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Burn control simulation experiments in JT-60U

K. Shimomura[a,*], H. Takenaga[b], H. Tsutsui[a], H. Mimata[a], S. Tsuji-Iio[a], Y. Miura[b], K. Tani[b], H. Kubo[b], Y. Sakamoto[b], H. Hiratsuka[b], H. Ichige[b], M. Sueoka[b], Y. Kawamata[b], R. Sakamoto[c], S. Kobayashi[d], R. Shimada[a]

[a] *Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo 152-8550, Japan*
[b] *Japan Atomic Energy Agency, 801-1 Mukouyama, Naka, Ibaraki 311-0193, Japan*
[c] *National Institute for Fusion Science, 322-6 Oroshi-cho, Toki, Gifu 509-5292, Japan*
[d] *Institute of Advanced Energy, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan*

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Abstract

Burn control simulation experiments were conducted in non-burning DD plasmas by using a burning plasma simulation scheme in JT-60U. In the burning plasma simulation scheme, two neutral beam (NB) groups were used, where one simulates α-particle heating and the other simulates external heating. The stored energy and the neutron yield rate were controlled at nearly constant values in both ELMy H-mode plasma and reversed shear (RS) plasma with an Internal Transport Barrier. In these plasmas, the NB power for the external heating simulation increased/decreased when the NB power for the α-particle heating simulation decreased/increased. Variation of the NB power for the external heating simulation was larger in the RS plasma than that in the ELMy H-mode plasma, indicating that larger control margin is necessary for the RS plasmas. In order to understand the detailed physical mechanism for the difference between ELMy H-mode and RS plasmas, we conducted numerical analysis using a 1.5-dimensional transport code. This calculation indicates the larger variation experimentally observed in the RS plasma could not be explained by the difference of the thermal diffusivity profiles or its temperature dependence.

Keywords: JT-60U; Burn control; Thermal excursion; Neutral beam injection; Transport analysis

1. Introduction

Burning plasma is in a self-organized state, where plasma pressure and heating power are strongly coupled through α-particle heating. This strong coupling could easily cause a thermal excursion without burn control in a burning plasma. DT burning plasmas will be first achieved in ITER. The mission of ITER is to achieve extended burn in inductively driven plasmas with *Q* (the ratio of fusion power to auxiliary heating power) of at least 10. In order to satisfy this mission, establishment of reliable burn control is indispensable.

The DT fueled fusion plasma research has been performed in JET [1] and TFTR [2] and a fusion power of

* Corresponding author.
E-mail address: shimomura.koji@torus.nr.titech.ac.jp (K. Shimomura).

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16.1 MW has been produced in a DT discharge in JET. In those studies, the heating by α particles has been confirmed. However, the α-particle heating power is too small compared with the auxiliary heating power in these plasmas to investigate the burn control.

In JT-60U, a new approach to the burn control study has been performed, where the coupling is experimentally simulated in non-burning DD plasmas. In order to study the coupling in non-burning plasmas, a burning plasma simulation scheme has been developed [3,4]. In this scheme, the NB heating power proportional to the DD neutron yield rate was applied using a real-time control system for the simulation of α-particle heating. A similar concept has been previously demonstrated using ion cyclotron resonance heating (ICRH) in JET [5–8], which has the advantage of electron heating similar to α-particle heating. However, in JT-60U, ion and electron heating by NB was used due to its high flexibility and capability. Note that isotropic heating by α particles is not simulated in these experiments with RF and/or NB powers. Through this study, we investigate the response and controllability of burning plasmas. In order to interpret the experimental results, numerical analysis using a 1.5-dimensional transport code was carried out based on the effective particle diffusivity and thermal diffusivities for ion and electron channels experimentally estimated from the particle and power balance analyses.

2. Burning plasma simulation scheme

In the burning plasma simulation scheme, 11 NB units were divided into two groups for (A) α-particle heating simulation and for (B) external heating simulation as shown in Fig. 1. The injected NB power was about 2.2 MW/unit (not being absorbed power). The number of injected NB units for group A (U^{α}_{NB}) was controlled proportionally to the measured DD neutron yield rate (S_n) using a real-time control system as follows:

$$U^{\alpha}_{NB} = G S_n, \quad (1)$$

where G is the proportional gain. The heating power is changed stepwise in this scheme. Large G values mean high confinement effectively, because high power α-particle heating corresponds to large plasma stored energy. In this scheme, the dependence of DT fusion

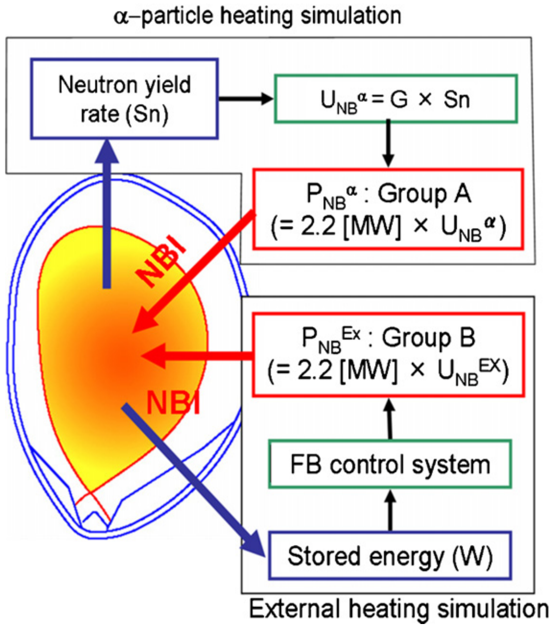

Fig. 1. Schematic drawing for a burning plasma simulation scheme in JT-60U.

reaction rate on the ion temperature and DT density ratio was not considered. Only the coupling of the plasma pressure and the heating power was simulated. Since the beam–thermal neutron yield gives a large contribution to the total DD neutron yield, the coupling becomes stronger than that in the real DT burning plasma, where thermal–thermal neutron yield is dominant. Furthermore, the heating profile and velocity distribution of α particles affecting the ratio of electron heating to ion heating, slowing down process and confinement of α particles cannot be simulated. By applying only group A (NB), we could make a simulated thermal excursion [3]. The zero-dimensional calculation for particle and power balance showed that the runaway increase of the NB power for the α-particle heating simulation triggered by rising G well reproduces a thermal excursion triggered by improved confinement [4].

On the other hand, the number of injected NB units for group B (U^{EX}_{NB}) was determined with a feedback (FB) control system against the stored energy (W) according to the following equation:

$$U^{EX}_{NB} = \frac{G_p \Delta W(t) + G_d\{\Delta W(t) - \Delta W(t-\Delta t)\}}{\Delta t}, \quad (2)$$