Parameter Research in Magnetic Field Structure around the outermostsurfaces of L=1 Helical Systems

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Abstract

The L=1 torsatron systems having a spatial magnetic axis have been studied. The features of magnetic field properties among high and low helical coil aspect ratio systems which are different pitch modulation α^* have been examined. Especially, magnetic field structure around the outermostsurface of each system, have been studied by examining the Lyapunov characteristic exponents. As the result, we propose the desirable properties of magnetic field of helical system.

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]. If we consider a compact system, a small field period number of the helical magnetic field *N* and low coil aspect ratio system is desirable for nuclear fusion device construction. On the contrary, particles transport properties of compact system become worse due to large usual toroidal effects. We have improved particles transport by controlling the effective curvature toroidal term defined as the sum of usual toroidal curvature term and one of the nearest satellite harmonics of helical field term [1]. The improvement of particles confinements evaluated by the Boozer coordinate is observed. But their effects are more limited than that of large aspect ratio cases. And the structures of magnetic field are also studied from viewpoint of the effective curvature term [2].

2. Device parameters

We have examined several type devices with different coil aspect ratio $A_C \equiv R_0 / a$, where R_0 is a major radius and a is a minor radius of helical system coil. 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 [2].

3. Evaluation of Lyapunov characteristic exponent

The Lyapunov characteristic exponent (LCE) gives the rate of exponential divergence from perturbed initial conditions. The equations of a magnetic field line have three LCEs, and the positive maximum LCE λ decides a chaotic property of system. Let the base solution as $\tilde{\boldsymbol{X}}(L)$, where L is the arc length of field line, and perturbed solution as $\hat{\boldsymbol{X}}(L)$. The deviation vector $\boldsymbol{w}(L) = \hat{\boldsymbol{X}}(L) - \tilde{\boldsymbol{X}}(L)$ and its magnitude $\varepsilon(L) = |\boldsymbol{w}(L)|$ are introduced to calculate λ, where λ is defined by

$$\lambda = \lim_{L\to\infty,\varepsilon(0)\to 0} \lambda(L), \quad \lambda(L) = \frac{1}{L} \log \frac{\varepsilon(L)}{\varepsilon(0)}. \quad (1)$$

It is difficult to calculate λ by using eq. (1) directly. Because the finite digits of computer treatment cannot process wide range data defined by eq. (1). The practical calculation method considered above problem are rescaling the data and the details are described in the literature [3,4]. We adopt $\lambda(L=1000)$ or extrapolated from $\lambda(L)$ behavior instead of $\lambda = \lambda(L \to \infty)$. The lower graph in the Fig.1 shows $\lambda(L)$ along the magnetic field line which starts from the point inside near the outermostsurface. The value $\lambda(L)$ is converged to 0, which means that this field line construct the nested surface. On the other hand, the upper graph is converged to positive value; this means magnetic field line has no flux surface. These two cases are confirmed by usual Poincare plots method. The value of $\lambda(L=1000)$ is dependent on the starting point, so that we decide λ by averaging some neighboring starting points denoted by r0. Figure 2 is that example cases, where five magnetic field lines are followed. It is seen that each $\lambda(L)$ is converged to positive value λ.

4. Magnetic Field Properties

The value of λ are shown against the system device period number N in Fig.3. The five different pitch modulation $\alpha*$ (-0.4, -02, 0.0, +0.2, +0.4) are noted in this figure. These helical systems have a peak to the change of N. And, it is possible to say that N=12 has a complicated field structure. In Fig.4, the value of λ for different N systems are shown against $\alpha*$. The four or five field lines started from the neighborhood points which are near outside region of the outermostsurface, are followed to evaluate LCE. These four or five data are averaged to obtain the value of λ. In Fig.4, this average values of λ are plotted. In four different N systems, the chaotic properties of magnetic field around the outermostsurface is low in N = 5 system and the tendency that the chaotic property is high in N = 12 system.

5. Conclusion

We have studied the chaotic behavior could be quantitatively evaluated by the LCE. Moreover, it grasped the tendency of the complexity of the field structure of the system in changing parameters of the devices and examining the LCE. The parameter $\alpha*$ controls the chaotic properties of fields around the outermost surface in large N system. The low N system has low λ properties though $\alpha*$ dependency is weaker than large N, namely high A_C cases.

