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Key words

CHS, JIPPT-IIU, neutral hydrogen, collapse, confinement improvement, IOC-mode, H-mode, density peaking, impurity accumulation

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ABSTRACT

Results are described on NBI plasmas of the Compact Helical System (CHS). An increase in the stored energy, which is called plasma 'reheat', is observed with density peaking when gas puffing is turned off in the high density region. A plasma collapse with large increase in radiation loss occurs even in discharges whose Z_{eff} values (typically, less than 2-3) do not show any increase when the gas puffing is continued. Both phenomena are basically explained by the edge electron temperature due to the difference in the amount of edge hydrogen neutrals. After turning off the gas puffing, the central electron density n_{e0} shows an increase of 80% and the density peaking factor ($n_{e0}/\overline{n}_e$) changes from 1.0 to 2.0, in typical cases, and a high inward velocity of the impurities appears (v = 20 m/s). The accumulation is studied in relation to the poloidal rotation and the edge temperature. These results are compared with results from plasmas with IOC– and H–modes in the JIPPT-IIU tokamak .

1. INTRODUCTION

Compact Helical System (CHS) (m/ℓ = 8/2, R = 1.0 m, $\bar{a}$ = 0.2 m, B_t = 2.0 T) is a low–aspect–ratio heliotron/torsatron, and it has favourable MHD characteristics [1]. In contrast with this, plasma–wall distance is not taken enough (typically 0 ~ 2 cm) and clear divertor configuration is not performed. On the other hand, in JIPPT-IIU tokamak (R = 0.93 m, a = 0.24 m, B_t = 3.0 T, I_p = 300 kA) advanced confinement regime is obtained for H– and IOC–modes as a result of well–optimized wall conditioning and gas puff control [2]. Then, it is especially important for CHS to study the relation between core plasma characteristics and edge particle behaviours and to compare the influence of the edge neutrals in helical and tokamak devices.

NBI heating experiment in CHS has been carried out with the vacuum wall conditioned by Ti gettering which covers 80% of the vacuum wall area. The plasmas following LHD scaling [3] are successfully obtained in low density region. However, the increase in plasma stored energy W_p saturates in high density region at $\bar{n}_e \geq 4\text{-}5\times10^{13}\mathrm{cm}^{-3}$ for 1 T operation when a continuous gas puffing is carried out.

Recently, it is observed that the W_p temporally increases with density peaking and impurity accumulation in high density region, when the gas puffing is switched off. In this paper, the results are reported on the increase in energy and particle confinements obtained after switching off the gas puffing, and comparison is made with JIPPT-IIU tokamak. In a series of studies the results are obtained on experiments using single beam line of tangentially injected NBI ($P_{NBI} \leq$ 1.1 MW, E_b (H^0) $\leq$ 40 keV).

2. PLASMA REHEAT AND COLLAPSE

Plasma 'Reheat' phenomena, accompanied by a temporal increase in the stored energy which is followed by impurity accumulation and density peaking, are observed in high density operations in CHS, when the continuous fueling by gas puffing is switched off (Fig. 1). After switching off the gas puffing at t = 100 ms, the H_α signal viewing horizontal chord decreases gradually, and the H_α decreases rapidly in the toroidal section where the gas puffing is carried out. Together with this decrease, the edge ion and electron temperatures increase significantly. Both temperatures become twice as high as those in the gas puff phase at t = 100 ms, whereas the central ion and electron temperatures change only slightly. The temporal increase in W_p can be explained by the increase in the temperatures in the outer region (ρ > 0.7) of the plasma.

Similar operation is carried out also in Heliotron-E and it is reported that the W_p does not show any increase, although the density peaking is observed with the appearance of the MHD activities [4]. In CHS the MHD activity is suppressed by the formation of the magnetic well due to the large Shafranov shift except for cases of inward–shifted axis ($R_{ax} \leq$ 88.8 cm) [5].

The stored energy obtained in the reheat mode is plotted against the line–averaged electron density $\bar{n}_e$ in Fig. 2(a). The solid line designates LHD scaling between W_p and $\bar{n}_e$. The reheat mode appears in the saturated region above 4.5 x 10^{13}cm^{-3}. In this case, the reheat operation makes an improvement up to 30% of the saturation level of the stored energy. Thus, W_p recovers up to the LHD scaling level in the conditions of the reheat mode. This behaviour is very similar to that of the IOC–mode [6] in JIPPT-IIU tokamak as shown in Fig. 2(b).

