Proceedings of ITC18, 2008

Study of α particle Confinemet in the LHD Type Reactor

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The α-particle confinement of the heliotron type reactor is investigated based on three typical LHD configurations with different magnetic axis positions in the major radius. The GNET code is applied, in which the drift kinetic equation for the α-particle is sloved including the particle collisions with background plasma, is applied to evaluate the velocity space distributions, the radial profiles and energy loss rates.

It is found that the inward shift of magnetic axis improves the alpha-particle confinement strongly and a sufficient confinement of alpha-particle for fusion reactor is obtained in the strongly inward shifted configuration.

Keywords: LHD, α-particle, confinement, finite-β, GNET

1 Introduction

D-T fusion reaction produces a high energy α-particle which has the energy of 3.5MeV and the plasma heating by the energetic α-particle is necessary to sustain a high ion temperature plasma in the fusion reactor. Therefore, it is important to confine the energetic α-particles until the energy slow-down to the thermal energy. Also, the lost of the high energy α-particles may cause the damage of the first wall of the reactor. Therefore, a sufficient confinement of the high energy α-partiles is required. In helical systems, the magnetic configuration is mainly genereated by the coil currents so that we can obtain steady state plasma without an additional plasma current drive system. However, the behaviores of trapped energetic particles are complicated due to the three-dimensional (3D) magnetic configuration compared with that in the tokamak configuration. Thus, the detail analysis of the α-particle confinement is necessary for the reactor desing assuming helical configurations.

In this paper we study the α-particle confinement in the LHD type heliotron reactor extending the LHD configuration. The LHD can be flexible about the configuration and we can move the plasma horizontally to shift the magnetic axis position inward or outward relative to the center of helical coils by controlling the axisymmetric poloidal fields. The shift of the magnetic axis position alters characteristics of the ripple-induced transport and, especially, a strong inward shift reduces the ripple-induced transport to the comparable level of “advanced stellarators”[1] The trapped particle orbits are also improved as the magnetic axis shifts to the inward (Fig.1), from R_{ax} = 3.75 to R_{ax} = 3.53.

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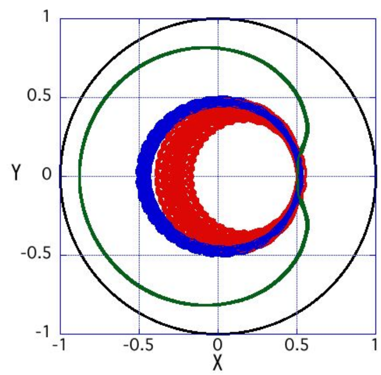

Fig. 1 Trapped particle orbits in the typical magnetic configuration of LHD.

2 Simulation Model

The α-particle confinements are investigated assuming reactor sized devices base on three typical configuration of LHD with different magnetic axis position in the major radius. The first one is the “OS” configuration based on the Rax=3.75m (standard heliotron configuration) of the LHD. The secound is the “IS” configuration based on the Rax=3.6m (σ -optimized configuration) and the last one is the “NO” configuration based on the Rax=3.50m (near the neoclassical-tarnsport-optimized configuration). The optimum axis position for the ripple-induced transport is 3.53m and a good confinement of energetic particle is expected in the NO configuration. The assumed parameters for extending to the heliotron reactors are the plasma volume : 1000m^3 and the magnetic field strength : 5T.

The GNET code [2] is applied to study the α-particle confinement. The drift kinetic equation in the

5D phase-space

$$\frac{\partial f}{\partial t} + (\boldsymbol{v}_{\|} + \boldsymbol{v}_D) \cdot \nabla f + \dot{\boldsymbol{v}} \cdot \nabla_V f$$
$$= C^{coll}(f) + L^{particle}(f) + S_{\alpha}, \qquad (1)$$

is solved with the pitch angle and the energy scattering, where f is the particle flux and C^{coll} is the collision operator term. $L^{particle}$ and S_{α} are the loss and the source terms of the α- particle, respectively.

The source term, $S_{\alpha}$is evaluated assuming the temperature profiles and thefollowing density .

$$T_e(r) = 9.5 \times 10^3 \left[1 - \left(\frac{r}{a} \right)^2 \right]$$
$$+5.0 \times 10^2 \quad \text{[eV]}, \qquad (2)$$

$$n_e(r) = 1.90 \times 10^{20} \left[1 - \left(\frac{r}{a} \right)^8 \right]$$
$$+1.00 \times 10^{19} \quad [\text{m}^{-3}]. \qquad (3)$$

Fig. 2 shows the radial profile of the source term of the α- particle.

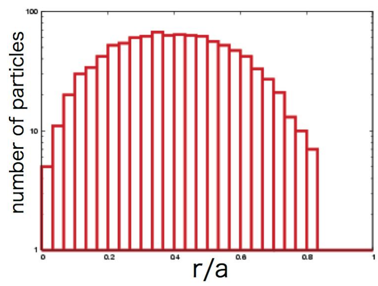

Fig. 2 Plot of the source term of the α-partile.

3 Simulation Results

We steady α-particle confinement in the heliotron reactor extending the typical three configurations of LHD; OS, IS, and NO. As a first step we study the configurations in a low beta limit to show a flexibility of LHD magnetic configuration. We run the GNET code until the steady state of the α-partile is obatined. The typical time to obtain the steady state is $t = 0.2$s.

