ADVANCED MULTI-GAP PSEUDOSPARK SWITCH *

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Abstract

The design and initial operation of an advanced multi-gap Pseudospark device is presented. Forced grading of the intermediate electrodes in the switch will be achieved by taps on the charging transformer. Gap synchronization is aided by UV illumination of all gaps from the primary gap trigger. Initial switch operation in triggered and self breakdown modes and the resulting rise times is evaluated. The switch is intended to be the critical part of a 500 kV, 10 kA, 200 ns Transmission Line Transformer based pulse generator.

I. INTRODUCTION

High power, high repetition rate modulators and pulsed power systems require fast switches capable of operating at high current and high voltage. Transmission Line Transformer based pulse generators relax the voltage hold-off requirements of the main pulsed power switch by about a factor 2 or 3, but for a 500 kV, 10 kA, 200 ns output TLT generator the switch still has to hold off 200 kV [1].

The Pseudospark discharge can be used as a fast, long life, High Voltage (HV) switch [2, 3, 4, 5]. Commercial versions of Pseudospark switches are now available [4]. They compete well with traditional hot cathode type Thyratrons, and just as the Thyratron, they suffer from some limitations. One of the limitations is that the hold-off voltage for a single gap device cannot comfortably exceed 32 kV without impairing the switch lifetime. For applications requiring low current (usually < 2 kA), short (< 200 ns), pulses the switch can be operated in the glow discharge mode as compared with the high current (> 4 kA) superemissive mode, and then the lifetime limit due to electrode erosion is not a serious problem. For a limited number of pulses the breakdown voltage can be increased to ~50 kV, basically limited only by electrode surface induced vacuum breakdown effects. In this mode, the switch lifetime is limited not by significant electrode erosion changing the effective geometry of the main discharge gap, but by impurities and electrode and insulator surface changes leading to loss of voltage hold-off even in vacuum.

Attempts to overcome the single gap voltage hold-off limit led to the development of multiple gap structures. An optically triggered version, the so called Back-Lighted Thyratron (BLT), was investigated early and a two gap BLT was found to hold off 70 kV DC, and triggered at ~65 kV, and a three gap BLT has achieved 100 kV hold-off voltage at slightly lower pressure [6]. These experiments used stacked single gap switches, so the switch size was not optimized for the voltage hold-off achieved. The problem of overvolting the upper gaps and thus causing rapid degradation of the electrodes was solved by simultaneously triggering all gaps with the help of optical fibers. These fibers, however, caused impurity release and subsequent rapid deterioration of hold-off voltage. The impurity problem could be reduced by restricting the optical trigger to the cathode and opening up 5 mm diameter holes along the axis through the partitions between the gaps, so the upper gaps could be illuminated by the cathode gap. This Ultraviolet (UV) trigger of the upper gaps eliminated the problem of upper gap overvoltage and erosion.

More recent experiments aimed at optimizing a two gap electrically triggered Pseudospark configuration [7, 8]. Frank et.al., reported a doubling of the hold-off voltage at constant pressure using a flat disk middle electrode with a circle of holes displaced from the center, so no reduction

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of holdoff-voltage would result from long path effects along the axis.

Luo et.al., explored structures with both flat and hollow middle electrodes with single axial holes, and concluded that the hollow structure had a higher hold-off voltage, as expected [8]. Here, we follow this path of using a hollow middle electrode in a modular device, ultimately aiming for the development of a four-gap switch operating as the main element of a 200 kV, 10 kA, 200 ns TLT based pulse generator, with forced grading of the intermediate electrodes achieved by taps on the charging transformer as shown in Fig. 1.

