The Changes of Ion Orbit and Radial Electric Field Effect in Tokamak

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Abstract: The formation of H-mode is always related to the same region where the negative radial electric field emerges. Due to the existence of the negative radial electric field or the $E_r \times B$ drift, the orbit of charged particles will be changed, especially for the ions. The velocity of $E_r \times B$ drift in H-mode is almost same as that of ion motion, but which is very smaller than the velocity of electron motion, so the $E_r \times B$ drift almost do not change the electrons orbit. In the radial electric field, the orbit of ions will be changed, and also will leads some mutually transformation of trapped and passing ions.

Key words: negative radial electric field, change of ions orbit, trapped and passing ions.

1. Introduction

The formation of H-mode is related to the parameters and motions of ions in edge region, where the negative E_r and the change of ions motion have been observed, such as the ions poloidal motion. The ion diamagnetic drift is changed in same direction of electron diamagnetic drift. In H-mode negative E_r, the $E_r \times B$ drift is almost same as that of ion motion, which will change the ions orbit. This paper mainly discusses the effect of negative radial electric field and the change of ions orbit through numerical simulations.

2. Ions orbit in tokamak configuration and negative radial electric field

In tokamak magnetic configuration, because of the gradient and curvature of magnetic field, there are trapped and passing particles. The □B and curvature magnetic field also drive charged particles to drift and move across magnetic field, the maximal displacement is about $\triangle d=2qr_L$ for passing one and $\triangle d=2qr_L(R_o/r_o)^{1/2}$ for trapped one, which will be larger for the ions with higher temperature and larger mass. The displacement may be in the outside, inside of the initial magnetic surface or across which decided by the initial position, velocity and direction of particles. The mid-plane and the direction of □B and curvature drift decide the motion direction of the particle moving across the magnetic surface, or decide whether the particle orbit is expanded or compressed. The side in the □B and curvature drift direction is the expansion region of orbit; the other side in the inverse □B and curvature drift direction is the compression region. For trapped particle, the orbit may be inward or outward decided by initial moving direction and position, so there is an inward orbit or outward orbit.

If there is a negative E_r, the $E_r \times B$ drift direction, poloidal component direction of ion motion along the magnetic field $\vec{v}_{m\theta}$ and initial position will decide the change of particles orbit and the displacement direction. Because the $E_r \times B$ drift is very smaller than the motion velocity of electron, so almost there is not change of electron orbit. The direction of combination poloidal velocity of $E_r \times B$ drift and $\vec{v}_{m\theta}$ decide the ion firstly move into which region expansion region or compression region, and that is an expanded orbit or compressed one. When the direction of $E_r \times B$ drift is opposite to the poloidal velocity component $\vec{v}_{m\theta}$, and they are almost same in numerical value, the combination poloidal velocity is smaller, so there is a very large change of ion orbit. In this time, the ion orbit will be from expansion region into compression one and vice versa.

In H mode, the formation of a negative E_r is connected with edge ions loss, and that is a continually process. With the change of negative E_r, some trapped and passing ions can mutually transform, the inward and outward banana orbit also can mutually transform.

The $E_r \times B$ drift is almost same as the ions motion velocity, so the ions are not moving alone the magnetic line anymore. The safety factor q is a factor describing the magnetic field line of tkamak configuration, if there is an $E_r \times B$ drift, which is inapposite using the q to calculate the ions transport and fluid et al. According to the definiens of q, an ion orbit factor q_E can be used in E_r, there is $q_E = q * |V_m/(V_m + Er/B_\theta)|$. Here V_m is the motion velocity of ion, B_θ is the poloidal component of magnetic field, and q is the safety factor.

If V_m and Er/B_θ are in same direction, than $q_E < q$;

Contrarily, the change of q_E is larger:

a. q_E is very larger, when $V_m \approx Er/B_\theta$ in numerical value, than $V_m+Er/B_\theta \approx 0$;

b. $q_E > q$, when $2|V_m| > |Er/B_\theta|$;

c. $q_E < q$, when $2|V_m| < |Er/B_\theta|$

In the negative Er, the maximal displacement of ions is $\triangle d=2q_E r_L$ for passing ion and $\triangle d=2q_E r_L(R_o/r_o)^{1/2}$ for trapped one; If there is not the Er, than $q_E = q$.

The $E_r \times B$ drift will change the trapped and passing ions, and can also mutually transform. The simulation results are showed in Fig.1, 2, 3 and 4, the parameters is as follows, R_o=1.75m, a=0.47m, I_p=0.5MA, B_o=1.97T, R_{in}=1.386m (LCFS in high field side), R_{out}=2.326m (LCFS in low field side). The δ is the angle between the initial direction of ion motion and toroidal magnetic field, the initial position of ion is on the equator plane in the low field side at R= 2.316m. Fig.1 and 2 show the region change of trapped and passing ions of D and H respectively. The ions are trapped within the region between the same color line. Fig.1 shows the region change of D trapped ions, with the E_r increase, the trapped ions region will shift to the smaller δ value. The $E_r \times B$ drift will lead a larger change for low energy ions. Compare the Fig.1 with 2, the D and H ions with same energy, the same negative E_r will lead a larger orbit change for D. For D ions with energy of 0.1keV(blue line), 1keV(green line) and 3 keV(red line), when the negative E_r is more negative than about -14kV/m, -90kV/m and -163kV/m respectively, there is not any trapped ions. All H ions will become the passing, that are needed more negative E_r than about -17kV/m, -117kV/m and -225kV/m respectively. Actually the $E_r \times B$ drift has a larger effect to the larger mass ions, because of smaller motion velocity.

