# CHARACTERISTICS OF REHEAT-MODE DISCHARGES IN LARGE HELICAL DEVICE

S.Morita, M.Goto, T.Morisaki, S.Masuzaki, K.Tanaka, K.Narihara, S.Sakakibara, S.Ohdachi, K.Toi, S.Inagaki, K.Ikeda, O.Kaneko, K.Kawahata, A.Komori, J.Miyazawa, O.Motojima, S.Muto, Y.Nagayama, K.Nishimura, N.Ohyabu, Y.Oka, M.Osakabe, B.J.Peterson, R.Sakamoto, H.Suzuki, Y.Takeiri, T.Tokuzawa, K.Tsumori, H.Yamada and LHD experimental group

*National Institute for Fusion Science, Toki 509-5292, Gifu, Japan*

## 1. Introduction

Improvement of plasma performance after turning off gas puffing ("reheat-mode") has been widely observed in relatively small-scale helical devices such as CHS [1], ATF [2] W7-AS [3]. A large increment of plasma stored energy and an improvement of energy confinement are observed in the reheat-mode discharges. The reheat-mode appeared not only in NBI case but also in ECH and ICRF cases. It is strongly suggested that the cause of the reheat-mode is not simply related to a recovery of the input power and originates in the transport phenomenon due to a change of the edge parameters. Neutral particle effects, however, were so big in such devices. For example, the density profile was largely affected by the edge neutral behavior [4]. Then, unclear points remained for understanding the physical mechanism of the reheat-mode in addition to a lack of temporal and spatial information.

In LHD [5] the LCFS is surrounded by an ergodic layer of which the thickness ranges between 1 and 7cm at the O-point and depends on magnetic axis position (see

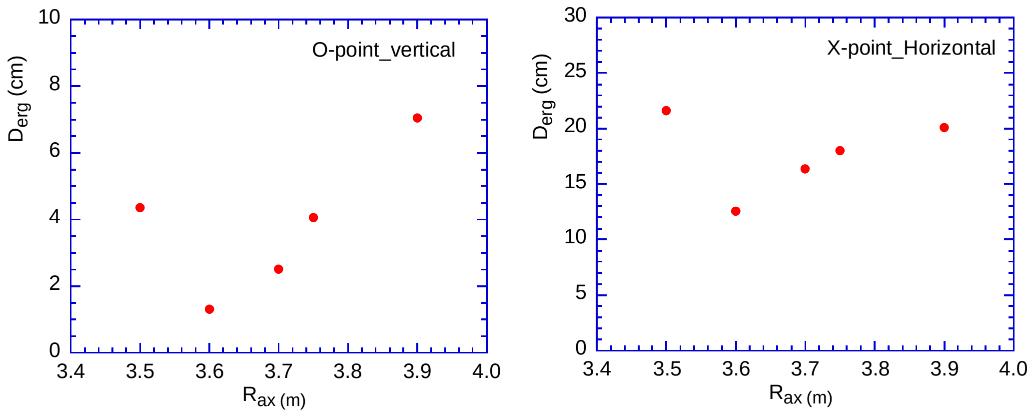


Fig.1 Thickness of ergodic layer averaged between inside and outside points (left: O-point at vertically elongated position, right: X-point at horizontally elongated position.)

Fig.1). Here, the $D_{erg}$ is taken at a region with connection length, Lc>100m. The edge temperature of the main plasma (ρ=1) normally exceeds 100eV. Then, hydrogen neutrals and radiation from light impurities are located in the ergodic layer surrounding the main plasma. Inserting a limiter, density profiles did not change in LHD, whereas those in CHS changed from hollow to peaked by an increase in reflected particles from the limiter [4]. The direct effect on the neutrals was completely removed from the plasma core of LHD. Therefore, it has been thought unlikely that the reheat-mode appears in LHD.

## 2. Reheat-mode discharges in LHD

After starting NBI experiments the reheat-mode operation was tried, and magnetic axis ($R_{ax}$) dependence was investigated in order to make clear the response to the ergodic layer thickness. A clear increment of $W_p$ was observed after switching off the gas puffing at the $R_{ax}$=3.70m position. Typical results are shown in Fig.2. The increment of $W_p$ in the $R_{ax}$=3.60m position is very small. In the $R_{ax}$=3.75m position the operation related to density control becomes considerably difficult because of the thick ergodic layer. The edge temperature at ρ=1 in the $R_{ax}$=3.60m position is higher than the case of $R_{ax}$=3.70m [6]. Then, the recovery of the edge temperature in $R_{ax}$=3.60m is relatively small (In LHD the best confinement is obtained in the $R_{ax}$=3.60m position). These results indicate that the existence of the ergodic layer plays an important role for the reheat-mode discharge. A direct reason is a recovery from a large drop of the edge temperature at high-density region due to the low $\tau_p$ in the ergodic layer.

