Energy conversion in electronically controlled discrete ion-plasma dynamics installations

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Session
Design and development of charged particle accelerators and ionizing radiation sources

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Problems

- The general problem of the resource of neutron sources.
  Solution: synthesis reaction of light elements on a plasma DT target.
- Creation of conditions for compaction of plasma flows in a compact installation.
  Solution: discretization of plasma flows in a cyclic magnetic system.

An object:
Nuclear Reactions with the Yield of Neutrons and Discrete Plasmodynamics

Subject:
Formation of a neutron flux in discrete plasma dynamics

Target:
Obtaining neutrons, $n=10^{10}$

Task 1.
Develop a scheme and sequence of processes in the PGN (plasma neutron generator).

Task 2.
Determine the compaction criteria for discrete plasma flows.

Task 3.
Estimate the output characteristics of neutron fluxes.

§2. Development of the problem and its relevance

In this field:

N.L. Dukhov All-Russian Scientific Research Institute, Moscow;

The New Sorgentina Fusion Source (NSFS), Rome;

Joint Institute for Nuclear Research, Dubna;

Training and Demonstration Tokamak MEPhI, Moscow;

Research Center "Kurchatov Institute", Moscow;

Institute of Nuclear Physics named after B.P. Konstantinov, Gatchina;

Institute of Nuclear Physics, Tashkent;

MIT, Cambridge.

Relevance: the creation of a compact source with a long resource.

§3. Fusion reactions with neutron yields

For generation of neutron fluxes, the three main reactions are the most advantageous, as well as variants with blanket modes

Table 1 — Synthesis reactions

№	Reaction	Energy release, MeV	σ_{max},barn (in the 1 MeV energy range)	Energy of a colliding particle σ_{max}, MeV
1	$D + {}^7Li \rightarrow 2{}^4He + n$	15	10^{-3}	0,2
2	$D + T \rightarrow {}^4He + n$	17,6	5	0,13
3	$T + D \rightarrow {}^4He + n$	17.6	5	0.195

§4. Generator circuit, main processes

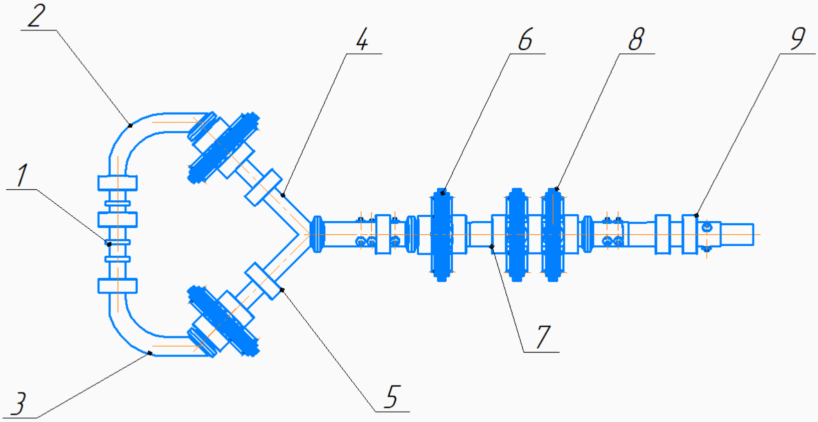

Figure 1 — Scheme of the generator

The patent on magnetic system: RU 2757666 C1 (RPC «NEW ENERGY»: Dolgopolov M.V., Zanin G.G., Ovchinnikov D.E., Radenko A.V., Radenko V.V., Svirkov V.B.)

§5. Discretization of flows

Input of ions and electrons into the first gas pedal

$$(I_{01}, T_{01})(I_{02}, T_{02}), \ldots, (I_{0n}, T_{0n}) \tag{1}$$

Stream splitting $(I_{01}, T_{01}), \ldots, (I_{0n}, T_{0n})$ with initial energy E_0

$$(I_{01}, T_{01})(E_{01}, \ldots, E_{0k}), \ldots, (I_{0n}, T_{0n})(E_{01}, \ldots, E_{0k}) \tag{2}$$

Setting the time sampling

$$\begin{aligned} \big[&(I_{01}, T_{01})(E_{01}, \ldots, E_{0k})(T_{01}, \ldots, T_{0k}), \ldots \\ &\ldots, (I_{0n}, T_{0n})(E_{01}, \ldots, E_{0k})(T_{01}, \ldots, T_{0k})\big] \end{aligned} \tag{3}$$

Discretization of flows

For movement discrete D_1

$$F_1(x, y, z, t) \tag{4}$$

describes the motion of the discrete in time t

Functional discretization

$$\left[F_1(x, y, z, t), \ldots, F_n(x, y, z, t)\right] \tag{5}$$

Radenko A.V., Radenko V.V., Dolgopolov M.V. Modeling magnetodynamic plasma flows (in Russian) // III INTERNATIONAL SCIENTIFIC CONFERENCE "Nonequilibrium Phase Flows. CONFERENCE "NONEQUILIBRIUM PHASE TRANSFORMATIONS". - 2017. - Vol. 1(1). - C. 107-108

Chipura A.S., Dolgopolov M.V., Radenko V.V., et al. Electron-controlled plasma-powered devices for stable and environmentally friendly technologies of electric power generation (in Russian) // Adv. of Engineering Researches. 2022. – Issue 210. – P. 197-205

Discretization of flows

Stream discretization

$$M\frac{d\vec{v}_I}{dt} = -\nabla p_I + en\left(\vec{E} + \frac{1}{c}[\vec{v}_I, \vec{H}]\right) - \alpha(\vec{v}_I - \vec{v}_e) \qquad (6)$$

$$m\frac{d\vec{v}_e}{dt} = -\nabla p_e - en\left(\vec{E} + \frac{1}{c}[\vec{v}_e, \vec{H}]\right) - \alpha(\vec{v}_I - \vec{v}_e) \qquad (7)$$

