Radial Current in a Radial Electric Field

X.D. Zhang

Institute of Plasma Physics, Academia Sinica, Hefei 230031, China

e-mail: xdzhang@mail.ipp.ac.cn

Abstract. The collision effect of cross-field transport in a radial electric field for ions and electrons is studied and the transport equations are obtained, leading to a better understanding of the relation of the collision effect with a radial electric field. The collisional transport equations indicate that there is a radial current generated by the damping of $E \times B$ drift. This current is in the direction of the radial electric field, so it will reduce the radial electric field and is unfavorable for forming the H mode.

1. Introduction

The H mode has been obtained on many devices. The ratio of improved confinement is different with different edge conditions. It is well known that high recycling and neutral pressure or collisions in the edge region are unfavorable for obtaining the H mode [1,2]. The quality of the H mode can be degraded by gas puffing to the main plasma or the divertor chamber. The H mode on COMPASS-D [3] normally appears after gas puffing is switched off. Regular boronization allows the H mode to be produced over a wide parameter range. On Alcator C-Mod [4], the L-H transition cannot be observed if the midplane neutral pressure exceeds about 0.6 mtorr. By blocking the gas passages connecting the divertor and the main chamber on PDX, the H mode was achieved. The threshold power was lower with good wall conditioning on JET [5].

In this paper, we will discuss the effect of collisional damping of ion and electron fluid on the radial electric field (or E_r), that will lead to a better understanding of the relation of collision effects with the radial electric field.

2. Collisional Transport of Ions and Electrons in E_r

In a cylindrically symmetric plasma, the pressure gradients are all in the radial direction. When there are collisions and a radial electric field, the ion or electron fluid velocity can be given from the single species particle fluid, so we have

$$\vec{j}_s = n_s q_s \vec{V}_s \tag{1}$$

The fluid equation for a quasi-steady-state plasma is

$$\vec{E} + \vec{V}_s \times \vec{B} - \frac{\nabla P_s}{n_s q_s} = \eta_s \vec{j}_s \tag{2}$$

where η_s is the electrical resistivity of the single species particle (ion or electron) fluid.

1.1 Collisional Transport of Ions in E_r

The perpendicular (radial and poloidal) components of ion fluid equations from Eqs (1) and (2) are given by

$$\hat{r}: \quad E_r - \frac{\nabla P_i}{n_i q_i} + V_{\theta i} B = \eta_i n_i q_i V_{ri} \tag{3}$$

$$\hat{\theta}: \quad V_{ri} B = -\eta_i n_i q_i V_{\theta i} \tag{4}$$

where q_i, n_i, η_i and ∇P_i are charge, density, electrical resistivity of the ion fluid and ion pressure gradient respectively. The ion fluid velocities of the radial and poloidal fluids are as follows

$$V_{ri} = \frac{B\eta_i n_i q_i}{B^2 + \eta_i^2 n_i^2 q_i^2}(V_{Di} + V_E) \tag{5}$$

$$V_{\theta i} = \frac{-B^2}{B^2 + \eta_i^2 n_i^2 q_i^2}(V_{Di} + V_E) \tag{6}$$

where V_{Di} and V_E are ion diamagnetic drift and ExB drift respectively. Equation (5) indicates that in a radial electric field, the damping of ExB drift by poloidal collisions leads to an additional ion radial transport in the direction of the radial electric field.

2.2 Collisional Transport of Electrons in E_r

The perpendicular (radial and poloidal) components of electron fluid equations from Eqs (1) and (2) are given by

$$\hat{r}: \quad E_r + \frac{\nabla P_e}{n_e e} + V_{\theta e} B = -\eta_e n_e e V_{re} \tag{7}$$

$$\hat{\theta}: \quad V_{re} B = \eta_e n_e e V_{\theta e} \tag{8}$$

where $-e<0$, n_e, η_e and ∇P_e are charge, density, electrical resistivity and electron pressure gradient respectively. The electron fluid velocities of the radial and poloidal fluids are as follows

$$V_{re} = \frac{B\eta_e n_e e}{B^2 + \eta_e^2 n_e^2 e^2}(V_{De} - V_E) \tag{9}$$

$$V_{\theta e} = \frac{B^2}{B^2 + \eta_e^2 n_e^2 e^2}(V_{De} - V_E) \tag{10}$$

where V_{De} and V_E are electron diamagnetic drift and $E \times B$ drift respectively. Equation (9) indicates that in a radial electric field, the damping of $E \times B$ drift by poloidal collisions leads to an additional electron radial transport in the inverse direction of the radial electric field.

