GENERATOR OF HIGH-VOLTAGE PULSE FOR HIGH-CURRENT ACCELERATOR OF DEUTERON WITH LASER STARTS

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Abstract

The report deals with the source of pulsed high voltage, and simultaneously, source of the pulsed current for the magnetic insulation of electrons near the cathode that was developed for a high-current accelerator of deuterons with laser-plasma anode. The accelerating voltage up to 400 kV and ion current about 1 kA have been achieved. The current in the spiral inductor has reached 5 kA and it excludes breakdown between the cathode and anode for 0.5 µs. For synchronization of physical processes in accelerator of deuterons with pulsed power, the laser control is applied.

INTRODUCTION

Currently for a number of applied problems of geophysics are used small-size pulse neutron generators [1]. The sources of neutrons with gas-filled or vacuum accelerating tubes are most developed and used in such researches. The alternative schemes of the neutron generator based on vacuum diode with coaxial electrode geometry and laser plasma as an efficient source of deuterons [2, 3] are developing in addition to these researches. In this diode is used the direct acceleration of deuterons to cathode and isolation of the electron current by using magnetic field. The laser plasma is generated by using of Nd: YAG laser with a wavelength of 1.06 µm and contains deuterons produced from TiD target placed at the anode. Diode system is placed in a vacuum chamber with a residual pressure of 10^{-2} Pa.

For diodes with coaxial geometry of electrodes, there are two possible schemes of suppression of electron current: a field of permanent magnets with azimuthal symmetry [4] and pulsed magnetic field of the spiral inductor [5]. Analysis of computer experiment showed that a permanent ring magnet does not provide the reliable insulation of electronic current near the poles. This leads to a rapid breakdown of the diode gap and decreasing the accelerating voltage.

In diodes with pulsed magnetic insulation, these problems occur to a lesser extent. In this case, for effective magnetic insulation it is necessary to synchronize three processes: expansion of a laser plasma, the formation of accelerating voltage and generation of the increasing magnetic field. To solve this problem the authors have developed the original scheme of the pulsed power supply, in which the laser-triggered gap runs Marx generator of the high voltage ($U \approx 400$ kV) and the magnetic field generator with high current ($I \approx 10$ kA). The features of the coordinated work of these generators with physical processes in the accelerator diode is considered in this article.

THE MARX GENERATOR

A high-voltage Marx generator is the main part of the pulsed power supply. The generator is made according to the scheme with unipolar charging and without change of the polarity of the output voltage. It consists of 30 stages (n = 30), each of them uses two capacitors K15-4 connected in parallel with a total capacitance of C_0 = 2 x 4700 = 9400 pF. In the charging circuits is used a high-voltage resistor with resistance R_0 = 16 kΩ. Each of stages stored 1.0 – 1.7 J of energy at a charging voltage of 15 –18 kV. Open circuit voltage is 400 kV, capacitance in peak is $C_{marx} = C_0 / n$ = 310 pF.

In the first stage of the Marx generator is applied the laser-triggered gap, the second stage uses the field distortion gap. In the rest stages of the Marx generator installed uncontrolled spark gaps. All gaps operate in air at atmospheric pressure.

Stable running of the laser-triggered gap (*LG*) with a time delay of not more than 50 ns is obtained at energies of laser are more W ≥ 80 mJ. In this case, the main energy of the laser pulse (85− 90%) is directed to the laser target. Note that the use of laser control greatly simplifies the synchronization of Marx generator with a laser plasma.

The field distortion gap (*FDG*) provides reliable switching of the second stage. To run this gap in the first stage of the Marx generator attached simple high-voltage generator. Its principle of operation is based on fast discharge of the capacitance (C = 470 pF) on the pulse transformer because of the switching of the laser-triggered gap (Fig. 1). Transformer is made on a rod core of ferrite M400HH. The number of turns in the primary and secondary windings of the transformer is equal to w_1 = 5 and w_2 = 25, respectively.

