THREE ELECTRODE SPARK GAPS WITH ELECTRODYNAMICAL ACCELERATION OF THE DISCHARGE CHANNEL *

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Abstract

IHCE and ITHPP have been developed for CEA (LMJ power conditioning) an alternative for ignitron switches. This alternative is a spark gap switch where the spark is initiated in a three electrode layout and then accelerates due to electro-dynamical force and moves along the two extended electrodes. At a given current amplitude the diameter of the extended electrodes allows to control the spark velocity and hence the erosion of the electrodes providing the required life time.

Two versions of such spark gaps are developed and tested: one for the pre-ionization and the other for the main circuits. First is designed for 24 kV charge voltage and ~4 C total charge transfer. This spark gap was tested at 25 kA peak current in 40,000 shots in a single polarity discharge and in 20,000 shots in bipolar discharge. Second spark gap is designed for 24 kV charge voltage and ~70 C total charge transfer. It was tested in 22,000 shots at a current of 250 kA with a pulse length of 360 µs.

In the report we present the design of these spark gaps and the thyristor trigger generator, describe the test bed and show test results.

I. INTRODUCTION

LMJ (Laser Megajoule) facility is now under development by CEA, France [1]. High voltage switch with high Coulomb transfer is one of the critical components of its power conditioning system. Several candidates are evaluated now, including but not limited to pseudospark switch, Maxwell high pressure gas switch, Titan rotating arc switch. The main criteria of the evaluation include stable performance during 20,000 shots for the main and 60,000 shots for the preionization switches, easy and cheap mass production, environmental safety. This report shows that the developed spark gaps are simple and reliable devices, and satisfy the requirements for the LMJ power conditioning system.

II. TEST BED SETUP

Fig. 1 shows the equivalent electrical schematics of the test bed discharge circuit. Here C1 is the preionization capacitance, C2 – capacitance of the capacitor bank, R2 – load resistance, L – pulse shaping inductance.

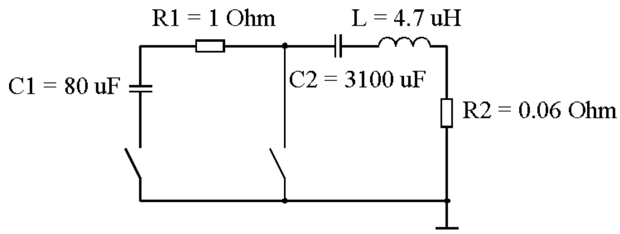

Figure 1. Schematics of the test bed circuit with the main and preionization capacitors connected to the load.

The capacitor bank for in the main circuit (see Fig. 2) is assembled of 10 parallel TPC capacitors (310 µF, 24 kV). The preionization capacitance consists of 2 TPC capacitors (40 µF, 24 kV). Switches are mounted in the middle of the bank. Both preionization and main switches operate in dry air at atmospheric pressure with purge after each shot. The load is located on the back side of the capacitor bank.

* Work supported in part by CEA under contract number 4600051101

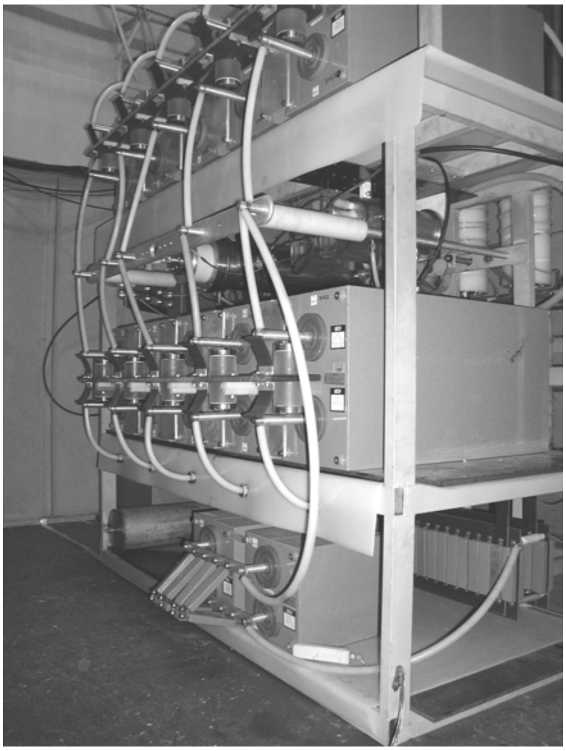

Figure 2. Picture of the test bed.

