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A STUDY OF THE PLASMA PROPERTIES UNDER AN LID CONFIGURATION IN THE CHS*

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A Study of the Plasma Properties under an LID Configuration in the CHS

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Abstract

An experimental study of the local island divertor (LID) was done in the Compact Helical System (CHS). The separatrix of an m/n=1/1 magnetic island, formed at the edge region by additional magnetic field was utilized as a divertor configuration. The main purpose of this configuration is to control the neutral particle recycling. The reduced line averaged density and radiation power loss, and improved energy confinement were obtained under an LID configuration.

Keywords:

Compact Helical System, local island divertor, edge plasma, magnetic island, particle recycling, density profile, screening effect

1. Introduction

A local island divertor (LID) has been proposed to enhance energy confinement through neutral particle control [1]. For the case of the Large Helical Device (LHD), the separatrix of an m/n=1/1 magnetic island, formed at the edge region, will be utilized as a divertor configuration. The divertor head is inserted in the island, and the island separatrix provides connection between the edge plasma region surrounding the core plasma and the back plate of the divertor head through the field lines. The particle flux and associated heat flux from the core plasma strike the back plate of the divertor head, and thus particle recycling is localized in this region. A pumping duct covers the divertor head to form a closed divertor system for efficient particle exhaust. The advantages of the LID are ease of hydrogen pumping because of the localized particle recycling and avoidance of the high heat load that would be localized on the leading edge of the divertor head. With efficient pumping, the neutral pressure in the edge plasma region will be reduced, and hence the edge plasma temperature will be higher, hopefully leading to a better core confinement region. An LID configuration experiment was done on the Compact Helical System (CHS) to confirm the principle of the LID[2,3]. The typical effects of the LID configuration on the core plasma are follows; 1) reduction of the line averaged density to a half with same gas puffing rate, 2) increase of the stored energy for same density. In this paper, the mechanism causing these effect is discussed.

2. Experimental setup

The CHS is a heliotron/torsatron type device whose major radius is 1.0m and averaged plasma minor radius is 0.2m, respectively. The toroidal magnetic field is 0.9T, and the magnetic axis is fixed at R=99.5cm in this experiment. Hydrogen plasma was produced with ECH or ion Bernstein heating, and was heated by neutral beam injection (0.82MW, 38kV, #1 injector). In this paper, neutral beam is applied by counter injection. The separatrix of the m/n=1/1 magnetic island formed by the perturbation field (B_{LID}) with 8 pairs of small external coils. The divertor head is inserted into the plasma from an outer measurement port at the horizontally elongated cross section where the island width is maximum. The position of the divertor head edge is R=1.258m ($\rho \sim 0.86$) which is well inside the island.

3. Results and Discussion

Figure 1 shows the typical time evolutions of the line averaged density, radiation power and stored energy for the cases of with and without B_{LID}. The line averaged density and radiation power reduced significantly with

B_{LID} with same gas puffing rate. On the other hand, the stored energy was not changed. This means that the electron temperature increased in the confinement region. The temperature rise was confirmed by YAG Thomson scattering measurement[3]. The reduction of radiation power is considered to be a primary reason for this temperature rise.

It must be confirmed that the change of radiation power is due to the effect of B_{LID} or merely reduction of the density. To confirm this point, the reduced gas puffing discharge without B_{LID}(#54357) was performed. Fig.1(a) shows that the time trace of line averaged density of this discharge and the discharge with B_{LID}(#54355) were almost same until the termination of gas puffing. On the other hand, Fig.1(b) and (c) shows the larger radiation power and the smaller stored energy for the reduced gas puffing discharge compared with the discharge with B_{LID}, respectively. These data indicate that the effect of B_{LID} is not only reduction in density but also other factor caused by an LID configuration. Figure 2 shows the line intensity of O^{4+} (62.97nm) measured by the VUV spectroscopy as a function of $<n_e>$ for with and without B_{LID}. In this $<n_e>$ range, stored energies are almost same for both cases or slightly larger in the case with B_{LID}. It is clearly shown that the line intensity for same $<n_e>$ is reduced with applying B_{LID}. It means that the concentration of oxygen in the core plasma is reduced with B_{LID}. This is considered to cause the reduction of radiation power.