When the gas puffing is switched off, the deposited power from fast ions (E_b = 40 keV) of NBI may be raised, because of the decrease in the charge–exchange loss, and may contribute to the increase in W_p. In the case of Fig. 2(a), however, the charge–exchange loss of the fast ions is estimated from computational analyses to be only 8% at $\bar{n}_e$ = 5x10^{13} cm^{-3} for a port–through power of 1 MW. Then, the reheat mode gives an increase in energy confinement time from τ_E = 3.0 ms to 3.5 ms for Fig. 2(a). The origin of the plasma reheat is mainly related to the recovery of the edge temperature, a drop of the radiation loss and appearance of the density peaking.

Radiation collapse is also a severe problem in helical systems [7,8]. To suppress it, Ti gettering and discharge cleaning are carried out to reduce mainly hydrogen and oxygen in CHS. After Ti gettering, the radiation loss is kept to a rather low level (normally, less than 300 kW), but radiation collapse is not avoided.

When the radiation collapse occurs, the radiation loss is usually large. There are, however, some cases where Z_{eff} does not show any increase as shown in Fig. 2(c). Figure 2(d) shows a comparison of the H_α intensities between CHS and JIPPT-IIU, measured along the midplane from horizontal outboard ports. The inverse of the vertical axis unit ($\bar{n}_e/H_\alpha$) generally gives the particle confinement time τ_p at plasma edge. It strongly demonstrates that discharges with higher τ_E involves better τ_p at plasma edge. Low τ_p in CHS leads to a drop of temperature in the edge region. The influence by the edge neutrals, of course, becomes larger in the high density region; it is accompanied by a growth in the electron density in the scrape-off layer (ρ > 1.0), as is shown in Fig. 1. The flat density profiles in the high density region enhance the radiation loss and accelerate the radiation collapse.

3. DENSITY PEAKING AND IMPURITY ACCUMULATION

Switching off the gas puffing also triggers density peaking and impurity accumulation. In typical cases, the density peaking factor, $n_{e0}/\bar{n}_e$, changes from 1.0 to 2.0 during 50 ms after switching off the gas puffing for high density NBI discharges.

The electron density and temperature profiles are shown in Fig. 3 for discharges in the low density region. It is seen that the hollow density profile changes to a peaked profile after turning off the gas puffing. There is a tendency for the density peaking to become remarkable at higher magnetic field and electron density. According to the density rise at the plasma centre, the ion temperature increases. The same phenomenon is also obtained with IOC–mode in JIPPT-IIU. This fact indicates that there is a common role for the density peaking.

Impurity accumulation is also investigated for a study of particle transport. The measurement is carried out with a scanning mirror VUV spectrometer system providing the radial profiles of the impurity line emissions. The analysis from TiXII (460.7 Å) profiles in a typical case yields impurity peaking parameters C_v (= $a_p v/2D$) of 0.1-0.3, when $n_{e0}/\bar{n}_e$ = 1.0 (before switching off gas puffing) and of 3.5-4.5, when $n_{e0}/\bar{n}_e$ = 1.5 (afterwards). This indicates the appearance of a large inward velocity and yields inward velocities of v = 1.0 m/s (before) and 20.0 m/s (after) for a diffusion coefficient of D = 0.5 m^2/s.

As a possible reason for this, the poloidal rotation is measured as is shown in Fig. 3(d). The poloidal rotation goes back to the initial value at t = 108 ms, although the rotation changes rapidly after turning off the gas puffing. Some discharges in other cases do not show any change of the rotation after turning off the gas puffing. There is, however, a good correlation between the density peaking factor, $n_{e0}/\bar{n}_e$, and the absolute value of the poloidal rotation. In addition, the impurity accumulation is enhanced for counter–NBI injected plasma. In the counter case a larger negative electric field is observed. This behaviour is also the same as JIPPT-IIU NBI plasmas. Then, at least it is clear that the density peaking and the impurity accumulation are closely connected with the negative electric field, the edge temperature and the amount of the edge neutrals.

In conclusion, from a series of the studies it is understood that also in helical system the particle control at plasma edge is important to obtain the confinement improvement and to avoid the radiation collapse. To realize it, high temperature divertor operation in next Large Helical Device (LHD) [9] may be a possible candidate.

