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Charge-Exchange Measurements During Ion Bernstein Wave Heating in HT-7 Tokamak

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Abstract

Ion heating by Ion Bernstein Waves (IBW) has been investigated in the deuterium plasma in the HT-7 tokamak. A perpendicular neutral particle energy analyzer provides information of the ion from the plasma with IBW heating. The fluxes and energy distribution of charge-exchange neutral particles are studied. The particle fluxes of lower energy decrease and which with higher energy increase evidently during IBW heating. The velocity distribution of particle appears to be Maxwellian with no significant tail observed. The bulk ion temperature increase and the ion heating efficiency of $\Delta \mathbf{T}_i \times n_e/P_{rf}$ to (3-4)eV.kW^{-1}.10^{13}cm^{-3} has been achieved .

1.Introduction

In tokamak experiments, the intensity and energy distribution of the charge-exchange fast neutral particle flux is measured separately for hydrogen or deuterium. From the energy distribution of the neutral particle flux, the ion energy distribution can be inferred. The measurement of fast neutral particle fluxes of charge-exchange has long been used to diagnose ion temperature profiles and non-Maxwellian high-energy component.

Now tokamak experiments have been devoted to the study of high-power additional heating, for instance by NBI, ICRF and IBW etc. Radio-frequency power absorption in the ion cyclotron range of frequencies is currently being studied as a supplementary method of heating plasma to fusion temperatures. IBW heating in a tokamak is based on the fact that the finite Larmor radius waves, excited in the range of ion cyclotron frequency, can penetrate to the hot plasma core without strong attenuation until approaching the harmonic cyclotron layers. The strong ion heading is realized when the wave passes the resonant layers, where strong ion cyclotron damping occurs. Good ion heating results by IBW were observed on JIPP-II-U [1] and Alcator-C [2] etc. IBW heating was also investigated in the HT-7 superconducting tokamak deuterium plasma with an injecting power of up to 320kW. In experiments, the ion and electron heating, as well as improved particle confinement are observed. A perpendicular neutral particle energy analyzer obtains information of the ion from the plasma with IBW heating. The escape neutral particle fluxes of lower energy from the plasma edge decrease and these with higher energy from the plasma core increase evidently during IBW heating. The increase of the bulk ion temperature is also obtained. Simultaneity, the central line averaged electron density increases, H_{α} emission decreases, particle confinement improvement has been observed in IBW heated plasma.

2.Experimental setup

HT-7 is a medium-sized superconducting tokamak with limiter configuration [3]. The major radius is 122cm and the minor radius is 27.5cm. A movable vertical limiter and horizontal pump limiter are made of molybdenum. Plasma current is about 120-200kA and toroidal magnetic field about 1.5-2T.

The RF frequency is 24-30MHz. the IBW antenna differs from the Nagoya Type-III shape [4]. A quadruple T-antenna is used with a central feeder and short ends. The antenna is orientated in the toroidal direction. Maximum RF power of the generator is 320kW.

A 10-channel neutral particle energy analyzer (NPA) measures the neutral particle flux and energy spectrum along the central chord of the minor cross section. The neutral particle energy analyzer consists of a stripping cell, a magnetic coil, ten-deflection plate and ion detectors. The fast neutral particles escaping from the plasma are ionized through the nitrogen gas cell. The momentum-analyzed and mass-separated ions are detected by channeltron. The analyzer has an energy rang of $0.2<E$ (keV)<50, with a design enabling mass-resolved measurements of H and D.

The HT-7 tokamak is equipped with more than diagnostics, such as a vertical 5-channel far-infrared (FIR) HCN laser interferometer to measure the electron density profile and a 3-channel soft x-ray spectrum analyzer to measure electron temperature. The fast ECE, soft x-ray diode array and fast-moving Langmuir probes are particularly utilized for IBW heating experiments.

3.Experimental result analysis

In HT-7 tokamak, the experiments of ion heating by IBW were performed with main parameters: B_t=(1.5-2.0)T, I_p=(120-200)kA, n_e=(1-3)$\times 10^{19}m^{-3}$ and IBW power of about (80-200) kW.

Figure.1 is a typical shot with injection power of 200kW. Plasma current was kept at 150kA during IBW heating. IBW started at 250ms and ended at 450ms. Central line-averaged electron density increased from 1×10^{19} to$2.0\times10^{19}m^{-3}$ and electric temperature increases from 0.6 to 1.0keV. The ion temperature increases from 0.45 to 0.75keV. After IBW ended, the plasma performance was degraded; electric and ion temperature dropped to 0.6 a 0.5keV respective.

The flux of fast neutral particle is measured by NPA; the ion temperature is determined by straight slope of the energy spectrum of the fast neutral particles.

Figure.2 has shown the charge exchange neutral particle fluxes. The neutral particle fluxes of lower energy from the plasma edge decrease evidently; these with high-energy from the plasma core increase after applying the IBW.

