Current Profile Control Experiments in the LHCD Plasma on TRIAM-1M

K. Nakamura, S. Itoh, H. Zushi, M. Sakamoto, K. Hanada, E. Jotaki, Y. D. Pan[1),
S. Kawasaki, H. Nakashima

Advanced Fusion Research Center, Research Institute for Applied Mechanics,
Kyushu University, Kasuga, Fukuoka, 816-8580 Japan
1) On leave from Southwestern Institute of Physics, 610041, China

e-mail contact of main author: nakamura@triam.kyushu-u.ac.jp

Abstract. Controllability of current profile in long term discharges is studied by two kinds of combinations of wave spectra. First by superposition of higher $N_{//}$-spectrum wave at 2.45 GHz on a target plasma driven by lower one at 8.2 GHz, a hollow j(r) has been achieved and sustained for 20 sec. The current profile can be well controlled below a threshold power of 14 kW by varying the power of 2.45 GHz. A spontaneous transition phenomenon to a peaked j(r), however, has occurred over the threshold power even after a reasonable steady state condition has been obtained. Second using two opposite travelling waves at 8.2 GHz the total current is clearly reduced and the j(r) becomes peaked when the backward travelling LHWs (BW) are superposed at low power of 20 kW. When the BW power is increased above 27 kW, further current reduction is suppressed, and then above 34 kW the direction of the current driven by BW is completely reversed and the j(r) becomes broad. Thus, current modification by BW shows a highly nonlinear behavior with respect to the BW power.

1. Introduction

Realization of a hollow current density profile is one of the most interesting issues for the confinement improvement in relation with the negative shear mode. In a fusion reactor it is required that such profile is sustained in steady state. In TRIAM-1M, proof-of-principle experiments for steady state tokamak (SST) were successfully completed[1] and steady state maintainability of controlled current density profile has been studied to advance the SST concept[2]. The alteration process of the current profile is considered to be dominated by various time constants such as current skin time τ_{skin} and characteristic current relaxation time $\tau_{L/R}$. It is indispensable to verify the controllability in the long term discharge, whose duration is longer than those time constants.

2. Methods for Current Profile Control

In order to realize a hollow current density profile, two kinds of combination of wave spectra are studied by using one 2.45 GHz and two 8.2 GHz LHCD systems which can launch waves with different parallel refractive indices $N_{//}$. The first experiment has been performed by the superposition of higher $N_{//}$-spectrum at 2.45 GHz on a target plasma driven by lower one at 8.2 GHz (Fig.1). It is expected that the peripheral current density profile will be modified. The second experiment has been carried out by the superposition of two 8.2 GHz LHW's with opposite $N_{//}$-spectra. It is expected that the plasma current will be reduced and the current density profile may be changed since the energy gap is larger in the opposite velocity space.

3. Results on Current Profile Control Experiments

The first experiment has been performed under the condition as follows: B_t = 7 T, $\bar{n}_e$ =1x10^{19} m^{-3}. The RF power of 8.2 GHz is up to 100 kW and that of 2.45 GHz is up to 25 kW. The phase difference $\Delta\Phi$ between the adjacent wave guides of the 8.2 GHz LHW is 90°, which corresponds to the peak parallel refractive index of 1.8 and $\Delta\Phi$ of the 2.45 GHz LHW is $90°$ to $270°$ corresponding to $1.4 < N_{//} < 4.2$. In this experiment, a concave hard X-ray profile corresponding to a hollow j(r) is achieved at t = 5 sec and sustained for 20 sec which is quite long compared with current skin time τ_{skin} of 0.1 sec and characteristic current relaxation time $\tau_{L/R}$ of 0.2 sec (Fig. 2). The current profile can be well controlled below a threshold power of 14 kW by varying the power of 2.45 GHz. A spontaneous transition phenomenon, however, has occurred over the threshold power even after a reasonable steady state condition has been obtained. This transition phenomenon is accompanied by reduction of plasma current, increase in electron density, peaking of current density profile, decrease in MoI line intensity, change in space potential in the scrape-off layer and increase in high energy neutral particle flux at the edge (Fig. 3). The peaking of current density profile is supported by the change in the hard X-ray emission profile as shown in Fig. 4. In order to guarantee the current profile controllability in the SST it is necessary that the origin of the transition threshold is studied and the transition problem is conquered.

