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Power delivery to the liner load in the Baikal generator for ICF experiments

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Abstract

A multi-gap megavolt-range vacuum closing switch is planned to be employed in the scheme of the Baikal superpower generator. The switch will be placed between multiple POS modules and the liner load to improve the front of the megaampere current pulse. Experiments aimed at increasing the electrical strength of the vacuum gap prototyping the gap of the vacuum switch are reported.

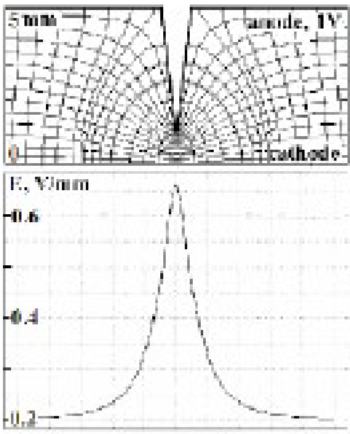
Introduction

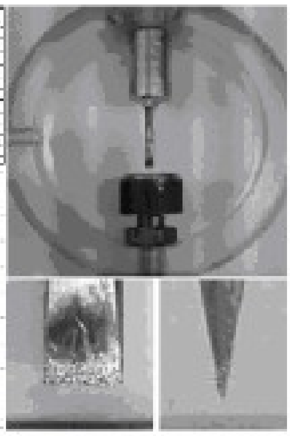
In the Baikal program to create a new superpower generator a MOL [1] single module facility is employed to prototype the scientific and engineering solutions [2, 3]. The output stage of the power conditioning system in the MOL machine will use a multi-module POS system. To synchronize POS modules and provide effective current pulse delivery to the load it was proposed place the closing switch (CS) between the POS output and the load. If the load has low impedance CS assists in such current redistributions in the POS modules that results in simultaneous growth of their impedances and closure of the CS which is shortening the vacuum gaps with a high voltage pulse appeared when POS opens [2].

When the system of several parallel POS modules employing applied external magnetic fields to create additional magnetic insulation of their plasma-vacuum gaps and the CS are used together it might be possible to switch the current effectively so that POS plasma erodes and the vacuum gaps in all POS modules form. This prevents undesired reclosure of the POS modules when the current pulse starts delivering to the low-impedance load.

Experiments

Experiments modeled the non-linear low-impedance load with a capacitor. In this case near 25% of inductive storage energy can be delivered to the load [3, 4]. A multi-gap CS with explosive emission electrodes has been employed [5]. Near 10 ns closing times could be achieved. However, this scheme has low electrical strength of the 1 mm vacuum gap. This requires increasing the total number of vacuum gaps to 50, which is not acceptable as being too complex. This contribution considers increasing the electrical strength of the vacuum gap retaining its fast closing times. It is proposed to use an electrode system with sharp anode and flat cathode. In this system the electric field strength is concentrated near the anode. Fig. 1 illustrates the electric field distribution in the proposed geometry.





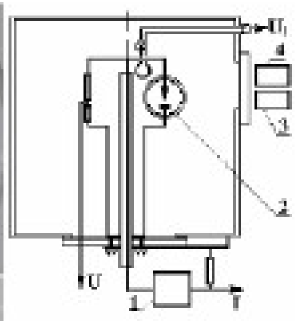


Fig.1 (left) Distribution of electric field. Fig.2 (centre) Photograph of the sharp anode test-bench. Fig. 3 (right) Experimental set-up: U – voltage monitor signal, 1 – pulsed voltage generator, I – current signal, 2 – closing switch, 3 – 50 ns electron-image converter, 4 – camera, U_I – dI/dt signal.

Maximum electric strength under the spike near the cathode surface achieves 0.66 V/cm with 1 V applied to the anode. With plane electrodes the electric strength is 1 V/cm. The test bench used in the experiments (Fig. 2) was created to measure the electric filed strength for the proposed geometry. The linear current density was 2 kA/cm and charge density 0.2 mK/cm. The current and charge densities were chosen to corresponde those of the MOl facility (6 kA/cm, 1 mK/cm). The test-bench was tested with a Marx-type voltage generator with C=1 nF, U=(40-120) kV, ?=25 Ohm. Fig.3. illustrates the experimental setup. The voltage monitor is placed closely the discharge circuit and the current starts when the voltage drops to zero, when the gap resistance becomes lower than wave resistance of the circuit.

The waveforms of the electrical signals are reported at Fig. 4. The moment of current appearance is 25 ns delayed with respect to the breakdown beginning. The photographs made by electron image frame camera (Fig. 4) illustrate that side surfaces of the anode are bombarded. It shows that the radial plasma luminescence moves from the anode to the cathode, cathode plasma expansion is also observed under the sharp edge of the anode. The electron bombardment of the anode surface can be observed at Fig. 2. Another experiment employed a circular switch with the edge length 50 cm (fig. 5). It was tested with more powerful pulses Ñ= 0,8 ?F, U=(40-120) kV, ?=1,9 Ohm, with linear

