# SOURCE OF THERMONUCLEAR NEUTRONS «JUPITER NS»

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The project on a plasma source of neutrons for technological tests of thermonuclear reactor materials is considered. The basis of the project is the multislit electromagnetic trap with axial symmetric magnetic field geometry. The results of electromagnetic trap «Jupiter 2» calculations were used as initial data. It is predicted that the source will be able to produce $8*10^{18}$ n/s with the flux density $10^{14}$ n/cm$^2$s onto the surface of samples under irradiation with tritium expenditure of $4*10^{-5}$g/s.

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## INTRODUCTION

The most important criterion of efficiency of a plasma source of the thermonuclear neutrons is a tritium expenditure refereed to a quantity of neutrons being produced. For two-component source, where neutrons are created as a result of injection of high energetic tritium beams into a deuterium plasma target, this expenditure is determined by energy of injected tritium ions and parameters of a target plasma. For example, in the neutron source GDT-NS [1] an injection of beam of tritium atoms with 94 keV energy and equivalent current 69.1A into a target plasma with parameters $n_e = 2*10^{14}$ $D^+/cm^3$, $T_e$ = 1.1keV and $T_i$ = 0.3keV, the neutron yield will be $10^{18}$ n/s with the tritium injection rate $2*10^{-3}$g/s. Of this value only $5*10^{-6}$g/s will be spent for the production of neutrons and all other quantity of injected tritium will leave the trap through axial holes together with deuterium plasma flow. Thus the efficiency of tritium use in GDT-NS is not more than 0.25% of the full-injected flow. The tritium extraction from deuterium-tritium plasma for repeated use is a problem which does not yield on the complexity and cost to its production in a nuclear reactor. The increase of energy of injected tritium atoms up to 300keV and the electron target temperature up to 10keV would allow to increase efficiency of tritium use up to 2.5% and to lower the tritium expenditure in the GDT-NS on the order in magnitude. But at the temperature 10keV the plasma target becomes to be an intensive source of neutrons itself, i. e. the problem of decreasing the tritium expenditure is reduced to achievement of thermonuclear plasma parameters in the installations of comparatively small sizes under Q<<1. The multislit electromagnetic trap can be used as one of such installations [2].

## DESCRIPTION OF INSTALLATION

Installation «Jupiter NS» represents multislit electromagnetic trap with axial-symmetric magnetic field geometry. The scheme of installation is presented in fig. 1. Magnetic system consists of three groups of co-axial coils located on an axis of a cylinder. The coils of the first group form a central part of the installation. They have alternated polarity of current switching on and create the layer of space-periodic magnetic field along the cylindrical surface of a central part. The coils of second group join the central part at both sides. These coils are intended to conjugate the space-periodic field of the central part with a field of axial magnetic mirrors. The coils of magnetic mirrors form a third group.

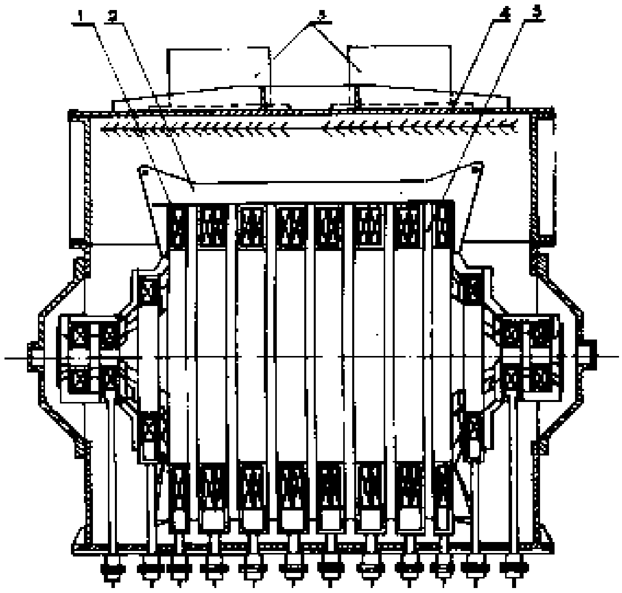

*Fig.1. «Jupiter - NS» scheme: 1 - magnetic field coils, 2 - support frame, 3 - helium pumps, 4 - vacuum chamber, 5 - magnetic slits*

They are located in pairs at the ends of magnetic system. All coils are placed in a vacuum-tight casing and fixed on the common support frame. The coils and the support frame are placed inside a vacuum volume, which is pumped out by helium condensation pumps. The sizes of magnetic system: an internal diameter 2R = 1.34m, the length between axial holes L = 4m. The value of magnetic field in the ring magnetic slits $B_A$ = 5T and in the axial holes $B_{A0}$ = 10T. Magnetic field configuration is characterized by deep magnetic well with an unmagnetized plasma volume $V_p$ =2m$^3$.