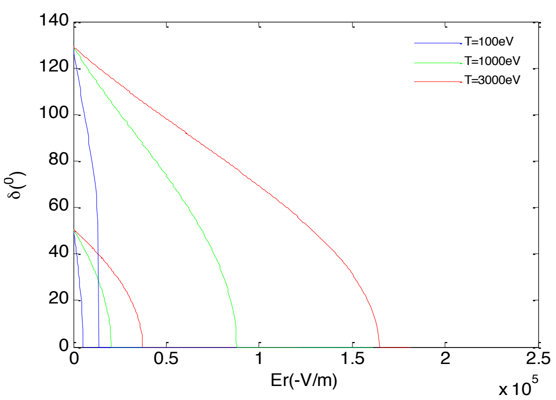

Fig.1 The changes of D ion orbit in negative E_r.

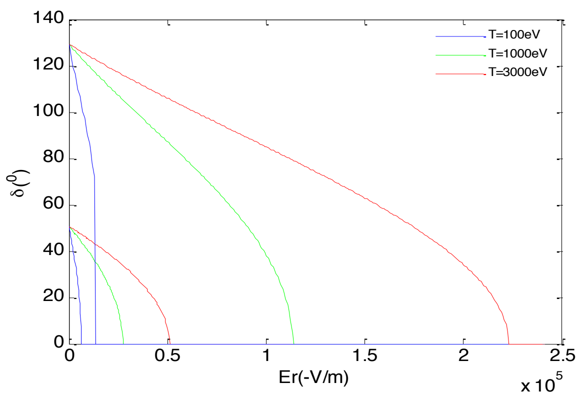

Fig.2 The changes of H ion orbit in negative E_r.

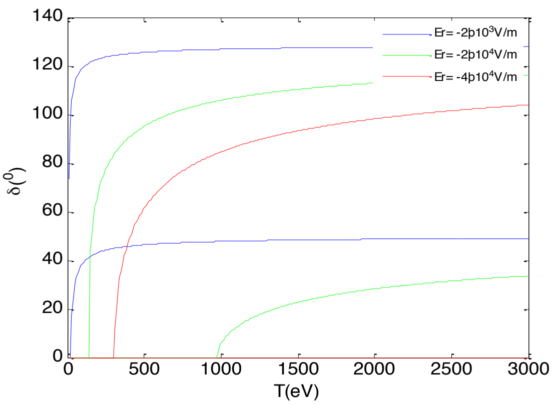

Fig.3 The changes of D trapped ions region.

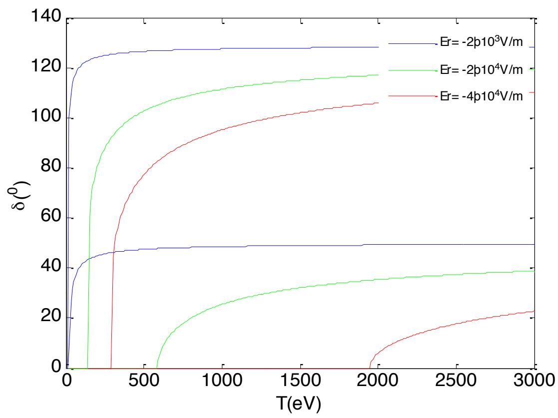

Fig.4 The changes of H trapped ions region.

With the ions energy increase, in the negative E_r of -2kV/m(blue line), -20kV/m(green line) and -40kV/m(red line), the change of trapped ions region shown in Fig.3 for D ions and Fig.4 for H ions.

When the directions of V_m and Er/B_θ are opposite, the ions orbit can be changed with different E_r: first, counterclockwise passing ions; second, trapped ions turned outward; then, clockwise trapped ions turned inward; last, clockwise passing ions. The changes of ions orbit in E_r are shown as Fig.5. The test ions energy is 200eV, located on the equator plane in the low field side and their initial motion direction is same that of toroidal field.

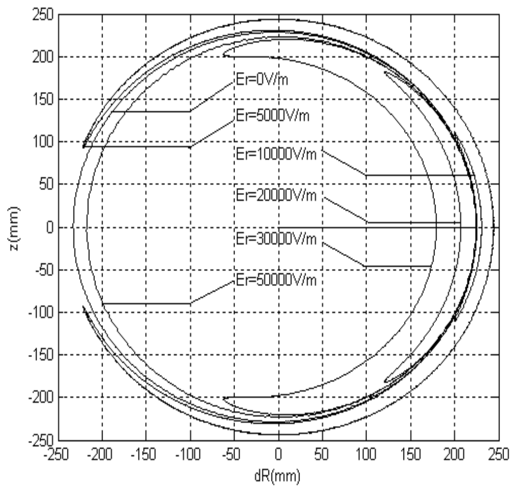

Fig.5 The changes of ions orbit in E_r.

3. Conclusions

The simulation results show that the negative E_r in H mode can change markedly the ions orbit, especially for lower energy and larger mass ions. The trapped ions with lower energy in larger E_r will become the passing ions. The trapped ions region will shift normally to the smaller δ value with the increase of E_r.