by one or two splitter plates placed in the up-stream position. The experimental setup is completed by a generator (capacitor bench with triggered switch), a high-speed camera and the electrical measurements. The arc ignition, arc displacement, arc splitting and arc re-strike have been observed. Different configurations of experiment and results will be described.

Keywords: LVCB, splitter plate, arc motion, voltagedrop.

1. Introduction

The LVCB is an electrical device widely used to protect the power system when a fault current appears in the circuit. The miniature circuit breaker (MCB) is one of LVCB which provides protect circuit below 1 kV in AC. The electric arc appears during the contacts opening of MCB and should be extinguished rapidly. The process includes the displacement of arc between the arc runners to the quenching chamber which is composed by a series of splitter plates. The technology of arc interruption consists to increase the arc voltage beyond the network voltage to achieve the current interruption. It is well known that the arc voltage increases by the arc elongation. But in the case of MCB, another parameter appears. Due to the voltage drops of the near-electrode region of splitter plates, the voltage increases too [1, 2]. This phenomenon is mainly responsible of the current interruption. Therefore, considering the arc motion (due to elongation) and arc voltage (due to voltage drop) are the most important parameters. The vent aperture plays an important role on the arc motion and splitter plates lead to increase the voltage drop. The study from Shin et al. [3] is devoted to the influence of vent aperture size and repartition on arc motion by arc imaging measurements. It is shown that the arc moves further and more quickly in case of larger area of vent opening in the quenching chamber. Nevertheless, the configuration with more vents helps to increase the arc motion velocity. In the previous researches, McBride et al. [4] studied arc roots motion from moving contact to arc runners. They developed a flexible test apparatus with a high-speed imaging system to investigate the influence of arc chamber venting on arc motion. The results show that the arc root time decreases when the vent area is increased. The arc voltage drop has been studied by experiment and theoretical approaches. Lindmayer et al. [5] and Mutzke et al. [1, 6] proposed to consider an additional voltage drop through the resistivity in the layer of electrode for arc splitting process. The solution is described by U-J relation obtained by experiments. This method allows presenting a realistic arc root voltage description for simulation. Series of experiments with one splitter plate in the arc chamber have been analyzed. They found that about 28-30 V more are added to the total voltage after arc splitting process [1, 5, 6]. Further, Yang et al. [7, 8] studied arcing phenomenon by considering a non-linear permeability of ferromagnetic materials. They focus their studies on the influence of eddy currents and the influence of metal vapors coming from iron splitting plate erosion. The experiment has been carried out and the results compared with the simulation. They show that before arc splitting, the anode arc root moves faster than the cathode one. Once the arc reaches the splitter plates, the cathode root moves more quickly than the anode root. In this paper, we present first the experimental setup and the configurations investigated. Then two parameters are studied by experiment: vent configuration on arc motion and the influence of the number of splitter plates on arc voltage. The results are presented and discussed before the conclusion.

2. Experimental setup

2.1. Configuration

A simplified arc chamber configuration with two parallel arc runners is used and presented Figure 1. The chamber allows the presence of zero, one or two splitter plates located in the up-stream position. A copper wire with 0.1 mm diameter is placed between the two arc runners for arc ignition. Two types of vent condition are used (Figure 2).The copper wire is located 10mm from the downstream vent. The distance between the initial position of the copper wire and the splitter plate entry is 30mm. The position of the copper wire corresponds to the birth place of the conducting channel. Then, the arc can move along 50mm from its initial position before to meet the upstream vent which could be totally or partially closed (85%) or totally open (table 1). In cases without any upstream vent, the arc could reach 20mm more before leaving the chamber. The distance between the two main arc runners is 20mm. The thickness of a splitter plate is 1mm.

Figure 3 presents a general view of the experimental setup. It includes a generator composed by capacitors and inductances that can produced a current half-wave of frequency 50 Hz, which has a prospective peak value up to 13 kA with a maximum voltage charge of 450 V in DC. A high-speed camera (Photron SA5) with a maximal recording speed of 12 000 images.s-1 is used with light filters to limit the images saturation. The high-speed camera allows observing the arc motion and the splitting process in the arc chamber. The observation requires the use of transparent walls in the experimental device. A differential voltage probe and a Rogowski coil for the electrical measurements are also used. The whole system (Half-wave of the current, high-speed camera and electrical measurements) is synchronized by an external Trigger.

