EXPERIMENTAL INVESTIGATION OF POS

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Abstract

The performance of a plasma opening switch has been studied experimentally using a ns pulsed power generator (600-800 kV, 40-60 ns) and also a small capacitor bank (20 kV, 15-20 kA, 0,25-1 μs). It has been shown that the initial stage of POS action is related to the formation of the cathode plasma. The reproducibility of results is related to that of the cathode plasma light emission pattern. Switch opening occurs at any load and the increase of POS resistance weakly depends on that of the load. The physics of opening is related mainly to some internal mechanism. It has been shown that a partially neutralized high-current electron beam directed to the load is formed at the final stage of switch opening. The appearance of this beam in the downstream coaxial structure or in the load diode limits the open POS impedance and explains the reported effect of decreased diode impedance that occurs even for large anode-cathode gaps.

Introduction

One of the possible ways to construct a compact high-power inductive-storage pulse generator for particle acceleration is based on plasma opening switch (POS) application [1,2]. POS operation research has been carried out over a wide current range for both short (≳100 ns) and long (~1 μs) conduction time. Most of the known results are summarized in the special issue of IEEE Trans. on PS [2]. Some new results have been obtained in experiments at P.N.Lebedev Physical Institute, Moscow, that can facilitate POS physics understanding. In particular, it has been shown that the final stage of switch opening is accompanied by high-current neutralized electron beam directed toward the load.

Experimental setup

The basic diagram of the coaxial experimental setup is shown in Fig.1. The POS region consisted of a coaxial inner cathode (diameter of cathode is varied from 2 to 6 cm) and outer anode of 21 or 31 cm diameter. The plasma with front velocity $v_p \approx (1-1.2)\cdot 10^7$ cm/s flows through the windows in the anode toward the inner conductor. We use two Mendel-type coaxial plasma guns or multi-spark stripline plasma source (flashbord type). The plasma sources are fired 2-3 μs before firing the current generator. Two types of generator are used in the experiments: ns pulsed power accelerator (11 Ohm, 600-800 kV, 120 ns) anda small capacitor bank (0.5-1.0 μF) that charged to 15-20 kV. For the high power machine, current rises up to 60 kA in 60 ns, and for the small scale experiment - up to 20 kA during 1.2 μs.

Standard diagnostics include a compensated for L·di/dt voltage divider and a set of current monitors to measure total upstream current I_0, downstream currents at various positions I_1, I_2, and collector current I_c of the load diode. Besides these the following instruments are used: a set of filtered pin-diodes to measure X-ray signal for electron energy calculation in high voltage experiments and time-resolved image converter tube to observe the luminosity from the POS region. For optical observations both coaxial and planar POS regions (Fig.2) are used.

Experimental results

Switching operation is closely related to pre-electrode phenomena, in particular to formation of dense cathode and anode plasma. Cathode plasma is formed during the initial stage of current flow through the POS. Optical measurements show that plasma formation occurs nonuniformly on the cathode surface (see Fig.2 for a plane POS). The light emitting zone on the cathode is formed initially near the generator end of POS region. This means that current through the POS flows nonuniformly. The reproducibility of current level at switch opening occurs is related to that of the cathode plasma light emission pattern. It may be improved by relativly weak magnetic field, generated for example by current along the cathode. The plasma light emission is more uniform if we use a low impedance resistor as the load (1 Ohm). Explosive emission is the most probable mechanism of cathode plasma formation.

Anode plasma glow appears only during the stage of increasing voltage on the POS. Its region of formation is displaced in the direction of the load, visually demonstrating disortion of electron trajectories (Fig.2).

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The current level at which switching occurs practically does not depend on the parameters of the external circuit, but is determined by the parameters of the plasma injected into the POS region. The rate of POS resistance growth during the switching stage practically does not depend on the load resistance. These results indicate that there exists an internal mechanism of POS action.

