INVESTIGATION OF HIGH-CURRENT PLASMA OPENING SWITCH AT LOW GAS PRESSURE

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The high-current plasma opening switch (POS), combined with the inductive energy storage, can be applied in the power electron accelerator of nano- and microsecond operation. The POS discharge characteristics should be stabilized and controlled. In the present work the POCS behaviour in dependence on gas pressure, kind of gas, time input of plasma density, its spatial distribution, extent of plasma ionization, its averaged charge has been investigated to attain the commuted current enhancement.

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I. INTRODUCTION

The obvious advances in deriving and researching heavy-current pulses of electron current and in clearing up the physical operation principles of electron accelerators of a direct action with the plasma opening switch are reached. However, it is expedient and necessary to research the physical and engineering peculiarities in creation and operation of similar devices in order to realize calculated modes of their operation. In the present work the experimental results of research on some features of the electron accelerator DI operation with the plasma opening switch (POS), in particular, filling the discharge gap with plasma at low gas pressure, are given and the switch efficiency is determined.

II. EXPERIMENTAL SETUP AND METHODS

The schematic diagram of the small-sized accelerating installation DI [1] with a plasma current switch is represented in Fig. 1. It comprises: vacuum chamber having ∅200 mm and 350 mm height with a set of electrodes, plasma guns and magnetic coils, generator of pulsed current (GPC), power sources of plasma guns and magnetic field, units of start-up and synchronization, noise protection tools, diagnostic infrastructure, pumping post. The compactness of the accelerator DI is illustrated by the weights of following components: vacuum chamber –15 kg, GPC - 200 kg (140 kg), feed of plasma guns - 46 kg (2 kg), feed of magnetic field - 12 kg (3 kg), units of start-up and synchronization - 5 kg, noise-protection and diagnostic tools - 7 kg, pumping post - 30 kg, measuring equipment - 28 kg, assembly frame - 17 kg. The total weight is 360 kg that makes the accelerator DI a convenient device to transport. The transition to pulsed converters of voltage allows to reduce essentially the mass of feeding devices (see the figures in brackets) and the final mass of the accelerating installation up to 200–230 kg. Its overall dimensions are 180×120×60 cm. Basic electric parameters of the accelerator DI by primary circuits are the following: voltage at the central electrode (cathode) up to 50 kV, capacity of the accumulating capacitor 3 µF, its inductance 40 nH, inductance of plasma current switch 122 nH, inductance of load (diode) 5 nH, power supply voltage of plasma guns up to 15 kV. The filling of discharge gap with plasma was carried out using 12 plasma guns of planar types [2] disposed uniformly in the equatorial plane of the vacuum chamber. The installation of DI is provided with the following tools of diagnostics: belts of Rogovsky for measurement of switch current and load current of accelerating diode, capacity divider for measurement of voltage on the cathode, X-ray transmitters of integrated and scintillation types, microwave interferometers at a frequency of 35 GHz for measurement of plasma density injected into the discharge gap with the help of plasma

