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ION HEATING EFFECTS OF LHCD ON HT-7

SUPERCONDUCTING TOKAMAK

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Abstract

In HT-7 superconducting tokamak, the ion heating usually occurs in the plasma density increased during LHCD experiments. The ten-channel neutral particle energy analyzer identifies the ion heating effects. The high-energy ions tail was observed on the perpendicular charge-exchange energy spectrum, the bulk ion temperature increased by 0.4KeV after the onset of LHCD. The ion heating efficient of 1eV/kW^{-1} was obtained in a plasma density range of n_e=(1-2)×10^{13}cm^{-3}.

1.Introduction

The lower hybrid wave (LHW) is one of the promising methods of plasma heating in Tokamak. This method is based on the absorption of slow waves by the electrons and ions of plasma. The lower hybrid current drive (LHCD) has been widely studied on many tokamak machines. These researches showed the non-inductive current drive and ion heating effect by LHW. The ion heating effect dependence on the electron density was investigated. Obvious ion heating effects were observed [1-2].

Usually the ion temperature is determined in magnetically confined plasmas by measurements of the energy distribution of the fast neutral particles. According to theory analyses and many tokamak experiments result, plasmas which are additionally heated usually have a non-Maxwellian high-energy tail. So, in order to provide ion temperature and ion energy distribution measurements, a wide energy range, mass resolving, spatial scanning charge exchange analyzer has been developed [3-4].

The lower hybrid current drive (LHCD) has been widely studied on HT-7 tokamak. The improved plasma confinement and full non-inductive current drive for several seconds by means of LHCD have been demonstrated [5]. The ion heating has been observed in a plasma density range of n_e=(1-2)×10^{13}cm^{-3}. The high-energy ion tail was created and the bulk ion temperature increasing during LHCD.

2.Experimental setup

The HT-7 is a superconducting tokamak. The tokamak with a major radius of R=1.2m,a minor radius of a=0.26~0.28m in the circular cross section. The 24 superconducting coils, which can creates and maintain a toroidal magnetic field (B_T) of up to 2.5T.

The 10-channel neutral particle energy analyzer is quasi-perpendicular to the direction of toroidal magnetic field and aim at plasma center. The system allowing spatial resolution 2cm moving about a pivot point which is located near the vacuum vessel flange; the temporal resolution 1-90ms freewill choose. The analyzer has an energy rang of 0.2<E (KeV))<50, and its design enable mass-resolved measurements of H and D. The experimental set-up is shown in Fig.1. The fast neutral particles escaping from the plasma are ionized through the stripping cell . During the discharge the pressure in the gas cell is kept constant at 1.2×10^{-2}p. The ionized particles entering the magnetic field are momentum-analyzed. In the next stage, momentum-analyzed ions enter the electric field. The energy-analyzed ions are detected in each energy channel by Channeltron.

In order to avoid any damage of the Channeltron, the high voltage of the deflection and the Channeltron are control by a controller. The controller depends on the air pressure of stripping cell.

Each signal from the ion detector is put through a preamplifier, a linear amplifier and discriminator. The signals from the discriminator are sent to a scaler and stored in the local memory. After the discharge, a PC computer processes the data obtained.

3. Experimental result analysis

3.1 The ohmic heating

The flux of fast neutral particle with energy E, produced in 1 cm^3 of plasma, is expressed as [6]

$$J(E)= n_a\, n_i\, f_i\,(E) < \sigma_{cx}(v_{ia}).v_{ia}>$$

Where n_a and n_i are the densities of the deuterium atoms and ions, σ_{cx} is the cross-section for the charge exchange, v_{ia} is the relative velocity of the ions and atoms and < >brackets mean an averaging over the velocity distribution of the atoms, f_i (E) is energy distribution function of the ions , is expressed as

$$f(E_i) = \frac{2}{\sqrt{\pi}} \frac{E_i^{1/2}}{(kT_i)^{3/2}} \exp[-\frac{E_i}{kT_i}]$$

When E_i is energy of ion, T_i is ion temperature. Usually, the ion temperature is determined by straight slope of the energy spectrum of the fast neutral particles.

The neutral particle analyzer has measured the energy spectrum along the central chord for HT-7ohmic heating. The metrical energy spectrum was shown Fig.2. The theoretical energy distribution of neutral particle emitted by the HT-7 plasma in the ohmic heating phase is given in Fig.2. The theoretical ion energy distribution function was calculated by Monte-carlo method in $n_e(0)=1.5\times10^{13}cm^{-3}$, $T_e(0)=1.0\times10^3$eV. The spectra of the experimental data and calculation by Monte-carlo method are a good agreement in the energy range from0.8-2.5KeV. The ion temperature is about 0.52keV from the slope of the energy spectrum.

3.2 The ion heating of LHCD

In HT-7 tokamak, the ion heating of LHCD experimental with main parameters: B_t=1.8T,I_p=110kA--150kA,n_e=(0.8-2.4)×10^{13}cm^{-3}. The lower-hybrid pulse with 360ms duration and about power of 300kW at $N_{//}$=2.9. The lower-hybrid wave power was launched into the plasma from 240ms. The plasma electron density at core increases from 0.8×10^{13}cm^{-3}to 2.4×10^{13}cm^{-3} during LHCD.

The charge-exchange (CX) neutral particle energy spectrum of deuterium ware measured by the plasma center at perpendicular direction. Fig.3.shown the CX spectra with and without RF power. We see a good Maxwellian distribution in the energy spectrum range for the ohmic heating plasma. The ion temperature is about 0.50keV. With RF, a remarkable feature of the CX spectrum is the existence of a high-energy ion tail and the ion tail extending up to at least14keV. The bulk ion temperature is about 0.86keV obtained from the slope of the energy spectrum in the energy range of 1.5keV-4keV. The tail -temperature i. e. the straight slope defined by the higher energy particle (E>6keV) is 10keV.