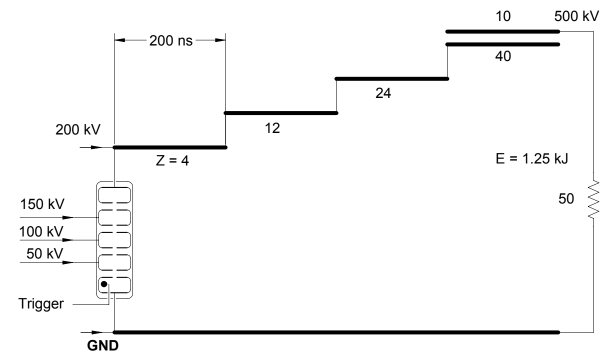

Figure 1. The four-gap Pseudospark TLT pulse generator. Each segment is 200 ns long. The impedances are noted next to each section. The last segment is a quasi-Blumlein DC isolation stage

II. DESIGN

The aim of this development is to build a reliable, compact Pseudospark switch operating at 200 kV. There are studies reporting procedures and formulas for the design of single gap pseudospark switches [9,10]. The basic cathode gap structure is based on such design information.

A. Electrode structure

Each gap is optimized to hold off the maximum voltage with comfortable margin to vacuum breakdown. The subsequent gaps are simply reproduced from stacking the single gap structures with the elimination of the redundant hollow cavities. The resulting switch configuration is similar to that reported by Luo et. al. [8].

The hollow cathode cavity is an essential part of any Pseudospark discharge. It is a cylindrical cavity, with 2.82 cm ID and 2.93 cm length. All central apertures are designed to be 3 mm diameter, and the electrode thicknesses are also 3 mm. All electrode gaps are designed to be 3 mm as well, although the first version of the switch, the operation of which we report here, has a gap of 6 mm, due to a mistake. The middle electrode is hollow to minimize the potential feed through from the high voltage electrode. The middle electrode cavity is 2.17 cm ID and 2.93 cm long. It may be possible to reduce the middle cavity length and we will explore such possibility in the future.

The high voltage electrode, or anode, is hollow to allow for current reversal without damage. The anode cavity is identical to the cathode cavity with the exception of the trigger wire opening.

All electrodes are made of Stainless Steel (SS304L) with molybdenum caps as the plasma facing components. The molybdenum end caps are attached by press-fit into the SS sockets. The insulators are Pyrex cylinders, 4.13 cm long. The electrode assembly hides all triple points, where gas, metal and insulator meet. In addition, the central discharge channel is displaced so that the insulators have no direct line of sight to the plasma.

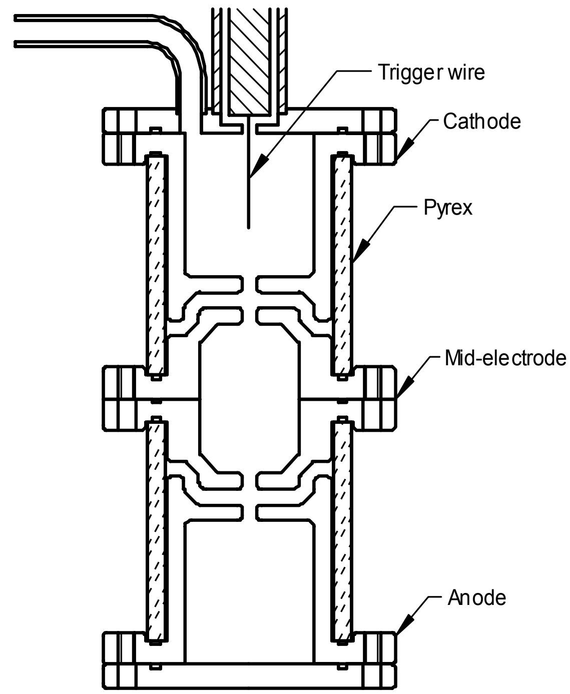

Figure 2. The Two-gap Pseudospark Structure. The intermediate electrode cavity reduces the potential feed-through from the anode.

B. Trigger arrangement

Pseudospark discharges have been triggered by many different methods. The discharge can be triggered optically, as in the BLT. The commercial FS2000 uses a keep-alive plasma and grid trigger. Modern versions of the electrically triggered Pseudospark employ the Corona igniter [11], and the surface flashover igniter [7].

