MAGNETIC SYSTEM OF THERMONUCLEAR REACTOR "ELEMAG"

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The conceptual project of thermonuclear reactor "Elemag" is developed. The multislit electromagnetic trap with axisymmetric magnetic field geometry is assumed as a basis of the project. It is most simple and most investigated thermonuclear system. The description of reactor magnetic system, accounts of magnetic fields, ponderomotive forces, electrotechnical accounts of magnetic field coils are given in this paper.
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INTRODUCTION

Creation of thermonuclear reactor on the basis of electromagnetic trap is the logic result of the "Jupiter" program [1]. It is supposed, that this purpose will be achieved by stepwise increase of the sizes and parameters of experimental installations. Within the framework of the program the projects of large experimental installations for researches of plasma confinement by electromagnetic method were executed: "Jupiter 2" [2] with plasma volume Vp = 0.5 m^3 and expected parameters $n_e = 3\times10^{13}$ cm^{-3}, T_e= 2 keV, T_i = 1 keV, τ_E = 0.1 s; "Jupiter T" - V_p = 4 m^3, $n_e=10^{14}cm^{-3}$, $T_e = T_i$ = 10 keV, τ_E = 1 s. As a first step of these projects realization in KIPT was constructed experimental installation "Jupiter 2M", representing model "Jupiter 2" in 1/3 of natural size [3].

The experiments on "Jupiter 2M" confirmed high efficiency of plasma confinement in multislit electromagnetic traps, absence of high-frequency activity and close to classical factors of particles and energy transfer. Plasma parameters experimentally measured on installation and the ones received by numerical modeling of the material and power balance equations are in the satisfactory consent. All these factors increase a measure of trust to plasma parameters which incorporated in the projects of large experimental electromagnetic traps of the following step, including the thermonuclear reactor project. Constructive simplicity, the stationary mode of operations, opportunity of high-temperature plasma reception without additional sources of heating put these projects in a number of the most perspective systems for solving of a controlled thermonuclear synthesis problem.

The most dangerous plasma instabilities are suppressed in electromagnetic traps, factors of particles and energy transfer are received to be close to classical ones [4]. The decrease of real losses from plasma on two - three orders considerably facilitates the achievement of thermonuclear plasma parameters.

Overall reactor dimensions: diameter of the vacuum chamber D = 10 m, length L = 70 m. Magnetic field in ring slits B_A=70 kGs, in axial holes B_{A0}=100 kGs, on a boundary magnetic surface, separating plasma from a vacuum magnetic field, B_0=15 kGs (β = 1). Electrostatic potential locking magnetic slits Φ_A=700 kV.
Plasma parameters: density $n_{e,i} = 8\times10^{19}$ m^{-3}, electrons temperature T_e = 34 keV, ions temperature T_i = 38 keV, plasma volume V_P = 1140 m^3.

Total thermonuclear capacity of the reactor W_f= 4 GW, neutron loading on the first wall P_n=2,3 MW/m^2 ($\approx 10^{14} n/cm^2\cdot s$). Total neutrons flow $N_n = 1,42\times10^{21}$, charge of thermonuclear fuel (equal-component of deuterium and tritium gas mixture) $m_{DT}=1,21\times10^{-2}$ g/s.

The complex researches including theoretical accounts, numerical modeling and experiments on a multislit electromagnetic trap "Jupiter 2M" are executed in a substantiation of the project. Basic result of these researches is confirmation of classical character of plasma confinement in an electromagnetic trap. Computer experiment confirms an exit of thermonuclear reactor "Elemag" on a stationary mode and achievement of settlement plasma parameters. After switching-off electron injectors the stationary condition in reactor is supported by α-particles energy recuperation in an electrical field of a volumetric electrons charge with subsequent recuperation of electrons energy in an external electrical field. 126 MW will be allocated directly as electrical energy - electrical current of a high voltage.

MAGNETIC SYSTEM

The thermonuclear reactor "Elemag" magnetic system consists of coaxial coils with alternating polarity of current inclusion (fig. 1). Parameters of magnetic system: internal radius of coils a – 2.99 m, external radius b – 4.2m, width h – 0.45 m, total current (ampere conductors) I – 70 kA.

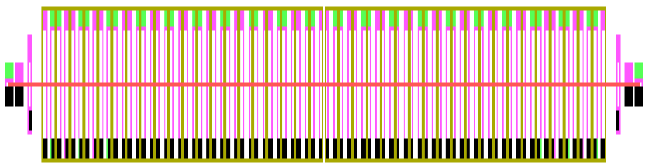
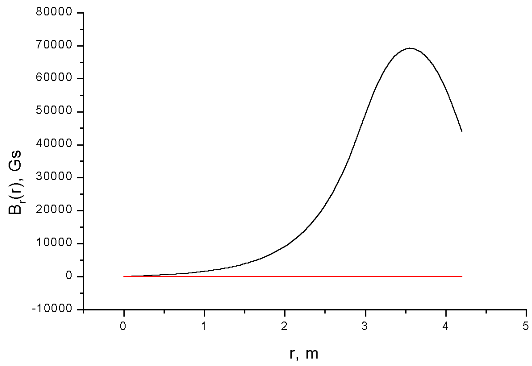