It is in accord with the D_α emission decreased that the neutral particle fluxes of lower-energy decrease during IBW heating.. The global particle confinement time, τ_p, is calculated from D_α measurements in Figure.2. It significant increase in τ_p is observed during IBW.

The charge-exchange (CX) spectra are shown in Fig.3. The CX spectra for Ohmic discharge is also shown as comparison. In Fig.3 shows a lot of high-energy particles were produced by IBW. Due to a lot of high-energy particles exist at plasma central, the bulk ion is heated through the collision between bulk ion and high-energy particle. The ion temperature in ohmic discharge is about 0.45keV derived from the slope of the energy spectrum in the energy range of 0.8keV-2.2keV. The bulk ion temperature is about 0.70keV obtained in the energy range of 0.8keV-3.6keV for IBW heating.

The CX spectra show a Maxwellian distribution of high-energy particle up to about 5keV with no significant high-energy tail, which was produced by IBW.

The ion heating efficiency with different IBW power and different plasma parameters are quantitatively analyzed. Fig.4 shows the analytical results for the different plasma densities and IBW powers. It indicates a strong correlation between the ion heating effect and the plasma density and IBW power. It is shown that the plasma density greatly influences ion-heating effect. The ion temperature increases with increasing electron density for IBW heating with different power. It may be better energy exchange between the high- energy ions and the bulk ions through collisions in higher density. The increment of the ion temperature depends on the IBW power also.

4.Discussion and summary

The IBW ion heating was investigated in the deuterium plasma in the HT-7 tokamak. In our experiments, a lot of high-energy particles were produced at plasma central by IBW. The ion velocity distribution appears to be Maxwellian with no significant tail from CX spectra by NPA. The particle confinement improvement has been observed. The ion temperature maximal increases about 300eV and the ion heating efficiency of (3-4) $eV.kW^{-1}.10^{13}cm^{-3}$ were achieved for P_{rf}~200kW.

The electric heating mode was carry out on HT-7 plasma for IBW heating [5] and the plasma density increased after IBW injection, So, the bulk ion heating by IBW attribute to the energy transfer by collisions between the ion and the electron. In addition, a lot of high-energy particles were produced, it indicates ion cyclotron harmonic was excited at the hot plasma core; therefore, ion cyclotron harmonic damping and the collisional energy exchange between the ions and electric are main ion heating mechanisms for IBW heating.

Acknowledgements

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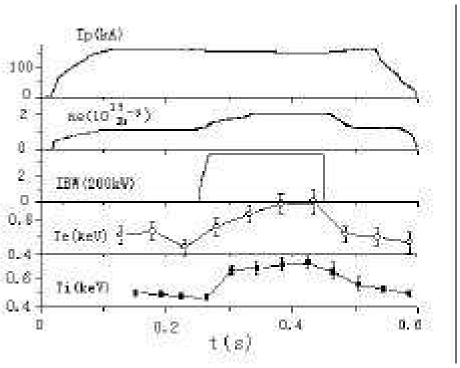

Fig.1. A typical shot of IBW heating

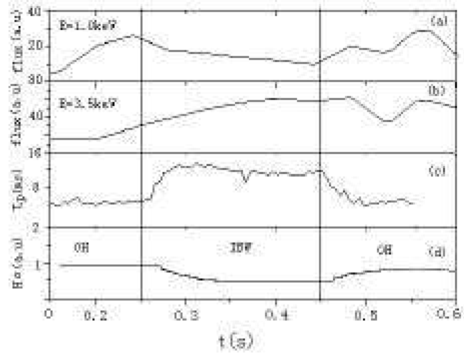

Fig.2.Particle fluxes and D_α signal and τ_p

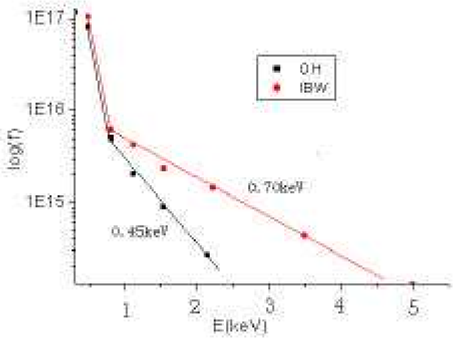

Fig.3 Spectra in ohmic and IBW heating

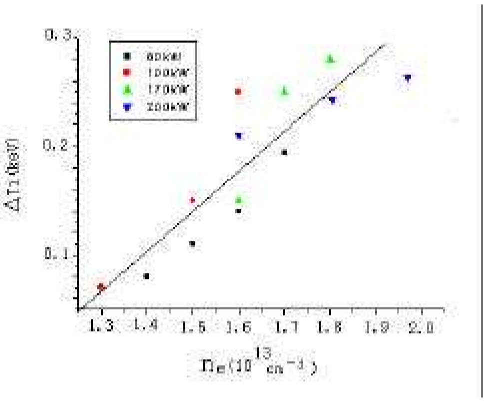

Fig.4 $\triangle T_i$ as functions of n_e and IBW power