Here, we chose a simple thin wire trigger which does not need a keep-alive discharge. The cathode structure hollow space houses the wire igniter. The trigger electrode is a 0.25 mm dia. tungsten wire, entering through a 3 mm aperture at the back of the cathode cavity. Applying greater than ~800V positive potential to this wire electrode it is possible to generate plasma in the cathode cavity at as low as 2 Pa pressure, significantly below the normal operating pressure range of the device.

Thin wire discharges have been used for many years in diverse applications and are very reliable plasma generators. Although the plasma density generated by thin wire discharges are somewhat limited due to the low dissipation allowed by the wire, it is adequate to trigger the device with reasonably short delay time.

The trigger generator is of the Flyback type, as shown on Fig. 3.

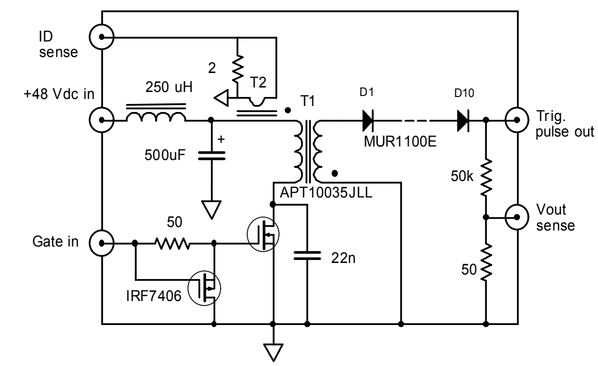

Figure 3. Flyback trigger generator circuit

The switch is triggered by applying a ~4 kV positive voltage pulse to the wire trigger electrode. The trigger pulse shape as measured at the trigger electrode is shown in Fig. 4.

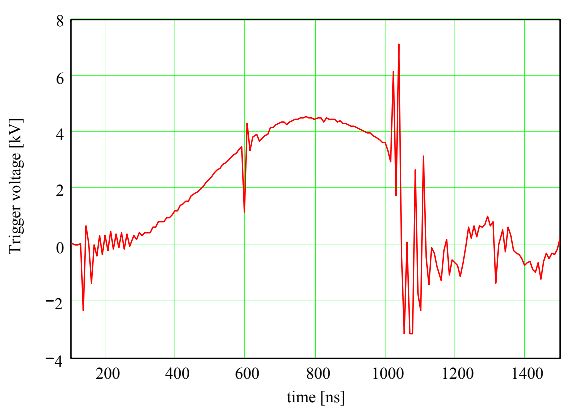

Figure 4. The trigger voltage as measured at the electrode. The switch closes at ~1 µs.

III. OPERATION

The electrical circuit used for preliminary testing of the prototype switch is shown in Fig. 5. The cathode electrode is at ground potential. A Glassman 60 kV DC supply is connected to the anode through a 500 kΩ current limiting resistor. A set of eight 2 nF / 40 kV ceramic capacitors are connected in parallel to form the 16 nF discharge capacitor. Two series connected 2 nF / 40 kV rated ceramic capacitors, each with 3 MΩ grading resistors in parallel, form a high speed, low impedance grading structure similar to that shown in [7] and similar to the low impedance that is expected of tapped transformer forced grading. The trigger delay time is expected to be significantly reduced by this grading arrangement.