III. PREIONIZATION SWITCH DESIGN AND PERFORMANCE

Figs. 3 and 4 show the picture and the design of the preionization switch. Sleeve for the car sparking plug 5 and pipe connectors for air purge are welded to the stainless steel body 4. High voltage electrode 1 is fixed by two insulators. One side of the low voltage electrode 2 is welded to the switch body, the opposite side is isolated. The total length of the switch is 540 mm, the diameter is 186 mm. The trigger electrode 3 is fixed on locates between the high and low voltage electrodes.

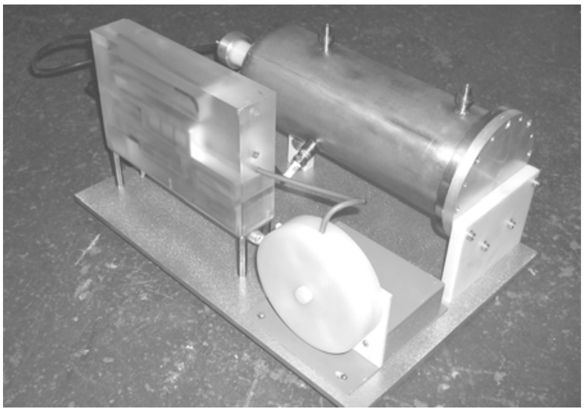

Figure 3. The preionization switch.

The car sparking plug (without internal resistor) is used as an UV source. Assembled switch is mounted on a console (Fig. 3), together with the trigger and high voltage distribution blocks. The last is used to deliver $(1/3)U_{CH}$ to the trigger electrode during charging.

All electrodes are made of Cu because the preliminary experiments have shown that the erosion of the electrodes made of Cu is much less than that made of stainless steel (probably due to higher heat conductivity of Cu). The switch was tested in 60,000 shots in total at 24 kV charge with reduced cleaning and maintenance, including 20,000 at 4 C in bipolar discharge and 40,000 shots at 2 C in single polarity discharge. No one prefire or misfire was observed in all these shots. When the switch was opened, no metal debris were observed on the insulators. The erosion of the electrodes was small and the inter-electrode gap did not change. The self breakdown voltage remained the same as it was at the beginning (48-50 kV). Lower limit of triggering remained 18 kV at atmospheric pressure. The delay between the trigger and the switch firing did not exceed 1 us at 24 kV charging voltage. The length of the erosion spot was ~ 7 cm in shots at 2 C and ~ 13 cm after shots at 4 C. Fig. 5 presents typical current in the preionization circuit in bipolar discharge at 4 C.

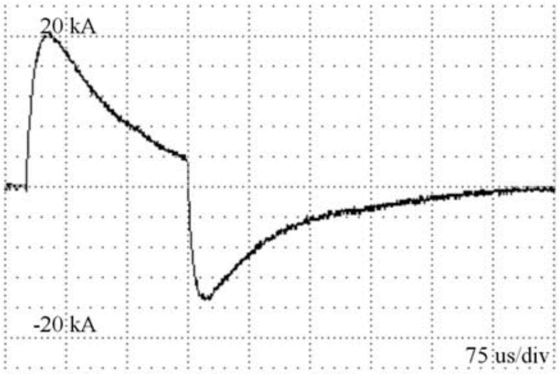

Figure 5. Current trace in the preionization circuit at 24 kV charge, 4 C charge transfer.

IV. MAIN SWITCH DESIGN AND PERFORMANCE

Unlike the preionization switch, the main switch was modified several times. First prototype was designed with flat electrodes supported by insulators on both ends. Small diameter inserts were made on the electrodes in order to enhance the magnetic field and thus increase the speed of the arc propagation. After ~ 1000 shots the switch was opened to examine the condition of the parts. The insulators were dusted, central parts of the inserts changed their shape increasing the gap to the electrodes. As a result, the region where the spark shifts from the inserts to the electrodes became eroded rather strong.

