Fast Electron Dynamics during Lower Hybrid Current Drive Experiments in the HT-7 Tokamak

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Abstracts: Characterization of fast electron dynamics during lower hybrid current drive (LHCD) experiments is a critical issue for achieving enhanced plasma performance. A new hard X-ray diagnostics system that has been installed recently on HT-7 with 10 lines of sight, and 128 energy channels between 20 and 200 keV for each detector, has allowed the investigation of the lower hybrid wave dynamics. The behavior of fast electrons was studied in several kinds of LHCD experiments, including long pulse discharges, high parameter discharges and counter-LHCD experiments.

1. Introduction

After a series of technical improvements [1] in the superconducting tokamak HT-7, significant LHCD experimental results were obtained in the latest experimental campaign (Nov. 2001 - Jan. 2002). Characterization of fast electron dynamics during LHCD experiments is a critical issue for achieving enhanced plasma performances. The behavior of fast electrons is investigated in this paper.

HT-7 is a medium-sized superconducting tokamak with a limiter configuration. The machine is normally operated with I_p = 150~220 kA, B_t = 2 T, a = 27 cm. Its main limiter is made of doped graphite coated by SiC film. The LHW system [2] with 1.2 MW power at a frequency of 2.45 GHz can be operated in CW mode. A multichannel hard X-ray (HXR) pinhole diagnostic [3] was used in HT-7 to study the spatial and energy distribution of bremsstrahlung emission in the 10-200 keV range. The time and spatial resolution of the diagnostic are respectively 5 ms and 4 cm.

2. Experimental Results and Discussion

2.1. Typical LHCD Experiment

In LHCD experiments in HT-7, the LHW power was usually injected into the plasma in plateau of plasma current that was built up first by Ohmic (OH) heating. The radial diffusion of fast electrons can be estimated by investigating the HXR emission profile. The Abel inverted profile of HXR was compared with the results from a two-dimensional Fokker-Planck lower hybrid simulation code [4]. Three

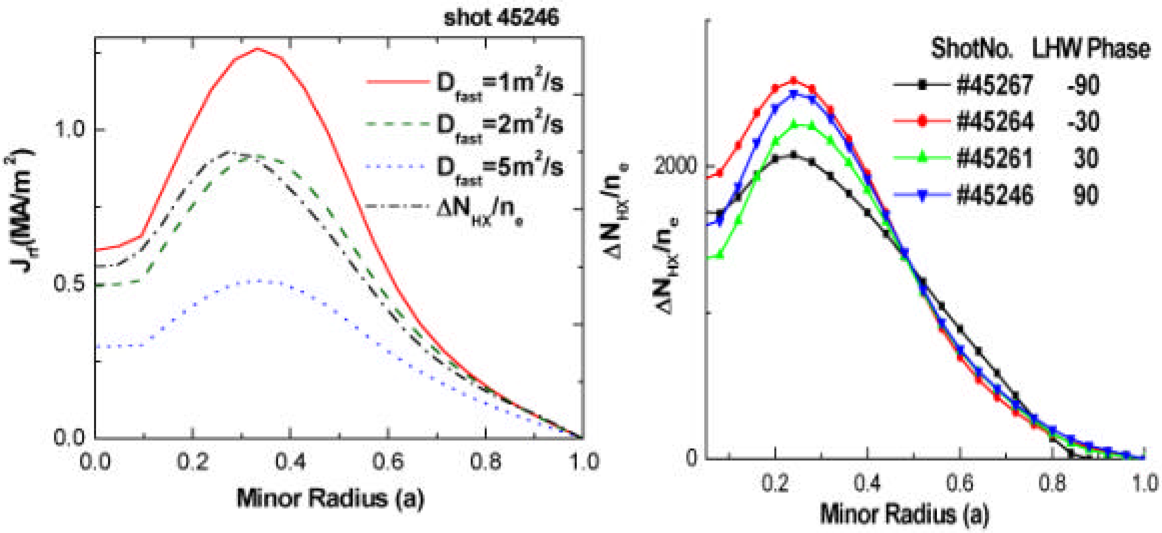

Fig. 1. Left: Abel inverted profile of HXR emission and the driven current profile calculated by a two-dimensional Fokker-Planck lower hybrid simulation code. Right: Abel inverted profile of HXR during LHW phase angle scan.