2.2. Test configurations

Ten configurations have been studied. The two parameters studied are the number of splitter plates from zero (0 Sp)to two (2 Sp), and the vent configuration open (O), close (C) or partially open (PO) for the upstream or downstream positions. These cases are presented Table 1. Each case is reproduced three times and the errors of the figures correspond to the maximum and minimum value obtained.

	Case 1	**Case 2**	**Case 3**	**Case 4**
0 Sp	O-O	C-O	PO-O	C-PO
1 Sp	O-O	C-O	PO-O	C-PO
2 Sp	O-O	C-O	—	—

Table 1. Test configurations

3. Results and discussion

Two kinds of measurements are performed with the ten configurations: electrical measurements (current, voltage) and fast camera. The results are difficult to analyze and it's preferable to associate the picture from the camera to the electrical measurement for the interpretation. In order to analyze all the movies, a tool was developed with @Matlab software. The arc roots position are calculated by the method of McBride [9], which evaluated by the center of intensity of arc imaging. Following the arc emissivity the tool allows determining the arc roots positions and the mean column position. Sometime the fast camera frequency is different from the electrical measurements and the tool allows interpolating to present all the results for the same time. The influence of vent conditions and of the number of splitter plates is now presented.

3.1. Influence of vent conditions on arc motion

- Cases without splitter plates:
  Figure 4 and Figure 5 present respectively the average anode root and cathode root positions versus time for the cases without splitter plate. The cases 1, 3, 2 allow showing the influence of the upstream event surface. For the three cases the upstream event is open. Closing progressively the upstream event leads to an increase of the arc motion. This difference is probably due to pressure effects. Decreasing the event surface of 85% (Case 3) allows increasing the mean velocity from v1=17.6m/s to v3=37.6 m/s. These velocities are deduced from mean positions given Figures 4 and Figure 5. A total closure of the upstream event leads to v2=38.4m/s (Case 2). In the studied cases the maximum AC current is I=800A. Of course in this case the plasma viscosity leads to a clogging effect and the pressure acts to push the arc. This phenomenon is possible as the downstream event is open and there is not obstacle at the hydrodynamic flow. On the contrary when the downstream event is partially closed (Case 4) we can observe a decrease of the mean v4 velocity.

  A comparison between Figure 4 and Figure 5 shows that the behavior is similar for the anodic and cathodic arc roots and that the velocities are in the same order of magnitude.