Ring magnetic slits and axial holes are closed by electrostatic mirrors, i.e., by electrodes with a high negative potential applied to them. The electrostatic system, fig. 2, is assembled on a rigid supporting skeleton and is inserted, as a whole, between coils. Special devices allow adjusting a plane of every ring slit with the plane of symmetry of a magnetic field while assembling. Anode diaphragms and external ring electrodes are under potential close to the ground potential and medium electrodes - under a high negative potential. It allows to distribute a high-voltage loading on several vacuum intervals between electrodes and thus to make easier the conditions of achievement of the high negative potentials.

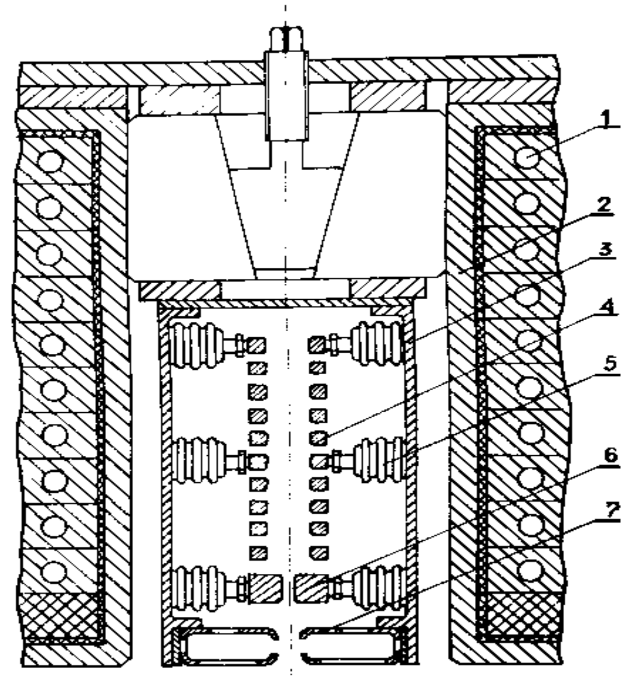

*Fig. 2. The system of electrostatic close of magnetic slits: 1 - magnetic field coils, 2 - vacuum-tight casing of coils, 3 - support frame, 4 - high voltage electrodes, 5 - insulators, 6 - anode diaphragms, 7 - radiating cover*

## PARAMETERS OF NEUTRON SOURCE

Magnetic field of 5T allows to have a plasma with parameters: $n_e = 2*10^{14}cm^{-3}$, $T_{e,i} = 20keV$ in the electromagnetic trap. Ousting a weak magnetic field from the central part, plasma is confined by a boundary magnetic surface with $B_0 = [8\pi n(T_e+T_i)]^{1/2} = 1.8T$. The longitudinal plasma confinement in magnetic slits is executed by electrical fields. Potential $\Phi_k$, enclosed to electrodes of electrostatic system, fig. 3, creates a potential barrier $\Phi_e$ for electrons, and a negative volumetric plasma charge creates a potential well with depth $\Phi_p$ and a potential barrier $\Phi_i$ for ions. The flow of electrons, circulating through magnetic slits, causes depression of potential $\Delta\Phi$, lowering height of potential barriers.

To make the electrostatic confinement of plasma effective the condition $\Delta\Phi \ll \Phi_p$ should be satisfied. Using theoretical calculations [3] we can find the flow of electrons $F=1.5*10^{24}s^{-1}$, circulating through the magnetic slit. This flow creates a volumetric electron density $n_A = 2.18*10^{12}cm^{-3}$ and the potential depression $\Delta\Phi = 19.7kV$ in an anode slit of $2a = 0.2cm$ in width. Values of potential barriers $\Phi_e$ and $\Phi_i$ are determined by the balance of the charged particle flows arriving into the trap and leaving it.

Electrons arrive into the trap in consequence of injection through axial holes and neutral gas ionization, and leave the trap in consequence of diffusion across a magnetic field (in the coordinate space) and diffusion along magnetic field lines (in the velocity space). We shall evaluate the diffusion flow in the coordinate space using results of theoretical calculations [4]:

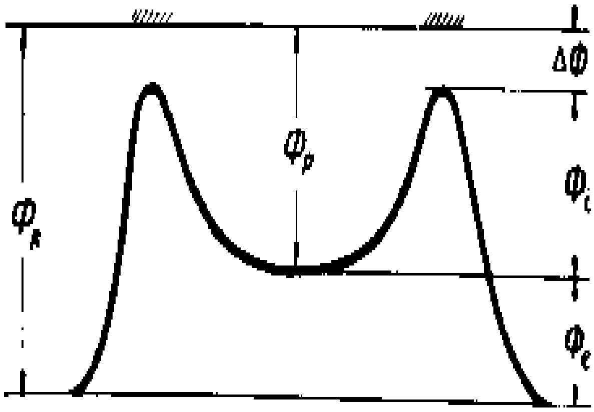

*Fig. 3. The scheme of electrostatic closing of magnetic slits: $\Phi_k$ - potential, enclosed to electrodes of electrostatic system, $\Phi_e$ - potential barrier for electrons, $\Phi_p$ - potential well depth, $\Phi_i$ - potential barrier for ions, $\Delta\Phi$ -depression of potential*

$$I_{e\perp} = D_{ei}R^2 n_{e0}(6F_c+F_k) = 6.23*10^{20}/s\ (=99.7A) \quad (1)$$

The electron diffusion flow in the velocity space is [5]:

$$I_{e||} = n_{e0}V_p/[(\pi\gamma_e)^{1/2}\tau_{sl}\exp(\gamma_e)] \quad (2)$$

where $\tau_{sl}$ is a lifetime of electrons in the trap at absence of a electrostatic confinement, when $\gamma_e = \Phi_e/T_e$.