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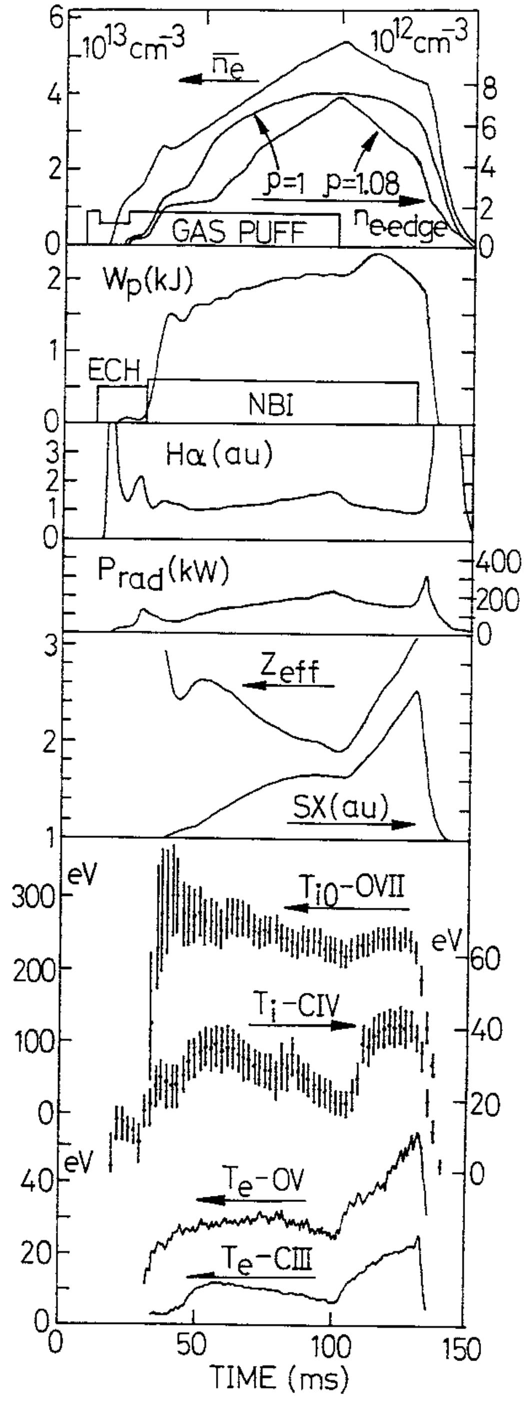
FIGURE CAPTIONS

Fig. 1 Reheat mode of NBI plasmas in CHS (B_t = 1T, R_{ax} = 92.1 cm). The neutral beam is injected with a port–through power of 800 kW.

Fig. 2 (a) Stored energies in CHS (1T, R_{ax} = 94.9 cm) (b) Stored energies in JIPPT-IIU (c) Z_{eff} in CHS (d) Comparison of $H_\alpha/\overline{n}_e$ between CHS and JIPPT-IIU as a function of line–averaged electron density $\overline{n}_e$. The $H_\alpha/\overline{n}_e$ in ICRF L–mode plasma is 1.7 times as large as ICRF H–mode plasma with ELM.

Fig. 3 Profiles of (a) electron density, (b) electron temperature, (c) ion temperature, and (d) poloidal rotation velocity in CHS at B_t = 1.5 T, R_{ax} = 94.9 cm and P_{NBI} = 1 MW. In this case the W_p does not increase after switching off the gas puffing.



