DYNAMICS OF PLASMA-BEAM FORMATIONS IN THE ACCELERATION GAP OF THE PULSE NEUTRON GENERATOR-BASED VACUUM NEUTRON TUBE

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Abstract

The analysis of dynamics of plasma flows containing deuterium, zirconium ions and electrons in the accelerating gap of the pulse neutron generator-based vacuum neutron tube (VNT) [1] is presented in the paper. The investigations have been carried out using the code KARAT [2] for the two-dimensional non-stationary mode. The limiting currents of each component for the real accelerating gap geometry have been determined. The differences between the values of these currents and those ones determined by the Child-Langmuir equation have been demonstrated.

The analysis of plasma emitter dynamics in the gap has been performed by the model of VNT with the accelerating voltage amplitude of 120 kV and the pulse duration of 1.2 μs. It has been shown that the value of the current entering the gap from the source of ions can be very different from the current value at the target. To increase this value the accelerating gap partition using the conductive grid which is transparent for a beam and has several geometric configurations has been proposed. The ring configuration of the emitter has been considered for the same purposes. The calculations have shown that the combination of these two methods described above can allow transporting the current of deuterons from the anode grid to the target without losses.

INTRODUCTION

All set of physical processes accompanying the operation of VNT can be structured as follows. Firstly, these are processes in the vacuum arc discharge including in particular the production of an erosion mass from the discharge gap electrodes. Secondly, these are processes accompanying the expansion of plasma products emitted by a vacuum arc. Thirdly, this is the transmission of a plasma flow through the anode grid of VNT and the acceleration of deuterium ions in the accelerating gap and, fourthly,these are the processes in the target accompanied with the generation of neutrons.

Modelling of the plasma dynamics in the accelerating gap has been carried out using the code KARAT. Initial data for plasma parameters were obtained from the designed model of VNT [3]. A voltage supply to the accelerating gap has been modelled using a TEM wave, therefore the diode has been shown as a shorted coaxial transmitting line. All computational region is divided into cells, a set of which forms a rectangular grid. The basic parameters for choosing the size of a grid unit cell are the Debye length λ_D and the collisionless skin depth. The above mentioned values of plasma parameters are:

$$\lambda_D = 2,35\times10^{-4}\,см, \qquad \frac{c}{\omega_{pe}} = 1,68\times10^{-1}\,см. \tag{1}$$

where ω_{pe} – the electronplasma frequency

The increase in the number of cells extends the running time. As a non-stationary process is under consideration and the Debye length is more statistic parameter, in this case, the collisioness skin depth is the characteristic scale. On that basis, the number of divisions is selected in such a way that a unit cell is a square with a side of 1,24 * 10^{-2}sm. The time step for every iteration is automatically selected by a code and comprises 1,87*10^{-4}ns that is agreed with the period of electron component oscillations of this plasma ~ 10^{-2} ns.

To estimate the space-charge limited current in a planar diode with the distance d between electrodes and the emitting surface of R, the Child-Langmuir equation can be used:

$$I_{CL} = \left(\frac{R}{d}\right)^2 \frac{\sqrt{2}}{9}\,\frac{mc^3}{e}\left(\frac{\varphi_a}{mc^2/e}\right)^{3/2} \tag{2}$$

where φ_a - the voltage across the diode, m – the mass of accelerated particles.

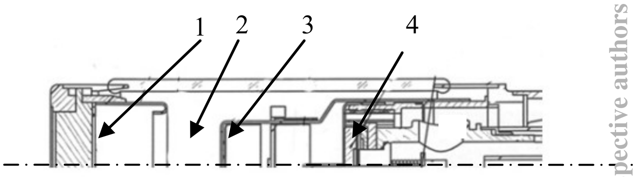


Figure 1: The design of VNT: 1 - the target, 2 – the accelerating (cylindrical) electrode, 3 – the anode grid, 4 – the ion source.

The code KARAT has been used to calculate limiting currents of each plasma component in the real geometry of the accelerating gap.

