LHW and IBW Synergy Experiment on the HT-7 Superconducting Tokamak

X.Gao, HT-7 Team

Institute of Plasma Physics, Academia Sinica, P.O.Box 1126, Hefei,
Anhui 230031, P.R.China

e-mail: xgao@mail.ipp.ac.cn

Abstract. A successful experiment on lower hybrid wave (LHW) and ion Bernstein wave (IBW) synergy has been carried out in the HT-7 superconducting tokamak. With 500 kW of LHW heating power and 200 kW of injected IBW power, it is observed that the ion temperature increases from 500 eV to about 850 eV, the electron temperature increases from 800 eV to 1.2 keV, and the averaged electron density increases from $0.9x10^{19}$ m^{-3} to $2.6x10^{19}$ m^{-3}. The plasma parameters were obviously enhanced by means of the LHW and IBW heating and their synergy. The charge-exchange spectra of the neutral particle analysis (NPA) diagnostics data clearly showed that the high-energy ion tail which was produced by the LHW was decreased by the synergy with the IBW, and the bulk ion temperature was increased. The mechanism of the LHW and IBW synergy effect is discussed.

1. Introduction

A lower hybrid wave (LHW) current drive system has been built for the HT-7 superconducting tokamak to deliver a 1.2 MW microwave at a frequency of 2.45 GHz for a pulse length of up to 5 s [1]. Partial non-inductive current drive and full non-inductive current drive for several seconds by means of LHCD were demonstrated in 1998 [2]. The main objectives of developing LHCD technology on HT-7 are to sustain long pulse discharges and to improve plasma confinement. An ion Bernstein wave (IBW) heating experiment has also been investigated in HT-7 [3]. A 1 MW long pulse (60 s) RF system was designed and constructed [4,5]. Since one of the main purposes of HT-7 operation is to achieve high performance of full wave current drive, the higher electron temperature can benefit the current driven efficiency.

Recently, a successful experiment on LHW and IBW synergy has been carried out in the HT-7 superconducting tokamak. The plasma parameters were obviously enhanced by means of the LHW and IBW heating and their synergy. It is observed that the plasma ion temperature increases from 500 eV to about 850 eV, the electron temperature increases from 800 eV to 1.2 keV, and the averaged electron density increases from $0.9x10^{19}$ m^{-3} to $2.6x10^{19}$ m^{-3}. The evolution of plasma parameter profiles is studied. In this paper, the preliminary results of the LHW and IBW synergy study are reported. The mechanism of the LHW and IBW synergy effect is discussed.

2. Experimental Setup

HT-7 is a medium-sized superconducting tokamak [6]. Its main purpose is to explore steady-state high performance plasma operation under full wave current drive [2], high density operation and fueling method [7-11], and the RF heating condition [5,12]. The machine is normally running at I_p = 150 kA, B_T = 2 T, a = 28 cm, with a molybdenum limiter configuration. LHCD experiments were successfully carried out [2]. The plasma current could be partially or fully sustained by LHCD to a steady-state condition. LHCD

efficiency dependence on different plasma parameters was studied. Effective ion heating by LHW at high density was observed on the HT-7 tokamak. IBW heating [3] was successfully carried out, and a clear electron heating was observed. A heating factor of 7.8 eV 10^{13} cm^{-3}/ kW was achieved. The fast increase of electron temperature and the low increment of ion temperature gave evidence that the electron heating was due to electron Landau damping. Recently, the synergy of LHW and IBW has been studied in the HT-7 superconducting tokamak. Plasma performance was improved when IBW was combined with LHCD. It is found that the better confinement could be attributed to the synergy between IBW and LHW.

3. Preliminary Results

Figure 1 shows profiles of a typical shot involving synergy between LHW and IBW on the HT-7 tokamak. The plasma current is about 140 kA, the toroidal field is about 2 T, the input power of LHW is about 0.5 MW, and the input power of IBW is about 0.2 MW. It is observed that the ion temperature (ΔT_i) increases to 250 eV, the electron temperature (ΔT_e) increases to 400 eV, and the averaged electron density (Δn_e) increases to $1.7x10^{19}$ m^{-3}. The plasma parameters were obviously enhanced by means of the LHW and IBW heating synergy on the HT-7 tokamak. Figure 2 shows the evolution of the density profiles during the LHW heating (at 230 ms), and during LHW+IBW synergy (at 480 ms). The experimental data gave evidence that the sharp gradient at the region of normalized radius 0.5-0.7 played a key role during the improved confinement phase. The edge fluctuation was significantly suppressed when the total injected power was over a critical power threshold. It is normally conjectured that LHW heating and current drive efficiency can be improved under a higher electron temperature plasma heated by IBW. Figure 3 shows the energy spectra from the neutral particle analysis (NPA) diagnostic for Ohmic heating, LHW heating, and LHW synergy with the IBW. At a higher density operation region, a clear ion heating effect from the high-energy ion tail by LHW is shown in Fig.3. The charge-exchange spectra of the NPA diagnostics data show that the high-energy ion tail which was produced by the LHW [2] was decreased by the IBW synergy, and the bulk ion temperature was increased. This phenomenon of the synergy effect is not fully understood. One of explanations of the LHW and IBW synergy is that there is a strong interaction between the LHW induced energetic particles and the RF waves [13,14]. The details will be studied in the next year of HT-7 experiments.