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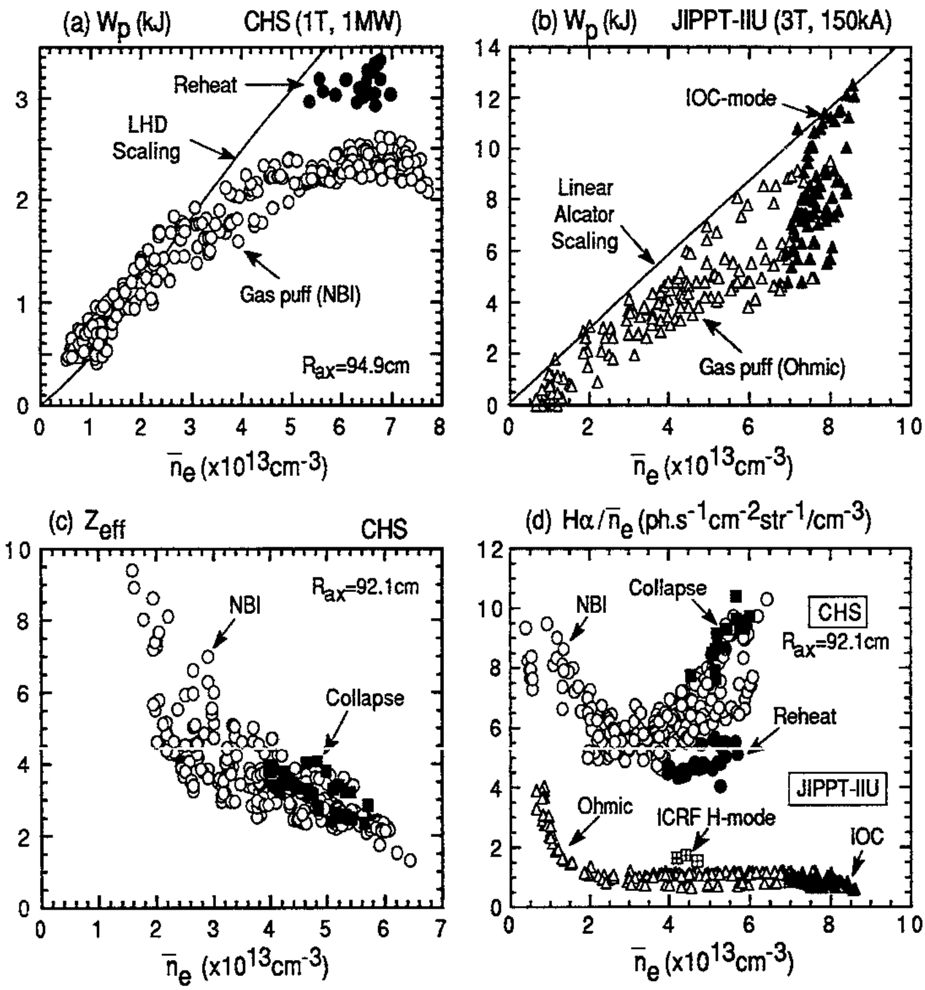

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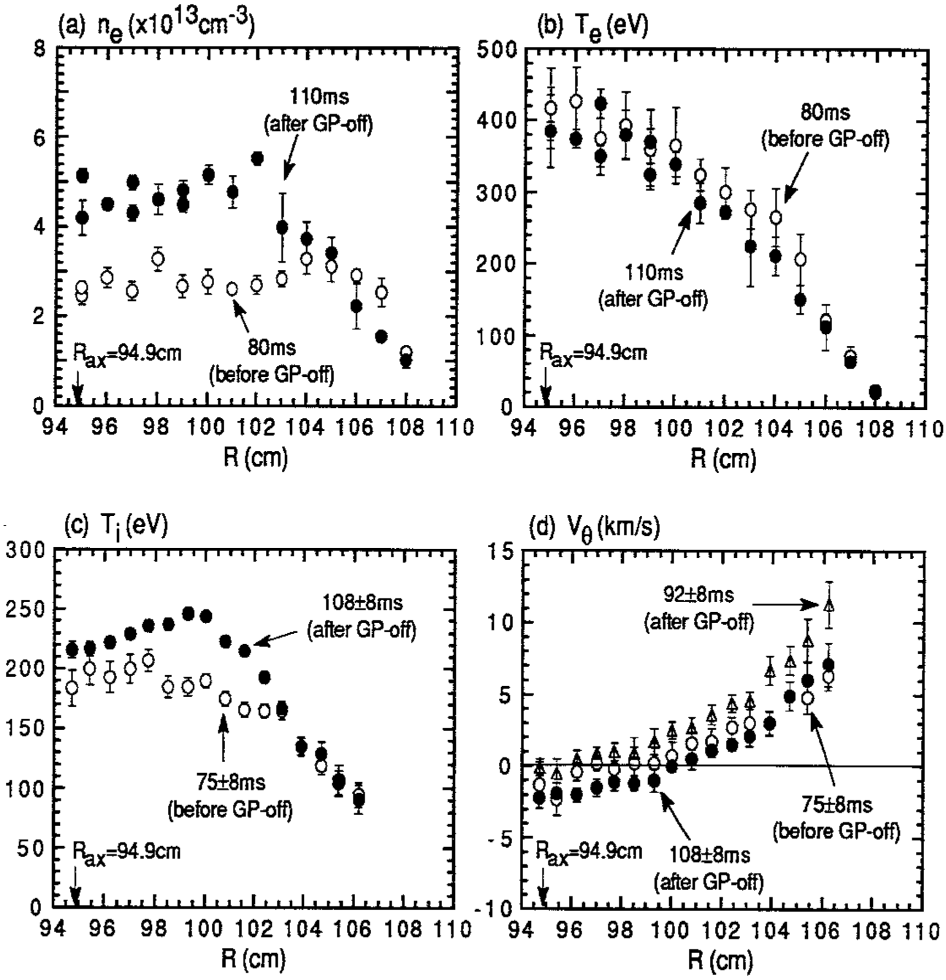

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