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VACUUM ACCELERATING TUBE WITH TWO SYMMETRICALLY LOCATED TARGETS FOR NEUTRON GENERATION*

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Abstract

Original neutron generator on the base of pulse accelerating vacuum tube with two targets, symmetrically located on the both sides of deuteron source is discussed. Two immersion lenses in front of each other uses as accelerating and focusing systems. Lenses cathodes are Faraday cups with targets for neutron production on the bottom. Symmetric ring magnetic elements cover immersion lenses for correcting focusing conditions. Computer simulation allows us to choose electrodes geometry and accelerating pulse value for electron flow from ion-electron emission oscillate between the targets and provide device operate as reflective triode. For simulation operation of the device was used code SUMA. Estimations of neutron flow and spatio-temporal neutron field structure are done.

INTRODUCTION

One of disadvantages of the high-power neutron tubes (NT) [1] is electron conductivity of a diode gap induced by ion-electron, auto-electron or explosive emission from the target surface or accelerating cathode. It leads to deuterons accelerating efficiency and neutron flow reduction due to power loses on electrons acceleration. Besides hit of the accelerated electrons to the deuterons source leads to their destructive impact on the electrodes that reduces a tube resource.

Suppression of electron conductivity is usually carried out by means of special electrodes (grids or rings) for creation of electric field near the cathode to prevent electrons emitted from the target to get to the accelerating gap. However for high currents and (or) high accelerating voltages this grids and rings becomes the emitter of electrons and the specified way of electron conductivity suppression ceases to work.

REFLECTIVE ION TRIODE SCHEME

For elimination of these negative effects, authors suggest to use the idea of the ion triode, consisting of the symmetrically located cathode and the anti-cathode and partially transparent anode electrode, located between them [2].

The electron from the cathode or the anti-cathode accelerates towards the partial transparent anode with coefficient of transparency s, near which plasma is formed. During the dispersion of electrons near the anode, they lose a part of the kinetic energy $T - \Delta T \approx F(T)L$ (L-the characteristic longitudinal size of a plasma cloud in anode area, $F(T)$ – the energy losses per unit length, determined by Bethe-Bloch formula). Estimates show that for electrons single passing of triode working volume these losses can lie within (0.1÷1) eV and it is enough for their capture in the periodic movement in a potential well between cathodes and the anti-cathode. This cloud of the negative charge partially compensate a space charge of the deuterons formed in ion source and accelerated from the anode to the cathode or to the anti-cathode.

Density of electrons in the formed cloud, according to the made estimates will be approximately in $k = \frac{1+s}{1-s}$ times (s – anode transparency) exceed density of electrons in the ordinary bipolar ion diode. Therefore, for big s values, deuterons extraction from ion source plasma and their subsequent acceleration are significantly improved due to partial compensation of deuterons space charge by charge of electrons.

Figure 1 shows the NT scheme on the base of the vacuum arc deuterons source (VADS) with an internal cavity where the idea of the reflective ion triode is used. The circuit of this device was first reported at the 12th International Scientific Workshop in Memory of Professor V.P. Sarantsev "Problems of Colliders and Charged Particle Accelerators".

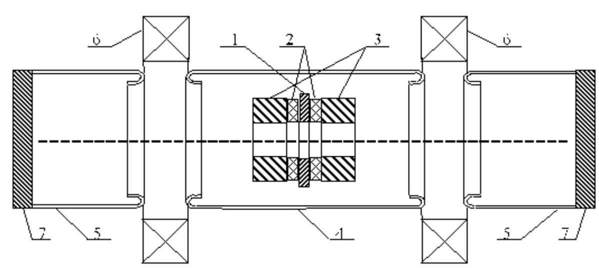

Figure 1: The NT schematic section with hollow VADS: 1-ignition electrode; 2- insulators; 3-deuteron source electrodes (cathode and anode); 4,5-NT accelerating electrodes; 6-magnetic lens; 7- NT targets.

