J. Plasma Fusion Res. SERIES, Vol.1 (1998) 27–29

Profile Control Studies on Heliotron-E

OBIKI Tokuhiro*, OKADA Hiroyuki, KONDO Katsumi[1], SANO Fumimichi, ZUSHI Hideki[1], HANATANI Kiyoshi, MIZUUCHI Tohru, BESSHOU Sakae[1], NAGASAKI Kazunobu, WAKATANI Masahiro[1], NAKAMURA Yuji[1], NAKASUGA Masahiko[1], IJIRI Yoshiyuki, SENJU Tohru, YAGUCHI Keiji, KOBAYASHI Sakuji, TOSHI Kiyoshi, SAKAMOTO Kinzo, KURIMOTO Yuji, HAMADA Takateru, SUDO Shigeru[2], SATO Motoyasu[2], IDA Katsumi[2], FUNABA Hisamichi[2], KADO Shinichiro[2], PETERSON Byron J.[2], MURAOKA Katsunori[3], SUGAI Hideo[4], TOYODA Hirotaka[4], SASAKI Koichi[4], KOKURA Hikaru[4], MATSUO Keiji[5], SERGEEV Vladimir Yu.[6], KHLOPENKOV Konstantin V.[6], CHECHKIN Victor V.[7] and VOITSENJA Vladimir S.[7]

Institute of Advanced Energy, Kyoto University, Uji 611-0011, Japan

[1]Graduate School of Energy Science, Kyoto University, Uji 611-0011, Japan

[2]National Institute for Fusion Science, Toki 509-5292, Japan

[3]Interdisciplinary Graduate School of Engineering Science, Kyushu Univ., Kasuga 816-8580, Japan

[4]Faculty of Engineering, Nagoya University, Nagoya 464-8602, Japan

[5]Faculty of Engineering, Fukuoka Institute of Technology, Fukuoka 811-0295 Japan

[6]State Technical University, St. Petersburg 195251, Russia

[7]Kharkov Institute of Physics and Technology, Kharkov 310108, Ukraine

(Received: 30 September 1997/Accepted: 22 October 1997)

Abstract

In Heliotron-E device, the effects of combined heating with ECR and NBI on profile formation and confinement have been studied. The various profiles can be obtained by the control of the heating power, the heating method and the density. With the high power NBI, the peaked electron density and ion temperature profiles are achieved simultaneously. On the contrary, the peaked electron temperature and flat density profile is brought by ECH. The profile effects on the global energy confinement in the medium density region are discussed in this paper.

Keywords:

global confinement, profile control, high T_i mode, LHD scaling, local transport, neutral beam injection, electron cyclotron heating

1. Introduction

In order to study the transport in the rare collisional region for the aims of improvement of the confinement and the expansion of the operation range, the combined heating of the ECH and NBI has been carried out in Heliotron-E under the boronized wall condition[1]. Typical ECH plasma is characterized by the broad density profile caused by strong particle 'pumping-out' phenomena[2] except for the high density case. When the ECH pulse is applied on the target NBI plasma, the electron temperature in the central region was increased and peaked since the power density of the ECH at the center is comparable to that of NBI although total ECH power is low (about 0.4 MW) compared with the total NBI power (1–3 MW). At the

Corresponding author's e-mail: obiki@iae.kyoto-u.ac.jp

©1998 by The Japan Society of Plasma Science and Nuclear Fusion Research

same time the density in the central region decreases because of strong 'pumping-out'. In NBI heating plasmas, high T_i mode was reported[3] for the example of the confinement improvement. In this mode, the central ion temperature increases as the peakedness of the electron density increases. We studied on the relation between the density peakedness and the appearance of high T_i mode.

In this paper, we discuss the global confinement time of the ECH and/or NBI heated plasmas in the medium density range (from 1.0×10^{19} m^{-3} to 6×10^{19} m^{-3}). The relation between the global confinement, the local transport and various plasma profiles is investigated. The electron temperature and density profiles are measured by Thomson scattering and the ion temperature profile is measured by the charge exchange recombination spectroscopy. The stored energy is calculated from these data with the assumption that the ion density equals to the electron density. The global confinement time τ_E^G is derived by the equation,

$$\tau_E^G = W/(P_{abs} - \mathrm{d}W/\mathrm{d}t) \quad (1)$$

where W is the total stored energy, P_{abs} is the total absorption power by NBI heating and/or ECH. The last term of the denominator on the right hand side is estimated from the diamagnetics signals. In most of all data processed, $\mathrm{d}W/\mathrm{d}t$ is less than 10% of P_{abs}.

