J. Plasma Fusion Res. SERIES, Vol. 3 (2000) 211–213

Magnetic Suppression Concept for Secondary Emission Electron End Flux in Open Systems

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(Received: 18 January 2000 / Accepted: 8 March 2000)

Abstract

The electron temperature in a mirror plasma is sufficiently lower then ion temperature. The most probable reason for this effect is the influence of relatively cold secondary emission electrons penetrating into the plasma along open magnetic lines. The principle of decreasing of secondary emission electron flux for a mirror configurations is suggested. In correspondence with the idea of the principle ends of open magnetic lines should be curved. It is shown that particle drift in curved magnetic field leads to reducing particle fluxes along lines, and the value of cold secondary emission electrons penetrating into plasma core decreases in this case.

Keywords:
tandem mirror, open lines, secondary emission electrons, toroidal end cells

1. Introduction

The tandem mirror confinement system is very attractive from the viewpoint of creation steady state fusion reactor because it has following advanced features:

1) simple geometry;
2) possibility of steady state operating;
3) possibility of high-β confinement;
4) possibility of using direct energy conversion systems; etc.

The features 3 and 4 are especially important for prospects of low-radioactive fusion reactor using D-^{3}He fuel [1,2] because for high efficiency D-^{3}He fusion $\beta > 0.5$ is needed, and the major value of fusion energy in D-^{3}He cycle is associated with charged particles.

Tandem mirror experiments showed one disadvantage of this system is low value of the electron temperature.

Experiments on GAMMA-10 tandem mirror showed electron temperature had sufficiently low value in comparison with ion temperature [3]. The study of potential formation [4,5] showed that the most probable reason of this phenomenon is the cooling of electron component by relatively cold secondary electrons emitted from the surface of chamber wall due to interactions with particles (ions and electrons) lost from the central cell along open magnetic field lines [4,5].

Secondary emission (SE) of electrons from metallic surfaces of ends of the system leads to additional power losses from plasma due to cooling effect of SE electrons, and limitation of electron temperature. This situation limits fusion prospects of the tandem mirror. To provide better power characteristics needed for steady state operating it is necessary to reduce the effect of cooling of the tandem mirror plasma by SE electrons.

The main goal of this work is to consider possible simple modifications of the tandem mirror confinement system possibilities of reducing SE effect. In this work we consider method of plasma insulation by curving

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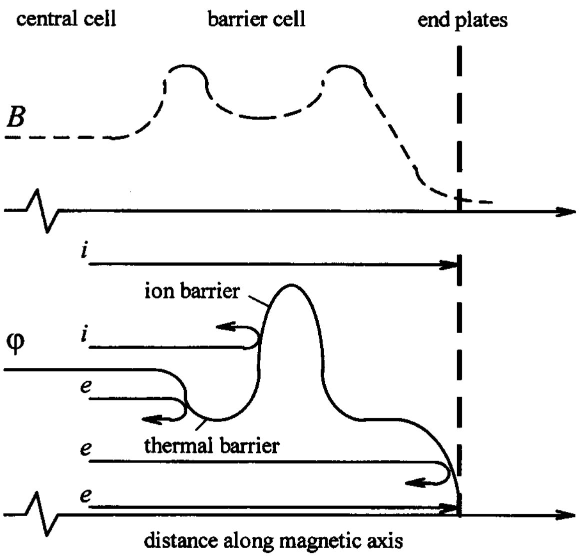

Fig. 1 Diagram of magnetic field profile, electrostatic potential and directions of trajectories of irons and electrons in the tandem mirror.

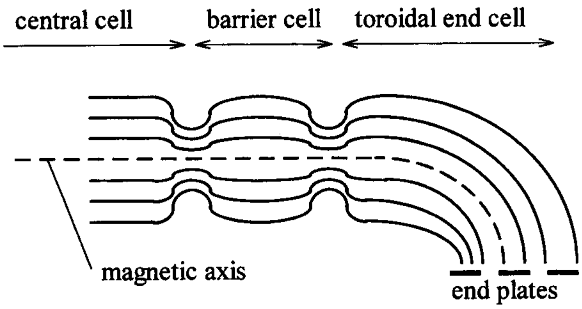

Fig. 2 Scheme of magnetic field configuration of tandem mirror with toroidal end cells.

ends of field lines. The idea of such insulation is based on the effect of ions drift perpendicularly to magnetic field vector in curved line magnetic field is considered in the next section.

2. Secondary Emission Electrons Problem in the Tandem Mirror

The problem of SE electrons cooling plasma is actual for different confinement systems. For example, in tokamak the flux of secondary emission electrons into plasma can be reduced using grids under positive electrostatic potential [6].

The main feature of considering problem for tandem mirror devices is the presence of open magnetic field lines piercing the surface of the camber wall of the device.

In the tandem mirror SE of electrons from the end plates appears due to the influence of ions and electrons lost from the central cell of the tandem mirror along open magnetic field lines. The scheme illustrating this phenomenon and distributions of magnetic field and electrostatic potential along the magnetic axis is presented in Fig. 1. The SE electrons penetrate into the plasma along and cool it.

The flux of SE electrons into the plasma grows with the growing of particle flux from the plasma along magnetic field lines. Consequently SE electron flux can be reduced by decreasing of fluxes of ions and electrons from the plasma. When ion flux from the plasma decreases, electron flux decreases too, because of these two fluxes are connected. Consequently decreasing of ion flux leads to decreasing of the total particle flux along magnetic field lines from the plasma. The method of the decreasing of particle flux along magnetic field lines based on the effect of ions drift perpendicularly to magnetic field vector in curved line magnetic field is considered in the next section.