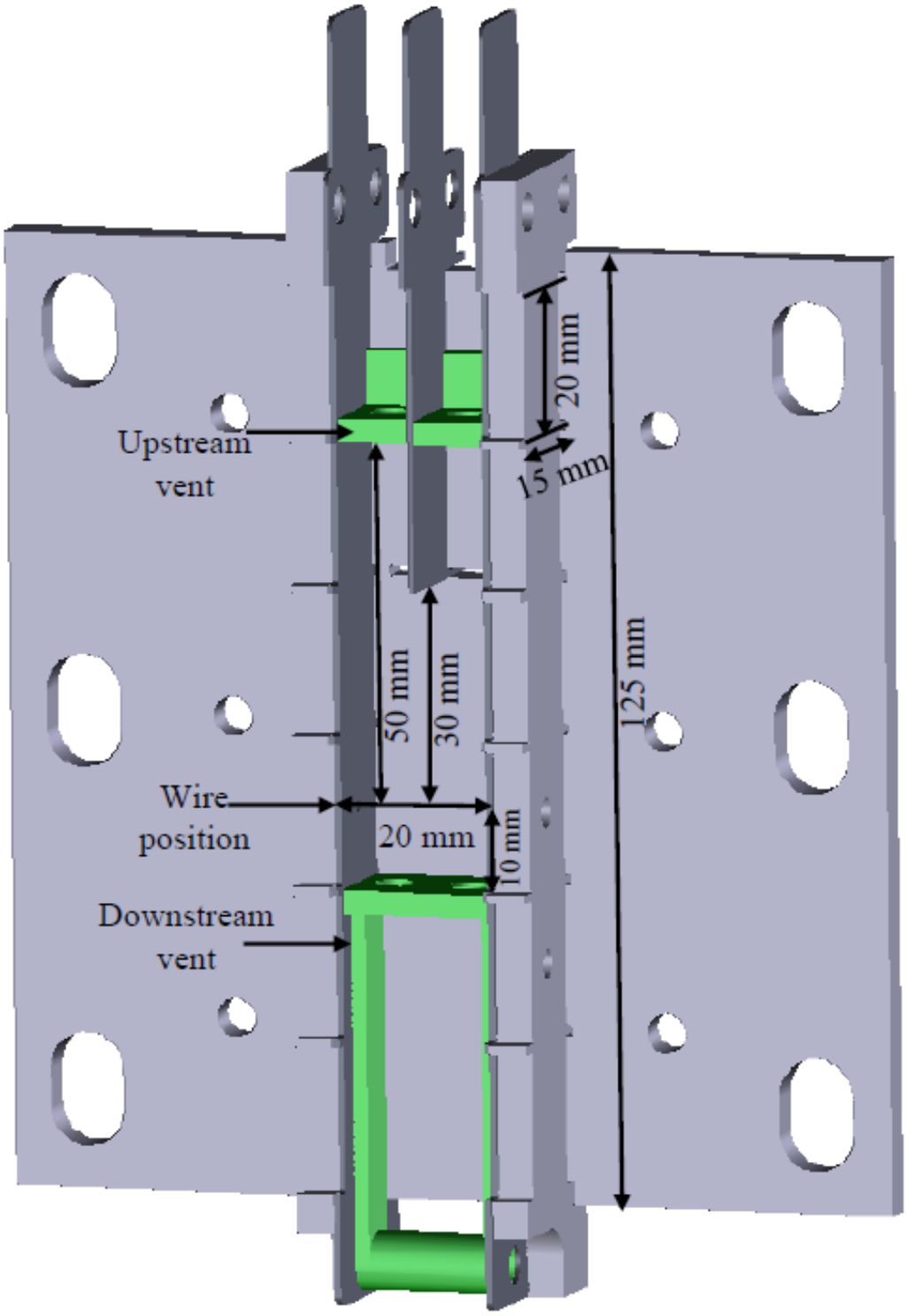

Figure 1. Arc chamber geometry in 3D

- Cases with one splitter plates:
  The same previous cases are now considered with the presence of one splitter plate Figure 6 and Figure 7. The splitter plate is located at 30 mm from the wire position (Figure 2). With the presence of one splitter plate in the arc chamber, the measurements of the arc roots motion are less reproducible and so they present higher error bars. Similar behavior on arc root velocities observed without splitter is found with one splitter plate. The splitter plate position is represented in the two figures. In case of the use of one splitter plate, of course it exists in the geometry two anodic and cathodic arc roots. The Figure 7 and Figure 8 represent the mean arc root positions on the runners.