2. Peaking Parameter Range

In this section, the peaking parameter range for the electron density ($\hat{n}_e$), the electron temperature ($\hat{T}_e$) and the ion temperature ($\hat{T}_i$) is described. The peaking parameter is defined as follows, $\hat{a}=a(0)/<a>$, where a(0) is the central value of the parameter 'a' and $<a>$ denotes the averaged value in the poloidal cross section. In this study $\hat{n}_e$ is from 1.2 to 4.5. This range is obtained only by NBI heated plasmas (P_{NBI} is from 1 to 3.3 MW). The parameter $\hat{n}_e$ of ECH overlapped NBI heating plasmas does not become large because of the particle 'pumping-out' in the core region by ECH effect. With higher NBI power, larger $\hat{n}_e$ is obtained.

The parameter $\hat{T}_i$ of NBI heated plasma is in the range from 1.4 to 2.7. $\hat{T}_i$ and $\hat{n}_e$ have positive correlation for high T_i mode plasmas, as shown in Fig. 1. This tendency agrees with the discussion of high T_i mode. There is no high T_i plasma in the low $\hat{n}_e$ region. But there is another branch in the large $\hat{n}_e$ region, *i.e.* the low T_i mode plasma exists in this region, too. The key issue of the bifurcation is still under investigation. ECH plasmas can not extend the range of $\hat{n}_e$ and $\hat{T}_i$. However, ECH has great effect on $\hat{T}_e$ (Fig. 2). Without ECH, the range of $\hat{T}_e$ is from 1.3 to 2.4. It is greatly extended by ECH up to 4.1. The on-axis 106GHz ECH realizes the highest $\hat{T}_e$. The electron temperature and the density cannot be peaked simultaneously because the density 'pumping-out' mechanism can not be overcome when $T_e(0)$ is high or ECH power in the central region is not sufficient when $n_e(0)$ is large. With high power NBI, the ECH effect on $\hat{T}_e$ and $\hat{n}_e$ disappears due to the insufficient ECH power and cutoff according to the high density of that parameter region.

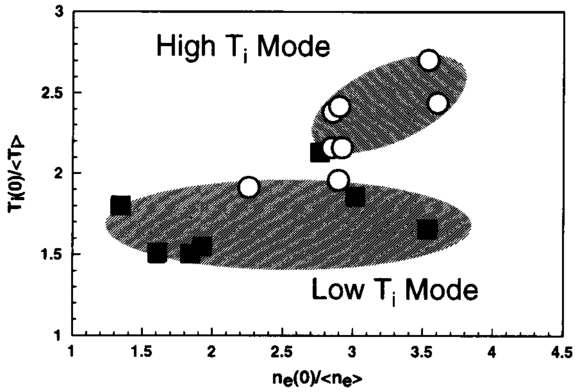

Fig. 1 The ion temperature-peaking parameter versus the electron density-peaking parameter (open circle: NBI, solid rectangular: ECH overlapped NBI). High T_i mode region and low T_i mode region are separated.

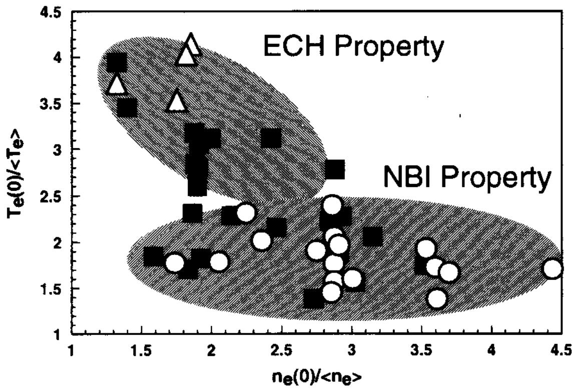

Fig. 2 The electron temperature-peaking parameter versus the electron density-peaking parameter (open triangle: ECH, open circle: NBI, solid rectangular: ECH overlapped NBI). The peaked T_e and peaked n_e profiles can not be achieved simultaneously.

3. The Profile Effects on the Global Confinement Time

When the characteristics of the global confinement time is considered, the empirical scaling is usually used to discuss the improvement, the parameter dependence, and so on. We use the LHD scaling[4] as the standard of the global confinement because it is deduced from the data set of Heliotron-E experiment. The parameter dependence is as follows,

$$\tau_E^{LHD} = 0.17 a^2 R^{0.75} P_{abs}^{-0.58} \bar{n}_e^{0.69} B^{0.84} \qquad (2)$$

where a is the minor radius (m), R, the major radius (m), P_{abs}, total absorption power (MW), $\bar{n}_e$, the line averaged density (10^{20} m^{-3}) and B, the magnetic field strength (T) at the axis.