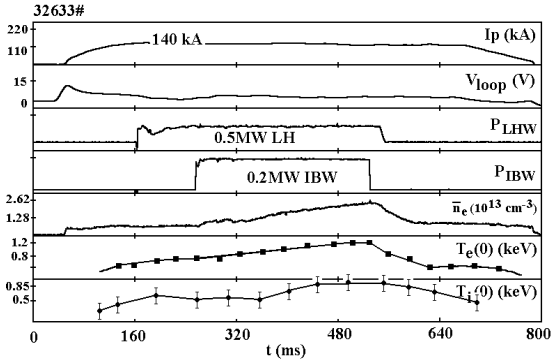

Fig.1. A typical shot of LHW and IBW synergy on the HT-7 tokamak.

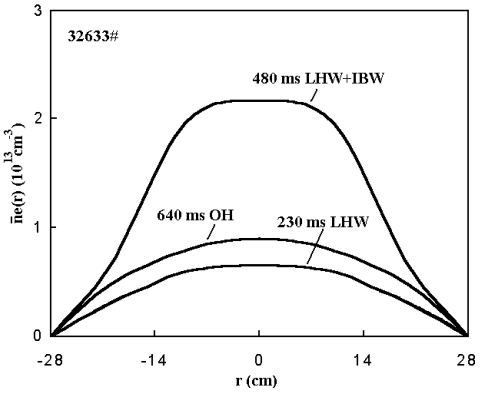

Fig.2. Evolution of density profiles in the LHW and IBW synergy experiment.

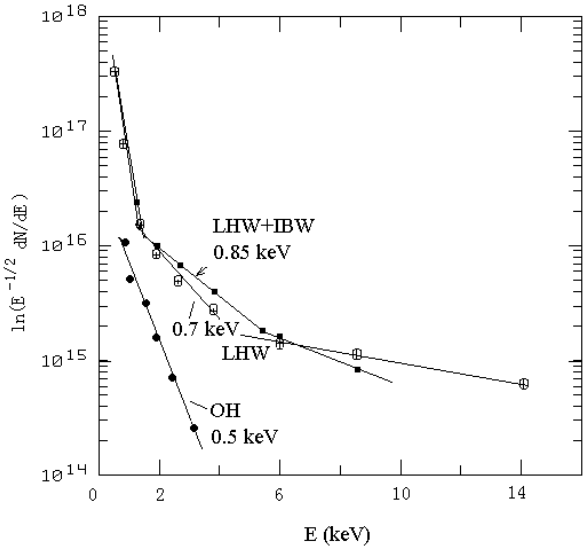

Fig.3. Energy spectra from NPA diagnostics.

4. Conclusion

In conclusion, the preliminary results of the LHW and IBW synergy study in HT-7 are reported. The plasma parameters were obviously enhanced by means of the LHW and IBW heating and their synergy. It is observed that the plasma ion temperature increases from 500 eV to about 850 eV, the electron temperature increases from 800 eV to 1.2 keV, and the averaged electron density increases from 0.9×10^{19} m^{-3} to 2.6×10^{19} m^{-3}. The evolution of plasma parameter profiles is studied. NPA diagnostic data show an interesting new result.

5. Acknowledgment

The authors would like to thank D.Li for useful discussions. This work has been supported by the Natural Science Foundation of China, Contract No. 10005010.

References

[1] KUANG, G.L., et al., Fusion Tech. **36** (1999) 212.
[2] KUANG, G.L., et al., Nucl. Fusion **39** (1999) 1769.
[3] LI, J.G., et al., Proceedings of the 2nd IAEA TCM on SSO (FURKU Report 99-05(66), 1999), Vol.**2**, p.384
[4] YANG, X.K., et al., Fusion Engineering and Design **39-40** (1998) 129.
[5] ZHAO, Y.P., et al., Chinese Phys. Lett. **14** (1997) 916.
[6] XIE, J.K. and the HT-7 team, Proceedings of the 16th IAEA Conference (IAEA, Vienna, 1997), Vol.**1**, p.685.
[7] YANG, Y., et al., Nucl. Fusion **39** (1999) 1871.
[8] GAO, X., et al., Phys. Plasmas **7** (2000) 2933.
[9] GAO, X., et al., Plasma Phys. Control. Fusion **41** (1999) 1349.
[10] ZHANG, S.Y., et al., Plasma Phys. Control. Fusion **42** (2000) 743.
[11] GAO, X., et al., J. Nucl. Mater. **279** (2000) 330.
[12] LI, J.G., et al., Nucl. Fusion **39** (1999) 973.
[13] FISCH, N.J. and HERRMANN, M.C., Plasma Phys. Control. Fusion **41** (1999) A221.
[14] FISCH, N.J. and HERRMANN, M.C., Nucl. Fusion **34** (1994) 1541.