Figure 2. Vent conditions

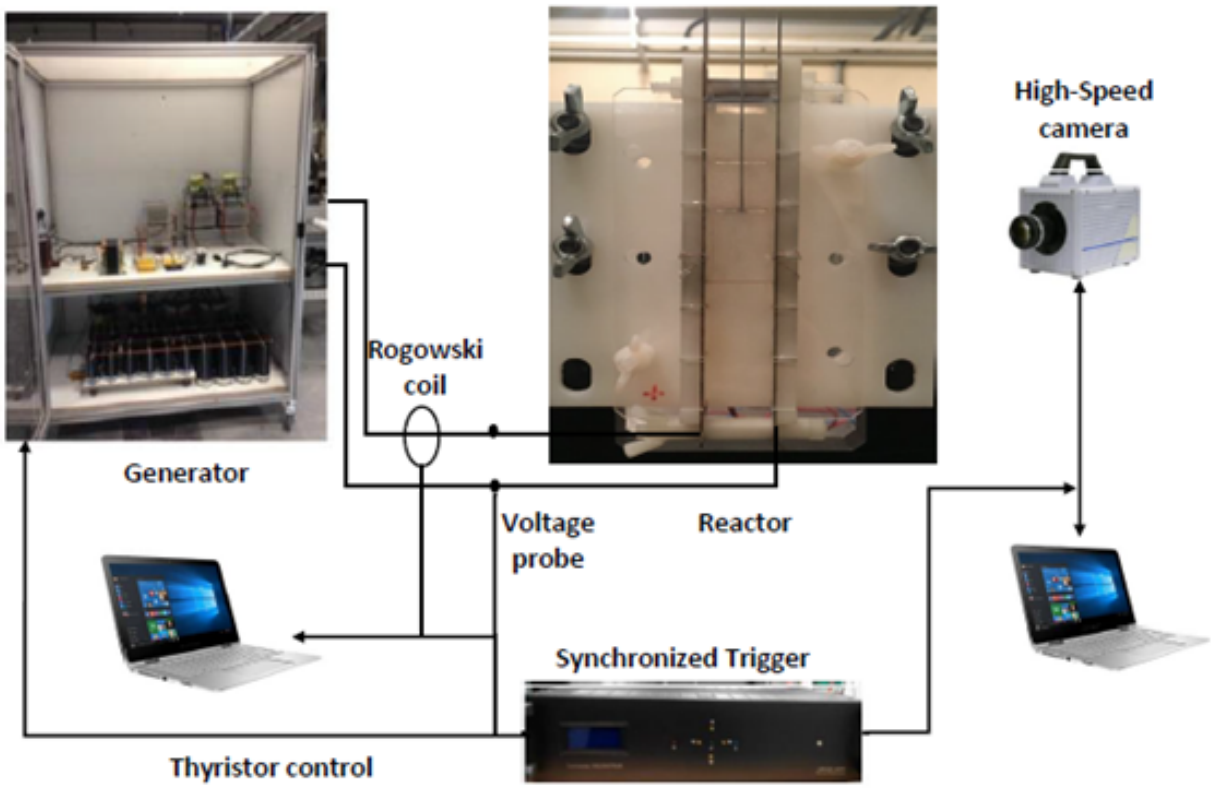

Figure 3. Configuration of experimental setup

The Figure 6 shows that the anodic arc root velocities is lower when one splitter plate is present in comparison to the Figure 4. This behavior is observed for the four cases. We can observe a real difficulty for the arc root at the anode to reach the splitter plate in case 1 (O-O). In the same time we observe a slope change in the case 3 (PO-O) indicating a stagnation and a not easy configuration for the arc to overcome the splitter. In the two cases where the event at the upstream side is closed, we do not observe the change on the slope, indicating that the difficulty for the arc to overcome the splitter is compensated by the pressure effect.

When we look at the mean cathodic arc root positions, it seems that the arc roots velocities are the same as in the cases without splitter plate. Excepted in the case 1 (O–O) all the cases seem to be affected by the splitter presence and arc stagnations are observed. In conclusion it seems that the splitter presence mainly affects the anodic arc root positions leading to a decrease of the velocities. The cathodic arc roots are sensible at the splitter presence and stagnation are observed, nevertheless the hydrodynamic effects heat the chamber during the stagnation, and then the arc moves on the splitter, its velocity increases.

