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1. 6 Edge Plasma Performance of Lower Hybrid Wave Injection on the HL-1M Tokamak

HONG Wenyu WANG Enyao GAO Jianyong LI Qiang

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Recently, the L-mode to H-mode (L-H) transition in tokamak plasma confinement was found to be related to the presence of the poloidal flow shear near the plasma edge. An important mechanism is the ion orbit loss caused by interaction with the limiter. A complementary explanation is the generation of poloidal flows by plasma fluctuations via the Reynolds stress and the poloidal spin-up of plasmas from poloidal asymmetry of particle and momentum sources[1]. Turbulent Reynolds stress plays a linking role between the turbulence and averaged flows. It has been suggested that sheared poloidal flows can be generated in fusion plasmas due to radially varying Reynolds stress. The determination of flow velocity in the scrape-off layer and edge of tokamak plasmas become important in confinement and the L-H mode transition[2].

In the HL-1M tokamak it is measured and investigated the variations and profiles of edge plasma fluctuation and flow velocity with Mach probe array for different case, and the role of suppressing the plasma density fluctuations and improving the local plasma confinement for different case.

During LHW injection, the poloidal sheared flow of edge plasma can be driven by the ponderornotive potential and induced magnetization resulting from a LHW electric field in tokamak plasma[3]. The injected LHW can drive the tokamak plasma to rotate poloidally in the velocity[3].

$$v_{\mathrm{pol}} = \frac{E_{\mathrm{r}}}{B_{\mathrm{T}}} + \frac{e^2}{4M^2 W_{\mathrm{ci}}} \frac{W^2 + W_{\mathrm{ci}}^2}{(W^2 - W_{\mathrm{ci}}^2)^2} \frac{\mathrm{d}E_{\mathrm{r}}^2}{\mathrm{d}r} + \frac{B_{\mathrm{pol}} V_{\mathrm{Z}}}{B_{\mathrm{T}}} \tag{1}$$

where M is the mass of ion, W_{ci} is cyclotron frequency of ion. Eq. (1) clearly indicates that in the system under consideration, the real source of' driving the poloidal sheared flow v_{pol} is the injected power and induced magnetization, which only represent the response of plasma to the injected LHW. The LHW generated poloidal sheared flow is just like a layer-built barrier against the development of edge turbulence. The poloidal sheared flow would quell the turbulence at the linear stage of its evolution. The injected LHW power is consumed to suppress the edge turbulence, as soon as the edge turbulence is quelled. The LHW power makes plasma rotate, as a result the magnitude in v_{pol} abruptly increase.

During LHCD, typical parameters of ohmic heated hydrogen plasma are: B_{T}=2~2.6 T, I_{p}=120 ~200 kA, $n_{\mathrm{e}}(0)$= (2~3)×10^{19} m^{-3}, electron temperature T_{e} (0) =0.5 ~1 keV and ion temperature T_{i} (0) =0. 3~0. 8 keV.

Neglecting the contribution of magnetic fluctuations, the Reynolds stress was determined by $R_{\mathrm{s}} = \langle \tilde{v}_{\mathrm{r}} \tilde{v}_{\theta} \rangle$ [1]. The $\langle \tilde{v}_{\mathrm{r}} \tilde{v}_{\theta} \rangle$ term of the Reynolds stress tensor can be related to the **E**×**B** drift velocities, it can be determined using the expression:

$$\langle \tilde{v}_{\mathrm{r}} \tilde{v}_{\theta} \rangle = -\langle \tilde{E}_{\mathrm{r}} \tilde{E}_{\theta} \rangle / B^2 \tag{2}$$

where $\tilde{v}_{\mathrm{r}}$ and $\tilde{v}_{\theta}$ is the fluctuating radial and poloidal flow velocities of edge plasma respectively, $\tilde{E}_{\mathrm{r}}$ and $\tilde{E}_{\theta}$ is the radial and poloidal electric field fluctuation respectively, and B is the toroidal magnetic field. The brackets $\langle \cdots \rangle$ mean time average.