The design of typical VNT developed in All-Russia Research Institute of Automatics named after N.L. Dukhova is shown in Fig. 1. The plasma flowing comes from the ion source (4). The accelerating gap itself represents a space between the anode grid (3) and the target electrode (2).

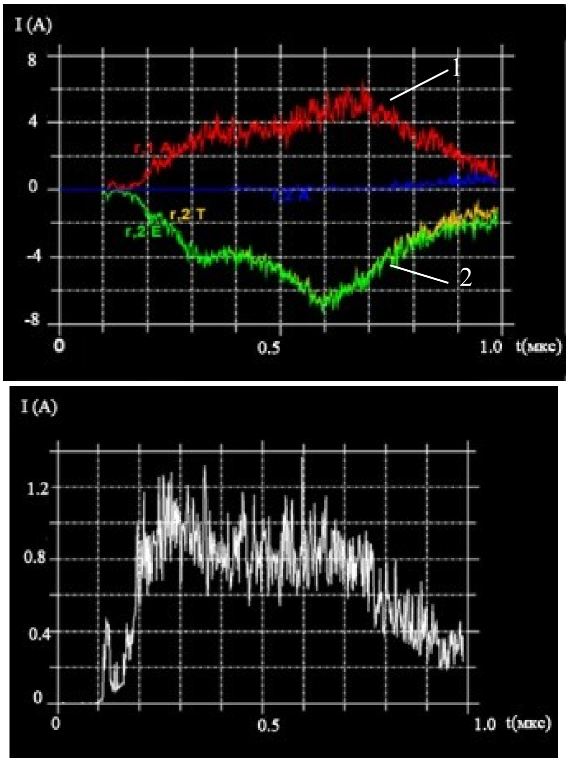
It was assumed that through the anode grid of radius 1sm in the gap there were emitted one-component beams of deuterons, electrons, zirconium ions which were accelerated by direct voltage of 100kV and the current of which knowingly exceeded relevant maximum values. The current flow has been fixed at the target electrode. The results of calculations are presented in the table.

Table 1: The results of current calculations

	e	d	Zr
Partial current (maximum value), A	6,3	6,3	$6,3*10^{-2}$
Limiting current, calculated by the formula (2), A	57,8	$9,5*10^{-1}$	$1,4*10^{-1}$
Limiting current modelling, A	100	1,8	$2,6*10^{-1}$

The “partial current” in the Table 1 refers to the current entering the accelerating gap of VNT.

As shown in Table 1, values of limiting currents in modelling have been greater than in calculations using a formula (2). This is due to the fact that the emitter (the anode grid) size is commensurate with the accelerating gap size. In this case the field amplification effect arises due to the edge effect on the emitter surface. As a result of an excess of the partial current over the limiting one, the plasma starts to penetrate into the accelerating gap.



a)

b)

Figure 2: The dependence of currents in the accelerating gap on the time: a – the current on the surface of a cylindrical electrode(1) и the current emitted from the anode grid(2), b – the current on the target.

The dynamics of a plasma emitter can be properly described as follows.As a consequence of an excess of the partial current over the limiting one, the plasma expands in the accelerating field for ions and emits positively charged particles from its surface. This plasma expansion takes place before reaching such an effective distance from the anode grid at which the limiting current of ions will be equal to the partial one. Thus if the partial current is greater than the limiting one, the partial current is removed from the outer edge of the plasma at any time and a fraction of particles accumulates in the plasma emitter. And if the partial current is less than the limiting one, in contrast, the plasma gives off a part of a stored charge together with the limiting current.

Data based on the modelling confirm the described above physics (Fig.2.). As seen in Fig.2., before the emitter comes to a standstill while moving to the target, less partial current is removed from it, whereas at the reverse movement - more partial current. This is due to removing the excess charge which was accumulated in the plasma. As follows from Fig. 2, about 20% of the deuteron current injected into the gap reaches the target. Most of particles settles on the cylindrical target electrode and on the dielectric case of VNT. As the plasma penetrates into the accelerating gap, the fraction of the current on the targetdecreases.

