Magnetic discharge accelerating diode for the gas-filled pulsed neutron generators based on inertial confinement of ions

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Abstract. The paper deals with magnetic discharge diode module with inertial electrostatic ions confinement for the gas-filled pulsed neutron generators. The basis of the design is geometry with the central hollow cathode surrounded by the outer cylindrical anode and electrodes made of permanent magnets. The induction magnitude about 0.1−0.4 T in the central region of the discharge volume ensures the confinement of electrons in the space of hollow (virtual) cathode and leads to space charge compensation of accelerated ions in the centre. The research results of different excitation modes in pulsed high-voltage discharge are presented. The stable form of the volume discharge preserving the shape and amplitude of the pulse current in the pressure range of 10⁻³-10⁻¹ Torr and at the accelerating voltage up to 200 kV was observed.

Nowadays compact pulsed neutron generators for the study and monitoring of oil and gas deposits are applied. The basic element of such pulsed neutron generators is usually a neutron accelerating tube, which characteristics largely determine the diagnostic capabilities of geophysical instruments. However, such neutron tubes have some disadvantages which are caused by a number of physical processes during their work and this reduces the competitiveness of neutron generators based on them. In particularly pulsed neutron generators based on accelerating tubes of direct action have limited resource (determined by the degradation of solid-state neutron targets), not high efficiency of energy transfer to accelerated nuclide of hydrogen and problems with radiation safety in operation and utilization [1]. Therefore, along with improvement of traditional neutron accelerating tube, there is an active search and development of new types of accelerating systems.

Such new developments include a gas-filled discharge-plasma diode with oscillation mode of ions between the electrodes, and interaction of ions flows with the structural elements is minimized. Abroad the similar systems are referred to Inertial Electrostatic Confinement (IEC) devices, as their work is based on the inertial-electrostatic confinement of deuterons [2]. There is no traditional solid target in IEC diodes filled with gaseous deuterium. The interaction of accelerated hydrogen nuclide is performed with plasma or with an opposite flow of nuclide (plasma target). In this case, the working resource of the pulsed neutron generator can be increased. The efficiency of neutrons generation also is increased using the special geometry of electrodes with high transmittance of ions in the center of discharge gap [3].

In this paper, we consider a new improved design of magneto discharge module of IEC diode and the results of different excitation modes in pulsed high-voltage discharge. The basis of this design, as

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in the previous version [3], is the electrode system with a hollow central cathode surrounded by the outer cylindrical anode. However, to improve the efficiency of ion generation in the electrode gap, the new version of diode module for acceleration of charged particles in crossed ExH fields is organized. This leads to additional electron drift and a substantial lengthening of their trajectories. Moreover, the magnetic field confines the electrons in space of hollow cathode (virtual cathode) and provides the space charge compensation of accelerated ions in the center of the system. This is important, because it allows to increase the ionic current in comparison with the current limited by the "law 3/2".

The scheme of the new design of diode module is show in the figure 1. A pulse of accelerating voltage comes into a vacuum chamber through a high-voltage dielectric input. Insulator is designed for operating voltage up to 200 kV. The anode is made in the form of a hollow cylinder (inner diameter is 6 cm, the height is 4 cm). In addition, it is made from permanent magnet, magnetized in the direction of the axis of the diode. The cathode consists of two coaxial magnetic rings (external diameter 3 cm), magnetized along the axis of the diode. The magnitude of magnetic field in the central region of discharge volume is about 0.4 T.

![Diagram of the diode module](image)

**Figure 1.** The scheme of a gas-filled diode module with magnet electrodes (P₁ and P₂ – Rogowski coil)

Diode module is located in a dielectric vacuum chamber, pumped up to $10^{-4}$ Torr. Vacuum system has the ability to control and vary the pressure and composition of working gas. In our experiments, the pressure is varied from $10^{-1}$ to $10^{-3}$ Torr. As a source of accelerating high voltage, unlike previous developments of IEC-diode, pulsed Marx generator was used. It provides the amplitude of the accelerating voltage up to 350 kV with duration less than 1 µs in the idle current and the pulse current up to 1 kA in the short circuit mode. To control the discharge current Rogowski coils (P₁ and P₂) are applied. In addition, probe for measuring the pulse voltage are included in primary diagnostic tools.

Experiments have shown that electrical breakdown of the insulator between the anode and the cathode in a vacuum limits the maximum amplitude of the accelerating voltage. Its value is equal to 200 kV for our geometry of electrodes and the pressure range $10^{-1}$–$10^{-3}$ Torr. For comparison, it should be noted that for gas-filled neutron tubes the maximum of accelerating voltage is usually about
100–120 kV. Thus, a new diode module with the magnetic electrodes provides the increase of the accelerating voltage in comparison with the previous variant without magnets.

According to existing concepts, the reduction of deuterium pressure in the discharge chamber reduces the ionization probability and falls the current. As a result it leads to a decreasing number of interactions between deuterons. This process defines the lower limit of the working pressure. However, on the other hand, a rapid increase of the current leads to a breakdown at high pressures. It's also possible to shunt the main discharge current due to the parasitic currents. These processes affect the upper limit of the operating pressure.

A stable discharge for the pressure range $10^{-2}$ to $10^{-1}$ Torr was observed without magnetic field and only in the presence of pre-ionization [3]. In this case, the amplitude of the accelerating voltage increased from 60 to 100 kV and the range of pressure was markedly decreased. In the presence of magnetic field, as we can see, the current pulse shape and current amplitude did not change in a wider pressure range from $5 \cdot 10^{-4}$ to $10^{-1}$ Torr, because in the region of smaller pressures the gas ionization takes place effectively. In addition to this, in the magnetic field it is expected to increase the neutron yield due to the better gas ionization and the increasing number of interactions acts between deuterons and the increasing number of oscillations at use lower pressure.

In order to optimize the magnetic system we made computer simulation of the magnetic field distribution in the electrode gap. The results are shown in figure 2 (a), (b).

![Figure 2](image)

**Figure 2.** The distributions of the magnetic field in the electrode gap.

In the first case (a) the magnetization direction of the anode and the cathode coincides and in the second one (b) it has an opposite direction.

One can see from figures, in the case of the first configuration (a) the magnetic lines of the anode and the cathode are partially closed against each other. In the second configuration (b) it is expressed much less. Consequently, the second configuration is more optimal, because of better inhibiting the electrons from their drift to anode. However, neither configuration is capable to completely suppress
the emission electron current. It is planned to consider various screens systems and the use of magnetic coils instead of permanent magnets.

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