The second experiment has been carried out by using two opposite travelling waves at 8.2 GHz and by varying the power ratio of these waves. It is observed that the total current is clearly reduced when the backward travelling LHWs (BW) are superposed at low power of 20 kW (Fig. 5). In this case BW is superposed from 2 to 4 sec. First the current dropped at the very early phase of BW superposition and thereafter it decreases to some level within 0.2 sec depending on the BW power. The toroidal electric field (= L dI/dt) is produced during this transient phase, and then the induced forward current fades out with the electric field. The time constant is determined by $\tau_{L/R}$ of 0.2 sec. The magnetic measurement of Shafranov Λ shows that the current density profile j(r) becomes peaked, which suggests that the backward current is driven in the peripheral region.

With increasing RF power the total current is reduced further, and the reduced value and the relative reduction factor reach -2 kA and -10 %, respectively. When the BW power is increased above 27 kW, further current reduction is suppressed, and then above 34 kW the direction of the current driven by BW is completely reversed; that is, the direction becomes the same as that driven by forward LHW and the total current increases. The magnetic measurement shows that the current profile becomes broad. In the early phase just after BW is superposed the current drops to almost the same value and then it decreases or increases to some level depending on the BW power during the rest of the pulse width. Thus, current modification by BW shows a highly nonlinear behavior with respect to the BW power. The electro-motive-force may be the toroidal electric field produced during the transient phase and it may accelerate the forward high energy electrons if the induced field is above a critical value[3], and enhances the forward current drive efficiency by filling the spectral gap.

4. Summaries

In the superposition experiment of higher $N_{//}$-spectrum to lower one, the current density profile has been changed from peaked to broad one and the broad profile has been sustained in the case of the superposed power lower than a certain value. In the superposition experiment of opposite $N_{//}$-spectrum, the current has been reduced and the current profile has been changed to peaked one in the case of the power smaller than a critical value, and the profile has been sustained for longer than the characteristic current relaxation time.

References

[1] ITOH, S., et al., in Fusion Energy 1996 (Proc. 16th Int. Conf., Montreal, 1996), Vol. 3, IAEA, Vienna (1997) 351-357.
[2] SAKAMOTO, M., et al., Nucl. Fusion, Vol. 40, No. 3Y (2000) 453-459.
[3] ROSENBLUTH, M.N., PUTVINSKI, S.V., Nucl. Fusion, Vol. 37, No. 10 (1997) 1355-1362.

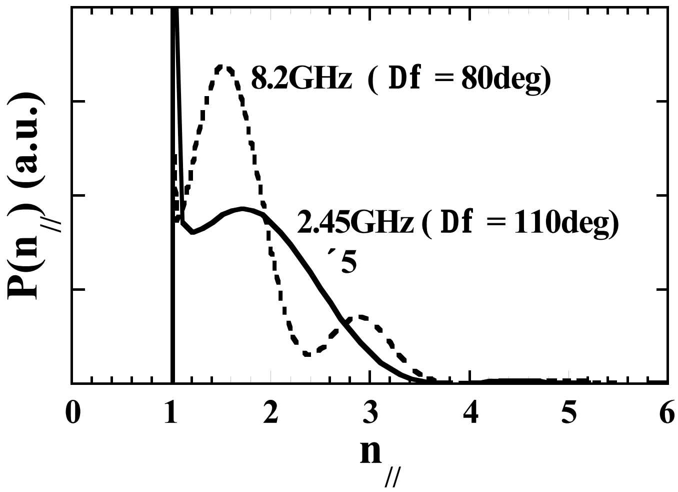

Fig. 1. Power spectra of lower $N_{//}$-spectrum at 8.2 GHz (dotted line) and higher one at 2.45 GHz (solid line).

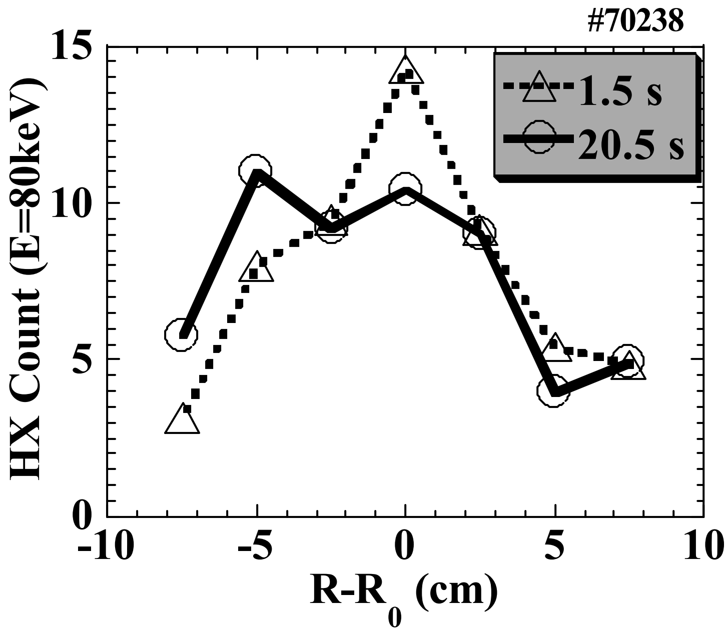

Fig. 2. A concave hard X-ray profile (open circles) is obtained by superposition of low power 2.45 GHz LHW on 8.2 GHz LHCD plasma (open triangles).