A Mach/Langmuir probe array[4] is comprised of six probe elements, two tips of probe array is aligned perpendicular to the magnetic field and separated poloidally 6 mm, which were used to measure edge fluctuations of the poloidal electric field $\tilde{E}_{\theta}$. The radial electric field fluctuations $\tilde{E}_{\mathrm{r}}$ were measured by other two probes radially separated 5 mm. The probes were oriented with respect to the magnetic field direction to avoid shadows between them. The radial profiles of radial and poloidal electric field fluctuations $\tilde{E}_{\mathrm{r}}$ and $\tilde{E}_{\theta}$ are measured shot-to-shot and the measurement at each radial position is carried out in identical discharge modes.

The poloidal flow velocity v_{pol} is estimated by[5]:

$$J_{\mathrm{pol}} = n_{\mathrm{e}}\, e\, v_{\mathrm{pol}} \tag{3}$$

where v_{pol} is the poloidal flow velocity which is basically the **E**× **B** flow, J_{pol} and n_{e} are poloidal current density and electron density respectively. Fig. 1 shows the radial profiles of E_r, E_θ and v_{pol} in the edge and scrape-off-layer (SOL) during LHCD. The electrostatic Reynolds stress (R_s) was determined by $\langle E_r, E_\theta \rangle$. In the experiment of LHCD, LH wave injection power is 100 kW, 200 kW and 250 kW respectively, the radial profiles changes of Reynolds stress R_s with LH wave injection power change are shown in Fig. 2.

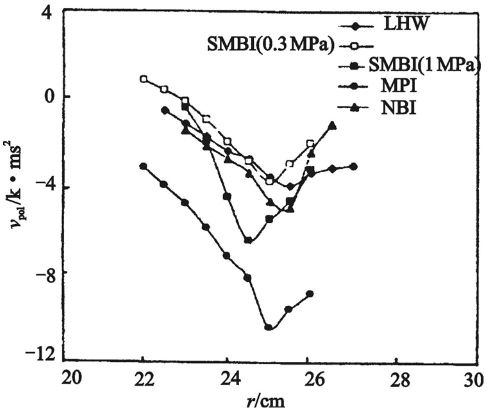

Fig. 1 The radial profiles of E_r, E_θ, v_{pol} and v_θ during LHCD

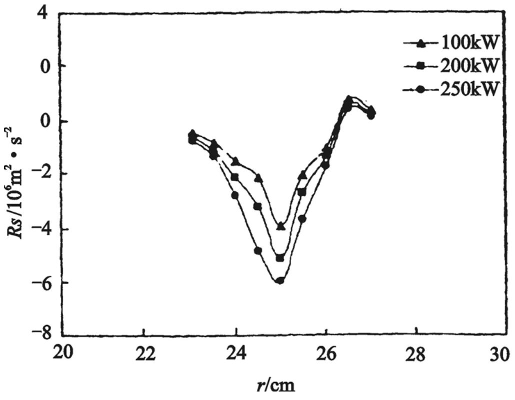

Fig. 2 The radial profiles changes of Reynolds stress R_s with LH wave injection power change during LHCD

The asymmetry in the ion saturation current collected by these two pins of the Mach probe represents the poloidal plasma flow. It was found that the ***E***×***B*** flow velocity was directly proportional to $2(R-1)/(R+1)$, where R is the ratio of top to under collector signals /top and I_{under}[6, 7]. This result establishes the fact that the value of R depends on the poloidal plasma velocity in a toroidal plasma. Since the normalized value of $2(I_{top}-I_{und})/(I_{top}+I_{und})$ measured at each position is used to qualitatively evaluate the temporal behavior of v_θ by assuming that $v_\theta \approx 2(I_{\rm top} - I_{\rm und})/(I_{\rm top}+I_{\rm und})$. Fig. 1 also shows the radial profiles of the poloidal rotation velocity v_θ. It can see from Fig. 1, the poloidal rotation presents a clear change in the propagation direction from the electron diamagnetic direction inside the limiter radius to the ion diamagnetic direction in the outer edge of the plasma behind the limiter.

From Fig. 1, it can be clearly seen that the enhanced negative poloidal flow $v_{\rm pol}$ well is dominantly sustained by the radial electric field $E_{\rm r}$, generating during LHCD. It can be also clearly seen that good quantitative agreement between $v_{\rm pol}$ and v_θ. These facts provide further strong substantiation for the identification of the Reynolds stress gradient as the origin of the development of the increasing v_θ, and indicating that the large change in $E_{\rm r}$ is associated entirely with the Reynolds stress-driven poloidal flow.

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