Continuity equation

$$\frac{\partial n}{\partial t} + div n\vec{v}_I = 0 \qquad (8)$$

§6. Output characteristics

Thermonuclear reaction (D, T)

$$D + T \to^4 He + n + 17.6\,\mathrm{МэВ} \qquad (9)$$

The dependence of the total cross section of reaction (9) on the energy of the deuterons

$$\sigma(E_d) = 1.3 \cdot 10^{-6} E_d^3 - 8 \cdot 10^{-4} E_d^2 - 0.14 E_d - 2.56 \qquad (10)$$

Neutron energy E_n

$$1.25 E_n - 0.5 E_d - 0.5\sqrt{2 E_n E_d} \cos\theta_n \approx 17.577\,\mathrm{МэВ} \qquad (11)$$

At low deuteron energies of $E_d \approx 100 - 150$ keV, the energy of the emitted neutrons is approximately 14.3 MeV.

Output characteristics

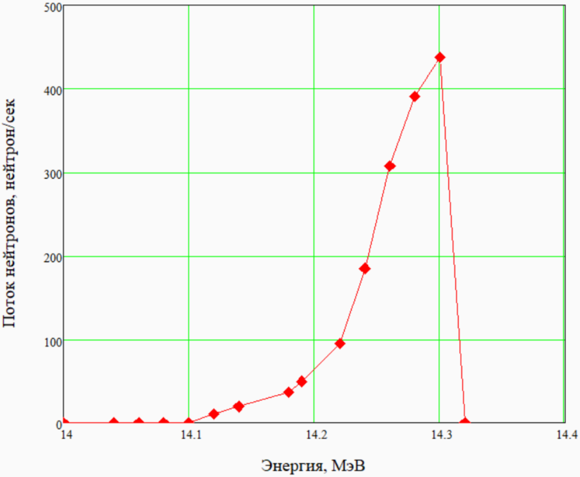

Figure 2 — Neutron flux density from energy

Output characteristics

Neutron yield equation taking into account the beam D:

$$\gamma = \frac{\eta_d i}{e}\rho\int_0^E \frac{\sigma_{dd}}{dE/dx}dE. \tag{12}$$

Bragg's law of additivity

$$\frac{dE}{dx} = \frac{dE}{dx_T} + \eta_d \frac{dE}{dx_D} \tag{13}$$

Stopping power of ions D in T-target

$$\frac{dE}{dx} = \frac{A}{A+2ar}\left(\frac{dE}{dx}\right)_T + \frac{2ar}{A+2ar}\left(\frac{dE}{dx}\right)_D \tag{14}$$

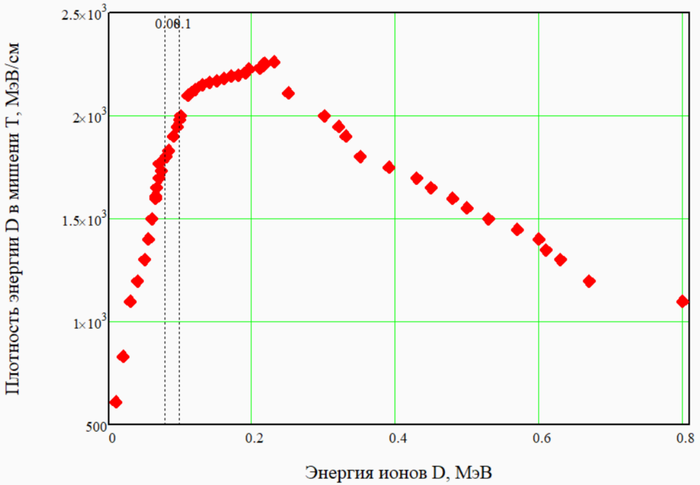

Figure 3 — Linear energy density D in the target T

Output characteristics

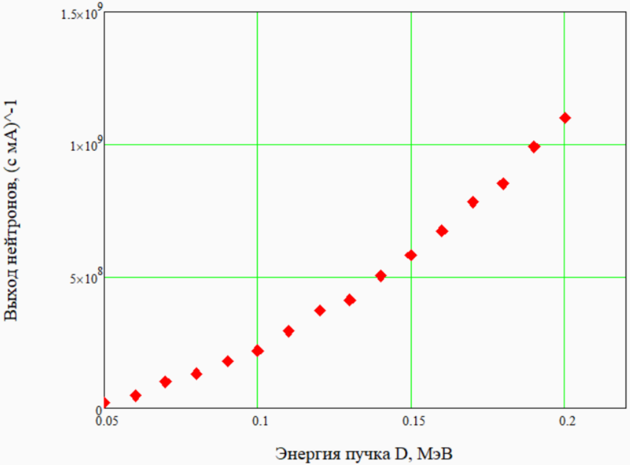

Figure 4 — Neutron yield in (s mA)$^{-1}$ as a function of beam energy D incident on T-target

§ CONCLUSIONS

Task 1.
Develop a scheme and sequence of processes in the PGN (plasma neutron generator).

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1. Developed scheme and described processes of PGN operation.
2. The mathematical model of plasma discretization is considered.
3. Characteristics for the neutron yield 10^{10} are estimated.

Prospects. An application for a patent has been prepared from RPC «NEW ENERGY». A joint project with JINR and an experiment under the Memorandum of Cooperation is being prepared.

Approbation. The results are published in a foreign article in 2022, the proceedings of international conferences 2020-2021 and the International Forum on Nuclear Physics and Technology in 2021.