Ions arrive into the trap in consequence of neutral gas ionization and leave it in consequence of diffusion in the velocity space and due to thermonuclear reactions. The diffusion flow of ions is determined by the rate of maxwellization of particles as a result of Coulomb collisions:

$$I_{i||} = 4(2\pi)^{1/2}e^4\lambda n_{e0}^2 V_p/m_i^{1/2}T_i^{3/2}\exp(\gamma_i) \quad (3)$$

where $\gamma_i = \Phi_i/T_i$. The flow of particles - the products of thermonuclear reactions is:

$$I_f = 0.5\sigma_f v_i n_i^2 V_p = 1.68*10^{19}/s\ (=2.69A) \quad (4)$$

From the condition of a charge balance

$$I_{e\perp} + I_{e||} = I_{i||} + I_k + I_f \quad (5)$$

we find the values of potential barriers $\Phi_e$ and $\Phi_i$. For the potential $\Phi_k = 300kV$ and electron injection current $eI_k = 15A$, these values are: $\Phi_e = 185.4kV$, $\Phi_i = 94.9kV$. Accordingly, $I_{e||} = 31A$, $I_{i||} = 113.1A$.

In the electromagnetic trap the principle of energy recuperation can be realized. Leaving the trap through potential barrier, charged particles loose only overbarrier additive portion of energy without return. It is determined by a ratio of particle maxwellization rate to the rate of their escaping from the trap through magnetic slits. For ions the time of maxwellization $\tau_m$ exceeds the time $\tau_{sl}$ of particle escape from the trap through the slits, thus the overbarrier additive is small. For electrons, on the contrary, $\tau_{sl} >> \tau_m$ and electrons have enough time to acquire the Maxwellian distribution before escaping from the trap. The overbarrier additive for electron is close to the maximum value $2T_e$. The electrons, diffusing across a magnetic field are spreading their kinetic energy, acquiring in electrical field, when collide with ions.

They transfer energy of the order of $T_e$ to the anode diaphragms. The rates of energy losses through diffusion channels are: $P_{e\perp}$=1.99MW, $P_{e||}$=1.07MW, $P_{i||}$=1.24 MW. The bremsstrahlung radiation loss in hydrogen plasma $P_r$ = 0.191MW. The whole energy losses from plasma are: $P_\Sigma$ = 4.5MW. This energy losses have to be compensated by electron injection $P_k = I_{ek}\Phi_k$ = 4.5MW. The energy lifetime can be estimated as: $\tau_e$ = 0.57s.

The equicomponent mixture of deuterium and tritium of a value $2.6{*}10^{-3}$g/s must be injected into a plasma for maintaining the neutron flux $8{*}10^{18}$n/s. The tritium expenditure for neutron production is $4{*}10^{-5}$g/s. The spent gas mixture arrives into a vacuum chamber, where deuterium and tritium are collected by a special cryogenic pump-accumulator, for repeated use in the neutron source. An opportunity to provide the complex technological tests of materials in conditions close to conditions of a real thermonuclear reactor should be related to merits of neutron source of a given type.

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# ДЖЕРЕЛО ТЕРМОЯДЕРНИХ НЕЙТРОНІВ «JUPITER NS»

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Розглянуто проект плазмового джерела нейтронів для технологічних випробувань матеріалів термоядерного реактору. В основу проекту покладена електромагнітна пастка з осесиметричною геометрією магнітного поля. В якості вихідних даних використовувались результати розрахунків електромагнітної пастки ”Юпітер 2”. При затратах $4{\cdot}10^{-5}$ г/с тритію джерело спроможне виробляти $8{\cdot}10^{18}$ н/с з флюенсом $10^{14}$ н/с на поверхні опромінюваних зразків.

# ИСТОЧНИК ТЕРМОЯДЕРНЫХ НЕЙТРОНОВ «JUPITER NS»

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Рассмотрен проект плазменного источника нейтронов для технологических испытаний материалов термоядерного реактора. В основу проекта положена многощелевая электромагнитная ловушка с осесимметричной геометрией магнитного поля. В качестве исходных данных использовались результаты расчетов электромагнитной ловушки “Юпитер 2”. При расходе $4{\cdot}10^{-5}$ г/с трития источник способен производить $8{\cdot}\,10^{18}$ н/с с флюэнсом $10^{14}$ н/см$^2$с на поверхности облучаемых образцов.