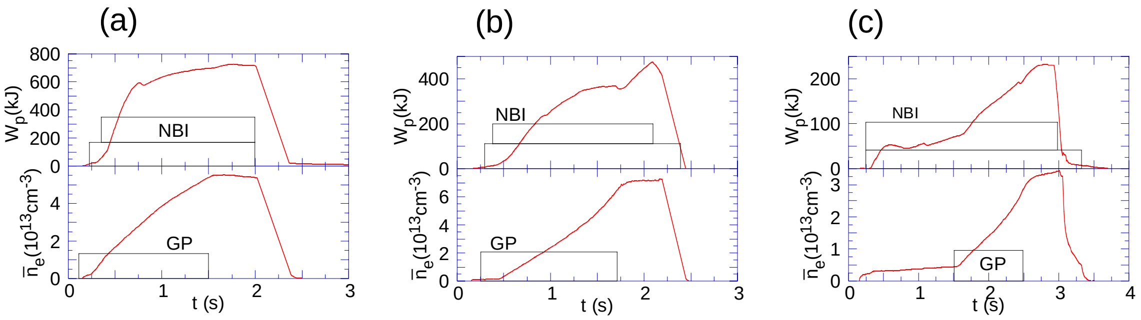


Fig.2 Reheat-mode operation during NBI discharge (upper: plasma stored energy $W_p$, lower: line-averaged density $<n_e>$). (a) $R_{ax}$=3.60m, (b) $R_{ax}$=3.70m, (c) $R_{ax}$=3.75m.

## 3. Behavior of the electron temperature

A typical result of the electron temperature behavior in $R_{ax}$=3.70m position is shown in Fig.3(a). Constant gas puffing is switched off at t=1.7s. After switching off the gas puffing the $W_p$ increases from 370kW (t=1.7s) to 480kJ (t=2.1s). The peak $W_p$ at t=2.1s gives a confinement improvement of 30% against ISS-95 scaling, although the gas puffing phase just behaves as the ISS-95 scaling. Unfortunately in this discharge the ICRF pulse is applied during 0.3s from t=2.0 to 2.3s and the NBI#1 pulse is turned off at t=2.1s. Then, the linear increase of the $W_p$ is suddenly stopped at t=2.1s. The temporal behavior of electron temperature measured from Thomson scattering is shown in the bottom trace. The edge temperature at ρ=0.95 increases with a time delay of 40ms after switching off the gas puffing. At this moment, however, the central temperature at ρ=0 is still drops. The temperature rise at the edge region propagates toward the plasma center with the same time scale as energy confinement time (=140ms). After 170ms (t=1.87s) the electron temperature goes up with edge and core regions until t=2.1s at which the NBI#1 is turned off. From these results we can clearly understand that the reheat-mode is a pure transport phenomenon accompanied with confinement improvement. The electron temperature profiles are traced in Fig.3(b). The profiles are taken at times of t=1.7s (gas puffing off), 1.86s (end of the heat propagation) and 2.10s (end of reheat-mode). It is understood that the temperature recovers in the whole region of the plasma. The main part of the increase in $W_p$, of course, originates in the edge temperature rise.

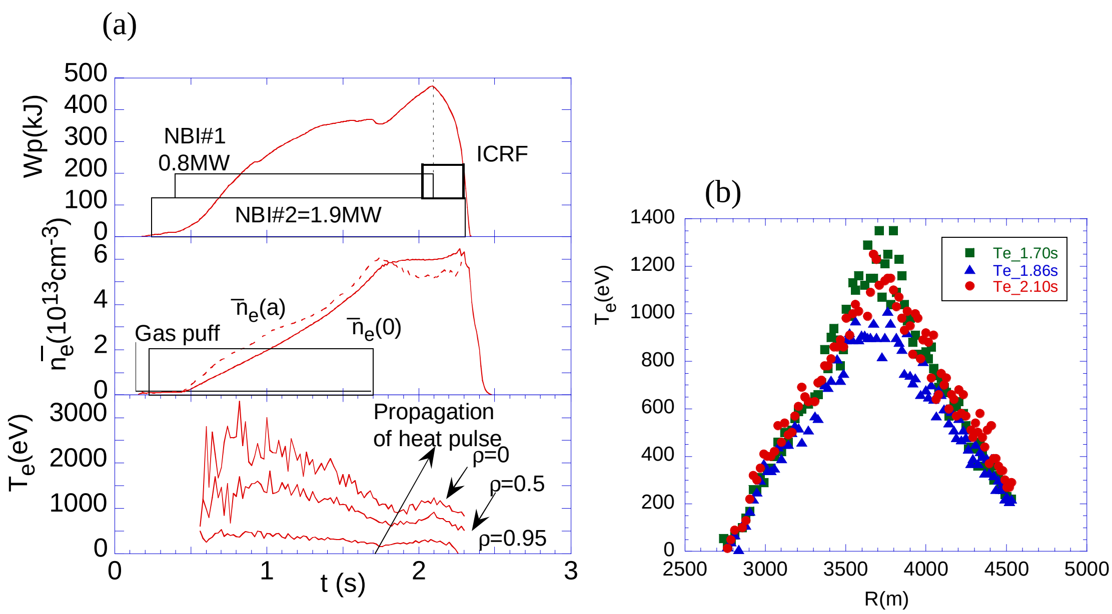


Fig.3(a) Temporal behaviors of $W_p$, $<n_e>$ and $T_e$. Gas puffing is switched off at t=1.7s.