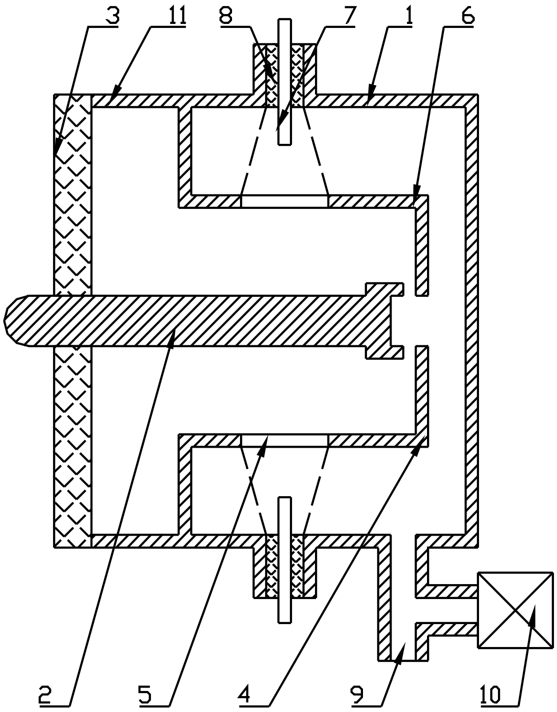

Fig. 1. *A schematic diagram of the accelerator DI: 1 - vacuum chamber; 2 - cathode; 3 - insulator; 4 - anode; 5 - slit-like slots; 6 - diaphragm; 7 - central electrode of a plasma gun; 8 - insulator of a plasma gun; 9 - pumping branch pipe; 10 - pressure transducers; 11 - packing ring.*

guns and its spatial distribution, sensors for pulse measurement of pressure in a phase of current commutation and after that. In Fig. 2 the geometry and the scheme of microwave investigation of plasma injected outside in the area near the cathode, for measuring its transversal sizes by microwaves reflection are presented. As the plasma guns are located at the vacuum chamber wall and the filling of a discharge gap with plasma is performed from periphery to center, so transversal size measuring is made from the reflecting wall to the center (see the coordinate axis R in Fig. 2).

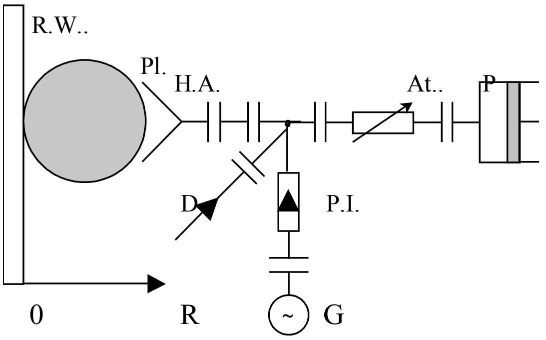

Fig. 2. *Scheme of a microwave investigation of plasma. G. - generator, P. - piston, D - detector, H.A. - horn antenna, Pl. - plasma, R.W. - reflecting wall, At. - attenuator, P.I. - phase inverter*

III. EXPERIMENTAL RESULTS

Measurement of injected plasma parameters, e.g. change of density and linear sizes as a function of time at $n \geq n_c$, can play an important role in determining the moment of GIC switching relatively to the plasma gun pulse, as well as in evaluating the total plasma amount in the discharge gap and, consequently, the value of commuted current.

In Fig. 3a the transversal size (radius) formation (front) with the critical density $n_c \geq 1.8 \cdot 10^{13}$ cm^{-3} as a function of time is shown.

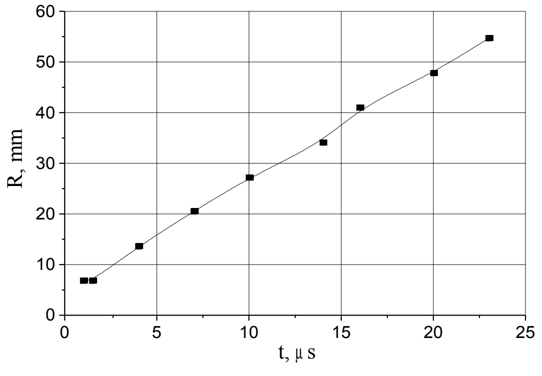

Fig. 3a. *The time dependence of the critical plasma front.*

The data obtained allow evaluating the driving velocity of plasma front with a critical density (i.e. reflecting layer) in the discharge gap. At the initial stage of plasma injection the velocity of reflecting layer propagation is maximum and equal to $7.2 \cdot 10^5$ cm./s. As the reflecting layer extends (displacement of the plasma front) its temperature and, respectively, the driving velocity drops up to a value of $3.4 \cdot 10^5$ cm./s. Proceeding from an average value of a velocity of plasma front propagation ~ $5 \cdot 10^5$ cm./s, we obtain the time of discharge gap filling with plasma of $n_c \geq 1.8 \cdot 10^{13}$ cm^{-3} being equal to ~ 15 μs, that approximately corresponds to the magnitude of in-time delay switching between GIC and plasma guns defined experimentally. This conclusion is confirmed also by the radial distribution of plasma density (Fig.3b) in the discharge gap in an instant t = 2-4 μs after switching the plasma guns pulse (curve 1), t= 12 μs (curve 2) and t = 20 μs (curve 3).

