

Single Helicity Steady State of Reversed Field Pinch Plasma

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1. Introduction

Single helicity steady state of reversed field pinch (RFP) plasma is studied by using a nonlinear resistive MHD stability code [1]. Experimental RFP plasmas are operating near the boarder of the stability boundary of MHD modes in the plasma core [2], which sustain the RFP equilibrium configuration as "dynamo action", the MHD dynamo model. Multi helicity steady state of RFP plasma is known to result in stochastic magnetic field lines in the plasma core from the overlapping of islands of many tearing modes. Single helicity equilibrium of RFP plasma is possible to create non-stochastic flux surfaces.

2. Initial conditions of calculation

In the MHD code, 3D(periodic in θ and z , and finite difference in r) nonlinear resistive MHD equation is time dependently solved by the finite difference method. The calculation is run under conditions of the cylindrical geometry, non-flux conserver, i.e. $B_p(a)$ and $B_z(a)$: constant in time, and finite plasma pressure. The perfect conducting shell is placed at the plasma surface. Plasma resistivity is spatially constant. Equilibrium configurations of RFP plasmas are characterized by the pinch parameter $\theta(=B_p(a)/B_{t_{av}})$ and the reversal parameter $F(=B_t(a)/B_{t_{av}})$, where B_p, B_t and $B_{t_{av}}$ are poloidal, toroidal and average toroidal magnetic field respectively and a is plasma minor radius. An initial equilibrium configuration similar to the experimental results [2], where $F=1-0.75*\theta$, is created by using α - θ_0 model [3] for μ ($=J/B$) profile, where $\mu=2*\theta_0(1-(r/a)^\alpha)$. Plasma pressure is inflated by Suydam parameter $C_{suydam}(r)=-4*\pi*p'/(rBz^2)(q/q')^2$, keeping the q -profile unchanged with a window function of decreasing pressure gradient to zero near the plasma edge. The magnetic Reynolds number of 10^4 is used in the calculation with $r_{mesh}=91$ and aspect ratio of 3.9. The basic dynamo mode is $m=1/n=-7$. In the calculation of low θ case the initial values of θ_0/α is $1.55/1.9(\theta/F=1.55/-0.08)$ and $\beta_p=0.1$.

3. Steady state of nonlinear run

Three cases of steady state are investigated. Case (a) multi helicity case of $m=1/n=-7$ to -20, 16 modes, (b) multi helicity case of $m=1/n=-7$ to -20, 16 modes, with $m=0/n=-1$ and (c) in single helicity case only $m=1/n=-7$ mode is selected. The initial magnetic field perturbation of the mode having maximum growth rate is grown linearly around 10% before starting a nonlinear run. In case (a), Multi helicity case without $m=0$ mode: After starting nonlinear run global plasma parameter such as F/θ , toroidal magnetic flux and q at the plasma center reach steady states in 0.05 resistive time. While mode amplitudes of magnetic field reach in steady state after around 0.2 resistive time. Perturbations of $m=1/n=-7$ to -10 grow up around 5-10% and keep constant until the final steady state reached. The toroidal magnetic flux inside the plasma decreases 6% and keep constant without the flux conserver. θ value goes up from 1.55 to 1.65 while F decreases only a little. $1/q$ value at the plasma center is keeping around $1/7$. In case (b), Multi helicity case with $m=0/n=-7$ mode: Time evolutions of plasma parameters are shown in Fig.1 (a). Black dots curves show time evolution without the dynamo mode. With $m=0/n=-1$ mode the toroidal flux recovers to 97% of initial value after decreasing 8% down and keeps constant. Magnetic perturbations of modes are fluctuating in time scale of a few hundredth of resistive time and no steady state exists, which shows the