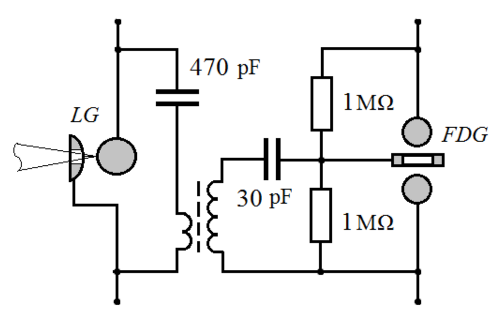

Figure 1: Electrical circuit of the simple high-voltage generator for switching field distortion gap (*FDG*).

In addition, more stable running was observed when the low-voltage electrode of gaps in the second, third and fourth stages of Marx generator was connected to the

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grounded conductor via capacitors with capacitance $C_{cor} \sim 7$ pF and working voltages of 40, 60 and 80 kV, respectively.

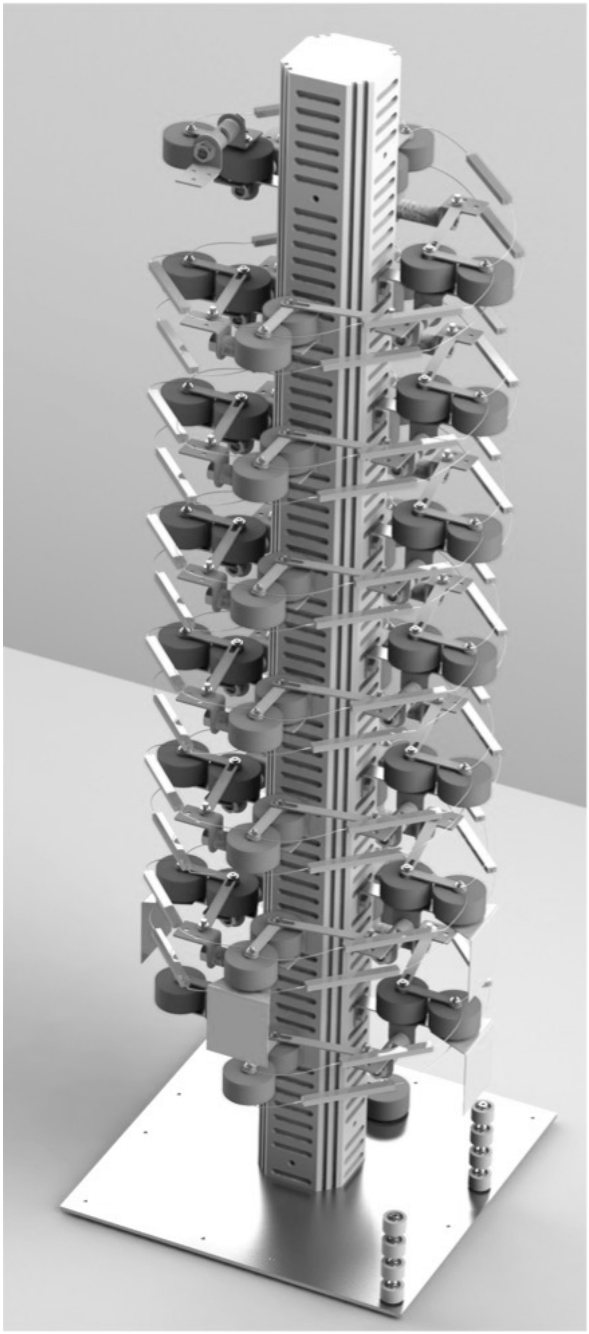

Figure 2: The Marx generator with a helical geometry.

The stages of Marx generator are mounted around the central cylindrical pillar (a height is 0.9 m, a diameter is 0.07 m), made from dielectric. The lateral surface of the cylinder-pillar are made with complex profile in order to enhance the dielectric strength of the insulation between the stages. A chain of capacitors and the spark gaps is located along a helix, which surrounds the central pillar.