The global confinement time for low T_i mode normalized by LHD scaling decreases with $\hat{n}_e$ as shown in Fig. 3. The flat density profile is preferable from this point of view. The LHD scaling is deduced from the data with low $\hat{n}_e$. This plot covers more wide area of n_e. High T_i mode plasma appears at around 2.5 or higher of $\hat{n}_e$. The slope for high T_i mode plasma is very small compared with that for low T_i mode. Therefore, the degradation of the global confinement in the peaked density seems to be compensated by high T_i mode. This factor of improvement is not so large compared with that of the ion local heat conduction coefficient in the plasma central region which decreases by factor 10.

The effect of T_e on the global confinement is different from that of $\hat{n}_e$ (Fig. 4). The plots for the global confinement of the combined heating plasma are located in the different region from those of NBI plasmas. The peaking parameter for the NBI plasma is narrow, therefore, there is no dependence of the global confinement time on T_e for NBI plasmas. The dependence of the global confinement on the pressure peakedness is similar to that of $\hat{n}_e$.

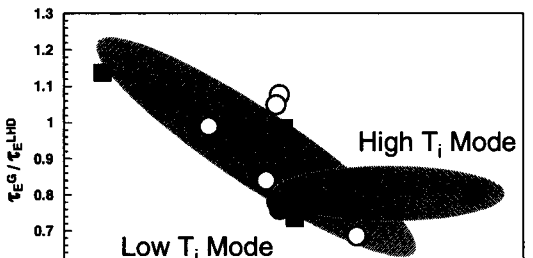

Fig. 3 The relation of the global confinement and the density-peaking parameter (open circle: NBI, solid rectangular: ECH overlapped NBI, solid circle: high T_i mode NBI). For low T_i mode plasmas, the global confinement decreases as the density-peaking parameter increases. The tendency for the high T_i mode plasma is different.

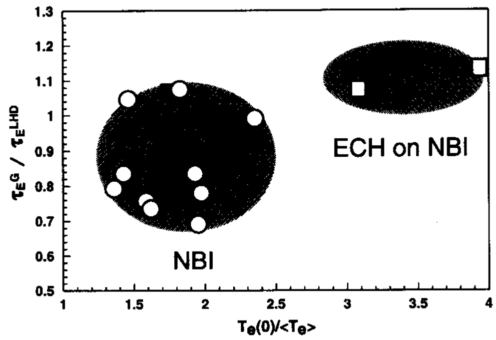

Fig. 4 The relation between the global confinement and the electron temperature-peaking parameter (open circle: NBI, solid rectangular: ECH overlapped NBI, open rectangular: ECH overlapped NBI in the low density region). The plots of global confinement of the combined heating plasmas in the low density region are located in the different region from the NBI data.

4. Summary

With ECH and NBI heating, temperature and density profiles have been controlled in the wide range. The peaking parameter range is as follows, $\hat{n}_e$: 1.2–4.5, $\hat{T}_i$: 1.4–2.7, $\hat{T}_e$: 1.3–4.1. But all parameters cannot be controlled independently. There are several restricted conditions, for example, the peaked electron temperature and the peaked density profile cannot be achieved simultaneously. Peaked ion temperature profiles appear only with the peaked density profiles. The two peaking parameters have linear correlation. The global confinement time for low T_i mode normalized by LHD scaling decreases as the density becomes peaked. But the slope of the global confinement of high T_i mode against $\hat{n}_e$ is very small compared with that of low T_i mode. This improvement of the global confinement property is considered to be due to high T_i mode effect.

Acknowledgment

This work was partly supported by the Collaboration Program of the Laboratory for Complex Energy Processes, IAE, Kyoto University.

References

[1] T. Obiki *et al., Plasma Physics and Controlled Nuclear Fusion Research*, 1994 (*Proc. 15th Int. Conf.*, Seville, 1994), Vol.1, IAEA, Vienna, p.757 (1995).

[2] K. Uo *et al., Plasma Physics and Controlled Nuclear Fusion Research*, 1982 (*Proc. 9th Int. Conf.*, Baltimore, 1982), Vol.2, IAEA, Vienna, p.209 (1983).

[3] K. Ida *et al.*, Phys. Rev. Lett. **76**, 1268 (1996).

[4] S. Sudo *et al.*, Nucl. Fusion **30**, 11 (1990).