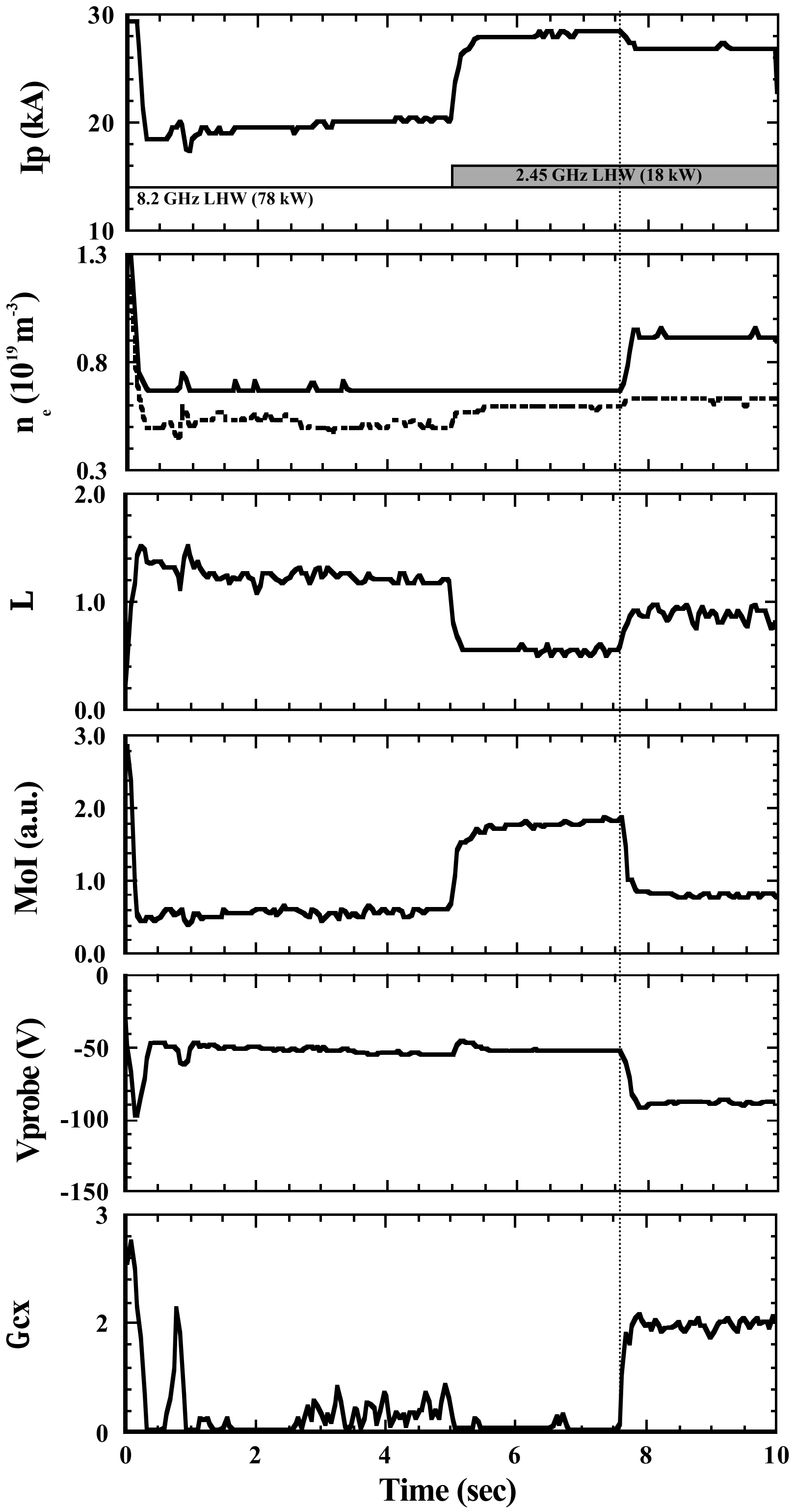

Fig. 3. The time evolution of plasma current, line averaged electron density at r = 0 cm (solid line) and –6 cm (dotted line), Shafranov Λ, MoI line intensity, space potential, and CX neutral flux (E = 2 keV) near the boundary.