VADS contains the central ring electrode for arc discharge ignition separated from the cathode and the anode of a source by ring insulators. Electrodes of VADS saturated with a deuterium and connected to the capacitive energy store, which charged from the rectifier up to the several kV. Two-electrode VADS can run with start in self-oscillation mode or with use of three-electrode discharger in power supply circuit.

The accelerating electrodes 5 are connected to high negative voltage pulse generator (VPG) such as pulse step-up

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transformer with the ferromagnetic core or Arkadyev's-Marx generator.

During the storage capacitance discharge, between electrodes 3 (the anode and the cathode) of VADS vacuum arch forms which electrode spots emitted plasma streams containing deuterons, since source electrodes contain a deuterium in an occluded condition. At the same time deuterium plasma with approximately sound velocity fills the internal electrodes space of the accelerating system 4 in both directions.

Synchronously with this process on external electrodes of the accelerating system 5, from VPG the negative impulse with an amplitude of 100 kV applied. It's result in extraction of deuterons from VADS plasma and their subsequent acceleration to NT targets, where reactions of $T(d,n)^4He$ or $D(d,n)^3He$ are carried out, accompanied with fast neutrons generation.

The electrons emitted from the target and the accelerating electrodes as a result of ion-electron, auto - electron or explosive emission are accelerated in diode gaps and focused by a magnetic lens in the first accelerating gap, and then slowed down in the second accelerating gap where electric field has the opposite sign. The focal length of a magnetic lens is selected so that the electron stream freely passed through a deuteron source cavity.

The structure of an electron cloud represents an oscillating electron stream. Current in NT high-voltage circuit consists of current of the accelerated deuterons and the current of the electrons, captured by VADS plasma and getting to its electrodes. The electron component of current decreases with anode transparency coefficient increased. The space charge of the electrons, oscillating in the triode, promotes more effective deuterons extraction from VADS plasma. All this as show calculations, increases the efficiency of deuterons acceleration in compare to the similar bipolar diode accelerating system. It is possible to use the following formula for estimation:

$$\eta = \frac{I_d}{I_d + I_e} \approx \frac{(1+s)\sqrt{m}}{(1+s)\sqrt{m} + (1-s)\sqrt{M}},$$

where I_e, m, I_d, M – components of current and mass of electrons and deuterons respectively.

Other positive factor characterizing the considered NT is additional ionization of plasma in VADS cavity by oscillating electrons, that allows us to increase deuteron emission.

The high transparency of the anode is provided with proper ion-optical system, consisting of magnetic and immersion lenses. A role of the immersion lenses is played by the accelerating gap.

SIMULATION RESULTS

First estimation of NT parameters was carried out by numerical solution of the following system of the differential equations, which describe electrons dynamic in the device in paraxial approach:

$$\begin{cases} \dfrac{d\gamma}{dz} = -\dfrac{\phi'(z)}{2\phi(z)}\gamma - \dfrac{1}{8\phi(z)}[2\phi''(z) - \dfrac{e}{m}B(z)^2]r, \\ \dfrac{dr}{dz} = \gamma, \end{cases}$$

in which z is axial coordinate of NT, function $\varphi(z)$ and $B(z)$ define electric field potential distributions and magnetic field induction on the accelerating tube central axis, e, m-respectively charge and mass of an electron.

Electric field on an axis of diode system was obtained by method of equivalent charges. Permanent ring magnet with longitudinal magnetization was used as a magnetic lens. Magnetic field on axes of such lens can be derived from the value of magnetic field induction in the center of a lens.

In this case the formula for magnetic field takes the following form:

$$B(z) = \frac{B_0}{2}\frac{1}{(a^2+\frac{L^2}{4})^{-1/2}(b^2+\frac{L^2}{4})^{-1/2}} \times$$
$$\begin{Bmatrix} [a^2+(\frac{L}{2}-z)^2]^{-1/2} + [a^2+(\frac{L}{2}+z)^2]^{-1/2} - \\ -[b^2+(\frac{L}{2}-z)^2]^{-1/2} - [b^2+(\frac{L}{2}+z)^2] \end{Bmatrix}.$$

where B_0 - magnetic field induction in the center of a lens, μ_0 - magnetic constant, and a - the internal magnet radius, b - the external magnet radius, L-thickness of a magnet, z, z_0 - longitudinal coordinates of the point of observation and the source.