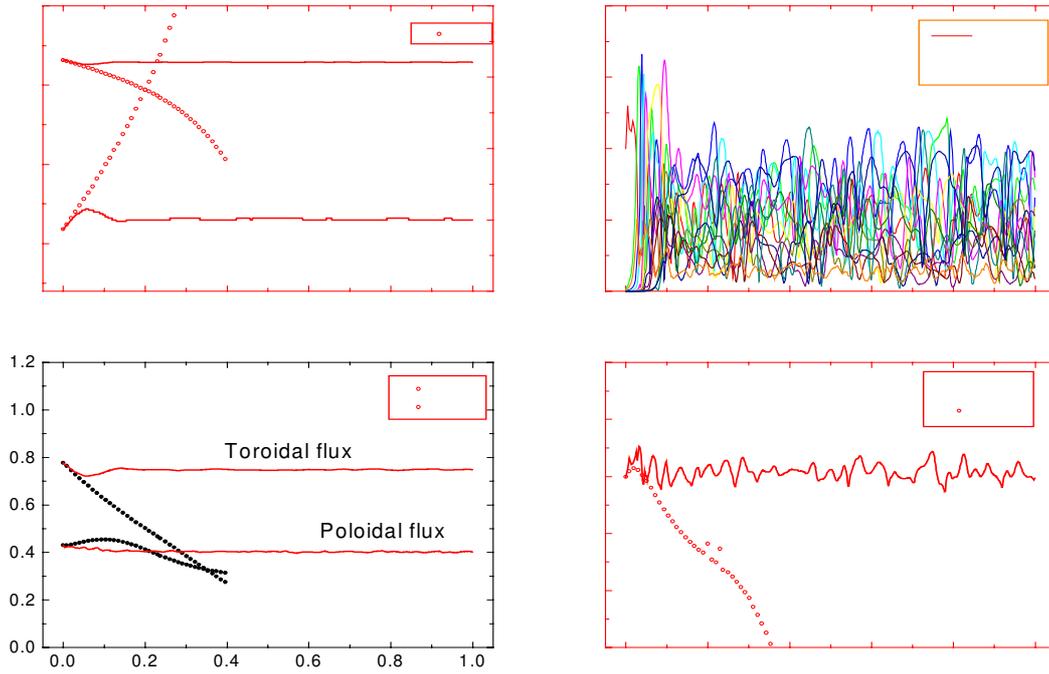


Fig.1(a) Time evolution of plasma parameters for the multi helicity of $m=1/n=-7$ to -20 with $m=0/n=-1$.

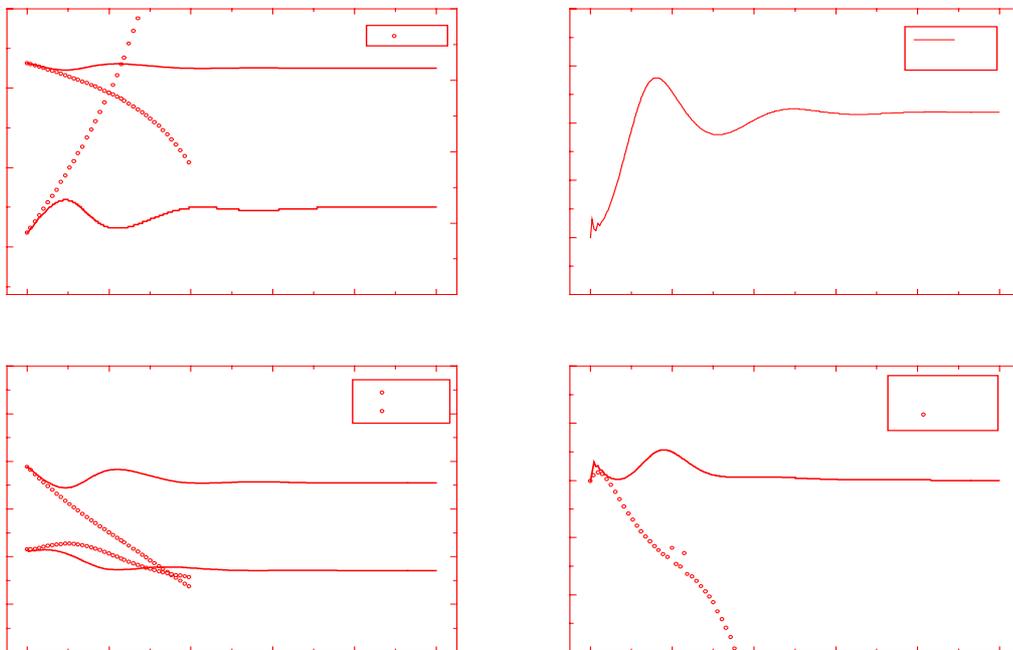


Fig.1(b) Time evolutions of plasma parameters for the single helicity of $m=1/n=-7$.