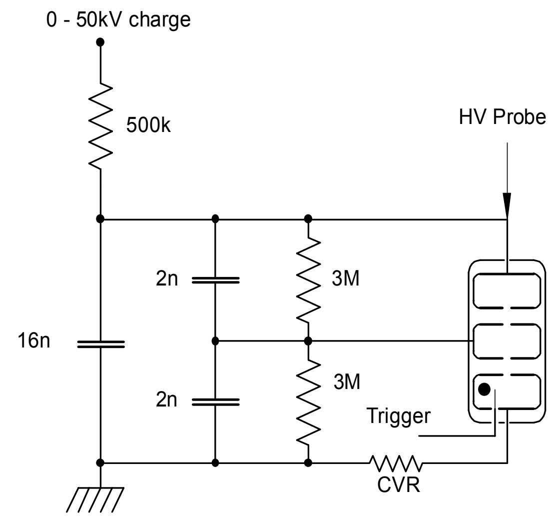

Figure 5. Switch prototype test circuit

Single and double gap breakdown voltages versus air pressure are shown in Fig. 6. The regions of reliable triggered operation are within 15% of the self-breakdown voltage.

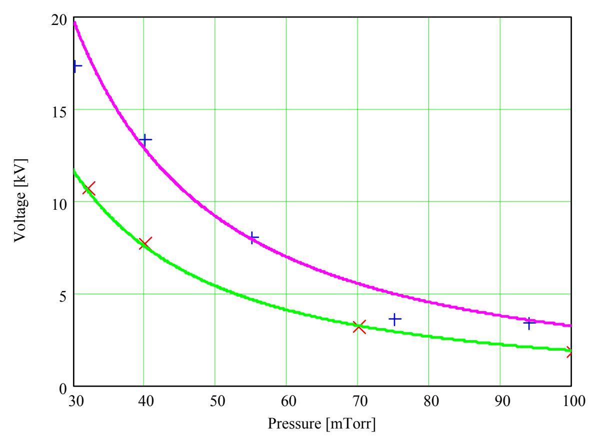

Figure 6. Single and double gap switch Paschen curve in air. The double gap holds ~1.7 times the single gap voltage.

In self-breakdown mode the upper gap usually fires earlier than the cathode gap. An example of this is shown in Figures 7 and 8. The grading capacitor across the upper gap rings and the voltage rises to 1.5 times the charging voltage at which point the lower gap breaks as well. This is due to the upper gap having a slightly larger distance and thus lower breakdown voltage. This problem will be eliminated in the improved version, with the correct 3 mm gap spacing under construction.

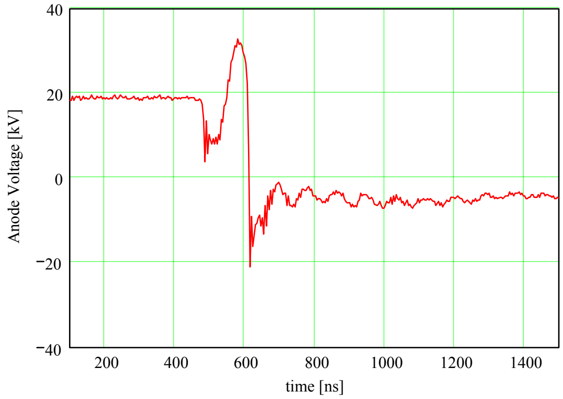

Figure 7. Anode voltage trace shows the premature firing of the upper gap.

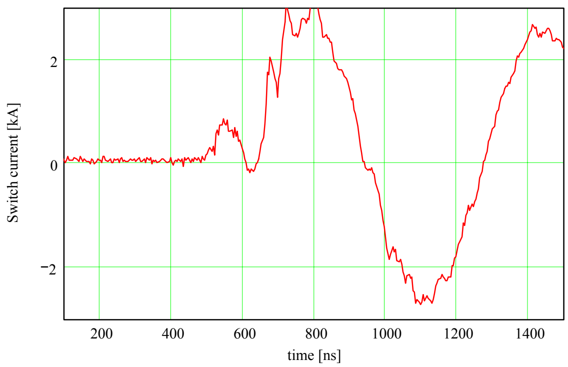

Figure 8. Switch current starts flowing after both gaps are closed.

IV. SUMMARY

We have described the design, construction and preliminary operation of an advanced multi-gap Pseudospark switch. Reliable long life operation is expected to be made possible by the elimination of overvoltage breakdown across the upper gaps using UV illumination from the cathode gap.

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