values for the diffusion coefficient of fast electrons (1, 2 and 5m^2/s) were tried (Fig. 1). It can be seen that the best match was obtained for 2 m^2/s. The HXR emission profiles were also measured by scanning the LHW launched parallel refractive index at constant electron density and plasma current (N_e = 1.0×10^{19} m^{-3}, I_p = 100 kA). The profile of HXR emission has little correlation with the LHW phase angle (Fig. 1). The possible explanation is the multireflection at the plasma boundary and mutli-pass propagation of the LHW. The parallel phase speeds of the LHW can change down or up due to toroidal effects as the path unfolds. Waves at high speeds cannot penetrate according to the basic LHW dispersion relation, so they slow down and penetration consequently increases. Absorption then occurs after sufficient electrons approach the resonant velocity of LHWs. This process has little dependence on the original phase speed.

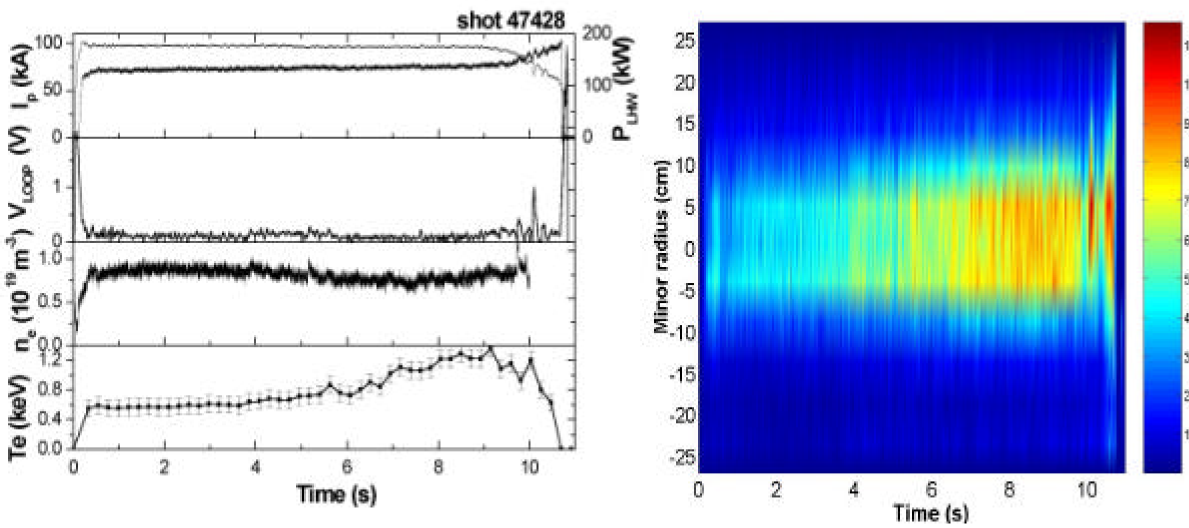

Fig. 2. Left: Waveforms of 10 s long-pulse discharge. Right: Time evolution of the profile of line integral HXR radiation.

2.2. Long Pulse LHCD Experiment

Steady-state high temperature plasma operation is one of the most important issues in the HT-7 experiments. The waveforms of a 10 s discharge are shown in Fig. 2, where the LHW power of 130 kW was injected into the plasma by a new multijunction

launcher with a narrow $n_{//}$-power spectrum ($n_{//peak}$ = 2.9, $\Delta n_{//}$ = 0.3, $n_{e0} \sim 1\times10^{19}$ m^{-3}, I_p = 100 kA and B_T = 2 T). Since a feedback control system keeps the plasma current constant, the loop voltage was decreased to 0.1 V by the injection of LH power. The time evolution of HXR emission profiles for a photon energy of 55 keV is shown in Fig. 2. The global improved confinement and increase of temperature take place after the broadening of HXR emission profile. The HXR emission profile is a good measure of the fast electron density profile (driven current density profile). The broadening of the HXR profile was accompanied by the increase of the central electron temperature. In a long-pulse discharge, the diffusion time of the plasma current is about 2 s and will affect the profile of driven current density. The total current profile becomes broader and broader and lead to the formation of a hot electron core regime.