The diameter of the helix is 0.15 m and the step is 0.1 m. At each full turn of the helix is used 4 spark gap. The generator has a size of 0.2 x 0.2 x 0.9 m. The appearance and the geometry of the Marx generator elements are shown in Fig. 2.

To analyze the inductance of the Marx generator we have considered a model in the form of a cylindrical helix with a radius of r = 0.075 m. The step of helix is equal to p=0.1 m, number of turns is equal to N = 7.5. The inductance of such cylindrical helix can been estimated according to the formula [6]

$$L = \mu_0 \cdot N^2 \cdot K \cdot (S/H) - \mu_0 \cdot r \cdot N\,(G^* + N^*) \approx 5 \text{ мкГн},$$

Where $S = \pi \cdot r^2 = 0.07$ м^2 is square round inside turn; $H = N \cdot p = 0.75$ м is the height of the helix; $K = f_1(H/2r)$, $G^* = f_2(2 \cdot r/p)$ и $N^* = f_3(N)$ is correction factors, depending on the geometry of the helix and number of turns. For our geometry $K(5) = 0.9$; $G^*(1.5) = 1$; $N^*(7.5) = 0.25$. For capacitance in peak $C_{marx} = C_0 / n = 310$ pF and inductance $L \approx 5$ мкГн it is possible to estimate the period of oscillation $T = 2\pi (L \cdot C_{marx})^{1/2} \approx 250$ нс. This value is in good agreement with the experimental data obtained from the oscillogram for open circuit voltage.

CURRENT GENERATOR

The insulating magnetic field to be generated by increasing pulse current. The generator is performed according to scheme with the discharge of the capacitor ($C_M = 0.25$ μF) on an inductive load. An inductor ($L_M = 0.65$ μH) is made in form of conical spiral. The rise time of current (i.e. magnetic field) is

$$\tau_M = \sqrt{L_M C_M} \approx 400 \text{ нс}.$$

The same laser-triggered gap *LG* is used for switching the capacitor C_M. Such technique is provided a reliable synchronization the pulse of current with the pulse of the high-voltage Marx generator. The start of the current pulse coincides with the moment of breakdown of *LG*.

The capacitor C_M stored energy of 25 – 40 J. The maximum current reached in the inductor can be estimated from energy balance

$$I_{max} = U\sqrt{C_M / L_M} \approx 9 \text{ кА}.$$

The corresponding estimate of a magnetic field in the center on the axis of the conical spiral gives

$$B_{max} \approx 0.5 - 0.6 \text{ Тл}.$$

It should be noted that the induction of magnetic field is $B \approx 0.7\, B_{max}$ after a quarter of a period from start of current pulse.

EXPERIMENT AND SYNCHRONIZATION OF GENERATORS

The experimental setup for accelerating deuterons with using Marx generator (1), current generator and a vacuum diode with laser-plasma ion source and a magnetic insulation of the electrons is shown in Fig. 3. A laser target in the form of a tablet made of TiD was placed on the

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anode (2). Deuterons are extracted from the laser plasma in an electric field formed by a positive high-voltage pulse on the anode.

We applied a pulsed magnetic isolation for suppression of parasitic electron current due to secondary electron emission at the cathode. Conical spiral (3) is placed in the diode gap in front of the cathode (4), which also had a conical shape. In addition, conical surface of the cathode and conical spiral are parallel. Diode system placed in a vacuum chamber pumped to a pressure of 10^{-2} Pa.

