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Influence of High Energy Electrons on ECRH in LHD
LHDにおけるECRHによる高エネルギー電子の発生と加熱への影響

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The central bulk electron temperature of more than 20 keV is achieved in LHD as a result of increasing the injection power and the lowering the electron density near 2×10^{18} m^{-3}. Such collision-less regime is important from the aspect of the neoclassical transport and also the potential structure formation. The presences of appreciable amount of high energy electrons are indicated from hard X-ray PHA, and the discrepancy between the stored energy and kinetic energy estimated from Thomson scattering. ECE spectrum is also sensitive to the presence of high energy electrons are discussed by solving the radiation transfer equation. The ECRH power absorptions to the bulk and the high energy electrons are dramatically affected by the acceleration and the confinement of high energy electrons. The heating mechanisms and the acceleration process of high energy electrons are discussed by comparing the experimental results and ray tracing calculation under assumed various density and mean energy of high energy electrons.

1. Introduction

Recent upgrade of the ECRH system in LHD [1] enabled to study the plasma confinement properties at the far low collisional or collision-less regime in the helical system where specific confinement features are predicted from the neo-classical transport theory. These specific features includes confinement degradation in the so called "$1/\nu$" regime where the ripple loss become dominant but radial electric field can drastically alter the situation [2]. In order to discuss the confinement properties in such collision-less regime, the accurate estimation of the behavior of the high energy electrons as well as that of the bulk electrons temperature is required, since the high energy electrons can absorb injected ECRH power at the relativistically down shifted frequency and can deposit their energy to the bulk electrons out of the region where they absorb the energy from injected EC wave. Thus, the power deposition profile which is the key parameter in the transport analysis can be much affected by the presence of high energy electrons. One of the most reliable and well established methods to experimentally deduce the power deposition profile is using the transient analysis of the electron cyclotron emission (ECE) [3].

It is known that the presence of high energy electrons can alter the ECRH absorption, mainly due to the finite Larmor effect. In an inhomogeneous magnetic field configuration, the relativistic down shift of the cyclotron resonance causes the shift in the absorption region and also the appearance of the higher harmonic resonances for high energy electrons. The ECRH heating scenario in such low collisional plasma have to be explored taking the relativistic effect into account.

2. Achievement of high electron temperature and production of high energy electrons

Using upgraded ECRH (of more than 3MW injection power), the plasma parameter region of the low density and high temperature is explored. With the careful adjustment of the magnetic field and the focal point, the central bulk electron temperature exceeded 20 keV at the center. This bulk electron temperature is derived by averaging over several shots of YAG-Thomson scattering data. It is confirmed that these estimations of the bulk electron temperature are not affected by the presence of high energy electrons discussed hereafter.

High temperature low density plasma produced by ECRH normally contains appreciable fraction of high energy electrons. In Fig.1 are over plotted the time evolutions of the plasma parameters for high n_e(1.2×10^{19}m^{-3}) low (0.2×10^{19}m^{-3}) and very low (0.1×10^{19}m^{-3}) density shots (as indicated in the column b))with identical ECRH injection pattern as shown in a). It should be noted that the diamagnetic stored energy (Fig.1c) for the low and very low density cases are almost comparable up to 3.8 s even though the difference in the density is about factor 3. Furthermore, the stored energy for the very low density case gradually approaches to that for high density case toward the end of the shot. These stored energy behaviors are well explained by the production and acceleration of high en-

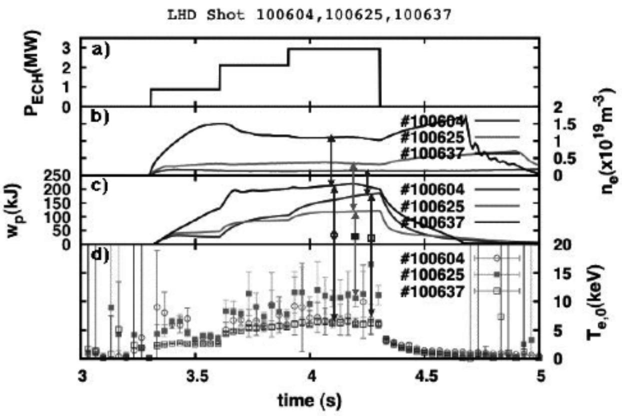

Fig. 1 Time evolutions of a) ECRH injection power, b) electron density, c) stored energy and d) central electron temperature for high ($1.2\times10^{19}\mathrm{m}^{-3}$) low ($0.2\times10^{19}\mathrm{m}^{-3}$) and very low ($0.1\times10^{19}\mathrm{m}^{-3}$) density shots.