References

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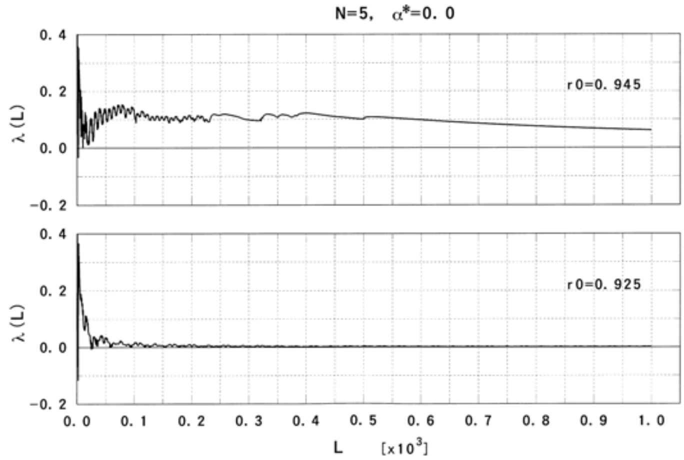

Fig.1

Maximum Lyapunov exponents along the magnetic field line are shown. The upper figure shows the field line which starts from outside of the outermostsurface, and the lower figure shows the field line which starts from inside region.

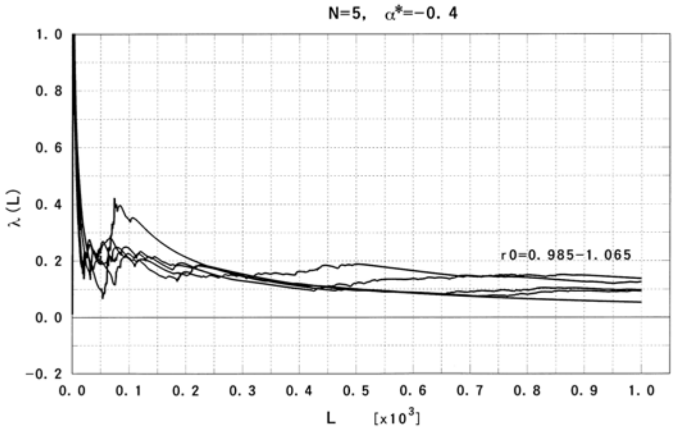

Fig.2

Maximum Lyapunov exponents along the magnetic field lines which are outside of the outermostsurface, are converged to positive values, where r0 denotes the starting points.

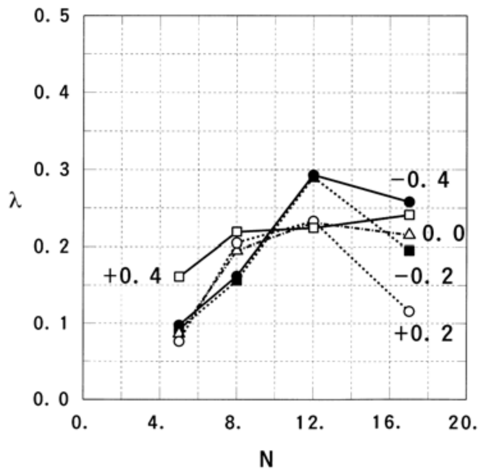

Fig.3

The converged maximum Lyapunov exponents λ are shown against the system period number N, where noted values in the figure describe pitch modulation α^*.

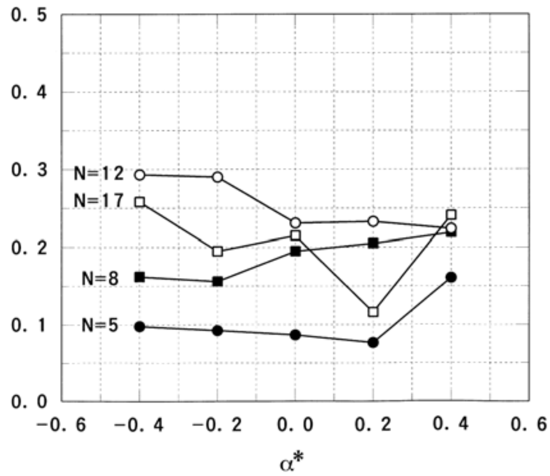

Fig.4

For each period number N, the averaged maximum Lyapunov exponents λ are shown against pitch modulation α^*. The compact N=5 device has low λ.