(b) Electron temperature profiles measured from Thomson scattering at t=1.7, 1.86 and 2.1s.

### 4. Behavior of the electron density

It was reported that density profiles become peaked during the reheat-mode [1], although the mechanism was unclear at the moment. In LHD an 11-channel interferometer is installed to get the density profile with a good time resolution. Results from LHD are shown in Fig.4 (the discharge is the same as before). We can see from Fig.4(a) that the density profile becomes peaked after switching off the gas puffing, and we can understand the reason seeing the temporal density behavior (see Fig.4(b)). An important issue for the mechanism can be pointed out to be an existence of the inward flow of particles supplied from the gas puffing and a difference between particle confinement times of core (0.3s) and plasma edge (0.01s). After switching off the strong gas puffing the supplied particle still moves toward the plasma center. The density in ρ=0 and 0.45 continuously goes up at t=1.8s, whereas the edge density in ρ=1.05, 1.00 and 0.90 begins to drop. This change in the density profile continues until t=2.1s, and finally such a peaked density profile is performed. The improvement of the energy confinement also continues until t=2.1s with the formation of the peaked density profile.

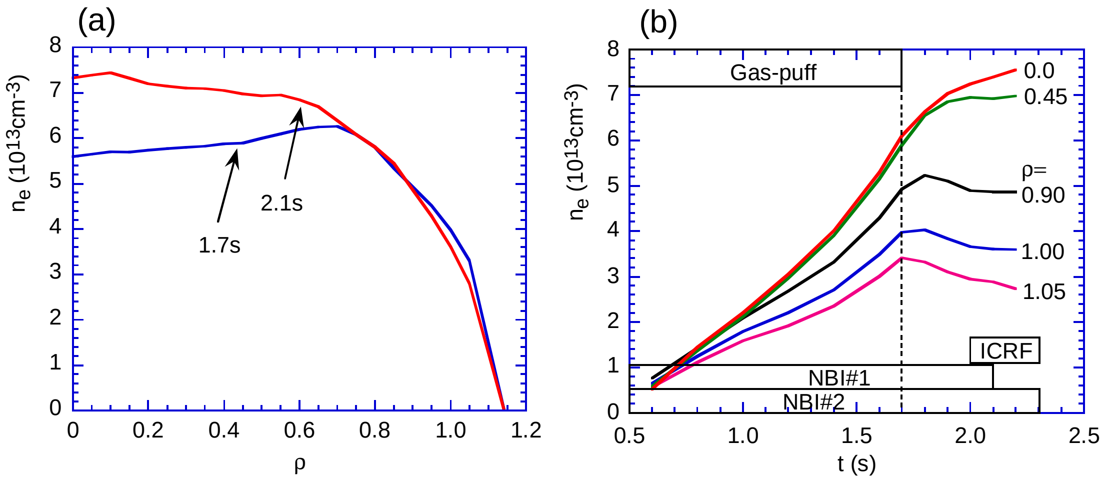


Fig.4(a) Electron density profiles after Abel inversion at t=1.7s and 2.1s. (b) Temporal behavior of electron density as a parameter of ρ (=<r>/<a>).

**5. Conclusions**

1) Reheat-mode was observed also in LHD. Thickness of the ergodic layer is strongly related to the confinement improvement during reheat-mode.

2) Heat propagation from edge to core was observed. The core temperature is strongly correlated to the edge temperature.

3) Peaked density profile was observed. It can be explained in combination with the inward flux from gas-puffed particles and a difference in the particle confinement time between core and edge region.

4) There possibly exists a relation between density peaking and confinement improvement.

**References**


[1] S.Morita et al., Proc. 14th IAEA conf., (IAEA, Vienna, 1993) IAEA-CN-56/C-2-5.

[2] S.Morita et al., ORNL report, ORNL/TM-11737 (1991)

[3] S.Morita et al., IPP-report (Garching, Germany), no.199 (1995)

[4] S.Morita et al., 16th IAEA conf., (IAEA, Vienna, 1997) IAEA-CN-64/CP-3.

[5] O.Motojima et al., Phys. Plasma 6, 1843 (1999).

[6] N.Ohyabu et al., Phys.Rev.Lett. 84, 103 (2000).