First Observation of High Density Edge Transport Barrier Formation during Reheat Mode of Helical Plasma in CHS

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An improved confinement mode with reheat and edge transport barrier is observed in the Compact Helical System (CHS). This mode provides enhanced confinement in high density region ($\overline{n}_e \sim 1.2 \times 10^{20}\,\mathrm{m}^{-3}$) due to the increase in temperature while high density is maintained in the peripheral region.

Keywords: reheat mode, edge transport barrier, H-mode, helical plasma, improved confinement, CHS

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A reheat mode and an edge transport barrier (ETB) are improved confinement modes that have been observed in the CHS. The reheat mode is initiated by shutting off fueling by stopping the gas-puff [1,2]. The electron temperature in the peripheral region is increased resulting from the suppression of neutral particle density which causes charge exchange loss. However, the reheat mode has a problem in that the peripheral density continues to decrease after the gas-puff is stopped. Meanwhile, the ETB mode in the CHS is problematic in the edge temperature decreases due to a large density increase in the peripheral region, thus degrading any improvement in confinement. This paper is the first to report the observation of confinement improvement in the high density range due to the simultaneous realization of both the reheat mode and the ETB. This simultaneous realization provides the enhanced confinement, because of the simultaneous increase in temperature and density in the peripheral region.

Figure 1 shows the global behavior of the reheat mode discharge with the ETB. Although a high field strength (B_T = 1.86 T) is favorable for the reheat mode, the formation of the ETB under a high magnetic field condition is difficult, because NBI power threshold of ETB formation depends on the magnetic field strength [3]. When the field strength increases, the NBI power threshold also increases. When the vacuum magnetic axis location (R_{ax}) shifts outwards, the threshold NBI power decreases. Accordingly, the experiment is carried out for a magnetic configuration of R_{ax}=94.9 cm, which is larger than that of the standard configuration (R_{ax}=92.1 cm). As shown in Fig. 1, the two co-NBIs (total power = 1.6 MW) are injected into the target plasma which is produced by the 54.5 GHz gyrotron. The ETB is formed below an upper density limit that is related to the NBI power threshold: the power threshold is determined by the heating power normalized by the electron density (P/n_e) [3]. On the other hand, because a higher plasma density is required for a high performance plasma

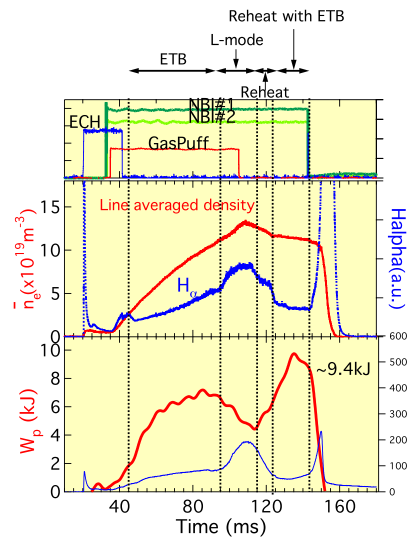

Fig. 1 Global behavior of ETB plasma during reheat mode: line averaged density, H_α signal, and the stored energy W_p are plotted with the injection timings of NBI and ECH heatings.

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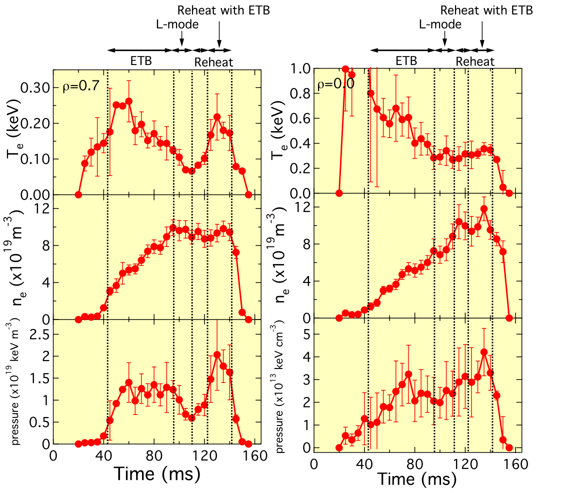

Fig. 2 Time evolutions of electron temperature, density and pressure in the peripheral region (ρ = 0.7) and the plasma center (ρ = 0) measured with YAG Thomson scattering.

