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Recent experiments in the HT-7 superconductive tokamak

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Abstract

After a series of technical improvements in the superconducting tokamak HT-7, some significant experimental results were obtained on the machine in its latest experimental campaign (November 2001 – January 2002). By means of lower hybrid current drive (LHCD), quasi-steady discharges with duration of longer than 20 seconds were repeatedly obtained; and improved confinements with a H factor (= τ_E / τ_E^{ITER89}) of about 2 were achieved. An internal transport barrier (ITB) was formed in the zone where the peak power of the lower hybrid wave (LHW) deposited. Obvious heating of plasma electrons by ion Bernstein wave (IBW) was observed. With IBW heating (IBWH), edge plasma fluctuation can be suppressed and plasma confinements can be improved greatly. It was found that IBWH enhanced LHCD.

1. Introduction

Steady state operation and high performance are two key issues for a tokamak type of nuclear fusion reactor. To accumulate some basic experimental data on the two issues is taken as the main mission of the superconductive tokamak HT-7. For the superconducting tokamak, an effective non-inductive current drive is necessary and determinant to realize long pulse discharge. For this reason, great efforts have been made to develop LHCD technology [1] on HT-7. The LHCD has been used not only to sustain plasma current, but also to modify plasma profiles so as to achieve high performance [2]. To achieve high performance of the machine with high plasma parameters, an IBW system was built up [3] and has been used for heating the plasmas and improving plasma confinements [4]. In the latest experimental campaign, the main work was put on the achievement of long pulse discharge by LHCD and improvement of plasma confinements by both LHCD and IBWH. The electron heating effects by IBW was also studied in the campaign.

In this paper, the experimental setup is briefly introduced and the latest experimental results from HT-7 are introduced.

2. Experimental setup

The superconducting tokamak HT-7 has a major radius of 1.2m, a stainless steel liner. The main limiter is made of special doped graphite coated by SiC film and it limits plasma minor radius to 27cm. The ohmic heating (OH) transformer of the tokamak has an iron core and it can offer a magnetic flux of 1.7VS at its maximum. Before the latest experiments, 24 ferrite boards were installed inside the vacuum vessel to reduce magnetic ripple from the original 4.2% to 1.6% at the edge of the lower field side. The first wall of the vacuum vessel was routinely boronized during the experiments by means of RF producing plasmas [5]. The toroidal magnetic field was usually set at around 2 T during the experiments.

The LHW system on HT-7 may deliver 1.2MW wave power at a frequency of 2.45GHz. The wave was launched to the plasmas through a coupler which is composed of 3×16 sub-waveguides. The launched wave spectrum can be adjusted in the range of $1.6 \leq N_{//}^{peak} \leq 2.8$. The LHW system can be operated in CW mode. The IBW system on HT-7 can deliver 350kW during the last experiments. The wave frequency can be adjusted from 15MHz to 30MHz. The Faraday screen of the IBW antenna is made of special doped graphite coated by SiC, the central conductor of the antenna is made of stainless steel coated by TiN. A two-T tuner is adopted to tune the wave coupling.

3. LHCD experiments

To realize long pulse operation of the superconducting tokamak is one of the main targets of the last experimental campaign. That needs stable plasma current drive, effective feedback control of the plasma position and density, low concentration of plasma impurities, and timely heat removal from the inner vessel. Due to lack of effective cooling method to release heat from HT-7 vacuum vessel, the input power had to be limited to a low level (around 100kW) for long pulse discharges. The waveforms of a 10sec discharge and a 20sec discharge are shown in Fig.1 and Fig.2 respectively. It was

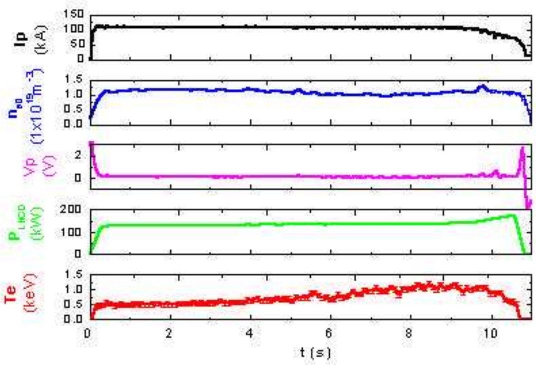

Fig.1: The waveforms of a 10sec discharge (#47428)