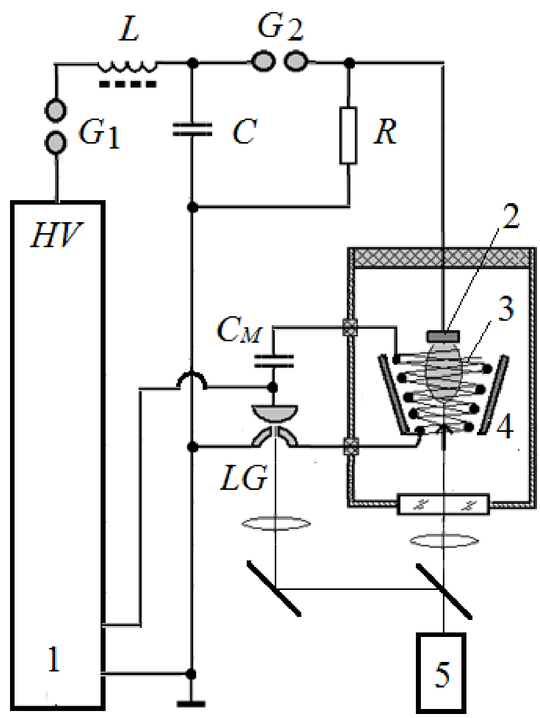

Figure 3: Scheme of the experimental set-up for the acceleration of deuterons in the diode with the laser plasma on the anode and magnetic insulation of electrons: 1 – anode; 2 –conical spiral; 3 – cathode; 4 – laser; 5 – Marx generator (L = 400 – 700 μH, R =100 kΩ, C = 30 pF, C_M = 0.25 μF).

To obtain a laser plasma, we used Nd: YAG laser (5) with wavelength $\lambda = 1.06$ μm (energy $W \leq 0.85$ J, duration is about10ns). The main part of the laser beam (85-90%) is focused on the anode target. Radiation intensity on the target is equal to $q \approx 10^{11}$ W/cm^2. The remaining energy of the laser pulse is focused to the laser-triggered gap LG. The breakdown of LG runs the first stage of the Marx generator and the discharge circuit of the current generator. This allowed us to synchronize three processes: expansion of a laser plasma, the formation of accelerating voltage and generation of the increasing magnetic field.

A laser plasma emission is accompanied by its expansion in the radial direction. The flow of deuterons reaches the conical spiral with a delay $\tau_P \approx 250 - 300$ ns.

To coordinate the work between the deuteron accelerator and pulse generators we have added a circuit of inductance L = 400 – 700 μH and capacitance $C \approx 30$ pF (time constant $\sqrt{LC} \approx 110 - 150$ ns) and the spark gap G_2. In this case, the total delay of the high-voltage pulse relative to the laser pulse is equal to $\tau_{HV} \approx 200$ ns.

The inductance L is a cylindrical spiral (the number of turns is 20) with a core made of ferrite M400HH (diameter 70 mm, length 500 mm). The spark gap G_1 separates the delay LC-circuit from the charging voltage of the Marx generator.

Estimation of the efficiency of generating the magnetic field showed that current in the conical spiral achieved 60% from its maximum value after 300 ns from the beginning of the expansion of a laser plasma (i.e. when the flow of deuterons reaches the conical spiral).

In our experiment, we measured the currents in the accelerator diode and a conical spiral by using of Rogowsky coil operating in the regime of current transformer. The peak diode current achievable with the magnetic insulation was about 1 kA when the energy of radiation on the laser target was 0.75 J and accelerating voltage up to 400 kV. The current in the conical spiral reached 5 kA, and its impedes the breakdown between the cathode and anode for 500 ns.

CONCLUSION

We showed the possibility of synchronization of the physical processes between the laser-plasma source of ions with pulse generators of voltage and of current. In the diode with magnetic insulation was achieved the fulfillment of a condition $\tau_{HV} \leq \tau_P \leq \tau_M$ what is important to effective acceleration of deuterons. This requires a compromise in the selection of the parameters of the LC-circuit in the delay line and the parameters of the L_M and C_M in generator of current. Running process in the diode system by using of a laser-triggered gap limits the possibility of optimizing the temporal characteristics, however, significantly simplifies the experiment.

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