Fig. 1. The magnetic system of thermonuclear reactor "Elemag"

The magnetic configuration "Elemag" is characterized by a deep magnetic well. The dependences of a magnetic field on radius in a plane of a magnetic slit B_r (r, 0), under the coil B_z (r, 0.84), and from z on an axis of system B_z (0, z) are given in a fig. 2 a, b, c. The plasma supersedes a weak magnetic field from the central area of reactor up to a boundary magnetic surface $B_0 = [8\pi n_e k(T_e + T_i)]^{1/2} \approx$ 15kGs, taking place on distance 0,9 m from a surface of coils. Radius of plasma under the coil: a_p=2,1 m (in the project ITER a=2 m). Volume of nonmagnetized plasma with the account of a magnetic field goffer Vp=1140 m^3.

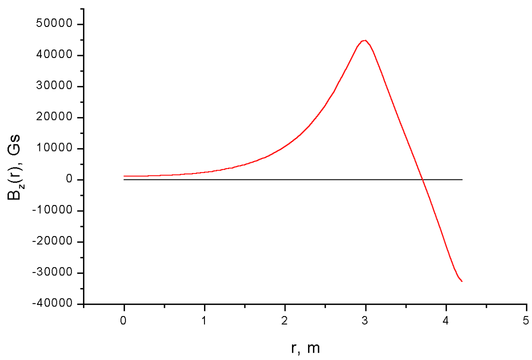
Ponderomotive forces in working "Elemag" are mutually counterbalanced, except for extreme coils: last section of the central part of magnetic system, coils of interface and cork coils. The balance of forces is broken at emergency switching-off one or several coils. The analysis of various emergencies allows to make a conclusion, that the maximal force of repulsion between coils does not exceed $1{,}49\times10^5$ T. Specific loading on the coil from this force (548,9 kg/cm^2) is in borders of elastic deformations of materials, of which the coils and power skeleton will be made. Application of the unified blocks is the successful decision of a ponderomotive forces problem.

1.



a

2.



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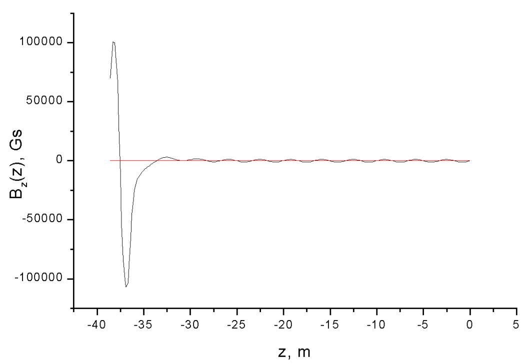
3.



c

4. *Fig. 2. The spatial distribution of a magnetic field:*

5. *a) on radius in a plane of a magnetic slit B_r (r, 0);*

6. *b) on radius under the coil B_z (r, 0.84);*

7. *c) from z on an axis of system B_z (0, z)*

Two one-section coils of magnetic system are incorporated in the unified block, fig. 3. A ring from corrosion-proof steel by an external diameter 10 m, width 1,66 m and thickness 0,3 m serves as power skeleton and, simultaneously, vacuum chamber. Steel bands of the coil are closely connected to a ring. The electrostatic system of magnetic slit lock-out is placed between coils.

Uniform block also consists of: blanket, coil protection against radiation, pipelines of the heat-carrier, branch pipes of system external spilling, inputs of the power supplies and cooling of magnetic field coils, high-voltage inputs.

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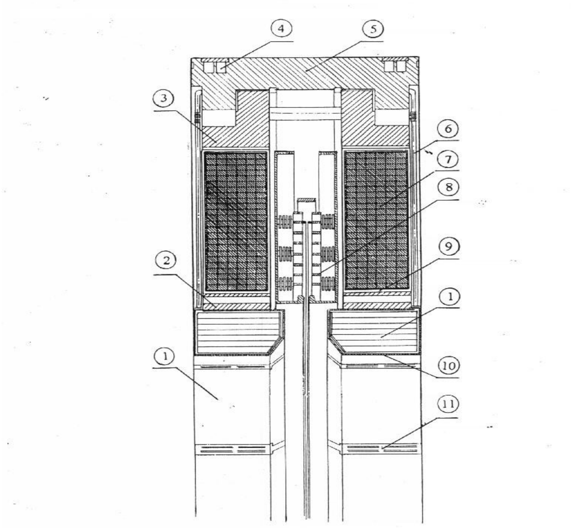

Fig. 3. The Unified block:
1- blanket, 2- protection of coils, 3- power band,
4- gas collectors, 5- ring of the vacuum chamber,
6- gas pipelines of the first wall and blanket, 7- coil of a magnetic field, 8- electrodes of electrostatic system of magnetic slits lock-out, 9- heat insulation, 10- the first wall,
11- the fuel injectors

The feeding of coils will be carried out with use of cryoresistive windings from superpure aluminium cooled by liquid hydrogen. The absence of restrictions on magnetic field value and current density, small sensitivity to radiating damages, opportunity of damage “annealing” at normal temperature are their advantages in comparison with superconducting winding. The technology of trunk manufacturing from industrial material is mastered. Cost of the trunk from superpure aluminium approximately in 120 times is cheaper than a superconductor.