3. Principle of SE Electrons Effect Suppression

In order to protect plasma from cold secondary emission electrons, it is possible to close magnetic force lines by the following method. Two "parallel" mirrors can be linked by semi-toroidal cells. The more simple method of reducing of SE electron flux due suppression of parallel plasma particle flux is based on properties of recently suggested magnetic configuration with toroidal ends [7]. We consider open configuration includes the tandem mirror and toroidal magnetic field cells installed on both ends of the tandem mirror. This magnetic configuration is presented in Fig. 2.

In toroidal field ions drift in direction perpendicular both magnetic field B and its gradient ∇B, and consequently they leave plasma across the magnetic field not along the open lines. This $B \times \nabla B$ drift for ions and electrons has opposite directions, that leads to charge sharing and formation of electric field parallel to the direction of $B \times \nabla B$ drift, and consequently $E \times B$ appears. Joint action of these two drifts forced particles leave plasma before they can achieve ands of the system. These particles can induce SE from the toroidal wall of the toroidal end cells, but in this case the influence of the SE electrons in this case will be localised in scrape-of layer. It means that SE electrons will not penetrate into core plasma the central cell and

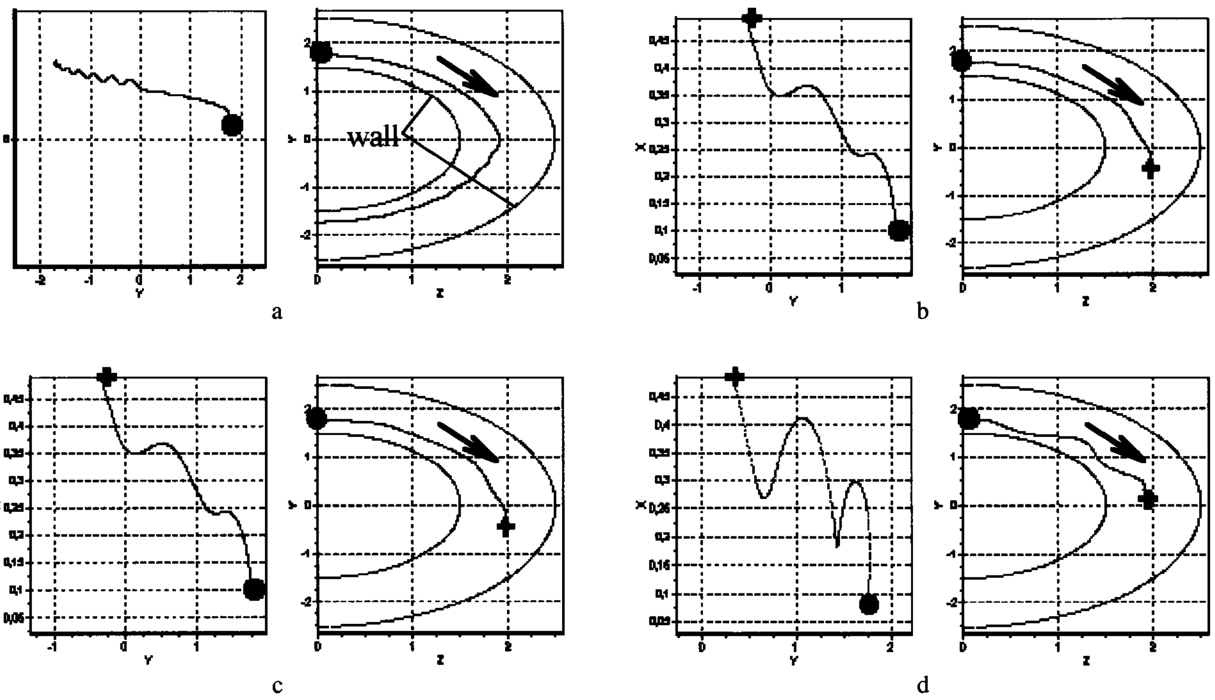

Fig. 3 Trajectories of particles in toroidal end cell. X-Y is the plane perpendicular to the toroidal field (on the left side of each figure), and Y-Z is the equatorial plane of tore (the right side). Start points are marked by rounds. Crosses mark points where particles achieve toroidal wall. Arrows show direction of the toroidal magnetic field. B_{ax} = 2 T, r_w = 0.5 m, R_T = 2 m; a - ε = 0.1 keV, θ_0 = 0; b - ε = 1 keV, θ_0 = 0; c - ε = 1 keV, θ_0 = 5°; d - ε = 1 keV, θ_0 = 20°.

cool it sufficiently.

Efficiency of suggested insulation method can be illustrated by ions trajectories in toroidal cells. Trajectories presented in Fig.3 where obtained as a numerical solutions of dynamics equation for particle motion in model magnetic field of considering configuration with toroidal end cells. This calculations were carried out neglecting the effect of the electric field. We assume that the magnetic field value on the magnetic axis of toroidal field B_{ax} is equal to the value of magnetic field in the central cell. In Fig. 3 ε is the ion energy, θ_0 is the ion pitch angle in the central cell, the sizes of toroidal cell wall are R_T (the tore axis radius) and r_w (the small radius of tore). The end cell toroidal angular size for calculation was assumed to be 180°, but as one can see toroidal angle about 90° is can be reasonable for the insulation. Calculations showed that presented insulation method has low efficiency for slow ions (see Fig. 3a), and it has high efficiency for relatively high-energy particles (see Fig. 3b-d).

4. Conclusion

It was shown the high efficiency reducing of parallel plasma flux on the wall of the ends of tandem mirror can. Presented concept of suppression is based on simple method of plasma insulation due to drift in curved-line magnetic field, and this method allows simple technical realization.

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