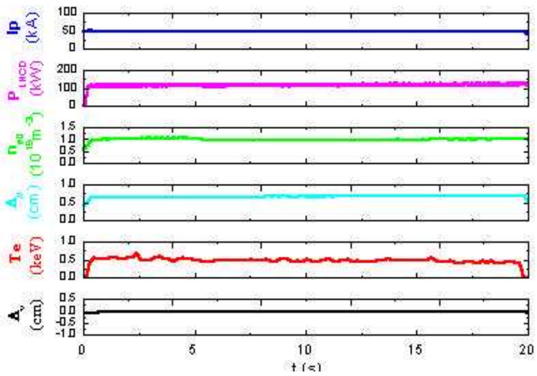

Fig.2: The waveforms of a 20sec discharge (#47696)

found that the electron temperature measured by a soft X-ray spectrometer increased gradually from 0.5keV to 1.0keV in 5 seconds while plasma density nearly remained unchanged. In the 20sec discharge, the plasma electron density is lower (in the center, it is about 1.0×10^{19} m^{-3}), the central electron temperature remains almost constant (about 0.5keV) over the whole discharge.

By means of LHCD, improved performance on HT-7 was obtained, the H factor ($= \tau_E / \tau_E^{ITER89}$) was a little above 2, as shown in Fig.3. Such performance was

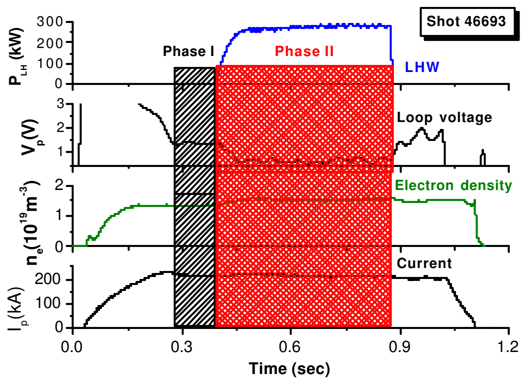

Fig.3: The plasma energy confinement times are 14.6ms (H=1.16) and 24.5ms (H=2.11) in phase I (without LHW) and phase II (with LHW) respectively.

achieved when the edge safety factor was around 2.5, the central line averaged electron density is above 1.0×10^{19} m^{-3}, and the LHW power mainly deposited in the zone around the half of the minor radius. In the improved discharges, an internal transport barrier (ITB) was visible from both the ion temperature profile and the electron temperature profile. It was found that the ITB was located around the peak deposition zone of the LHW, as shown in Fig.4. The evidence suggests that the formation of the ITB correlate with LHCD. The peak deposition zone is shown by a ray-tracing simulation and verified by hard X-ray diagnostics. It was shown by Langmuir probes that the radial electric field was changed and the density fluctuation in the plasma edge was suppressed in the improved performance, as shown in Fig.5.

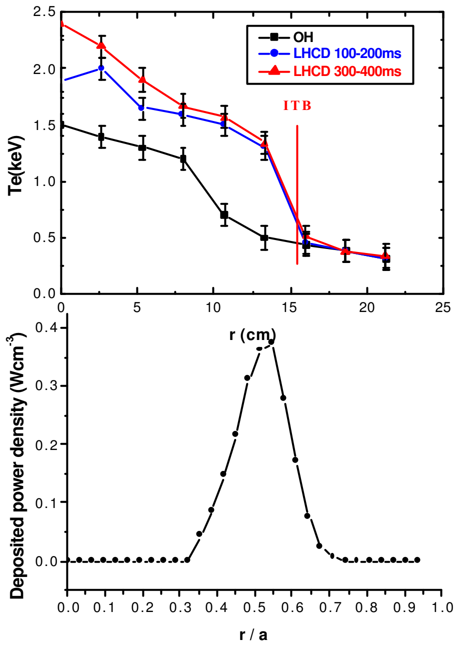

Fig.4: Above are the Te profiles measured by soft X-ray spectrometers in the discharge as in Fig.3; The below is the calculated LHW deposition profile.

4. IBWH experiments

During the latest experiments, obvious electron heating effects by means of IBWH were observed. It was found that the heating corresponded to the ion resonance layer ($2\omega_{CD}$), as shown in Fig.6 and Fig.7. The correlation strongly suggests that IBW directly heat ions due to resonance absorption and then the ions transport some energy to electrons by means of ion-electron collisions. It was also found that IBWH could suppress edge plasma fluctuation greatly and improved plasma confinements in some cases. The suppression of MHD instabilities by IBWH was also observed, but the reason remains unclear.