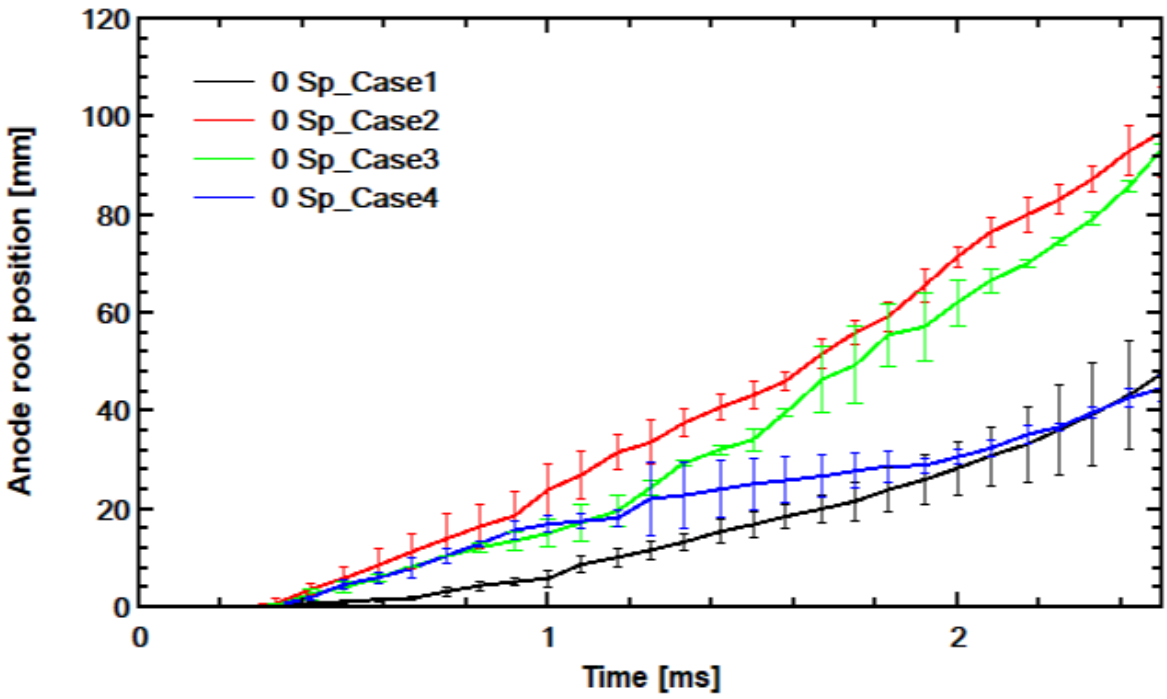

Figure 4. Average anode roots displacement for different vent configurations without splitter plate

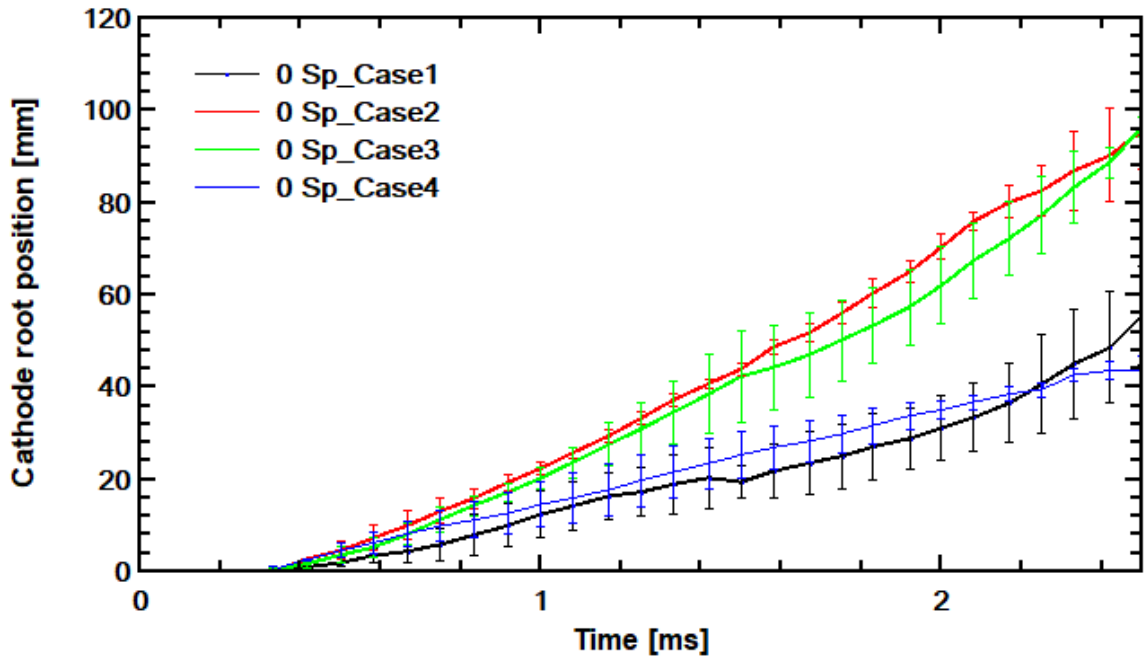

Figure 5. Average cathode roots displacement for different vent configurations without splitter plate

3.2. Influence of splitter plates on arc voltage

In this section we study the influence of the splitter plate presence on the electrical measurements (current, arc voltage). The Figure 8 presents the total voltage measured between the two runners. One peak located at time t=0.33ms is observed, it corresponds the copper wire explosion used to ignite the arc. The diameter of the wire is 0.1mm. After the wire explosion, in case without splitter plate, the drop voltage keeps the same with a value around 70V. This voltage value corresponds to the sum of the arc column voltage and the values of the anodic and cathodic arc roots.