Fig.4 shows the time evolution of the bulk ion temperature. It obtained from the slope of the CX energy spectrum at different times of the discharge. The ion temperature increases from about 0.50keV to 0.90keV after LHCD. The drop of the ion temperature in the time interval of 500 to 600ms is attributed to much high-energy particle escape from plasma. When electron density increases excess 2.0×10^{13}cm^{-3} causing particle escape increasing, the ion-heating effects decreasing during LHCD. The electron temperature in the plasma centers about 0.95KeV from the three-channels the soft X-ray spectrum analyzer. The central ion temperature is nearly the same as the electron temperature in the LHCD phase.

4. Discusses and summarizes

In the LHCD experiment on HT-7 tokamak, the RF power of 300kW was launched into plasma. When electron density higher than 1×10^{13}cm^{-3}, the higher efficient of ion heating has been observed. A non- maxwellion high-energy ion tail is measured in the perpendicular CX energy spectra of the deuterium. The bulk ion temperature rises about 0.4keV. The ion heating efficient of 1eV/kW^{-1} has been obtained. The ion heating by LHW is mainly attributed to the energy exchange between the ion tail and the bulk ions through collisions. The electron temperature of the peripheral plasma plays an important role in bulk ion heating. In addition, the many high-energy particles escape from plasma bring ion heating effects decreasing, the high-energy ions loss seem to be a loss channel for RF power.

REFERENCES

[1].G. Kuang et al, in Acta Physica Sinica Vol.8 No.1(1999)33-39.

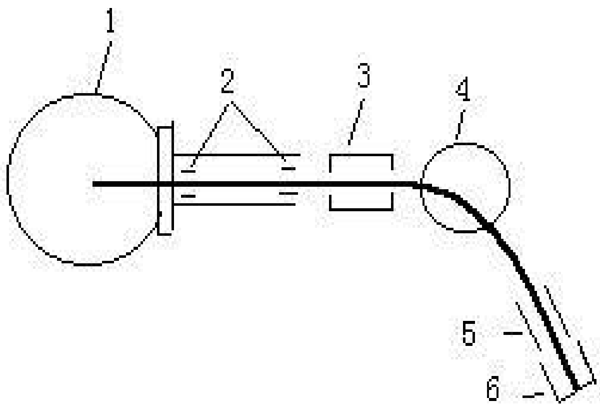
[2].X.T.Ding, et.al,25th EPS Conf. On Contr. Fusion and plasma physics. ECA Vol.22C(1998) 1348-1351.

[3] Rev. Sci. Instrum. 54(3).Mer.1983.

[4] Nuclear Fusion. Vol.24. No.2(1984).

[5] .G. Kuang et al, in Chinese Physics Letters Vo.15 No. 6(1998) 435-437.

[6] 3.V.V. Afrosimov et al, EUR 8351-1 EN volume1



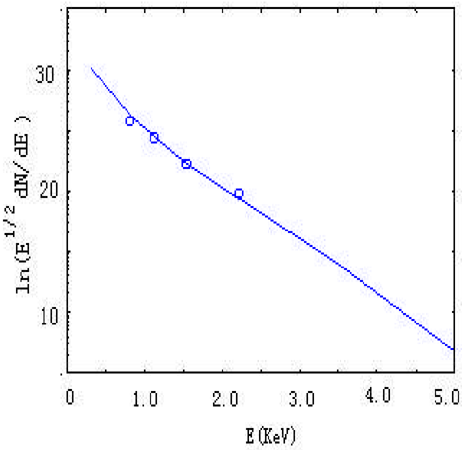
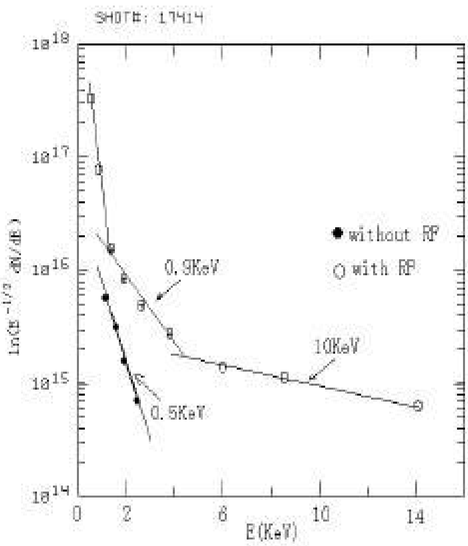


Fig.1. Experimental apparatus with
a ten-channel analyzer
1 plasma 2.slit 3.stripp cell
4.electo-magnet coil 5.curved plates
6. detectors

Fig.2 Energy spectra of the neutral
particles for ohmic heating
o-------experimental data
Line is the spectrum of calculation



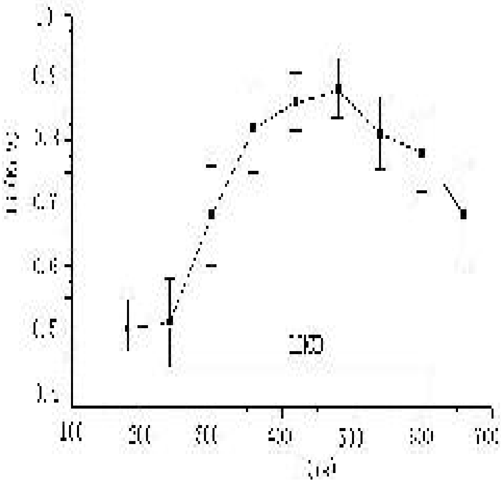


Fig.3. Energy spectra of deuterium particles
with and without LHW

Fig4. Time evolution of the central
ion temperature