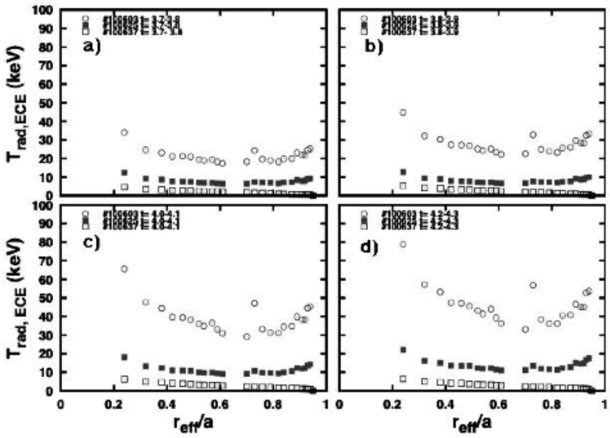

Fig. 2 ECE spectra plotted as a function of averaged minor radius corresponding to a second harmonic resonance position for the time slice at a) t = 3.7-3.8 s, b) t = 3.8-3.9 s, c) t = 4.0-4.1 s and d) t = 4.2-4.3 s of each shot shown in Fig.1.

ergy electrons. The presence and acceleration of the high energy electrons are confirmed by the Hard X ray pulse height analysis. The results show that the energy reaches to 100 keV in the very low density case. The electron cyclotron emission non-thermal features are also consistent with the energy range and the density of high energy electrons as shown in Fig.2.

In Fig.1d) are shown the time evolution of the central electron temperature measured by YAG-Thomson scattering for these three cases. The central bulk electron temperature exceeds far above 10 keV for the low density case, but stays below 10 keV for both high and very low density cases. This decrease in the central electron temperature of very low density case can not be explained by the decrease in the absorption ratio depending on the density, since the one path absorption is almost 100 % even in the very low n_e of $0.1\times10^{19}\mathrm{m}^{-2}$ at 10 keV. These results suggest that the power reached to the bulk electrons at the center decreased for the very low density case as compared with low density case.

3. Effects of high energy electrons on the ECRH power deposition

Fig.2 suggests that the high energy electrons exist not only in the central region of the plasma but also peripheral region. That is also expected from the difference in the drift surface of the high energy electrons from that of bulk electrons [4].

Such effect of high energy electrons must appear also in the power absorption in the ECRH. In order to simulate the effect of high energy electrons on ECRH, ray-tracing code (LHDGauss) is extended to accommodate to calculate the multi-Maxwellian electron distribution function. It was demonstrated that the injected power from the low field side partly absorbed at the relativistically down shifted second harmonic resonances in the low field side by decomposing the absorption fraction to bulk and high energy electrons. This second harmonic absorption amount to about 20% of injected power in the case where 10% 100 keV high energy fraction. Such absorption can work as a screening effect for the central bulk electrons. The relativistic shift of the fundamental resonance is toward the high field side. The broadening of the power deposition profile can not be explained in the case of low field side injection.

4. Conclusions

The central bulk electron temperature, T_{e0}, exceeded 20 keV at averaged electron density, $n_e \leq 3\times10^{18}\ \mathrm{m}^{-3}$. The presence of high energy electrons are confirmed in such low density and high temperature, collision-less plasma. It is demonstrated that the presence of the high energy electrons can drastically alter the the power deposition profile that is mainly due to the relativistically down shifted second harmonic resonance at low field side.

Acknowledgement

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