Now change of the core plasma characteristics under the LID operation can be summarized as below; 1) reduction of density, 2) reduction of radiation power (oxygen line intensity), 3) larger stored energy than the discharge without B_{LID} with same density.

The LID configuration modifies the edge plasma region by forming the m/n=1/1 magnetic island. Thus, the edge plasma properties is considered to be responsible for the change of the core plasma characteristics under the LID operation mentioned above.

Figure 3 shows electron density in the region of outer LCFS measured by thermal Lithium beam probe[4] which locates at 135° ccw away from the LID divertor head. In this poloidal cross section, the X-point of the m/n=1/1 island locates with B_{LID}, and the O-point of the island locates when inversed B_{LID} (i-B_{LID}) is applied. In Fig.3, the Z_{Li} axis is corresponding to the line of thermal Li beam, and Z_{Li}=0 locates on the midplane. The position on the Z_{Li} axis corresponding to the edge of the divertor head and LCFS are Z_{Li}=13.3cm and 14.2cm, respectively. The density profile shrinks with B_{LID} (near the X-point), and slightly spread outward with i-B_{LID} (near the O-point). These results are considered to be due to changes in magnetic structure, that is, the ergodic region surrounding the LCFS is broader with B_{LID}, and outer separatrix of the m/n=1/1 island is formed at almost same position of LCFS with i-B_{LID}. These measurements were done with same gas puffing rate, and $<n_e>$ for the case without B_{LID} is about 2 times larger than the other cases. However, the density near the O-point of the island (with i-B_{LID}) is larger than the case without B_{LID}. The particles flowing outwards from the core region cross the inner separatrix of the island, and come around to the outer separatrix. Thus, near the outer separatrix, the density and temperature are expected to become higher compared with the discharges without B_{LID}. Figure 4 shows the ion saturation current profiles, that is, particle flux profiles on the divertor head measured by the Langmuir probes attached on the head. The outer separatrix of the island can be seen for the case with B_{LID}. The particle flux comes along the outer separatrix is dumped on the divertor head, and thus, the particle flux inside the island becomes very small. The width of the particle flux λ_Γ is estimated to be several cm using a simple model[5]. The experimental result is consistent with this simple estimation. Figure 5 shows the electron density and temperature profiles at the exterior of the outer separatrix measured by a Langmuir probe which sweep the region above the back plate of the divertor head. The electron temperature is about 2 times larger for the discharge with B_{LID} than that without B_{LID}, and the electron density also larger for former case.

Now the characteristics of the edge plasma under the LID configuration can be summarized as below; 1) in spite of smaller $<n_e>$, the edge density near the O-point is not reduced by applying B_{LID}, 2) higher electron temperature, 3) the edge of the divertor head is clearly separated from the confinement region by the m/n=1/1 island.

The edge plasma under the LID configuration can be considered to modify the core plasma properties. The main role of the edge plasma is screening of hydrogen neutrals and other impurities. Due to the higher electron temperature, the recycled particles can be ionized relatively easy. For example, the penetration length of the recycled hydrogen molecule under the LID configuration is several cm for the case of Fig. 5 ($n_e \sim 10^{18} m^{-3}$, $T_e \sim 10 eV$), an order of magnitude smaller than that for the case without B_{LID} ($n_e \sim 10^{18} m^{-3}$, $T_e \sim 5 eV$). Thus the influx to the confinement region can be reduced significantly, and the density and radiation power also reduced. The recycled particle ionized at the outer separatrix region can be removed by the LID pumping easily.

4. Summary

The plasma properties under the LID configuration are studied experimentally. The outer separatrix of the m/n=1/1 magnetic island leads to the relatively higher temperature plasma in the edge region, and the screening effect works effectively. As a result of this effect, the density of the confinement region reduced. The radiation power also reduced due to the impurities screening, and the temperature of the core plasma becomes higher. This might lead to the improved confinement. The screened particles can be easily removed by the LID divertor head.