In cases of one and two splitters after 1 ms, the voltage increases. We have seen in previous Figure 6 and Figure 7 that the splitter was located for one position reached in the range 1 and 1.3ms. In this range the

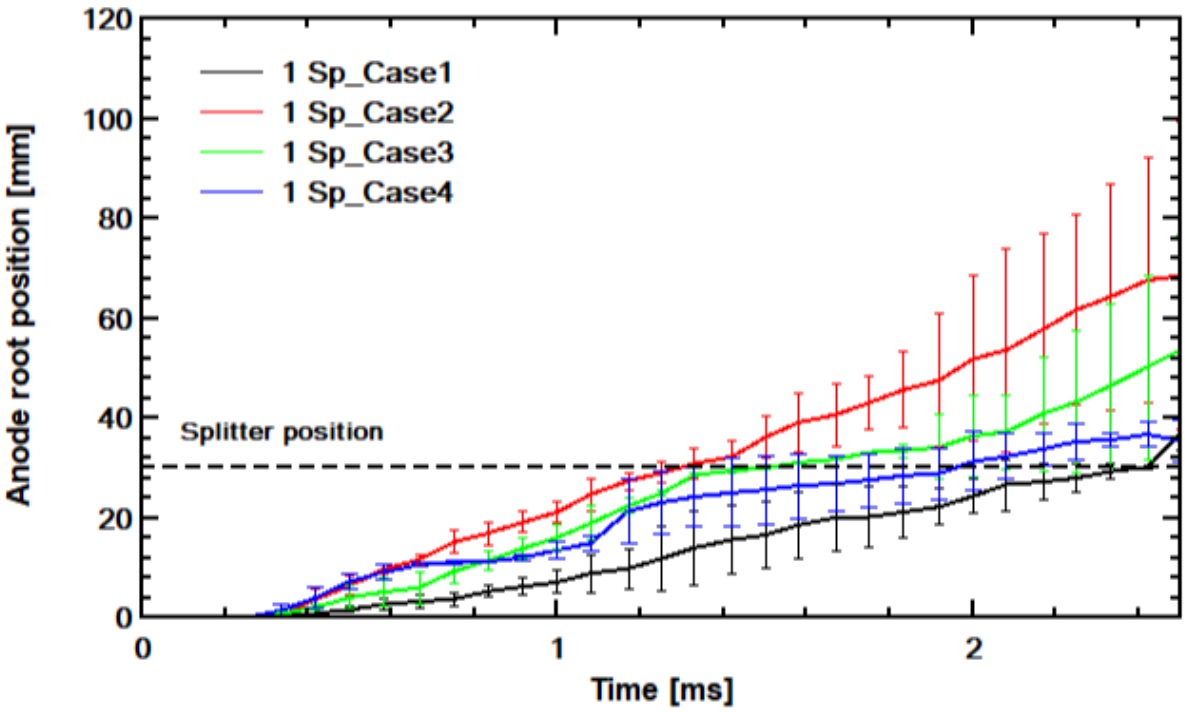

Figure 6. Average anode roots displacement for different vent configurations with one splitter plate