Let us review an example of NT realization, taking into account results from expressions above with the following device geometry: radius of accelerating system electrodes R=2.5.10^{-2} m; internal radius of ion source electrodes r=2.5.10^{-3} m; width of the accelerating gap d=5.10^{-3} m; thickness of a ring magnet H =5.10^{-3} m. VPG parameters: amplitude is 150 kV and half-amplitude pulse duration (0.2-0.3) μsec. The energy saved in ion source circuit is 0.5 J.

For more accurate simulation 2.5 dimensional relativistic particle in cell (PIC) code SUMA was used [3]. The code is a time dependent model that describes self consistently the dynamics of charged particles in rectangular, cylindrical, and polar systems of coordinates. The system of equations used in mathematical model consists of the Maxwell equations, the equation of the medium, and the equation of motion.

At each step of the solution at running instant t, the charge and current densities, appearing in the Maxwell equations, are calculated first. The charges and current are distributed among the nodes of the spatial mesh and smoothed by weighing the areas of a particle (cloud) and a mesh. The arrival of new particles at a simulation step Δt

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to the region under investigation is simulated by the mechanism of injection, emission or secondary emission with corresponding laws of distribution. Then the Maxwell equations are solved numerically and the resultant solution is corrected for matching to the Poisson equation. The correction is carried out by solving the Poisson equation for the difference of charge density distribution obtained from the divergence Maxwell equations and the actual distribution of charges. Poisson equation is solved using the algorithm of fast Fourier transformation in one coordinate and Thomas algorithm in the other coordinate. For a complex boundary as well as in the presence of electrodes in the domain, the capacity matrix method is used, which relates the potential and charge at the required nodes. For integration, the relativistic version of the method is employed with overstep using a time shift of the spatial coordinate and momentum. The particles falling on the walls of the chamber or electrodes are removed.

The typical result of such modeling presented at Fig. 2. The electrons (red points on the figure) are emitted from the target. Figure 2 shows that practically all electrons are accumulated inside the accelerating tube.

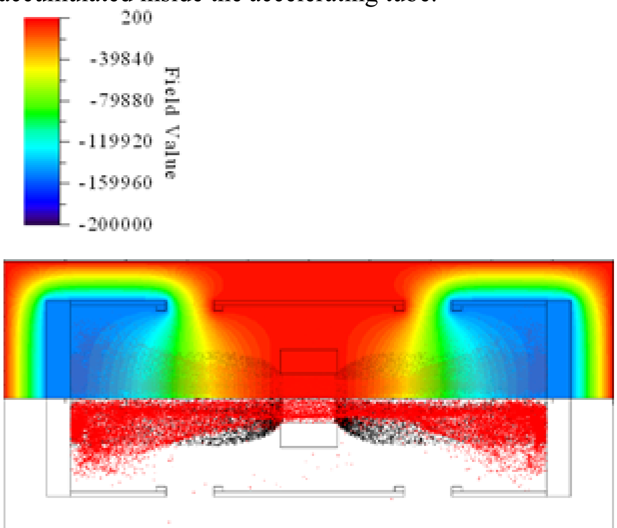

Figure 2: Field potential (upper part) and charge particle distributions (lower part of the picture). Deuterons - black points, electrons -red points.

Calculations show that for these parameters with a neutrons pulse repetition rate 25 Hz the average VNT neutrons flow can exceed 10^{10} neutron per second.

REFERENCES

[1] A. S. Tsybin and A. E. Shikanov, “Generation of neutrons in the small-sized sealed accelerating tubes”, *Izvestiya visshikh uchebnikh zavedeniy. Fizika*, No. 8, pp. 3 – 31, 1985.

[2] V. M. Bystritsky and A. N. Didenko, “Powerful ion beams”, *Energoatomizdat*, M., pp. 152, 1984.

[3] V. I. Rashchikov, “Electromagnetic field calculation in complex geometry structures”, *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations*, No. vol. 10, no. 18, pp. 50-53, 1990.