Experimental investigation of short-time plasma propagation recorded by high speed camera

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ABSTRACT

The experimental research shows the behaviour of the short-time plasma in a narrow gap. The plasma is recorded by a high speed camera with 350 000 fps and an exposure time of 0,369 µs. Three geometries of narrow gaps are tested by a surge current formed as an 8/20 µs impulse, with amplitudes of 5 kA, 11 kA and 23 kA. The comparison of the different recorded plasmas shows differences by propagation of the plasma and voltage.

1. INTRODUCTION

The quenching of plasma in a narrow gap is used to control the plasma and to increase the voltage. This is important to extinguish the plasma in switching systems. During comparable long-lasting occurrences such as the 50 Hz technology, this is already long in use. During transient occurrences of the plasma in narrow gaps it is still poorly understood [1, 2].

In previous works it is shown that the interaction between the plasma and the side walls leads to an ablation of the material [3]. The amount of interaction with the chamber wall is dependent on the size of the arc-wall interaction area [4].

During a short-time current the plasma propagates in the narrow gap. This propagation has an influence on the voltage. It is dependent on geometry of the narrow gap and on the surge current. The plasma propagation is investigated with a high speed camera to study its influence on the plasma voltage.

2. EXPERIMENTAL SET-UP

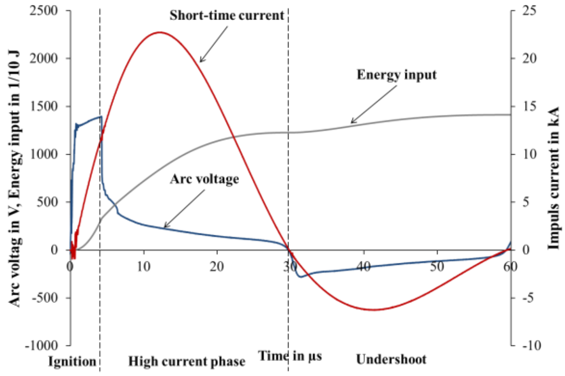

Fig. 1: Typical impulse current diagram [3].

The model spark gap is tested with an 8/20 µs impulse current with amplitudes of 5 kA, 11 kA and 23 kA. The impulse is defined in the IEC 62 475. For analysis, the arc voltage is recorded together with the current. The oscillogram (Fig. 1) shows a typical 8/20 µs current curve which is described in three sections [3]. The propagation of the plasma is recorded with a high speed camera. The recording of a trigger signal allows an assignment of the images to the electrical measurements. A description of the impuls generation and electrical measurements can be found in [3].

2.1 MODEL SPARK GAP

The research is carried out in a self-developed model (Fig. 2). The spark gap is built by two parallel tungsten copper electrodes (75%25%) and a surrounding chamber wall. The width of the gap is 1 mm and the distance between the electrodes is 5 mm at the ignition point.

The model spark gap is equipped with an open end. The plasma ignites at the ignition aid and will be pushed towards the open end.

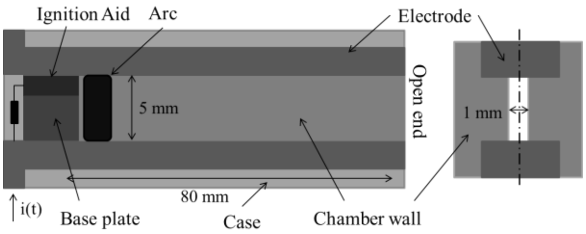

Fig. 2: Top view (left) with section line for the side view (right) of the test model [3].

The chamber wall is made of Polyoxymethylen (POM) at the non-transparent site, also the Base plate. At the transparent side the chamber wall is made of Polymehtylmehtacrylat (PMMA). This design allows a look into the spark gap with a high speed camera. Both materials form a gas flow along the plasma, which leads to cooling.

For this research project, three different geometries of the electrodes are tested (Fig. 3). The model A is composed of long parallel electrodes, and C of short parallel electrodes. The electrodes of the model B are diverting. All three forms are known from the switching device technology.

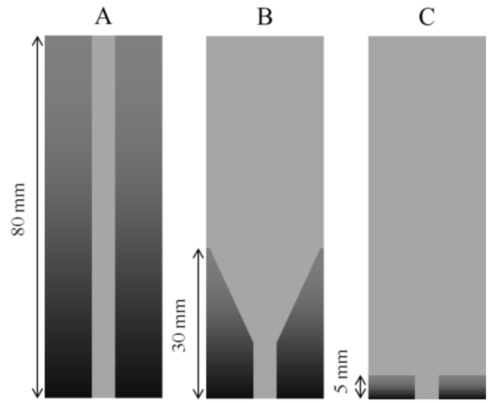

Fig. 3: Three different geometries of model spark gap [4].