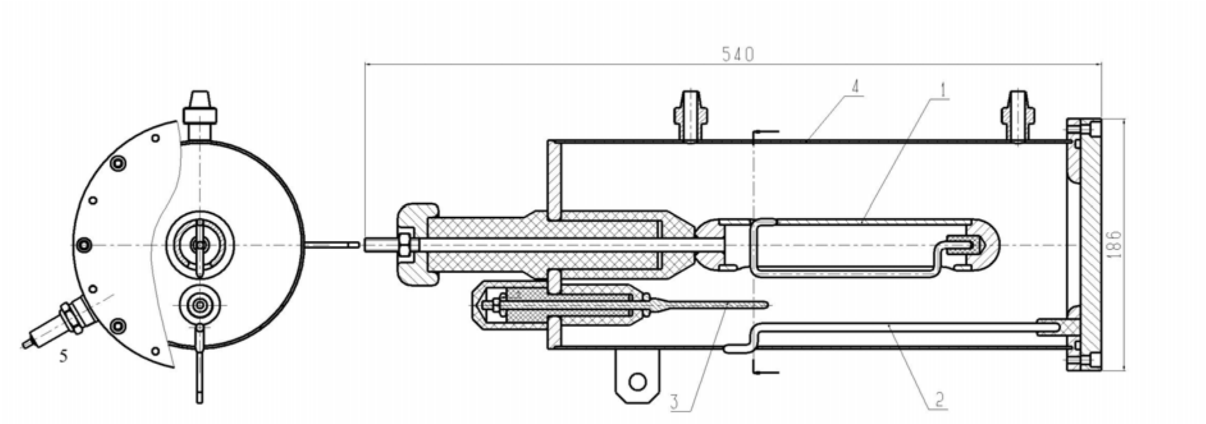

Figure 4. Design of the preionization switch.

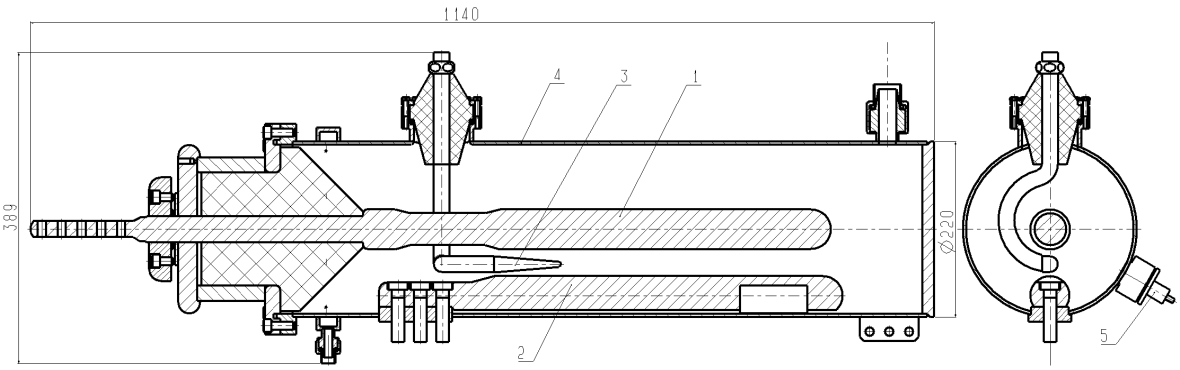

Figure 6. Design of the main switch

In second prototype both high and low voltage electrodes were made of 50 mm diameter Cu rods with holes along the axis and perforated fissures increasing the local magnetic field. The high voltage insulator was removed from the region with the moving spark. Tests have shown that in this prototype the erosion of the electrodes and the debrising of the insulator were sufficiently reduced, but after ~ 7.000 shots the high voltage electrode was damaged because of mechanical force loading the electrode during the shot.

In third prototype (which turned out to be the final design) the high and low voltage electrodes were made of solid 50 mm diameter Cu rods without of holes and perforation. In the main switch the current rise time is about 10 times longer than that in the preionization switch, resulting for the given diameter of the electrodes in approximately the same rise rate of the magnetic field in vicinity of the electrodes as that in the preionization switch. The design of this switch is shown in Fig. 6, it was tested in 22,000 shots at 24 kV charge voltage and 70 C charge transfer with reduced cleaning and maintenance.

The idea of this switch is very similar to that of the preionization switch. The high voltage electrode 1 locates on the axis of the switch. One side of the low voltage electrode 2 is connected to the switch body, and the other side is isolated from the body. Trigger electrode 3 locates between the two main electrodes. Vertical position of the trigger electrode can be adjusted by special washers, during charging this electrode stays at (1/3)U_{CH}. Total length of the switch is about 1100 mm, the diameter is 220 mm. Assembled switch with trigger and high voltage distribution blocks is mounted on a console in same way as the preionization switch. Fig. 7 shows typical waveform of the current in the main switch circuit.