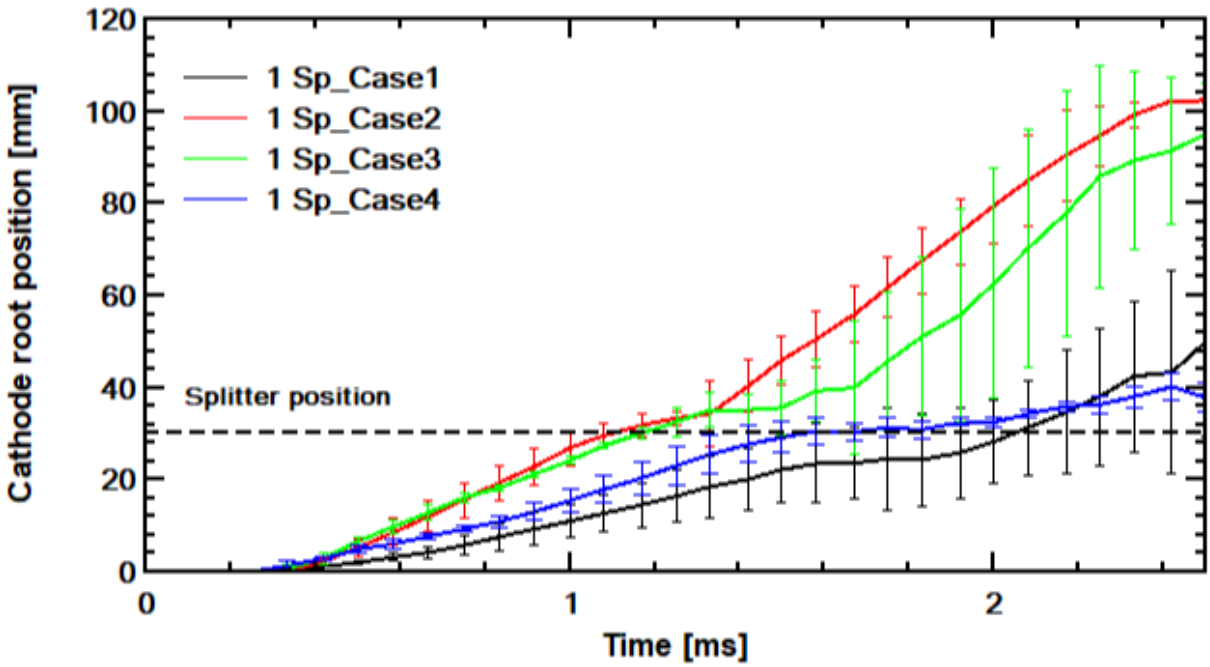

Figure 7. Average cathode roots displacement for different vent configurations with one splitter plate

voltage increases due to the bent of the arc increasing its length, this is why we do not really observe difference between one or two splitters. After 1.3ms, the two curves have different evolutions with higher values in case of two splitters. The difference between the two curves is around 30V. Figure 6 and Figure 7 have shown different positions versus time for the anodic and cathodic arc roots. This indicates that the arc length changes during time and that the arc is not perpendicular to the runners. It is so difficult to discuss more the additional voltage value which is a combination of changes on arc length and additional drops due to the splitters presence. In the Figure 9 we have represented the current intensity evolution versus time for zero, one and two splitters corresponding to the case 2 (C-O). In the same picture the presumed current intensity corresponding to the