Fig. 3 shows the velocity space distribution of the α-particle in the NO and OS configurations. We can see the slowing-down distribution of the α-particle from the energy of 3.5MeV. It is also found that the distribution near $V_{\|} = 0$ rigion (trapped particle region) is decreased compared with other regions due to the radial diffusion and the orbit loss of trapped particles. Also the less decrement is found in the NO configuration than that in the OS configuratin.

Fig. 4 shows the radial profile of the α-particle after the slowing-down to the thermal particle; t = 0.2s. We can see the radial broadening of the α-particle from the initial profile in both cases and the larger change in the radial profile is found in the OS configuration than that in the NO configuration.

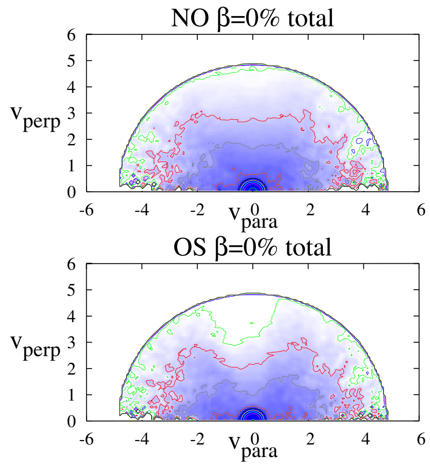

Fig. 3 The velocity space distributions of the α-particle; in the NO (top) and OS (bottom) configurations.

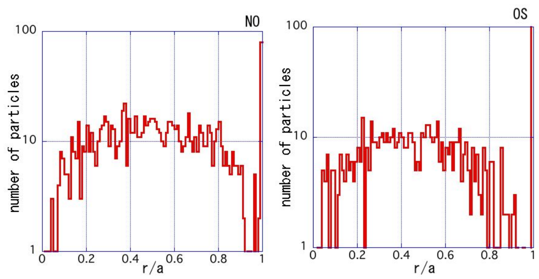

Fig. 4 The radial profiles of the α-particle after slowing-down in the NO (top) and OS (bottom) configurations.

Next we study the distribution of the lost α-particle in the energy and velocity space. The energy spectrum of the lost α-particle in the OS configuration is shown in Fig. 5. The large loss near the initial energy 3.5MeV can be seen in the OS configuration and this indicates the large prompt orbit loss of particle. This loss is strongly reduced in the NO configuration where the trapped particle orbit is improved largely.

Fig. 6 shows the velocity distribution of the lost α-particle in the OS configuraton. It is found that the lost α-particle has the similar pitch angle close to the trapped and passing particle boundary in the velocity space. This shows that the radial diffusion of the transition particle between the trapped and passing motions is large.

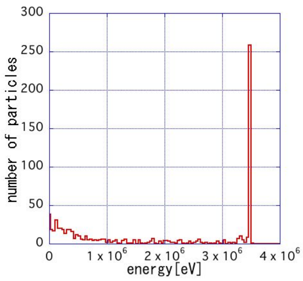

Fig. 5 Energy spectrum of lost α-particles in the OS configuration.

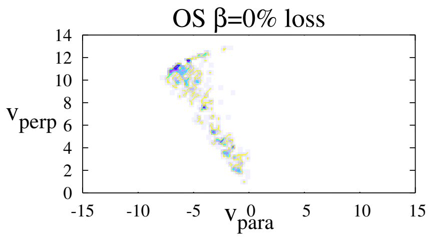

Fig. 6 Velocity space distribution of lost α-particles in the OS configuration.

We, next, show the time development of the energy loss rate of α-particle in Fig.7. We can see large energy loss after very short time ($t < 10^{-3}$s) in the OS configuration due to the prompt orbit loss and the initial loss is very small in the IS and NO configurations. The loss rate increased to about 5% in the NO configuration.

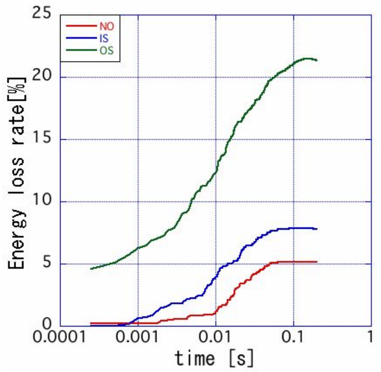

Fig. 7 Energy loss rate

4 Conclusion

We have studied the α-particle confinement of the heliotron type reactor assuming reactor sized LHD based on three typical configurations with different magnetic axis positions in the major radius. The GNET code has been applied, in which the drift kinetic equation for the α-particle is sloved including the particle collisions with background plasma. The velocity space distributions, the radial profiles and energy loss rates have been evaluated chainging the magnetic configurations. It is found that the inward shift of magnetic axis improves the alpha-particle confinement strongly and a sufficient confinement of alpha-particle for fusion reactor is obtained in the strongly inward shifted configuration.

[1] S. Murakami, et al., Nucl. Fusion, 42 (2002). L19

[2] S. Murakami, et at., Fusion Sci. Technol. 46 (2004) 241.