2.2 HIGH SPEED CAMERA AND SETTINGS

Due to the short time range of the test impulses special equipment is needed for optical analysis. Three main requirements have to be fulfilled by the camera system.
Firstly for sharp outlines during the expected fast plasma processes the camera system has to possess a short exposure time. This exposure time has to be in the lower microsecond range for different sharp images during the rise time of the test impulse. A second benefit of a short exposure time is the prevention of a blooming effect because of overexposure.

Secondly for capturing different images during the current rise, and to display fast changes of the plasma behavior, a high frame rate is necessary. This frame rate has to be at minimum 125 000 frames per second (fps) to display two pictures during current rise time.

At last there must be a sufficient resolution of every image. The higher the resolution of the single images, the higher is the accuracy of the plasma propagation. However, the resolution is inversely proportional to the frame rate. To display even small plasma shapes, the resolution was adjusted to match the minimum frame rate.

For these special needs the high speed camera SA5 from the company Photron is used with different neutral density filters in the experimental set-up.

Thus, the minimum exposure time of 369 ns is used for this experimental setup. For three different model spark gaps two different frame rates and resolutions are chosen to provide the best performance. For model A a frame rate of 350 000 fps is chosen at a resolution of 384 x 40. For model B and C a frame rate of 271 000 fps is chosen at a resolution of 192 x 88 due to the wider construction than model A.

3. RESULTS

First, a plasma propagation for the described short-time current is shown on model A. Fig. 4 shows the plasma propagation with the voltage and current curves. Through the spark gap flows a surge current with a maximum amplitude of 23 kA during this test. The capturing moments of the images are shown in the oscillogram with connection through dash lines between the images and the timeline.

Fig. 4 is separated in the three described phases, ignition, high current phase and undershoot.

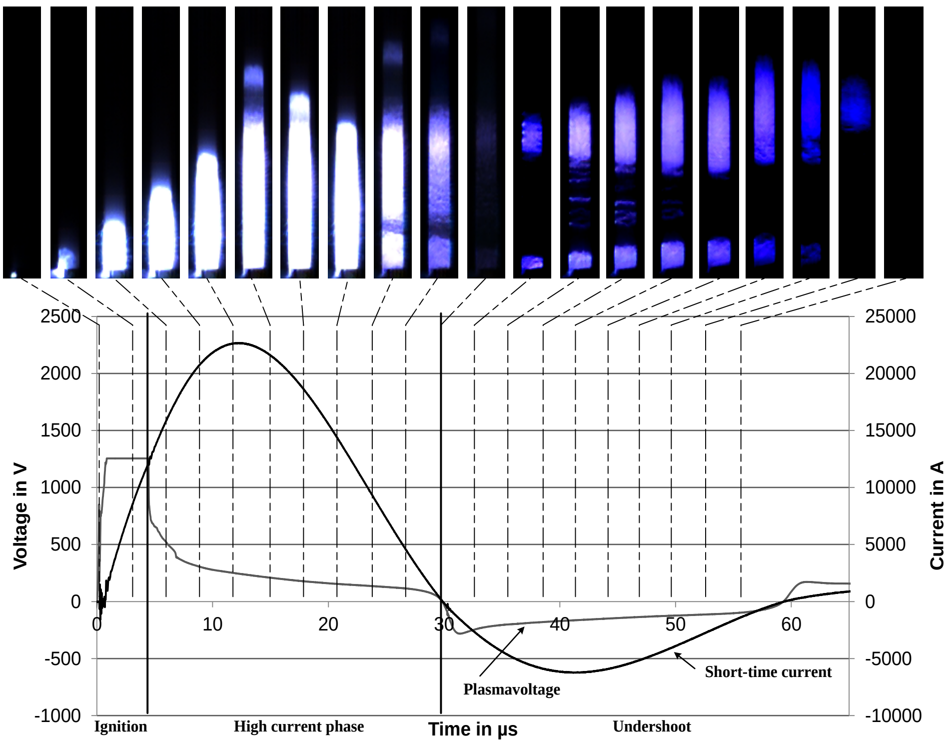

Fig. 4: Plasma propagation in a narrow gap by short-time current 23 kA, filter transparency 1,6 %, Modell spark gap A.

During the ignition phase the ignition aid initiate an electrical breakdown between the electrodes. In the high current phase a plasma front propagates towards the open end. As a result, a plasma channel is created. With a decreasing current the plasma decreases as well with an inertia. This is visible with the height and the luminance of the plasma. The plasma exists nearly invisible by low luminance during current zero. It ignites again in different positions during the undershoot phase. Several plasma channels are shaped by recurring current until it decays.

In the following the plasma propagation of the three different electrode geometries are presented for 5 kA, 11 kA and 23 kA. The images are taken at the current maximum in the high current phase. They show a segment of the spark gap, seen in Fig. 3

At currents of 5 kA the plasma propagation is nearly the same for the three different geometries (Fig. 5a). The plasma reaches in each of these a height of nearly 9 mm. The influence of the various geometries is not present in this low plasma spread. The upward trend is the same for all models with a minimal lateral spread for Model C because of the small electrodes. Models A and B have the same geometries of electrodes for the height of the plasma propagation.