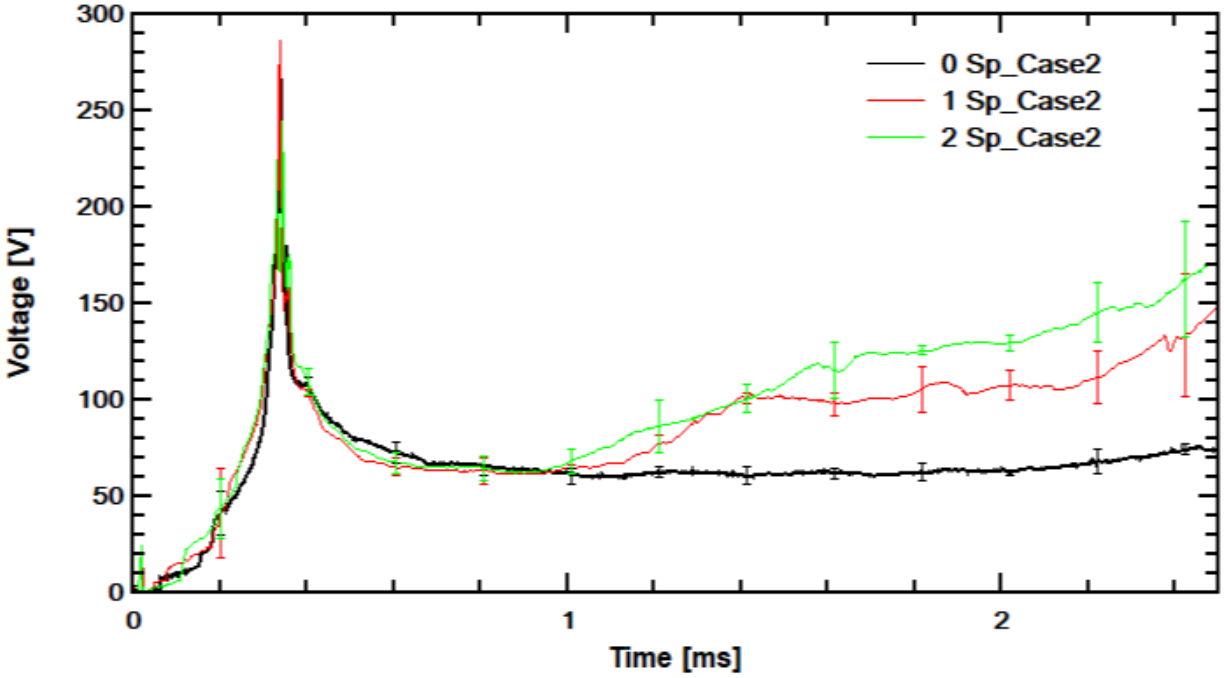

Figure 8. Average voltage for second vent configuration (C-O) with zero, one and two splitter plates

applied current without limitation is plotted. The current limitation occurs around 1ms and 1.3ms as indicated previously. From the curve of the presumed current, we can note a greater limitation versus the number of splitter.

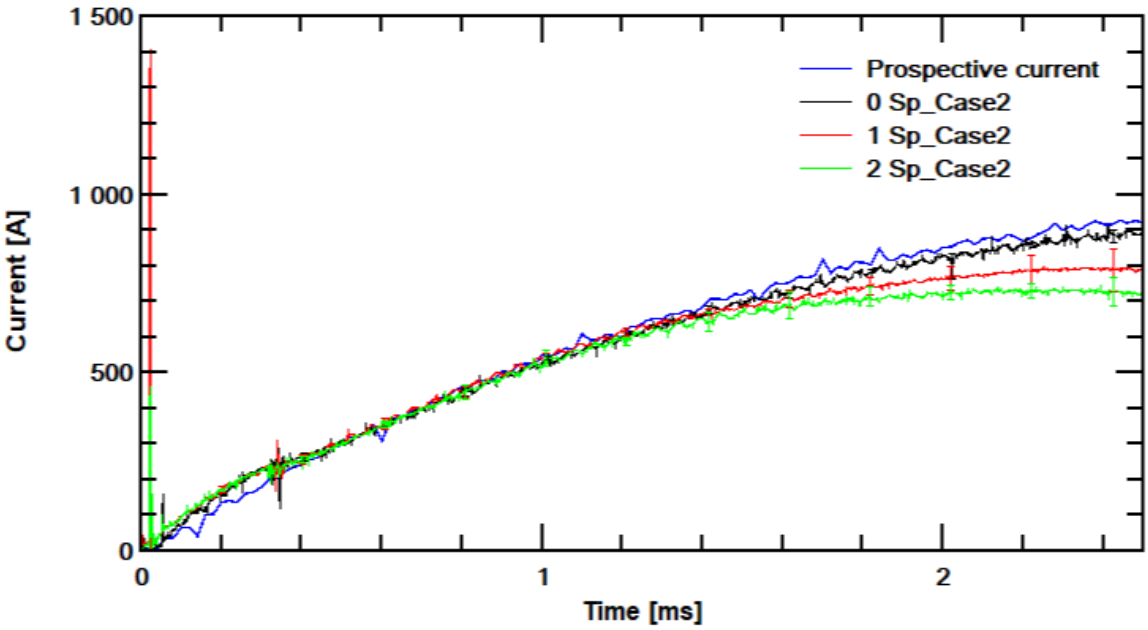

Figure 9. Average current intensity versus time. Case 2 for zero one and two splitters

4. Conclusion

In this paper the arc behavior in a simple chamber of HVCB is studied. The experimental setup is presented. The geometries investigated are related to the surface of the events and on the number of splitter plate. The results show that the arc ignition occurs at around 0.2 to 0.3 ms. Depending on the event surface the pressure effect is highlighted. The pressure effect added to the Lorentz forces acts on the arc motion. For a given downstream event surface the arc root velocity increases with a decrease of the upstream event surface. Depending on

the number of splitter the total voltage increases leading to a current limitation. The total voltage is directly correlated to the number of splitter. Due to the changes on arc length following the configuration and the fact that the velocities are not the same, the arc positions between two configurations are not the same. It is so difficult to estimate deeper the splitter contribution. Nevertheless a contribution of around 30V by splitter is estimated.

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