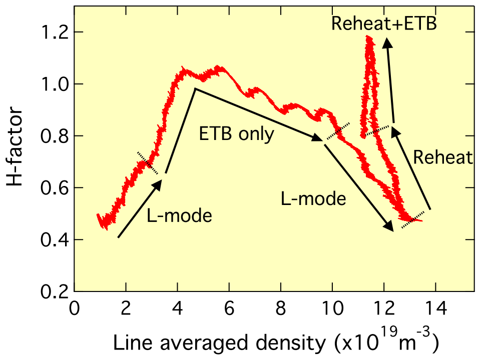

Fig. 3 H-factor plot for the same discharge as the shot of Fig. 1 as a function of the line averaged plasma density.

by the reheat mode, the plasma density is increased by gas-puffing until the ETB formation disappears. As shown in Fig. 1, the initial ETB mode was formed at 45 ms, after which the ETB disappeared and the plasma returned to the L-mode again at 95 ms resulting from the electron density exceeding the upper limit. The plasma density, as shown in middle of the Fig. 1, decreased after the gas-puff was stopped at 105 ms. The onset of the reheat mode is denoted by increase of stored plasma energy from 115 ms due to the temperature increase in the peripheral region. When the density decreased below the upper limit, the density reduction was suppressed due to the reformation of the ETB (123 ms) during the reheat mode. As a result, the stored energy increased up to ~9.4 kJ.

Figure 2 shows the time behaviors of the electron temperature, density and pressure at the peripheral region (ρ = 0.7, ρ is normalized minor radius of torus plasma) and the plasma center (ρ = 0) on the same shot as that shown in the Fig. 1. These results were obtained using YAG Thomson scattering measurements. During the initial ETB phase, the temperature from the plasma center to the edge decreased due to the rise in density. In the subsequent L-mode phase, the peripheral pressure decreases due to the temperature decrease in the peripheral region resulting from the disappearance of the ETB. In contrast, in the ETB during the reheat mode, the density reduction is suppressed and is increased slightly by the ETB formation in the peripheral region, and the temperature continues to increase due to the improvement by the reheat mode. Consequently, the peripheral plasma pressure and the pressure gradient becomes larger than that of the ETB alone.

In typical L-mode plasma or ETB plasma, the improved confinement is degraded by the increase in density. However, in the reheat mode with the ETB, enhanced confinement is realized in high density range. Figure 3 shows the H-factor (improvement factor compared with the stellarator confinement scaling) plot derived from ISS04 CHS/Heliotron/ATF [4] scaling as a function of the line averaged plasma density. The H-factor decreases with the density increase during the L-mode or the initial ETB phases. However, in the ETB phase during the reheat mode, the enhanced confinement is realized even in the high density range ($\overline{n}_e \sim 1 \times 10^{20}\,\mathrm{m}^{-3}$). Although the H-factor (~ 1.2) of the ETB plasma during the reheat mode is same level as the value of the typical ETB plasma in the R_{ax} = 92.1 cm configuration [3], this value at R_{ax} = 94.9 cm might be underestimated, because the scaling is derived from the data of the R_{ax} = 92.1 cm configuration. The CHS L-mode confinement is degraded by the outward shift [5]. Although the H-factor increases during the reheat mode only, the plasma density continues to decrease. In contrast, during the reheat mode with the ETB, the H-factor increases while the high density is maintained. A key issue in the realization of a helical fusion reactor is the need for the density and energy confinement time ($n\tau_E$) to increase with the increase in ion temperature. In the reheat mode with the ETB, the triple product of $n\tau_E$ and the temperature increases by ~200 % compared to the value of the ETB alone and five times compared to the L-mode value. Although the improvement of the reheat mode with the ETB is transient at this time, it is a candidate for the confinement improvement method of the helical plasma.

In conclusion, the simultaneous realization of two improved confinement modes: the reheat mode and the ETB is demonstrated. The observation of improved confinement in the high density plasma confirms that this mode could be useful for the realization of high performance helical plasma.

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