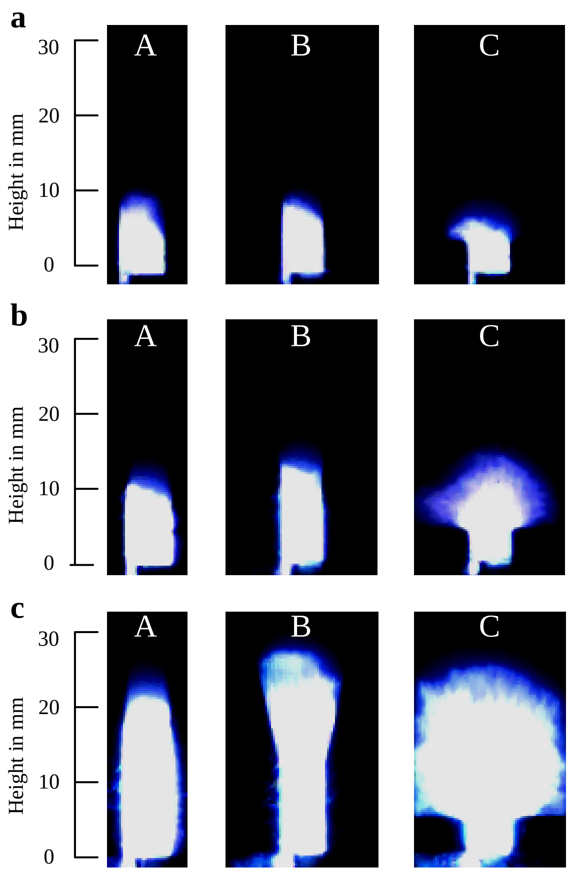

Fig.5: Plasma propagation in narrow gaps by short-time currents of 5 kA (a), 11 kA (b) and 23 kA (c) for three different geometries of electrodes, images at current maximum, filter transparency 6,25 %.

At currents of 11 kA the plasma propagation is reached at a height between 11 mm and 13 mm for all models (Fig. 5b). Hence, there is no difference in the shape of the plasma for model A and B. Model C shows differences. A significant lateral propagation above the electrodes can be seen because of the short height of 5 mm.

At currents of 23 kA the images show a high propagation of the plasma until 28 mm (Fig. 5c). The plasma in Model A propagates straight along the given electrode shape. Due to the higher current, the plasma spreads out in the model B over the parallel range of the electrodes. The diverging section allows a lateral spreading of the plasma. The current path between the electrodes becomes longer. The current flow through the electrodes remains in parallel like in Modell A with a little difference at the diverging part. For model C other conditions are valid. The plasma exceeds the electrodes and fills the area above the electrode to a height of 24 mm. Only a small area of 5 mm is drained by the current parallel. A much larger area of the plasma rises above the electrodes.

4. DISCUSSION

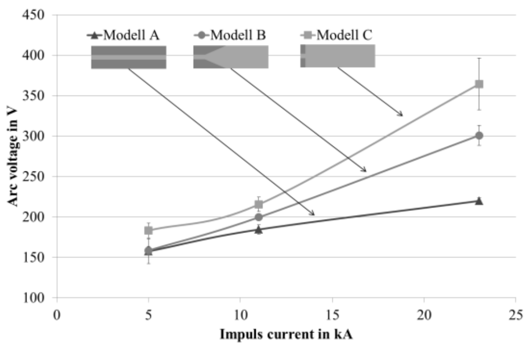

Fig. 6: Plasma voltage of three model spark gaps for different short-time currents [4].

In Fig 6 the plasma voltage is presented with the confidence interval for the three different currents. Further information can be found in [4]. At low current intensities (5 kA to 11 kA), the influence of the geometries is not as high as shown by the plasma voltage. At higher currents (23 kA) the influence increases. The highest influence is found for Model C, then for B and at last for A.

The images, shown in chapter 3, show a nearly equal plasma propagation for 5 kA and 11 kA. This is especially true for models A and B. Model C already shows small differences, which are reflected in a slightly higher voltage. For 23 kA the plasma propagations are more different between the models, which become also apparent in the voltage. Model A has a linear increasing trend with a parallel current flow. The result is a low plasma voltage with a low cooling effect of the chamber wall. Model B has the same propagation up to 15 mm above this, the plasma can spread laterally. The current flow is also parallel but longer than for Modell A. The result is a higher plasma voltage compared to that of parallel current flow. Modell C shows only a little parallel current flow in the lower part. Above 5 mm the plasma propagation spreads laterally and the current flow is not parallel. The plasma voltage is thus dependent on the plasma propagation and its shape as well as the current flow. The highest plasma voltage is recorded.

4. CONCLUSION

A visualization of the plasma propagation and a recording of electric measurements at short-time current of some microseconds were achieved. The results are in accordance to physical processes. A dependency between plasma propagation, current density and plasma voltage is presented. The arc voltage characteristic reflects model geometries and impulse current intensity.

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