THE PLASMA ACCUMULATION AND HEATING IN THERMONUCLEAR REACTOR "ELEMAG". *

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Introduction.

The electromagnetic traps \[1\] have unique properties favourably distinguishing them from others thermonuclear systems. The application of the combined electrical and magnetic fields allows to solve a problem of plasma stability, to receive close to classical factors of particles and energy cross transfer. Energy recuperation in an electrical field facilitates an exit of reactor on a stationary mode supported at the expense of direct transformation of kinetic energy of \(\alpha\) - particles in electrical one. Ions oscillation in a radial electrical field of a potential well, them focusing essentially reduces the requirements to a boundary magnetic field, allows to use a less power-intensive magnetic systems.

In the report the circle of questions connected to plasma heating and confinement in the thermonuclear reactor “Eelmag” is considered: plasma formation and heated by electron injection, electron cross transfer in a space of coordinates and in a space of speeds, ion losses through ring magnetic slits and axial holes, recuperation and direct transformation of \(\alpha\) - particles kinetic energy in electrical one. The results of computer experiment describing a starting mode and a stationary state of reactor are given.

Reactor’s geometry

The magnetic system of thermonuclear reactor “Elemag” consists of coaxial coils with alternating polarity of a current inclusion. The dimentions of magnetic system are determined by allowable thermal and neutron loading on the first wall. The complete area of the first wall surface should make \(\approx 1000 \text{ m}^2\) at thermal capacity of reactor 4 GWt and safe neutrons load \(\approx 2.5 \text{ MWt/m}^2\). It can be realized in the reactor with plasma radius \(r_p \approx 2 \text{ m}\), length of a cylindrical part \(L = 70 \text{ m}\) and plasma volume \(V_p = 1140 \text{ m}^3\). The density of emitted thermonuclear energy \(P = 3.54 \text{ MWt/m}^2\) is provided by choice plasma parameters: \(n_{e,i} = 8 \times 10^{13} \text{ cm}^{-3}\), \(T_{e,i} = 40 \text{ keV}\).

The value of magnetic field is determined by parameters of confined plasma: magnetic field in ring magnetic slits \(B_A = 7 \text{ T}\), in axial holes - 14 T.
Plasma heating and confinement.

In electromagnetic trap the plasma is created and heated by electron injection. Accumulating in the trap electrons create negative volume charge and potential well for ions confinement. Entering into plasma particles of neutral gas are ionized on the slopes of the potential well. The electrons and ions being formed as a result of ionization are accelerated by an electrical field of a space charge and thus acquire total kinetic energy that is equal to the height of potential. The distribution of energy between electrons and ions depends on the point of potential barrier slope where ionization took place. As the neutral atom run in plasma before ionization is proportional to plasma density and the depth of electrical field penetration into plasma is proportional to a square root of density then with plasma density increase the ionization point displaced upwards on potential well slope and the energy portion coming to ion component of plasma rises.

With plasma density of $10^{13}$ cm$^{-3}$ this energy appears to be approximately 20% of potential barrier value, i.e. it is enough for thermonuclear reaction to proceed.

Electrons are lost from a trap as a result of cross transfer through a magnetic field with an exit on limiting anode diaphragms and also as a result of longitudinal diffusion in space of speeds with overcoming of an electrostatic barrier $\Phi_c$ and exit on electrodes of electrostatic magnetic slits lock-out system.

The cross diffusion flow in a multislit electromagnetic trap with axisymmetric geometry of magnetic field in view of electrons mobility in a strong electrical field was calculated in works [2, 3]

\[
I_{e\perp} = N[D_{ea}(1+\Phi_p/2T_{e0}) + D_{ei}] n_{e0} F R^2
\]

where $N$ – quantity of magnetic slits in a trap, $D_{ea} = T_e \nu_{ea} / m_e \omega_{ce}^2$, $D_{ei} = T_e \nu_{ei} / m_e \omega_{ce}^2$ - factors of electrons diffusion on plasma neutral atoms and ions, $\Phi_p$ - plasma potential (in power units), $n_{e0}$, $T_{e0}$ - plasma density and electrons temperature in the central area of a trap, $F$ - factor which is taking into account magnetic field geometry, $R$ - radius of a trap on a ring magnetic slit.