This is demonstrated by measurements performed in a no-load regime, when the electrodes of a butt diode were separated by a 40-cm drift gap. Typical oscillograms of current and voltage pulses are presented in Fig.3. A rapid rise in a POS voltage begins at the instant when current drops. A collector shunt registers a current of 8 kA with some delay relative to this instant. A pure electron beam with such a current cannot traverse a significant distance in vacuum, since it quickly decays on the walls of the chamber under the action of space-charge forces. Hence, the observed flow must be at least partially charge-neutralized. As can be seen from the oscillograms, the maximum voltage on the POS is nearly 30 kV. For beam propagation with such energy of electrons neutralization factor n_e/n_i must be close to 1, because even for force balance $n_i \sim n_e/\gamma^2$, where $\gamma = 1 + eU/mc^2 \sim 1$ for $U \sim 30$ kV.

Beam current pulses registered for one shot at various distances from the POS region are shown in Fig.4. Current monitor I_3 is located at the end of the added vacuum chamber of 60-cm length and 11-cm diameter. Using the measured time delay between the moments of rise of currents, we can calculate a mean beam front velocity. It is close to the velocity of protons that have energy eU, where U is POS voltage. Approximately the same picture is observed in high-voltage experiment, but in the MV voltage range the time delay is an order of magnitude less. It should be noted that the form of the current pulse changes as it is propagated. This indicates that there is considerable spread in the energy of particles.

Current decreases relatively slowly during propagation. An analogous picture can be observed when high-current beams are transported in vacuum channels with dielectric walls and when using a Luce diode. The decrease in amplitude of current pulses is due to some electrons hitting the chamber wall as well as to the change in pulse form as a result of the large energy spread. The steepness of the pulse edge increases during propagation.

Beam diameter at various distances from the POS region was estimated from witness plates. Near the cathode butt, beam diameter is close to 15 cm and decreases to 6-8 cm at the chamber butt during propagation. Additional beam focussing probably occurs due to the appearance of additional positive charge as a result of ionization of molecules of residual gas ($(0.5-1)\cdot 10^{-4}$ Torr) during pulse duration.

A biased Faraday cup (FC) was used to determine the beam energy spectrum. The scheme of measurements is shown in Fig.5. Oscillograms of FC current pulses for various values of initial bias voltage on the capacitor are presented in Fig.6. The duration of current pulses--even for small bias-decreases from several microseconds to 200-250 ns (at half-amplitude) due to cut-off of low-energy electrons of the "tail". When bias voltage is increased beyond $|U_{bias}| > 25$ kV, electron current is practically not registered. Oscillograms indicate that there exists a broad spectrum of electrons with an upper limit of about 25 kV.

The generation of a compensated electron flow constitutes one of the characteristic features of POS, related to the mechanism of operation. This flow is formed at the stage of current switching. The impedance of neutralized beam may be quite small, so that the beam shunts the load diode and limits the possibility of increasing voltage. In our experiments the voltage amplification does not exceed 2 for both high-power accelerator and small-scale experiment.

The obtained data explain the previously observed effect of anomalous low impedance of a butt diode in a POS system. It should be noted that such a low-impedance high-current beam, as well as a simple method of its generation, can be independently of interest for a number of practical applications. The obtained results go beyond the known theoretical model [3]. On the basis of analysis of all the experimental data, a model [4] is proposed that involves the formation and evolution of Hall layers in the POS plasma. A detailed description of the model is given in separate paper at this conference [5].

References

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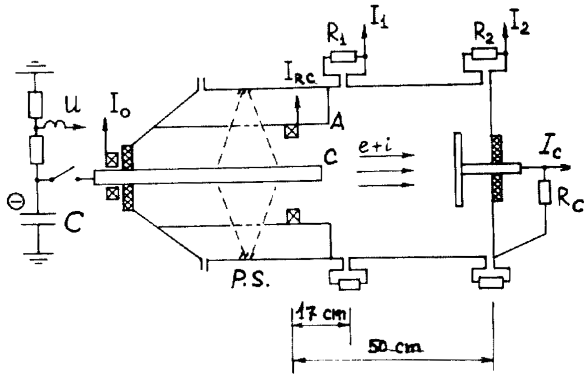

Fig. 1. The basic scheme of the coaxial experimental setup.