2.3. High Performance LHCD Experiment

When the plasma current was high at around 200 kA, it was very easy to obtain enhanced confinement with the LHW power threshold of 250 kW. When the LHW was injected into the plasma, the electron temperature was increased from 1.5 keV to 2.2 keV (Fig. 3). In the LHEP discharge, an ITB-like structure was formed at 0.55 normalized minor radius from the profile of electron temperature. It was found that the ITB was located around the peak position of the Abel inverted local HXR emission profile (Fig. 3). This evidence suggests that the formation of the ITB is correlated with the LHW driven fast electron current. The profile of HXR emission

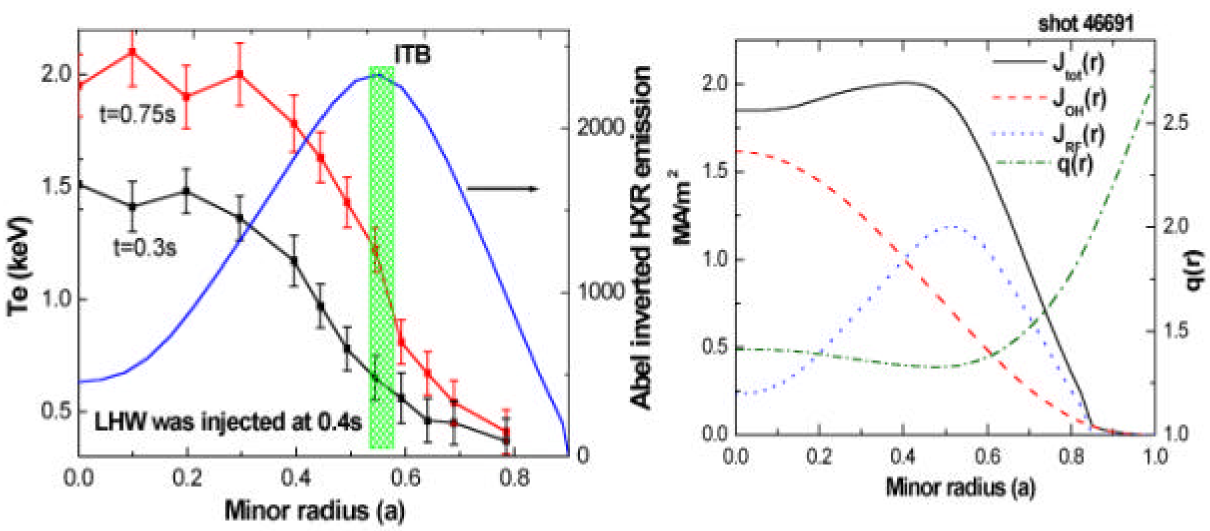

Fig. 3. Left: Profiles of electron temperature and HXR emission in a high parameters discharge. Right: Profiles of current density and safety factor.

indicates that the profile of lower hybrid driven current was off-axis from the core plasma. The off-axis driven current makes the total current profile flat or hollow, which may form weak or reversed magnetic shear in the plasma core region and cause the plasma performance to improve. The profiles of current density and safety factor was roughly estimated by the profile of electron density and HXR emission, as shown on the right in Fig. 3. It can be seen that the position of the lowest safety factor corresponds to the ITB, which coincides with the experimental observation.