mode coupling activities between $m=1$ modes via $m=0/n=-1$ mode. Also central q value is fluctuating about 10% around $1/7$. Both two cases radial profiles of B and j after the nonlinear run are very close to the initial profiles because the initial profiles are close to the final steady state configuration, which is also close to the experimental one. In case (c), Single helicity case: Fig.1 (b) shows the time evolutions of the single helicity case. The initial toroidal flux decreases 10% at first and then increases again to the initial value and finally reaches steady state of 7% down after 0.5 resistive time. The central $1/q$ is kept around $1/7$ same as case (a) and (b). The magnetic field perturbation of $m=1/n=-7$ single mode reaches 30% high. In this case the poloidal flux decreases about 20% while it is almost constant in multi helicity cases. Magnetic field configuration changes mainly in the plasma center compared with the initial one. In the q profile a shoulder appears near the plasma radius of $0.5 r/a$ compared with the initial parabolic like profile. After compensating the beta poloidal with the experimental value, F and θ values in steady states after nonlinear run come close to the universal F/θ curve [2] based on the MHD dynamo model with α - θ_0 model.

4. Magnetic flux surfaces

The investigation of magnetic flux surfaces of dynamo driven steady state RFP plasmas have been done by helical magnetic flux surface contour, magnetic field line tracking and magnetic field line trajectory methods. In case of the multi helicity plasma the magnetic flux surfaces by the field line tracking show very stochastic magnetic field lines extending to r/a of 0.7-0.8, which is shown in Fig.2 (b). There is no relation with and without $m=0/n=-1$ mode. In case of the single helicity plasma non-stochastic magnetic flux surface exists as shown in Fig.2 (a). The magnetic axis has the position of almost same as the $m=1/n=-7$ dynamo mode axis, which exists r/a of around 0.5, because of its large mode amplitude. The magnetic field lines in the core plasma have excursions to r/a of around 0.8 shown by the field line tracking. Magnetic field line trajectory shows almost 90% of the field lines stay around plasma central region even though occasional excursions to the plasma periphery appear.

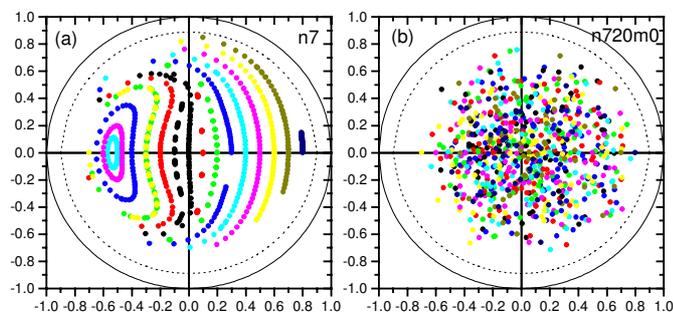


Fig.2(a) Magnetic flux surface for the single helicity state and 2(b) for the multi helicity state.

5. Toroidal loop voltage

Balances of the electric field on the toroidal, poloidal and the parallel components to the magnetic field line are investigated for the single helicity case. In Fig.3 (a) the toroidal electric field E_z and the resistive components $E_{z_j} (=E_{z_{jz}} + E_{z_{jt}})$ are shown. The toroidal electric field E_z is the sum of the resistive component of the toroidal plasma current $E_{z_{jz}}$, the MHD mode driven component $E_{z_{mod}}$ and the component $E_{z_{vr}}$ driven by the paramagnetic pinch velocity. In steady state $E_z(r)$ is constant in radial space. The anomalous toroidal electric field driven by the MHD mode, shown in Fig.3 (b), is the subtract of the toroidally equivalent electric field $E_{z_{jt}}$ of the resistive electric field of the poloidal plasma current from the sum of $E_{z_{mod}}$ and $E_{z_{vr}}$, i.e. $E_{anomaly} = E_{z_{mod}} + E_{z_{vr}} - E_{z_{jt}}$. Also $E_z - E_{z_j}$ becomes $E_{anomaly}$ naturally. The poloidal plasma current is sustained by the combination of the MHD mode driven electric field $E_{t_{mod}}$ and the electric field $E_{t_{vr}}$ driven by the paramagnetic pinch velocity, which is