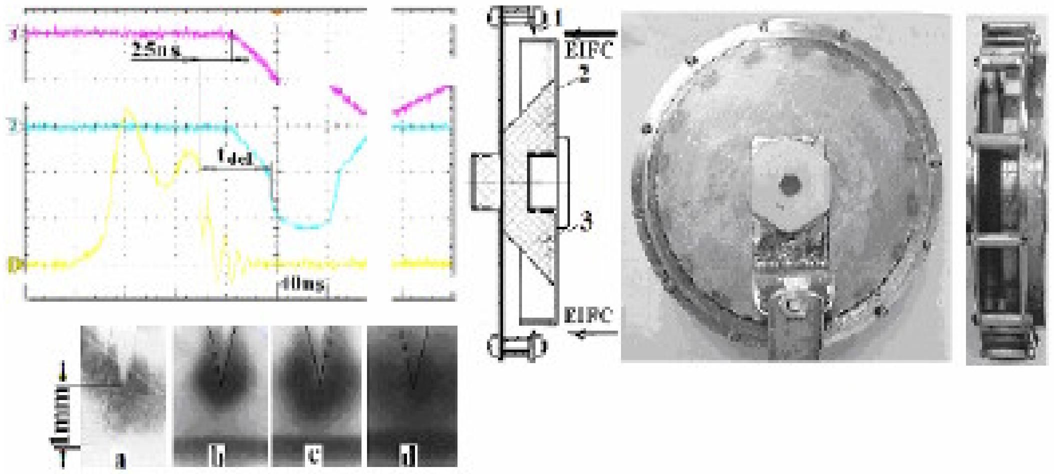


Fig. 4. (Left side) Top: 1- switch voltage (50 kV/point), 2 – electron image camera pulse, 3 – switch current (2kA/point). t_{del} – delay time between the voltage and the electron image camera pulse. Bottom - Electron image frames exposition 50 ns. a) - gap photograph, b) - t_{del} =60 ns; c) - t_{del} =100 ns; d) - t_{del} =200 ns. U= 100 kV. Fig. 5. (Right side) Switch cross-sectional view (left) and photographs of the switch from top (center) and side view Figure captions: 1 – anode ring - sharp edge, 2 – cathode, 3 – insulator.

density of current and charge 0.4 kA/cm and 6 mK/cm respectively. The signal wave forms at Fig. 6 illustrate the breakdown duration is near 40 ns if consider the time between the breakdown initiation to the shortening. With voltage increasing to 150 kV the current appearance delay is reduced to ~20 ns. Voltage from the voltage monitor and the signal of the loop dI/dt allow recalculating the energy spent during the switching. It can be estimated as ~ 0.1 J/cm. This energy weakly depends on the voltage switched as the duration of the active phase is reduced when the voltage increase. Fig. 6 illustrates that number of breakdown channels increases with the increase of the voltage. The number of channels does not change within whole duration of the current pulse. The switch kept its parameters unchanged after 1000 shots. Fig. 7 illustrates the function of the hold-off voltage for various types of electrodes limiting the vacuum gap. The annular edge-to-plane gap has higher electric strength than the one could be expected from filed simulations (fig. 1). One of the reasons for electrical strength increase is change of the directions of electric field (Fig.1) and anode plasma expansion resulting in bombardment of 1 mm anode area. Another reason for electric strength increase is a reduction of effective surface area. Employing circular closing switch with sharp anode allowed achieving higher electrical strength of 1 mm vacuum gap 2.5-4 times compared to plane electrodes.

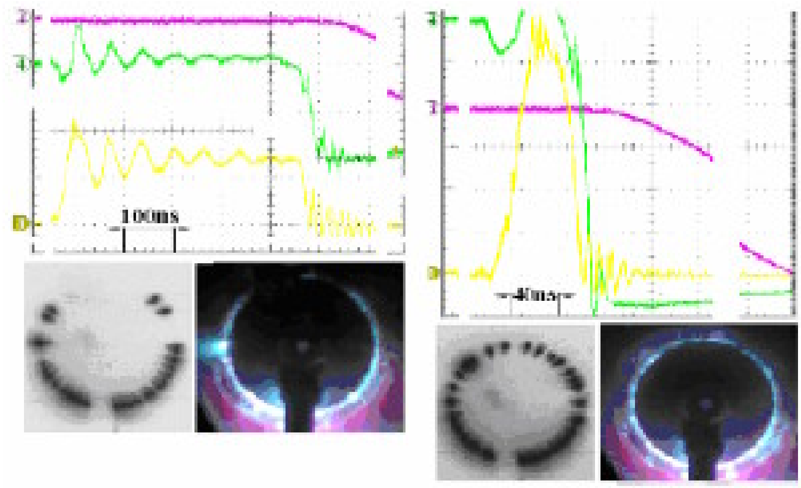


Fig. 6 Top: 1 – voltage (25 kV/div), 3 – dI/dt signal ($8x10^9$A/div), 4 – current (12.5 kA/div). Bottom: electron image frame 100 ns after current beginning and integral photo.

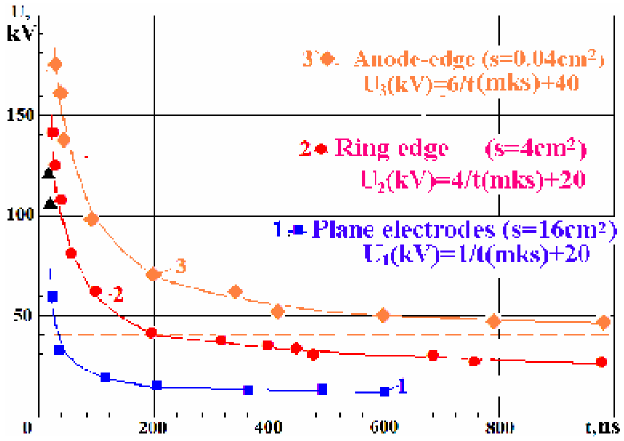


Fig.7. Pulse duration as a function of the hold-off voltage for various types of electrodes

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