1. 5 Role of Advanced Refueling and Heating on Edge Reynolds Stress-induced Poloidal Flow in the HL-1M Tokamak

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Key words: Reynolds stresses, Poloidal flow velocity, Radial and poloidal electric field

The plasma confinement is sensitive to the edge conditions. Generally, edge parameters such as the edge density, temperature, Reynolds stress, poloidal flow velocity, radial and poloidal electric field are measured by using Mach/Langmuir probes. In brief, theories attempt to explain the L-H transition focus on the turbulence-induced Reynolds stress R_s, poloidal velocity v_{pol} and radial electric field E_r structure at the edge[1]. 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[2]. Turbulence Reynolds stress plays a linking role between the turbulence and averaged flows.

The radial profile of electrostatic Reynolds stress, plasma poloidal rotations, radial and poloidal electric field have been performed in the plasma boundary region of the HL-1M tokamak using a multiarray of Mach/Langmuir probes. In the experimental of lower hybrid current drive (LHCD), supersonic molecular beam injection (SMBI), multi-shot pellet injection (MPI) and neutral beam injection (NBI), the correlation between the Reynolds stress and poloidal flow in the edge plasma is presented.

The Reynolds stress measures the degree of anisotropy in the structure of fluctuations. Radially varying Reynolds stress allows the turbulence to rearrange the profile of poloidal momentum, generating sheared poloidal flows.

Two tips of Mach/Langmuir probe array[3] are 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 $\tilde{E}_r$ 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. And $\tilde{E}_r$ and $\tilde{E}_\theta$ are measured shot-to-shot and the measurement at each radial position is carried out in identical discharge modes. The electrostatic Reynolds stress has been calculated as $(\tilde{E}_r\tilde{E}_\theta)$. Fig. 1 shows the $R_s = \langle\tilde{v}_r\tilde{v}_\theta\rangle = -(\tilde{E}_r\tilde{E}_\theta)/B^2$[2, 3] radial profile of LHW, SMBI, MPI and NBI experiments respectively. From Fig. 1, it can be clearly seen that the maximum of Reynolds stress appears at 1 cm beyond the limiter.

During the experiment of LHW, SMBI, MPI and NBI on the HL-1M tokamak, we have measured the plasma poloidal flow velocity v_{pol} associated with equation $v_{pol}=\frac{J_{pol}}{n_e e}$. Fig. 2 plots the radial profiles of v_{pol}. The poloidal flow direction is reversed, supporting that poloidal rotation velocity becomes more negative. Poloidal rotation velocity suddenly increases in electron diamagnetic drift direction after pellet injection. The maximum of poloidal rotation velocity appears at 1 cm beyond the limiter. The change tendency of poloidal rotation velocity resembles very much that of electrostatic Reynolds stress. Poloidal rotation velocity can produce remarkable change after the MBI, depending on their radial position and their directions are whether opposite or not. However, The change amplitude of edge parameters after MBI is smaller than that after MPI.

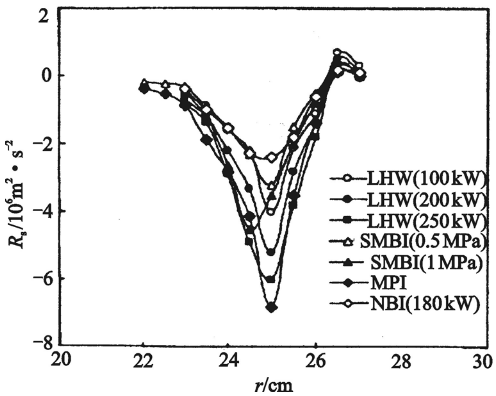

Fig. 1 The radial profiles of Reynolds stress R_s in the edge and SOL during LHW, SMBI, MPI and NBI respectively

In the experiment of LHCD, LH wave injection power is 100 kW, 200 kW and 250 kW respectively, the radial profile changes of Reynolds stress R_s with LH wave injection power change are obvious, as shown in Fig. 1. In the experiment of SMBI, the beam injection orifice gas pressure can change continuously from 0.3 MPa to 1.2 MPa. The depth of SMBI injection into the plasma increases with enhance of the working gas pressure of the beam injection port, namely with the beam injection velocity increases. As the beam injection orifice gas pressure increases from 0.3 MPa to 1 MPa, the supersonic flow velocity increases, and the peak value of the plasma poloidal velocity v_{pol} has an apparent increment from 3.8 km • s^{-1} (at r=25 cm) to 5 km • s^{-1} (at r =24.5 cm) in the electron diamagnetic direction (see Fig. 2). When the beam injection orifice gas pressure increases from 0. 5 MPa to 1 MPa, the peak value of Reynolds stress R_s changes from the locality r=25 cm to r = 24.5 cm (see Fig. 1). Therefore the injection velocity and the injection efficiency of SMBI has been enhanced.

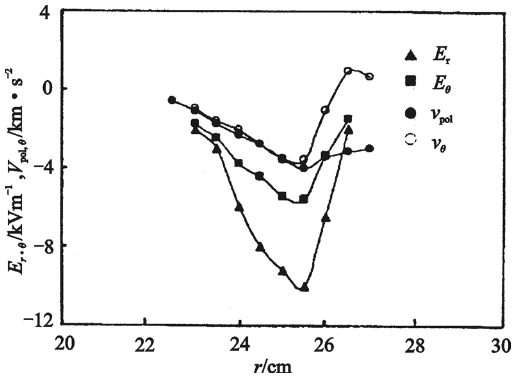

Fig. 2 The radial profiles of v_{pol} in the edge and SOL during LHW, SMBI, MPI and NBI respectively

From Figs. 1~2, it can be also clearly seen that the change tendency of electrostatic Reynolds stress resembles that of poloidal rotation velocity. These facts provide further strong substantiation for the identification of the Reynolds stress gradient as the origin of the development of the increasing v_{pol}. The results indicate that sheared poloidal flow can be generated in tokamak plasma due to radially varying Reynolds stress.

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

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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].

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