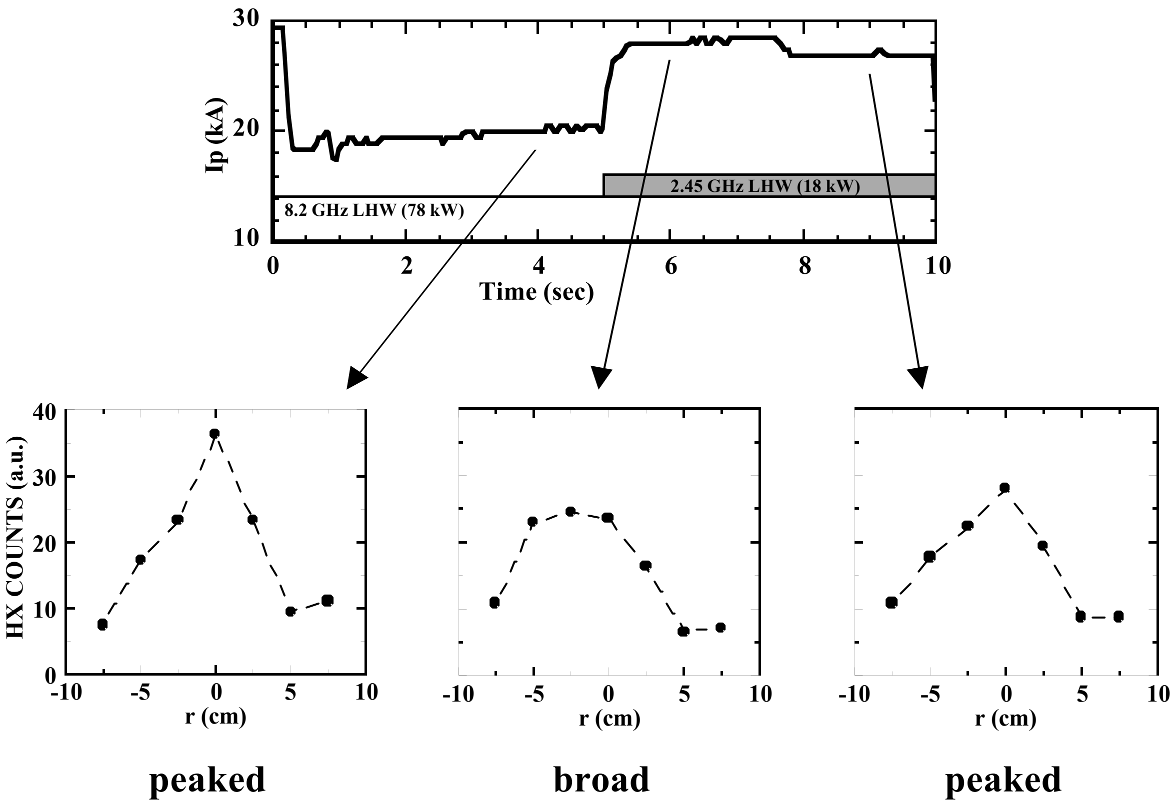

Fig. 4. Hard X-ray (E = 80 keV) emission profile at each phase of plasma current.

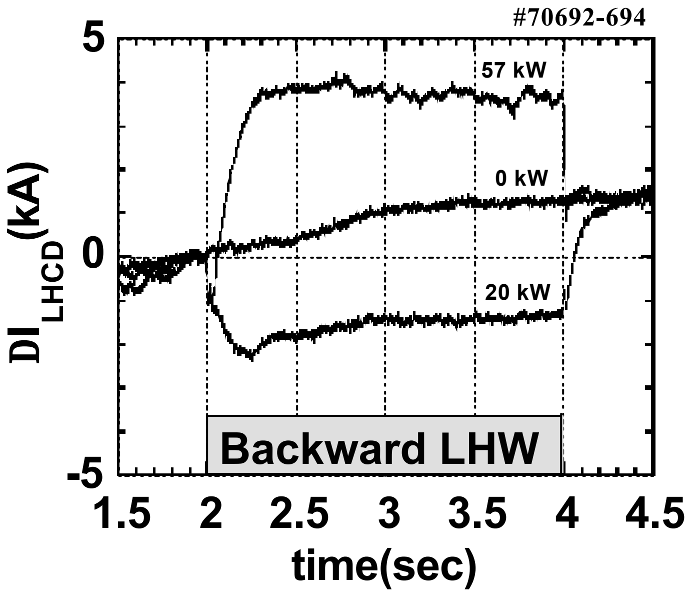

Fig. 5. The relative change in the driven current is shown at various backward LHW power. Forward LHW power is fixed at 85 kW.