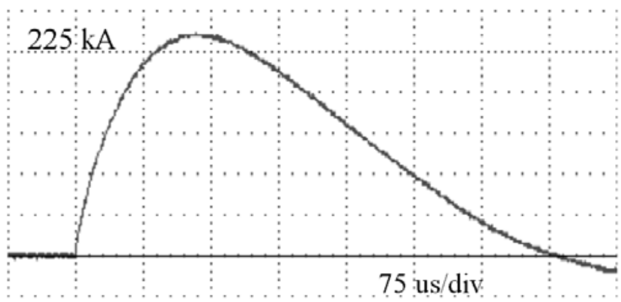

Figure 7. Typical current trace in the main switch at 24 kV charge voltage and 70 C charge transfer.

After the main set of life time shots at atmospheric pressure was competed, an additional experiment has been carried out at reduced pressure to check the possibility to operate at lower voltage. Table 1 presents the delay and jitter at specific charge voltage and pressure for the main and preionization switches observed in 15 shots at each pressure by using the thyristor trigger generator (see Section V).

Table 1. Test at reduced pressure.

P, ata	U, kV	Main switch		Preionization switch	
		t, ns mean	σ, ns rms	t, ns mean	σ, ns rms
1.0	24	437	34.6	802	99
0.9	22	473	30.3	690	26.5
0.8	20	458	37	663	32
0.7	18	482	58	693	44
0.6	15	559	107	1872	689
0.4	10	740	142	1923	444

Fig. 8 shows the main switch being installed into the capacitor bank.

Figure 8. The main switch in the capacitor bank.

V. TRIGGER CIRCUIT

Main part of the shots has been done by using the thyratron high voltage trigger generator. The thyristor trigger generator which is cheaper and simple in manufacturing was developed for the use with the mass production switch. Thyristor generator consist of the control and triggering blocks that are assembled in separate boxes and connected by two coaxial cables (see Fig. 9). Triggering block is based on a pulsed step-up transformer.

The thyristor trigger generators were tested in about 5000 shots during the life time tests of the main and preionization switches. Fig. 10 shows typical output pulse of the thyristor trigger generator providing ~ 50 kV amplitude.

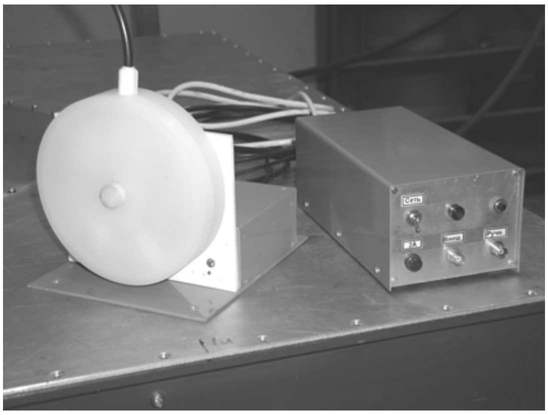

Figure 9. The thyristor trigger generator consisting of 2 blocks.

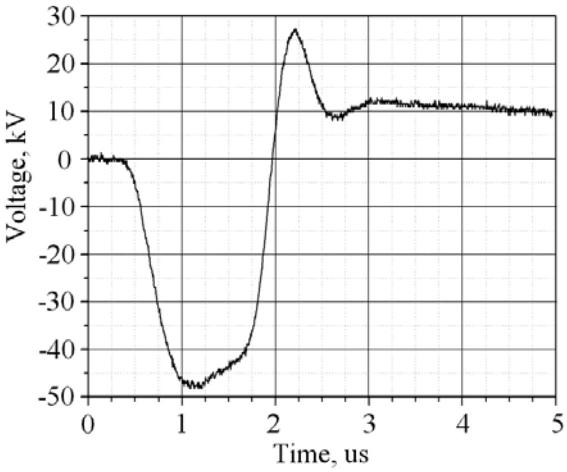

Figure 10. Output pulse of the thyristor trigger generator.

VI. SUMMARY

The electrodynamic acceleration of the arc combined with proper material and geometry of the electrodes allows to produce the switches able to transfer tens of Coulombs in tens of thousand shots without of any maintenance. The developed switches operate during the life time without of misfires and prefires, and can be triggered by simple thyristor trigger generators.

VII. REFERENCES

[1] J.M. Mexmain, D. Rubin de Cervenes, J. P. Marret, et al., "Pulsed power conditioning system for the megajoule laser", Proc. 13th IEEE Pulsed Power Conf., 2003, p. 89.