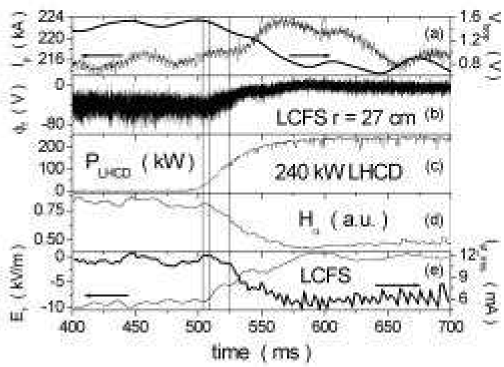

Fig.5: The related changes of I_P, V_P, edge floating potential (ϕ_f), H_α intensity, edge E_r, probe's saturated ion current after the onset of LHCD in the discharge as in Fig.3.

5. Synergetic effects of LHCD & IBWH

By input LHCD together with IBWH to HT-7 plasmas, a high performance with high plasma parameters was successfully achieved. In such performance scenario, the edge safety factor was normally around 2.5, the line average electron density was above 1.5×10^{19} m^{-3}, the central electron temperature was normally beyond 2.0keV, and the central ion temperature was around 1.0keV. An ITB was also observed in the case. The situation was quite similar to that of the improved performance by LHCD alone, except higher electron temperature. It was found that LHCD efficiency was increased by IBWH. A hard x-ray spectrometer showed that the photon temperature increased after input IBWH, as shown in Fig.8.

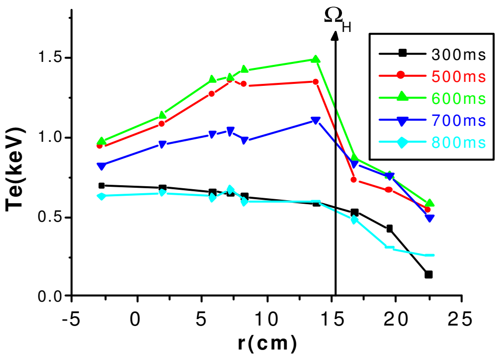

Fig.6: The evolution of electron temperature profile in an IBWH discharge. The profiles at 300ms and 800ms were taken just before and after IBWH. Electrons in the zone near H^+ resonance layer were clearly heated.

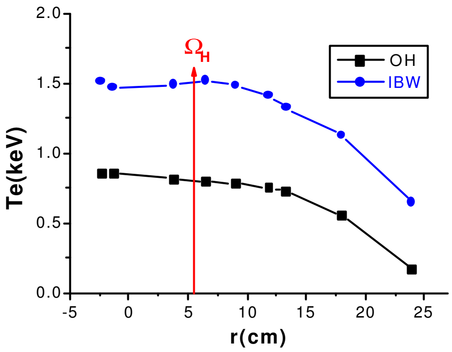

Fig.7: The comparison of T_e profiles w/o IBW in a discharge. The H^+ resonance layer is close to the center.

6. Summary

After several technical improvements, HT-7, in its latest HT-7 experimental campaign (November 2001 – January 2002), made the following results:

Long discharge with a pulse length of 20 seconds and moderate plasma parameters was successfully obtained; High performance with H >2 & Te > 2.0keV was achieved by LHCD. In the case, the edge fluctuations were suppressed and an ITB was visible in the region where LHW deposited. IBWH correlated with the ion cyclotron resonance layer and it was effective to improve plasma confinements; IBW may enhance LHCD.

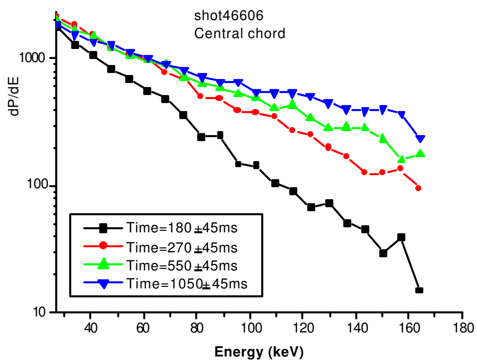

Fig.8: Central channel hard X-ray spectra from a LHCD and IBWH discharge. The black one was taken at the time (180ms) only with LHCD. The color ones were taken with the two waves together.

Acknowledgements

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