The enhancement of the accelerating gap geometry implies seeking such a design which contributes to obtaining the maximum deuteron current on the target. The way to achieve this objective is by increasing the limiting current for the accelerating gap and, consequently, decreasing the plasma penetration in the accelerating gap. This can be achieved by the insertion of a grid transparent for particles in the gap and by the division of the accelerating gap into two accelerating regions. In addition the grid transparent for particles will be located at the end of the target electrode and be under its potential. As a result, the accelerating gap will be divided into two gaps: of acceleration and of drift region. This way allows reducing the effective acceleration distance at the same accelerating voltage.

Another way is by developing such a gap design at which the emitting surface (the anode grid) represents a ring. In this case the limiting current value increases due to the electric field intensity increase on the surface of the emitter. Moreover, with this emitter geometry there will not be the spacial charge in the paraxial region.

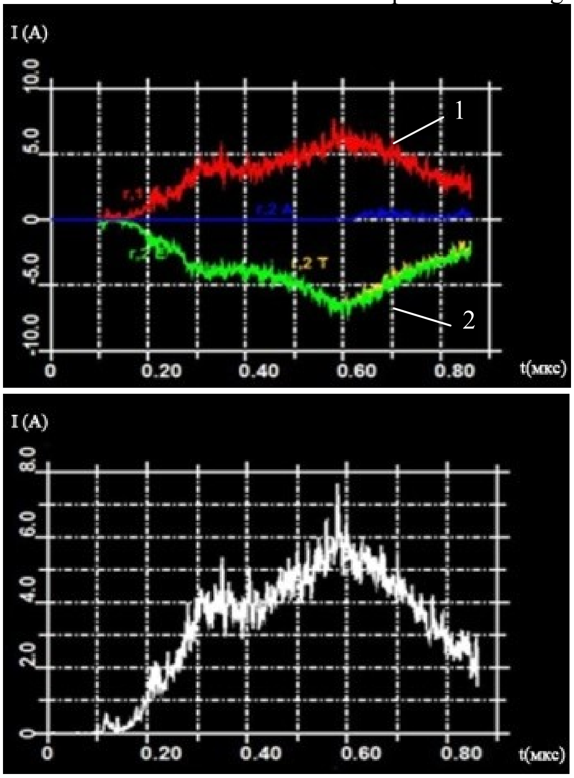
As calculations have shown, in this case the current on the target increases up to 35% from the injected current, whereas previously this figure comprised 20% from the total current on the accelerating electrode.

It should be noted that the use of a ring emitter of the same area leads to the same effect.

The application of this emitter topology allowed increasing the current share on the target up to 45%. In comparison with the contiguous emitter of the same area the increasing of a current can be explained by reducing the spatial charge action due to decreasing the emitter size in cross direction.

With regard to the use of a grid in the accelerating gap, Fig. 8 shows the design of the accelerating gap with an additional grid, whose surface represents a fructum of cone. In addition the length of the accelerating gap is reduced by 2 times.

The reduction of the accelerating gap size due to the insertion of an additional grid leads to the decrease of the plasma penetration rate in the accelerating gap. On the other hand, the grid surface generates the electric field, the radial component of which leads to the focusing effect. The results of calculations are presented in Fig. 3.



a)

b)

Figure 3: The oscilloscope pictures of currents for the partitioned gap: a - the current on the surface of a cylindrical electrode (1) and the emitted (partial) current of deuterium (2), b –the current on the target.

As seen in Fig.3, such a gap design allows increasing the current share on the target up to 90%.

Calculations have shown that the use of the gap design with the cone-shaped grid and the ring emitter allows transmitting practically all deuterons passing through the anode grid.

CONCLUSION

The analysis of dynamics of plasma flows in the accelerating gap of VNT has shown the possibility of a substantial increase of deuterons’ current on the target in comparison with its standard operation procedure. Currently, All-Russia Research Institute of Automatics named after N.L. Dukhova develops and carries out the experiments of different designs of the accelerating gap on the dynamics of ion flows.

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