Characteristic Magnetic Field Properties of Improved Low Aspect Ratio L=1 Helical Systems

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Abstract

The L=1 torsatron systems having a spatial magnetic axis have been studied. If we consider a compact system, a small pitch number of the helical magnetic field *N* and low aspect ratio system is desirable. The transport properties of these compact systems are described. The improvement of particles confinements evaluated by the Boozer coordinate is observed. And the structures of magnetic field are also studied from viewpoint of the effective curvature term.

1. Introduction

The trapped particle confinement in the L=1 helical system with a large *N* is considerable satisfactory by the particle orbits tracing and calculating the neoclassical transport particle and heat fluxes[1]. This helical axis systems applying the control of effective toroidal curvature term ε_T defined as the sum of usual toroidal curvature term and one of the nearest satellite harmonics of helical field term, have been studied to improve particles confinement properties[2]. If we consider a compact system, a small *N* and low aspect ratio system is desirable.

2. Consideration of different coil aspect ratio devices

We have examined several type devices with different coil aspect ratio $A_C \equiv R_0 / a$.
A minor radius a is hold constant $(= 0.3[m])$ and a helical coil current is 1000[kA] in

each case. The length of one helical field period is also fixed with standard case $N_0 = 17$ device so that new coil aspect ratio will be obtained for an appropriate N by $A_C = NA_{C0} / N_0$. The subscript "0" denotes standard device case. The characteristic parameters are summarized in the reference [3].

3. Particle confinement

The transport properties of small N systems will be worse than that in the larger N systems. We have investigated the test particles confinements under the assumption of no-collision by two methods, simultaneously [3]. One method is calculated by using Cartesian coordinates in the real space and another method is calculated by using Boozer coordinates. In the latter case, the particle loss boundary is set by the outermost magnetic surface. The test particles energy are set at 0.9-10KeV with equal velocity intervals and equal velocity pitch angle distribution from 0 to π, and starting point is set at magnetic axis in any cases. It seems that the test particle tracing from the axis informs us the basic radial behavior of core plasma in these devices. The confined particle rate defined by the ratio of confined particles number to all test particles number after long time particles tracing is depend the value of ε_T .

4. Pitch-modulation and effective curvature effects

We can see that the particle confinement becomes worse in low N (low A_C) case as expected. But, the particle confinement rate can be controlled by the pitch modulation parameter α^*, and improvements of confinement properties are achieved by the negative pitch modulation. For L=1 case, the magnetic field strength B is approximately

$$\frac{B}{B_0} = 1 + \varepsilon_T \cos\theta + \varepsilon_L \cos(N\varphi - \theta) ,$$

where $\varepsilon_T = \varepsilon_t + \varepsilon_0$, $\varepsilon_t = 2B_{0,1} / B_{0,0}$, $\varepsilon_0 = 2B_{N,0} / B_{0,0}$, $\varepsilon_L = 2B_{N,1} / B_{0,0}$ and $B_{n,m}$ are the amplitudes of the corresponding harmonics $\cos(n\varphi - m\theta)$. In this case, helicaly trapped particle feels effective toroidal curvature ε_T rather than usual toroidal curvature ε_t . It determines the collisionless confinement conditions of trapped particles. We have reported that this small effective term leads to the good collisionless confinement of helically trapped particles. These phenomena are clearly seen in $N = 17$ large aspect ratio case [1] . It is shown from the form of the bounce action that the angular separation along a magnetic field line of any two contours of the same value of B is constant on a magnetic surface [5]. Though the desirable features are not attained in the *N*=5 cases, the pitch modulation effects are work effectively as shown in Fig.1.