Longitudinal losses according to [4] are determined by speed of particle maxwellization in plasma. All particles which have achieved energy of a potential barrier leave plasma volume at small speed of maxwellization and

\[
I_l = 4(2\pi)^{1/2} c^4 \lambda n^2 V_p m^{1/2} T^{-3/2} \exp(-\gamma)
\]

At the large speed of maxwellization the barrier exit of particles is limited by throughput of magnetic slits.
\[ I_i = 2(\pi)^{1/2} c r_p n k T (B_0/B_A)^{1/2} \exp^- \gamma e B_A^{-1/2} \]

\( V_p \) - plasma volume, \( \gamma = \Phi / T \), \( r_p \) - radius of plasma, \( B_A \) - magnetic field in a ring slit, \( B_0 = B(r_p) \). We take the smaller value from these two expressions for longitudinal electron losses \( I_e \) and longitudinal ion losses \( I_i \).

Starting mode.

The duration of starting mode is determined by a current of injection and quantity of fuel inputing in reactor. For \( I_e = 100 \) A and \( m_{D,T} = 4.63 \times 10^{-2} \) g/s a stationary mode reaches in time \( t = 30 \) sec. with parameters: \( n_{e,i} = 8 \times 10^{13} \) cm\(^{-3}\), \( T_e = 33.9 \) keV, \( T_i = 38.6 \) keV. Accumulated plasma density is regulated by neutral gas submission. In a stationary mode the quantity of gas, acting in plasma, should correspond to quantity of substance leaving a trap \( \alpha \)-particles and ions of deuterium and tritium. Plasma density will remain constant during all operating time of thermonuclear reactor at performance of neutral gas balance. Increase of gas submission or reduction of gas submission leads to plasma density increase or reduction with exit on a new stationary level. Other plasma parameters are arranged under a new stationary condition.

The mechanism of thermonuclear reaction \( \alpha \)-particles energy recuperation and connected with it energy recuperation of fast electrons in an external electrical field is included with growth of density and temperature of plasma ions. When the capacity of recuperated energy becomes equal to capacity of electron injection, feeding of electrons injectors can be switched to a source of recuperated energy. At the further increase of plasma parameters the external electron injection is switched off and work of reactor proceeds in an independent mode. Thermonuclear fuel is entered in plasma, there is an ionization of neutral gas, having heated electrons and ions in a potential well volumetric charge, thermonuclear reaction between ions, energy recuperation \( \alpha \)-particles and energy recuperation fast electrons, restoring power balance. The de-energizing of electrons injection does not render essential influence on process of plasma accumulation, the accumulation proceeds for the account of \( \alpha \)-particles energy recuperation.

One of the unique properties of electromagnetic traps is the presence of radial electrical fields forming and accelerating ion flows in the center of system. Charged particles focusing into the center of system leads to appreciable increase of plasma density and, as a consequence, to increase of thermonuclear capacity at the same charged particles and energy losses. Depending on the chosen magnetic field geometry it is possible the spherical or cylindrical charged particles flows focusing.
Increase of plasma density at the centre which exceeds average density on ten times was observed in experiments on an one-slit electromagnetic trap "Jupiter 1A" [5]. The same increase of plasma density in "Elemag" would increase thermonuclear capacity in six times, that would allow either to reduce the reactor’s geometrical sizes twice, or to lower the magnetizing force from 70 to 45 kGs.

Conclusions

The main result of work is plasma parameters theoretical account and modeling in thermonuclear reactor «Elemag». Reactor comes on calculated plasma parameters for \( t \approx 30 \) sec in a starting mode at a current of electrons injection 100 A and lap joint of the equal component of gases deuterium and tritium mix \( 4.63 \times 10^{-2} \) g/s. Energy recuperation of thermonuclear \( \alpha \)-particles in an electrical field of electron volumetric charge with subsequent energy recuperation of electrons in an external electrical field allows to disconnect electron injection. The stationary condition with plasma parameters \( n_{e,i} = 8 \times 10^{13} \) cm\(^{-3}\), \( T_e = 36 \) keV, \( T_i = 38.6 \) keV is achieved by reduction of neutral gas submission up to \( 2.44 \times 10^{-2} \) g/s. The complete thermal capacity of thermonuclear reactor \( P_f = 4 \) GWt, \( P_{net} = 141 \) MWt transforms directly in electrical energy (electrical current of a high voltage).

Plasma parameters of a stationary mode are confirmed by theoretical accounts of the thermonuclear reactor basic characteristics.

References


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