2.4. Counter-LHCD experiment

The counter-LHCD experiment was performed in the last campaign. The majority of fast electrons produced by LHW in counter-LHCD cannot be accelerated to more high energy by the residual electric field. So the photon temperature (T_{ph}) of hard X-ray in couter LHCD is obviously lower than that in co-LHCD (Fig. 4). The decrease of loop voltage in counter-LHCD is not larger than that in co-LHCD. It was found that the core electron temperature measured by soft X-ray PHA increased from 0.8 keV to 1.8 keV in counter LHCD, which is the main reason for the decrease of loop voltage. The Abel inverted profiles of soft X-ray and HXR emission are shown in Fig. 4. It can be seen that the profile of soft X-ray emission became peaked in counter LHCD. The profile of HXR emission shows that the LHW power was mainly deposited in the core and heated the plasma in this area.

3. Conclusion

The new HXR diagnostic system installed on HT-7 has allowed investigation of the fast electron dynamics. The HXRradial profile can directly show the profile of LHW driven current density. The main experimental results can be summarized as follows: Good agreement between the profile of HXR emission and the result of Fokker-Planck modeling was obtained when the value of the diffusion coefficient of fast electrons is $2m^2/s$. The profile of driven current density has little variation at lower plasma parameters as the LHW phase angle is changed. Based on the HXR diagnostic and other diagnostic information, the improved plasma confinement in LHCD experiments on HT-7 has been analyzed. The results show that a hollow or flat driven current density profile is favorable for the improvement of plasma performance. The profile of driven current density can affect the formation and position of the ITB. The LHW can heat the core plasma in counter LHCD experiments with moderate LHW power.

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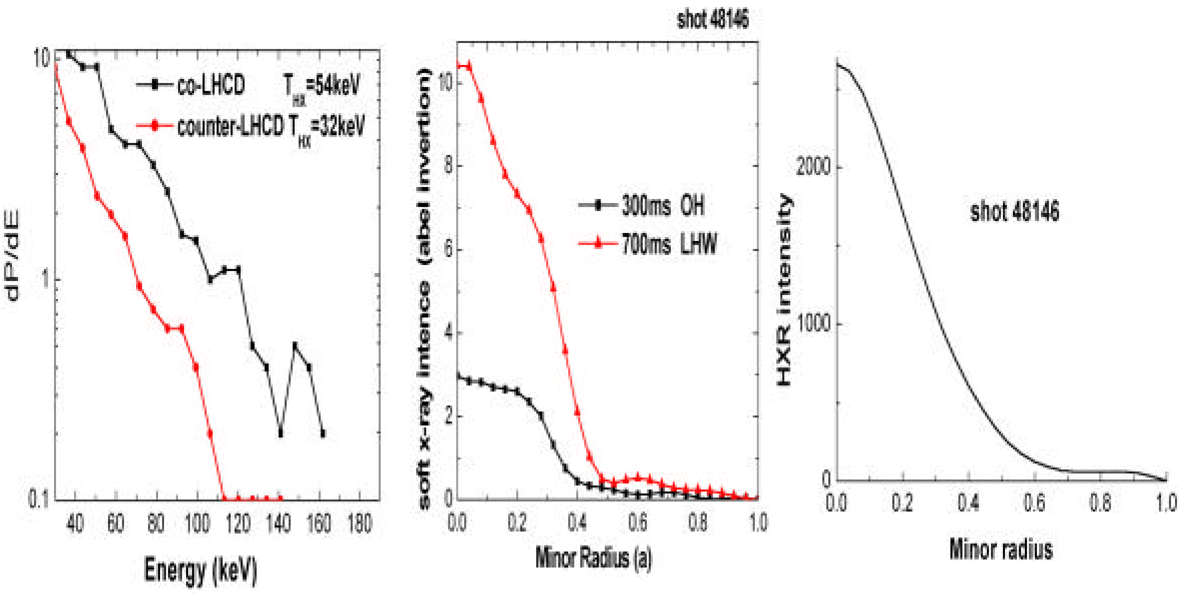

Fig. 4. Left: Photon temperature in counter- and co-LHCD. Middle: Abel inverted profile of soft X-ray radiation. Right: Abel inverted profile of HXR emission.

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