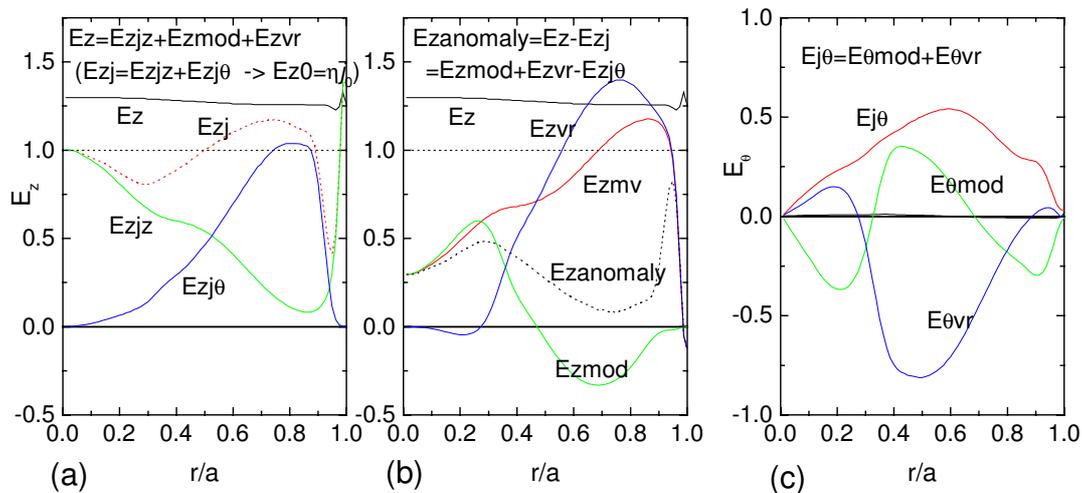


Fig.3(a)(b)(c) Radial profiles of toroidal electric field components.

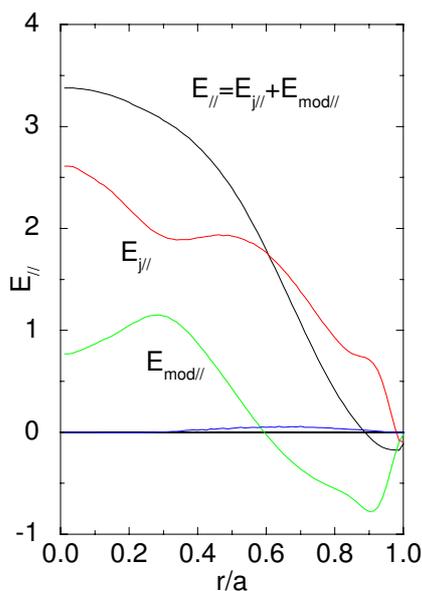


Fig.4 Parallel electric field $E_{||}(=E_{||j}+E_{||mod})$.

shown in Fig.3(c). Electric field components parallel to the magnetic field line is shown in Fig.4. The parallel electric field $E_{||}(=E_{||j}+E_{||mod})$ is the sum of the resistive component $E_{||j}$ and the MHD mode driven component $E_{||mod}$. The electric field driven by the paramagnetic pinch velocity, $E_{||vr}$ is perpendicular to the magnetic field line. It is clearly seen that the MHD mode driven electric field suppress the toroidal plasma current in the plasma core region, which raises the toroidal loop voltage, and drives the poloidal plasma current in the plasma peripheral.

6. Summary

The single helicity dynamo mode driven steady state of RFP plasma has been studied using the resistive MHD stability code. It is shown that the single helicity RFP without stochastic magnetic flux surfaces exists with the non-flux conserver shell. The magnetic axis becomes helical type because of the large amplitude, about 30% large, of the single helicity dynamo mode. A

test of the magnetic field line by the field line trajectory shows 90% of magnetic field lines starting from the plasma core stay in the central plasma area. Nonlinear run on the bifurcation from the multi helicity state to the single helicity state [4] is underway.

References

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