The data from [5] are taken for account. Resistance of aluminium with cleanliness 99,999 % at temperature of liquid hydrogen 20 ^{0}K is accepted ρ = 2.7*10^{-11} Ω/m, charge of energy refrigerator 30 W/W. Section of the aluminium trunk 5x6 cm^2 (in view of channels for pumping of liquid hydrogen S = 27 cm^2). Number of coils in two section n= 288, total length of the trunk L=6508 m, resistance R = 6,51*10^{-5} Ωm. The magnetic field in a ring slit achieves 70 kGs at a current $I=10^5$ A. The energy charges on Joulean losses in windings and work of refrigerators are P= 19,5 MW, the thermonuclear capacity recalculation on the unified block is equal 100 MW.

It is supposed to use ceramic oxide materials cooled by the gaseous heat carrier as a blanket in thermonuclear reactor "Elemag". Factor of tritium reproduction K_T in such blanket has saturation at blanket thickness D=50 cm. For lithium oxide Li_2O K_T=1,2. The increase K_T up to meaning 1,5 in the circuit with neutrons multiplication in reaction (n, 2n) is possible on lead or beryllium[6]. Accommodation blancet in the unified reactor "Elemag" block is shown on a fig. 3 and 4. Structurally blanket consists from beryllium elements with tubes from oxide ceramics and channels of gas cooling built in them, fig. 4.
9.

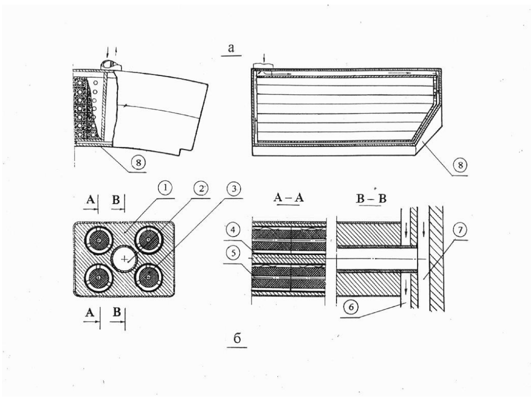

Fig. 4. Thermonuclear reactor "Elemag" blanket:
1- a beryllium element, 2- channel of cooling,
3- ceramic element, 4- channel of the gas - carrier external, 5-channel of the gas - carrier axial,
6- distributing collector of the gas – carrier, 7- channel of the first wall cooling, 8- first wall

Focusing of the charged particles flows gives additional opportunities for improvement characteristics of thermonuclear installations, which work on the basis of a multislit electromagnetic trap. Cylindrical focusing of ions flows, accelerated to the center by an electrical field of electrons volumetric charge is possible in thermonuclear reactor «Elemag» with axisymmetric magnetic field geometry. It gives logarithmic dependence of thermonuclear reactor capacity from accuracy of focusing R/r_0. In accounts is chosen R/r_0 = 10, which is proved by experiments on an one-slit electromagnetic trap "Jupiter 1A". In this case thermonuclear reactor capacity is increased in 5.6 times. It allows to reduce plasma density near with a boundary magnetic surface up to 3.38 $\times 10^{13}$ cm^{-3} and to reduce a magnetic field up to 45kGs for thermonuclear reactor "Elemag", working on equal component of a mix deuterium and tritium. It allows to reduce ponderomotive forces on magnetic system coils up to 226.8 kg/cm^2 and capacity spent for their feeding up to 8 MW on uniform block.

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МАГНИТНАЯ СИСТЕМА ТЕРМОЯДЕРНОГО РЕАКТОРА "ЭЛЕМАГ"

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Разработан концептуальный проект термоядерного реактора "Элемаг" на основе многощелевой электромагнитной ловушки с осесимметричной геометрией магнитного поля. Это - наиболее простая и наиболее исследованная среди электромагнитных ловушек термоядерная система. В работе приведены описание магнитной системы реактора, расчеты магнитных полей, пондеромоторных сил, электротехнические расчеты катушек магнитного поля.

МАГНІТНА СИСТЕМА ТЕРМОЯДЕРНОГО РЕАКТОРА "ЕЛЕМАГ"

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Розроблено концептуальний проект термоядерного реактора "Елемаг" на основі багатощілинної електромагнітної пастки з осесиметричною геометрією магнітного поля. Це - найбільш проста і найбільш

досліджена серед електромагнітних пасток термоядерна система. У роботі приведений опис магнітної системи реактора, розрахунки магнітних полів, пондеромоторних сил, електротехнічні розрахунки котушок магнітного поля.