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Figure Captions

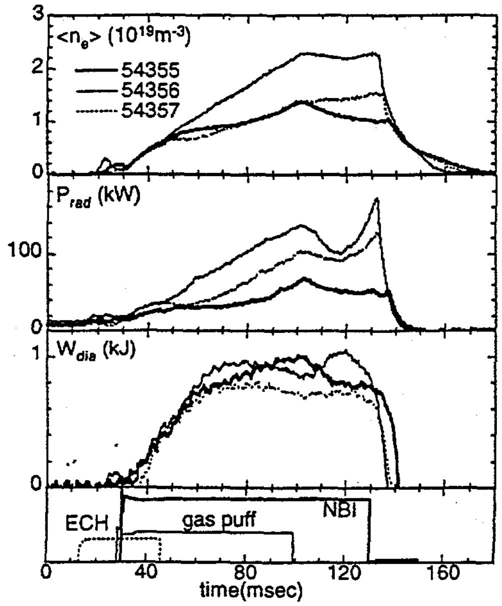
Fig.1: Typical time evolutions of (a) line averaged density(center chord), (b) radiation power, (c) stored energy. The same gas puffing rate was applied for #54355(with B_{LID}) and #54356(without B_{LID}), and reduced one applied for #54357(without B_{LID}).

Fig.2: Line intensity of O^{4+} as a function of $<n_e>$. Both cases, stored energy is almost same in this $<n_e>$ range.

Fig.3: Electron density profile measured by thermal Li beam probe. The Z_{Li} axis is corresponding to the thermal Li beam line, and originate on the midplane.

Fig.4: Ion saturation current profile measured by the attached Langmuir probe on the divertor head. The R axis is the direction of the major radius.

Fig.5: Electron density and temperature profiles at the exterior region of the outer separatrix of the m/n=1/1 magnetic island measured by a Langmuir probe which sweep above the back plate of the divertor head. The Z_{probe} axis is probe's trajectory. The larger Z_{probe} indicate the position nearer the plasma center.



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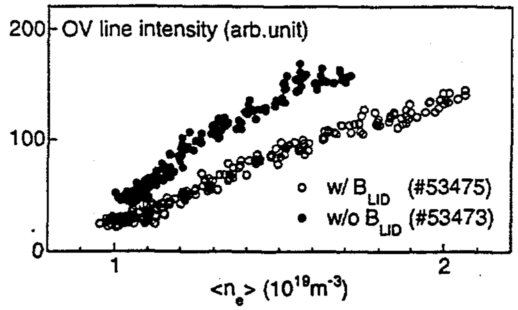

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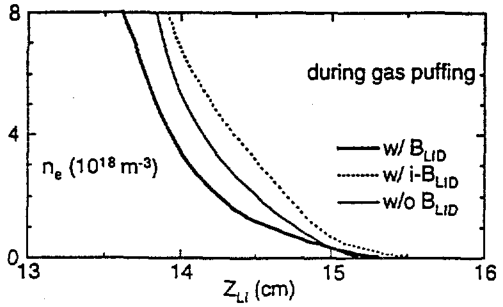

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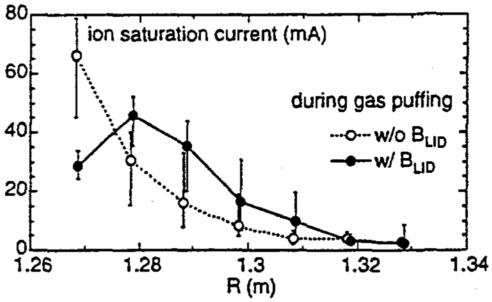

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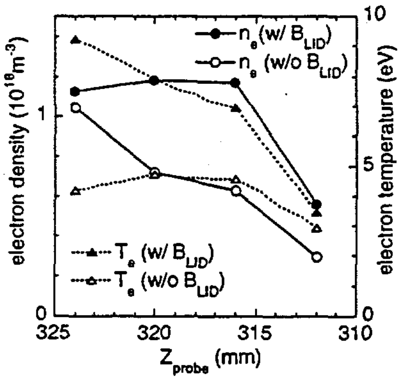

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