Effects of the radial dependence of the fast electron diffusion coefficient on the current driven by lower-hybrid waves in tokamak

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The lower hybrid current drive (LHCD) is one of the promising methods not only for driving the non-inductive current required for steady-state tokamak operation, but also for controlling the plasma current profile to improve confinement in tokamak experiments. In this paper, the radial profile of the fast electron diffusion coefficient D_{st} is estimated to investigate its effect on the current driven by LHW in EAST. Compared with the case of the constant radial diffusion coefficient, the efficiency of LHW driven current with the radial dependent distribution coefficient $D_{st}(\rho)$ becomes either higher or lower with respect to the density profiles. The profiles of the LHW driven current are also different. It is necessary to consider the radial dependence of D_{st} in order to get an accurate and reliable result in LHW simulation.

1. Introduction

In the theory of the transport of fast electrons the radial diffusion coefficient of fast electrons (D_{st}) is an important parameter describing the degree of the diffusion of driven current and the LHCD current profile becomes flat and broad with the increase in the radial diffusion coefficient.[1] The coefficient is assumed to be a constant for simplicity in such as LSC[2], CURRAY[3] and CQL3D[4] codes. However, the effect of the radial dependence of the fast electron diffusion coefficient on the current driven by LHW in tokamak is necessarily studied. In this paper, we present a model with the radial dependent diffusion coefficient $D_{st}(\rho)$ to calculate LHW driven current due to fast electrons, and we apply this model to EAST. The purpose of this study is to obtain a reliable estimate of the current driven by LHW in EAST tokamak.

2. Radial dependence of the diffusion coefficient of the current driven by LHW

To investigate the effect of the radial diffusion of fast electrons, the Fokker-Planck equation of the electron distribution function can be written as[5]

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$$\frac{\partial f}{\partial t}=\frac{\partial}{\partial \upsilon}(D_{rf}\frac{\partial}{\partial \upsilon}f)+\frac{\partial}{\partial \upsilon}(\nu_s \upsilon f)+\frac{1}{r}\frac{\partial}{\partial r}(rD_{st}\frac{\partial f}{\partial r})\,. \qquad (1)$$

On multiplication by charge and velocity and integration over velocity at both sides of Eq.(1), one obtains

$$\frac{\partial J}{\partial t}=-e\int D_{rf}\frac{\partial f}{\partial \upsilon}d\upsilon-e\int \nu_s \upsilon f d\upsilon+\frac{1}{r}\frac{\partial}{\partial r}(rD_{st}\frac{\partial J}{\partial r})\,. \qquad (2)$$

The steady-state equation straightforwardly can be rewritten as:

$$\nu_s(J_0-J)+\frac{4}{a^2}\frac{\partial}{\partial \rho}(\rho D_{st}\frac{\partial J}{\partial \rho})=0 \quad . \qquad (3)$$

As documented in reference [6], D_{st} can be expressed as

$$D_{st}(\rho)=D_0(1+3\rho^3)[n_{e0}/n_e(\rho)]\,, \qquad (4)$$

The central radial diffusion coefficient is estimated by using $D_0=0.5a^2/4\tau^L_{E,th}$ (5)

For simulation on the EAST, we choose two typical profiles of electron density to investigate the influence of different diffusion profiles $D_{st}(\rho)$ on the LHCD current.

n_e profile #1 is expressed as $n_e(\rho)=n_{eo}[0.9(1-\rho^3)+0.1]$. (6)

n_e profile #2 is expressed as $n_e(\rho)=n_{eo}[0.9(1-\rho^2)^3+0.1]$. (7)

For studying the property of the current driven by LH waves with the radial dependence of diffusion coefficient on the EAST tokamak with the following plasma parameters: $R=1.84m$, $a=0.48m$, $I_P=360KA$, $P_{rf}=1MW$, the phase of the LHCD antenna $\Delta\phi=135^\circ$, $B_t=2T$, $f=2.45GHz$.

According to Eq. (5), the central diffusion coefficient D_0 can be estimated on EAST. $D_o\approx 0.8m^2/s$ for n_e profile #1 and $D_o\approx 1.0m^2/s$ for n_e profile #2.

In Fig.1 the profiles of the LHCD current are shown for the cases of radial dependent diffusion coefficient and averaged coefficient respectively. The result for n_e profile #2 is shown in Fig.2.