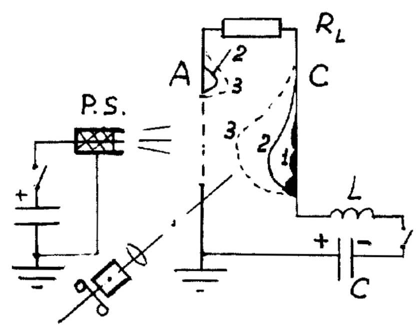

Fig. 2. Planar POS region for the optical observations. 1, 2, 3-cathode and anode plasma boundaries for unloaded POS at various moments: beginning of total current rise, fast increase voltage on the POS and the end of current pulse.

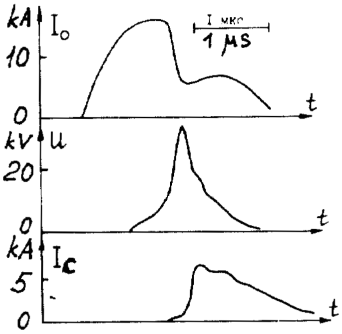

Fig. 3. Typical oscillograms of the total current, POS voltage and collector current for unloaded POS small scale experiment. The distance between the cathode and collector plate is 40 cm.

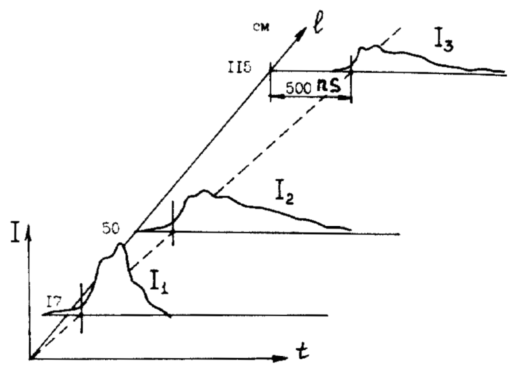

Fig. 4. Electron beam current pulses at various distances from the switch region, recorded for one shot.

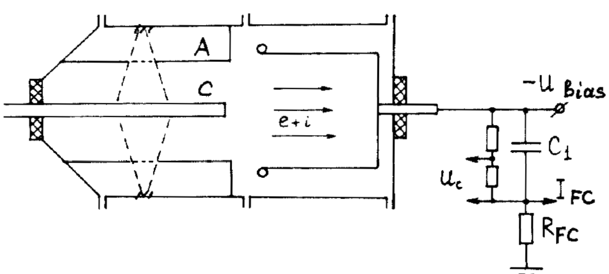

Fig. 5. The scheme of biased Faraday cup measurements C = 0.1-0.5 µF.

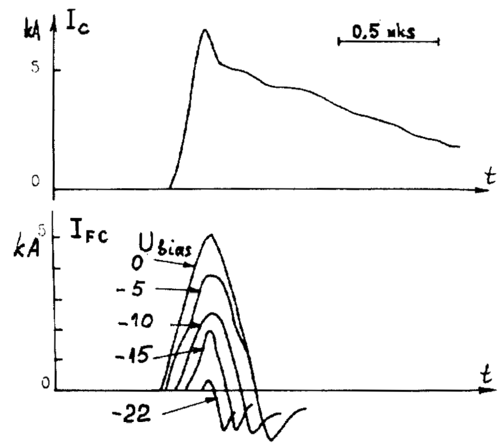

Fig. 6. Faraday cup current pulses for nonbiased (capacitor is shorted) and biased regimes U_{bias} is initial capacitor voltage.