§19. Orbit Topology and Confinement of Neutral-Beam Injected Beam Ions in Quasi-Axisymmetric System

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The quasi-axisymmetric stellarator CHS-qa, which is one of the so-called advanced stellarators, has been designed to provide good neoclassical confinement as well as magneto-hydrodynamic stability while realizing a tokamak-like, toroidally-symmetric magnetic structure in Boozer coordinates [1,2]. In CHS-qa, the neoclassical transport is significantly improved compared with that in the existing CHS [3]. However, we must verify orbits and confinement property of energetic ions since residual non-axisymmetric magnetic field components exist in the edge region and these residual ripples can enhance the radial diffusion of toroidally trapped energetic ions. In this work, the orbit topology of collisionless beam ions is numerically studied for CHS-qa configuration in both Cartesian and Boozer coordinates[4,5]. The global confinement property of neutral beam (NB)-injected energetic ions is also investigated by use of particle simulation code DELTA5D following guiding center orbits in presence of slowing-down and pitch angle scattering processes on Boozer coordinates.

Figures 1a and 1b show three-dimensional plots of typical passing and toroidally trapped orbits of neutral beam(NB)-injected energetic ions in Cartesian coordinates by following full gyro motions in the vacuum magnetic field produced by 20 modular coils for B_t of 1.5T[6]. It can be seen that particle orbits in CHS-qa are quite similar to those in tokamaks because of the quasi-axisymmetry of the system.

In an evaluation of NB ion confinement, it is important to consider the slowing down and pitch angle scattering processes. In order to evaluate the global beam ion confinement in the presence of collisions, the particle simulation code DELTA5D was employed. The guiding center beam ion orbits are tracked in the equilibrium magnetic field obtained from the VMEC code which are then transformed to Boozer coordinates. Figure 2a and 2b show the time evolution of the percentage of energy lost (<*E*> lost) from the beam averaged over the ensemble of 1,000 ions in volume-averaged magnetic field strength <*B*> of 1.5 T with R_{tan} =1.85 m, corresponding to the parallel injection and the pitch angle distribution of escaping ions, respectively. The plasma parameters used here are $n_e(0)$=6.0×10^{19} m^{-3} with a profile of $n=n(0)\bullet(1-(r/a)^2)$, and $T_e(0)=T_i(0)$=1.5keV with a profile of $T = T(0)\bullet(1-(r/a)^2)^2$. n_i (hydrogen) is given as $0.91\bullet n_e$ and one impurity component is considered. The percentage of <*E*> lost is determined when it reaches a saturated plateau in its time evolution ; this plateau is associated with the average beam ion decelerating to the thermal energy level of $3/2\bullet T_i$. It appears that tangentially co-injected beam ions are well confined even in the presence of collisions, and <*E*> lost is evaluated to be about 9.5% in this case. The pitch angle distribution is very peaked around the deeply trapped range, indicating that some of banana particles are lost due to residual non-axisymmetric magnetic field ripples. In regard to this study, detailed description is available in Ref. 4 and 5.

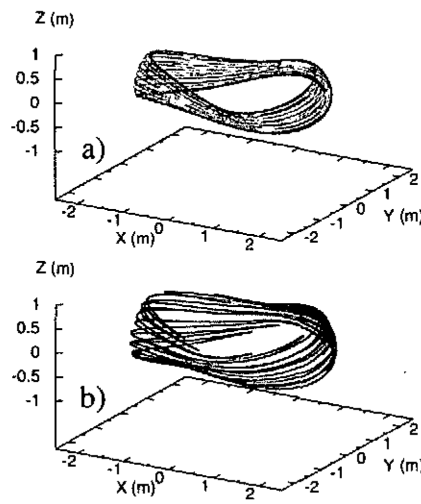

Fig. 1. Collisionless beam ion orbits in Cartesian coordinates for CHS-qa. Three-dimensional plots of orbits of (a) energetic passing H$^+$ ions ($v_{//}/v$~1) and (b) toroidally trapped ions ($v_{//}/v$~0.26) with an energy of 38keV in B_t of 1.5T.

Fig. 2. (a) Time evolution of <*E*> lost (%), (b) Number of exiting beam ions as a function of pitch angle $v_{//}/v$

References

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