5. Characteristic Magnetic Field Properties

The field-line Hamiltonian H_{FL} contains all the information on the existence of surfaces, islands and stochastic regions[5]. The representation

$$\boldsymbol{B}(\boldsymbol{r}) = \nabla\Psi \times \nabla\theta - \nabla H_{FL} \times \nabla\varphi$$

is known as the canonical form, where $\boldsymbol{B} \cdot \nabla\varphi$ must be non-zero. When we consider this equation with $\Psi = \Psi(\psi, \theta, \varphi)$ and $H_{FL} = H_{FL}(\psi, \theta, \varphi)$, and expand $\nabla\Psi$ and ∇H_{FL} along basis vector $\nabla\psi$, $\nabla\theta$, $\nabla\varphi$. We obtain

$$\frac{\partial H_{FL}}{\partial\psi} = -\boldsymbol{B}(\boldsymbol{r}) \cdot \frac{\partial \boldsymbol{r}}{\partial\psi} \times \frac{\partial \boldsymbol{r}}{\partial\varphi},$$

$$\frac{\partial\Psi}{\partial\psi} = \boldsymbol{B}(\boldsymbol{r}) \cdot \frac{\partial \boldsymbol{r}}{\partial\psi} \times \frac{\partial \boldsymbol{r}}{\partial\theta} \quad .$$

The RHS of these equations is known, if $\boldsymbol{r}(\psi, \theta, \varphi)$ is known after field line Fourier decomposition. Figure 2 shows the field-line Fourier decomposition by two-line method which can separate the even and odd Fourier modes for high resolution. The characteristic difference of H_{FL} for *N*=5 and 17 is now understudying.

6. Conclusion

We have examined the test particle confinement properties in the zero-beta magnetic field of low coil aspect ratio devices. Though absolute value of radial transport is still large, we have found that our methods are effective to decrease a transport as a large aspect ratio case. When we consider the compact system with low aspect ratio and small N value, it is expected that the effective toroidal curvature would play important roles.

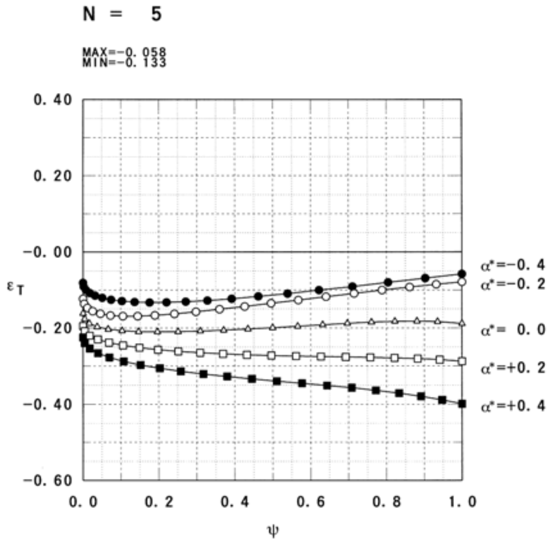

Fig.1 The effective toroidal curvature for N=5 low-aspect ratio devices. The reduction of effective toroidal curvature applying negative pitch modulation is correspondent with the particle confinement properties.

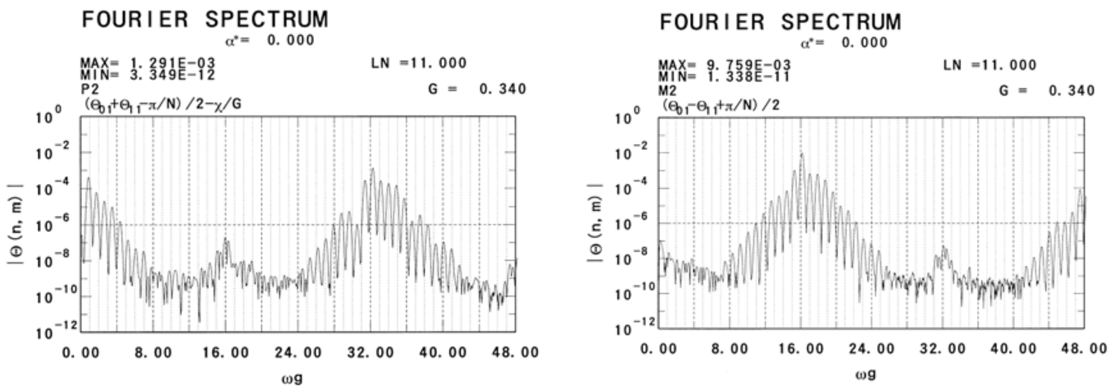

Fig.2 The spectrum analysis of an azimuthal angle Θ for Cylindrical coordinates (r,Θ,z) along field-line, the angle Θ is correspond with the toroidal angle in the Helical systems.

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