Magnetic Field Properties of Confining Particles in 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 worse than large aspect ratio devices. 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 particle orbits tracing and calculating the neoclassical transport particle and heat fluxes [1]. These 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. 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 larger *N* systems. We have investigated the test particles confinements under the assumption of no-collision by two methods, simultaneously. 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 which is automatically decided as follows. The temporal convergences of Lyapunov exponents corresponding to field lines trajectories are evaluated and the maximum Lyapunov exponent is decided as shown in the Figure 1. 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. 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 [4]. 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, helically trapped particle feels effective toroidal curvature ε_T rather than usual toroidal curvature ε_t.

4. Magnetic Field Properties

It is well known that the differential equation of a field line trajectory is rewritten to the form of Hamilton's equation of motion by using the magnetic flux coordinates. The magnetic field is equivalent to a one degree of freedom, time-dependent Hamiltonian system. We can also deal with an equivalent time-independent Hamiltonian in two degrees of freedom. When a field is represented by means of a magnetic field line Hamiltonian H_{FL}, the field line can be identified with the phase-space trajectory produced by this Hamiltonian. In case flux surfaces exist, the magnetic field line Hamiltonian is given by

$$H_{FL}(\psi) = \psi_{ex}\int_0^{\psi} \iota(\psi)d\psi + \psi_{p,0}^{d} ,$$

where ψ_{ex} is an outermost surface toroidal flux, $\psi_{p,0}^{d}$ is a poloidal-disk flux enclosed by the magnetic axis, and $\iota(\psi)$ is a rotational transform. We have evaluated by $\alpha^* = -0.2$ with $N = 17$ and $\alpha^* = -0.4$ with $N = 5$ fields, and show the H_{FL} (excluding $\psi_{p,0}^{d}$:constant.) normalized by ψ_{ex} in Fig. 2. These fields are best confinements in each N case. The field-line Hamiltonian contains all the information on the existence of surfaces, island and stochastic regions. We are now studying the L=1 helical field-line Hamiltonian $H_{FL}(\psi,\theta,\varphi)$ which is obtained even if there are no perfect flux surfaces.

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 radial transport as a large aspect ratio case.

References

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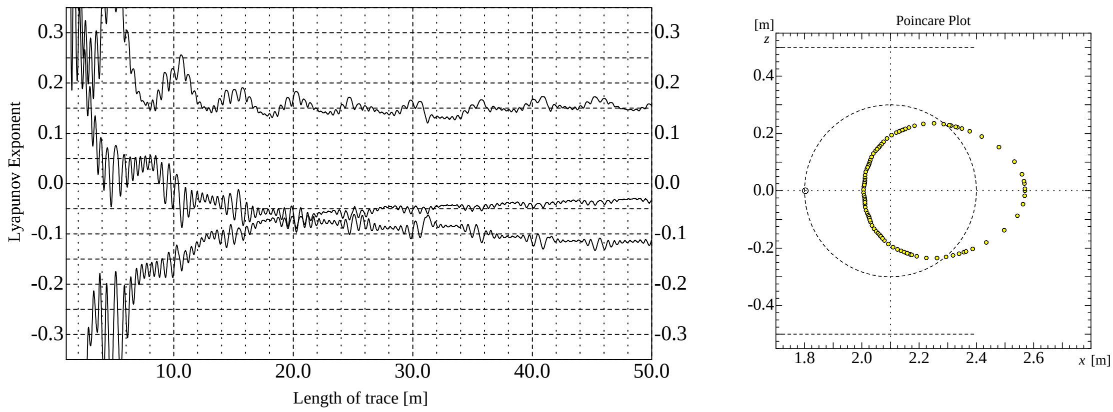

Fig.1 The temporal convergence of Lyapunov exponents corresponding to a field line trajectory which is slightly beyond outermost surface for *N*=17 devices. The maximum Lyapunov exponent converges to 0.15. This fact means chaotic behavior.

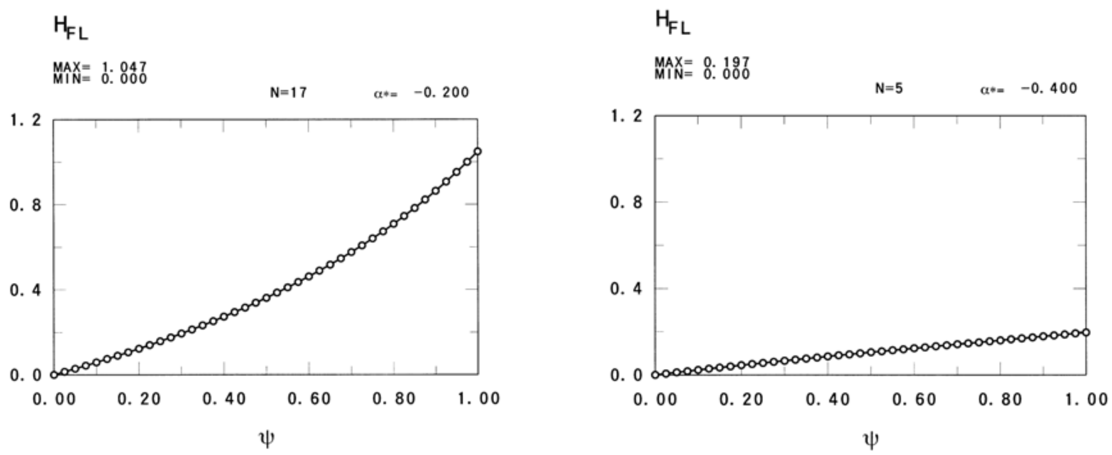

Fig.2 The Field line Hamiltonians for *N*=5 and *N*=17 systems in case flux surfaces are exist.