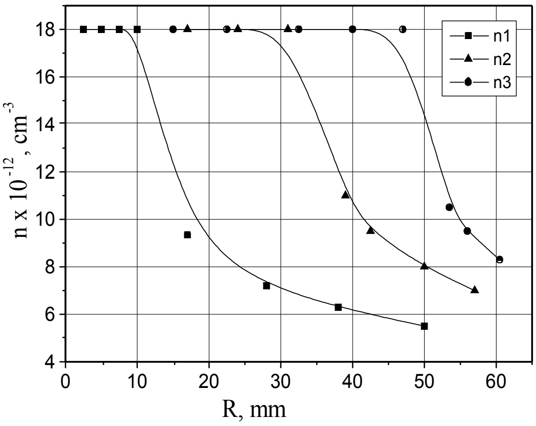

Fig. 3b. *Plasma and critical density by three time moments.*

Apart from this the dependence of the lifetime of plasma with a critical density of $n_c \geq 1.8 \cdot 10^{13}$ cм$^{-3}$ on the plasma gun voltage is established. This time consists of ~ 25 μs under operation of 4 guns, and ~ 50 μs for 12 guns. Besides, the dependence of $n = f$ (R) indicates precisely that the plasma bunch injected by a gun, consists of two parts: fast one of a low-density n ~ $5 \cdot 10^{12}$ cm^{-3} and slow one of a density $n \geq 1.8 \cdot 10^{13}$ cm^{-3}. The fast low-dense plasma fills the discharge gap during several μs after the plasma gun firing; the dense plasma fills it 10-15 μs later. Apparently, just the fast part of the bunch ionizes the neutral gas filling the discharge gap and the chamber of the POS.

Fig.4 shows the distribution of n -number of pulses by k- multiplicity of voltage multiplication in a series of 55 pulses for various number of operating plasma guns (4 or 12). As is seen, the increase of a number of plasma guns from 4 up to 12 results in appreciable increase of the average factor of voltage multiplication, and also in reduction of its scattering from pulse to pulse. The maximum value of voltage in the given pulse series was 378 kV at GIT voltage up to 37 kV.

The maximum value of the load (diode) power was $4.92 \cdot 10^{10}$ W. In this case U_{max}=360 kV, I_{max}=136.7 kA, t=30 ns. In Fig. 5 a part α of the GIC maximum current, commuted into the load, i.e. into the electron diode, is represented as a function of the energy capacity of plasma guns. In the given series of pulses the maximum value of GIC current was 129 kA. It is seen, that increasing the number of plasma guns from 4 (curve 1) to 12 (curve 2) leads to noticeable (above 25-30%) growth of the commuted current value, that, apparently, is connected with increasing the amount and density of plasma in the discharge gap, as well as with changing its spatial distribution along the clearance to more uniform case. Even the more significant (by 50%) increasing of the commuted current was observed under the POS chamber filling with argon at pressure $1.5\cdot10^{-3}$ Torr (curve 3). The argon presence results in increasing the density and the life time of plasma due to the higher values of ionization cross-section in the energy range 20-30 eV, i.e. near to ionization potentials and, as a consequence, leads to growth of the commuted current value. Besides, the availability of argon, probably, reduces the recombination velocity of primary plasma injected from the outside, and, as a consequence the lifetime of plasma in the discharge gap increases. Thus, more effective means for increasing the commuted current value in comparison with increasing the number of plasma guns is the argon filling to low pressure. In the greater extent this influences on the uniformity of the discharge gap filling with plasma due to argon ionization by electrons of primary plasma. The similar effect was observed also for the presence of carbon containing atmosphere (CO_2, CO, CH_4, C_2H_2) in the POS chamber.