2.3 Radial Current in E_r

If we assuming the perpendicular components of collisional damping for ions and electrons are

$$\eta_{\perp i} n_i q_i = k_{\perp i} B \quad \text{and} \quad \eta_{\perp e} n_e e = k_{\perp e} B$$

then the radial and poloidal fluid velocities of ions and electrons can be written

Ions:
$$V_{ri} = \frac{k_{\perp i}}{1+k_{\perp i}^2}(V_{Di} + V_E) \tag{11}$$

$$V_{\theta i} = \frac{-1}{1+k_{\perp i}^2}(V_{Di} + V_E) \tag{12}$$

Electrons:
$$V_{re} = \frac{k_{\perp e}}{1+k_{\perp e}^2}(V_{De} - V_E) \tag{13}$$

$$V_{\theta e} = \frac{1}{1+k_{\perp e}^2}(V_{De} - V_E) \tag{14}$$

In the radial electric field the additional radial fluids of ions and electrons generated by damping of ExB drift are

Ions:
$$V_{Eri} = \frac{k_{\perp i}}{1+k_{\perp i}^2} V_E \tag{15}$$

Electrons:
$$V_{Ere} = \frac{-k_{\perp e}}{1+k_{\perp e}^2} V_E \tag{16}$$

There is an additional radial current in the direction of the radial electric field.

$$j_{Er} = n_i q_i V_{Eri} - n_e e V_{Ere} = \left(\frac{n_i q_i k_{\perp i}}{1+k_{\perp i}^2} + \frac{n_e e k_{\perp e}}{1+k_{\perp e}^2}\right) V_E \tag{17}$$

where $-e$ ($-e < 0$) is the electron charge.
Assuming $e = q_i$ for H, D and T plasmas, $n_i = n_e = n$ in same region, we can write Eq. (17) as

$$j_{Er} = \left(\frac{k_{\perp i}}{1+k_{\perp i}^2} + \frac{k_{\perp e}}{1+k_{\perp e}^2}\right) n e V_E \tag{18}$$

The additional radial current is the ratio to the electrical resistivity of ions and electrons. In the edge plasma, low temperature and poor edge conditions will lead to a larger radial current in the radial electric field.

For smaller k_i and k_e ($\ll 1$), we have

$$j_{Er} \approx (k_{\perp i} + k_{\perp e}) n e V_E \tag{19}$$

We can also write the additional radial current by damping of $E \times B$ drift in the radial electric field as follow

$$j_{Er} \approx (k_{\perp i} + k_{\perp e}) ne \frac{E_r}{B}$$

2. Discussion and Conclusion

In the H mode, *E*x*B* drift is dominant and ion drift is in the direction of the electron diamagnetic drift. Because of poloidal collisional damping, the poloidal drifts of ions and electrons are always smaller than the *E*x*B* drift. These ions and electrons lose some energy by collisions with other particles (including ion and electron collisions). The ions and electrons must shift in the direction of force of the electric field and get some energy from the electric field to replenish the loss energy.

The poloidal collisional damping of *E*x*B* drift also leads to an additional radial transport of ions and electrons and generates a radial current in the direction of the electric field. This radial current will reduce the radial electric field due to the separation of ions and electrons.

Collisional damping is dominant effect that prevents a radial electric field from being generated and that degrades the quality of the H mode. In any device, H mode requires a higher temperature of the edge plasma, good wall conditions, low recycling and small neutral pressure in the edge region of the plasma.

References

[1] KAYE, S.M., et al., J. Nucl. Mater 121 (1984) 115
[2] JACKSON, G.L., et al., J. Nucl. Mater 162-164 (1989) 489
[3] FIELDING, S.J., et al., Plasma Phys. Control. Fusion 38 (1996) 1091
[4] SNIPES, J.A., et al., Plasma Phys. Control. Fusion 38 (1996) 1127
[5] JET Team in 13th IAEA Corf. on Plasma Physics and Controlled Nuclear Fusion Research, Washington, 1990, Vol. 1, IAEA,Vienna (1991) 261