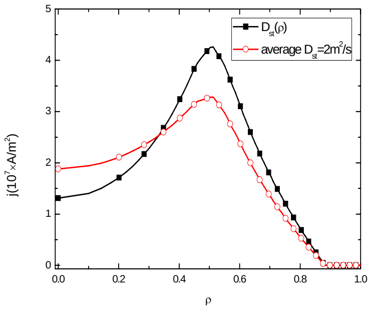

FIG.1. Comparison of LHW current density profiles between $D_{st}(\rho)$ and $\overline{D}_{st}$ with n_e profile #1.

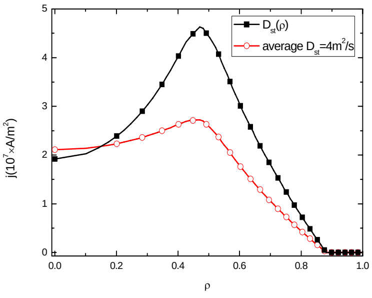

FIG. 2. Comparison of LHCD current density profiles between $D_{st}(\rho)$ and $\overline{D}_{st}$ with n_e profile #2

We also make a comparison between the cases for $D_{st} = D_{st}(\rho)$ and $D_{st} = D_o$ with respect to the two density profiles. The driven current distributions for density profile #1 and #2 are respectively shown in Figs. 3 and 4.

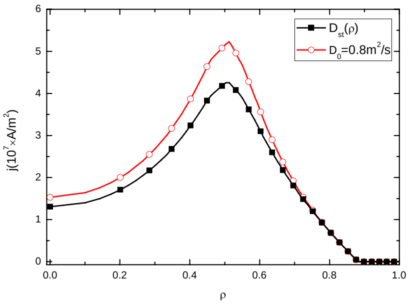

FIG. 3. Comparison of LHW current density profiles between $D_{st}(\rho)$ and the constant D_0 with n_e profile #1.

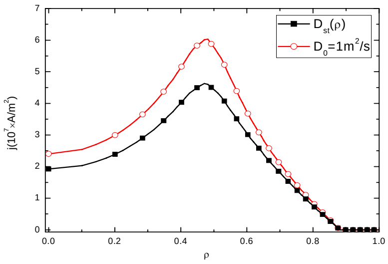

FIG. 4. Comparison of LHW current density profiles between $D_{st}(\rho)$ and the constant D_0 with n_e profile #2.

The magnitude of the total LHW driven current with different radial diffusion coefficient is shown in Tables I and II for n_e profile #1 and 2 respectively.

TABLE I. Comparison of driven current by LHW between $D_{st} = D_{st}(\rho)$ and the constant value D, the averaged data $D_{st} = \overline{D}_{st}$ and the central value of $D_{st}(\rho)$ for n_e profile #1

$D_{st}(m^2/s)$	$D_{st}(\rho)$	$\overline{D}_{st} = 2.0$	$D_0 = 0.8$
Driven current (kA)	182.80	145.26	206.14

Ratio of driven current to the total plasma current	50.8%	40.4%	57.3%

TABLE II. Comparison of driven current by LHW between $D_{st} = D_{st}(\rho)$ and the constant value D_{st} the averaged data $D_{st} = \overline{D}_{st}$ and the central value of $D_{st}=D_0$ for n_e profile #2.

$D_{st}(m^2/s)$	$D_{st}(\rho)$	$\overline{D}_{st} = 4.0$	$D_0 = 1.0$
Driven current (kA)	209.32	127.02	255.37
Ratio of driven current to the total plasma current	58.1%	35.3%	70.9%

There are obvious effects on LHCD when we use the radial dependence $D_{st}(\rho)$ to calculate the driven current profile and total driven current compared with a constant data D_{st}.

3. Conclusions

It is meaningful to consider the radial dependence of the fast electron diffusion coefficient D_{st}. The radial dependence of D_{st} has a great effect not only on the current profile but also on the total driven current by LHW. To some degree, the precise estimate of D_{st} can effectively improve the driven efficiency. In this paper, we only discuss the relationship between n_e and diffusion coefficient D_{st}. The radial dependence of diffusion coefficient may be explicit or implicit through other plasma parameters, for example the electron temperature T_e, safety factor q, or even $\partial n / \partial r$, which themselves depend on the position.

Acknowledgments

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