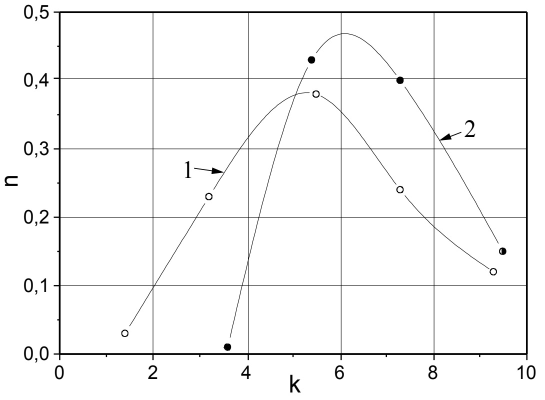

__Fig. 4.__ Distribution of voltage multiplication on a number of plasma guns: 1 - 4 guns, 2 - 12 guns.

In Fig. 6 the experimental results of a research on influence of a density of residual gases in the pos chamber on the commuted current value (in terms of α) are represented. It is seen, that the dependence $\alpha = f(n_0)$ has a threshold character. The switching of a current begins at $n_0 \geq 3.5\cdot10^{12}$ cm^{-3}, and at $n_0 \geq 1\cdot10^{13}$ cm^{-3} the magnitude αi.e. The part of a maximum current of gic commuted into the load, grows insignificantly (in limits of 10 %).

IV. SUMMARY

From dependencies shown in Figs. 5 and 6 the only conclusion follows that for increasing the commuted current value of a decisive importance is the creation and maintenance of conditions for uniform plasma density distribution in the discharge gap. It can be achieved by increasing the number of plasma guns (4 to 12), i.e. increasing the amount of plasma injected from the outside (curve 1 and 2 in Fig. 4), filling argon into the POS chamber (curves 3 and 2, 3 and 1 Fig. 5) or increasing the residual gas density in the discharge gap (Fig. 6).

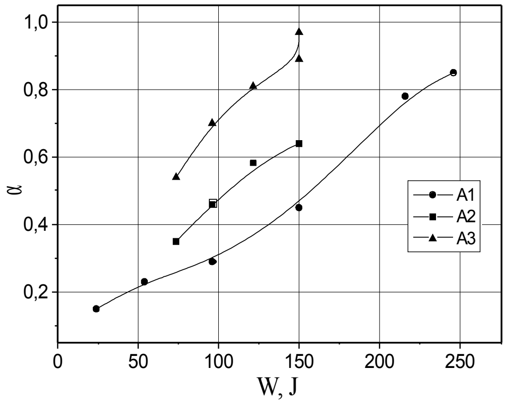

__Fig. 5.__ The load current vs the energy capacity of injected plasma for various number of guns and Ar presence.

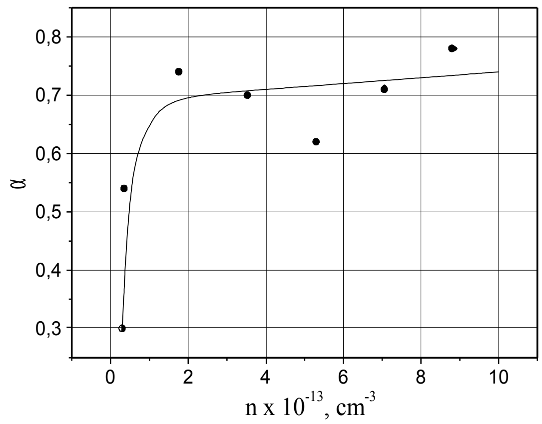

__Fig. 6.__ The load current vs the gas density

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