§3. Search for the Feedback Control Method of the Heating Power during the Access to the Thermally Unstable Ignition in FFHR

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Access to a thermally unstable high density and low temperature ignition regime in FFHR reactor with 15.7 m and a=2.5m has been studied [1]. New operation scenario to access the high-density ignition has been proposed using NBI with 1.5 MeV [2]. In such operation, NBI with 50 MW is used during the low-density phase less than 2-3x10^{20} m^{-3} where NBI can penetrate into the half minor radius for effective heating, and then alpha heating takes over above the density. In the previous study, NBI heating power was preprogrammed, and only fueling was feedback controlled to stabilize the unstable operation. In this report, we demonstrate that feedback control method of the heating power was discovered for ignition access, which is based on the characteristics of ignition regime.

For feedback control of the external heating power in the thermally stable low-density and high temperature operation, the density limit scaling (Sudo density limit) depending on the heating power can be used. The external heating power depending on the density, alpha heating and loss powers is applied for the density limit to exceed the operation density. The operating point exists near T axis on POPCON (n-T diagram) in this case. On the other hand, the operating point of thermally unstable regime exists near the n-axis on POPCON. These two operating points are inverse function each other on POPCON. Thus by analogy of the feedback control in in thermally stable low-density and high temperature operation, the temperature limit may provide the feedback control method in thermally unstable high-density and low temperature operation. As the temperature limit scaling has not been obtained experimentally so far, we postulate such relation similar to the density limit. Thus the external heating power for feedback control depends on the temperature, and alpha heating and loss powers.

In Fig. 1 is shown the temporal evolution of high-density operation in FFHR with the R=15.7m, a_{eff}=2.5m and B_o=4.5 T. The fusion power of P_f=3.0 GW, the confinement factor over ISS95 scaling of γ_{ISS}=1.43 (γ_{LHD}=0.9), $\tau_p{}^*/\tau_E$=3, $\tau_\alpha{}^*/\tau_E$=4, and alpha heating efficiency of η_α=98 % have been used. The density profile is assumed to be peaked with α_n=3 and the temperature profile parabolic. The heating power of 30 MW was initially applied, and feedback controlled after 20 s, and then reduced to zero after 60 s automatically, leading to ignition. During the heating phase, the fusion power is preset to lower the density for NBI penetration over the half minor radius (Fig.1-(c)).

In Fig.2 is shown the operating path on POPCON corresponding to Fig. 1. It can be clearly seen that the operating point passes over the saddle point, and approaches the ignition boundary. There the heating power is switched off automatically and fusion power is increased with the density to reach the low temperature and high-density thermally unstable regime by alpha heating power.

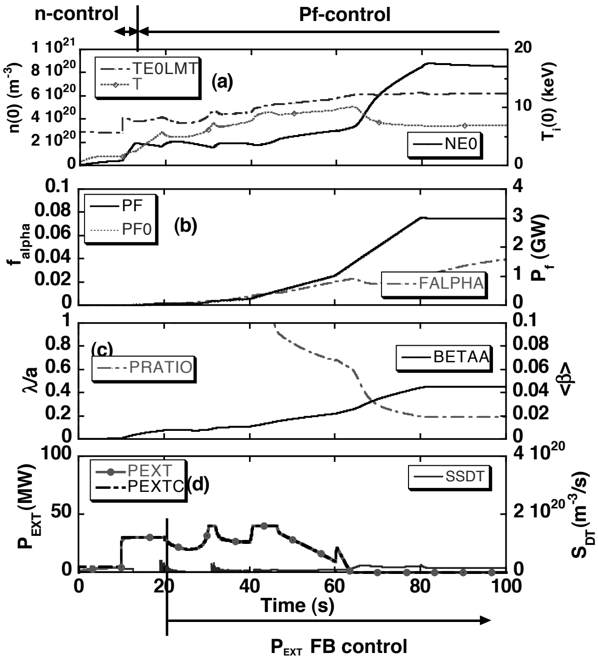

Fig. 1. Temporal evolution of the plasma parameters in FFHR with 15.7 m. (a) Peak temperature, peak density, assumed temperature limit, (b) alpha ash fraction, fusion power and its set value, (c) NBI penetration ratio to the minor radius, beta value, and (d) D-T fueling rate and the with feedback controlled heating power after 20s.

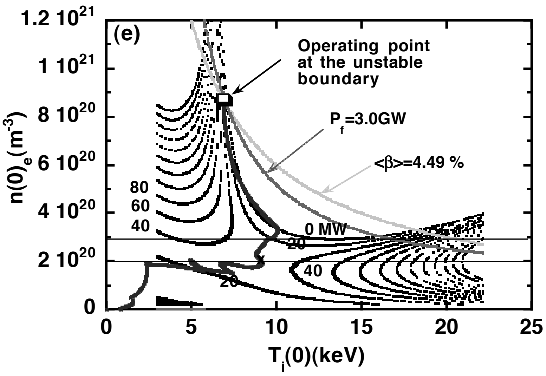

Fig. 2. The operation path to the unstable ignition point on POPCON corresponding to Fig. 1-(a) using the feedback controlled heating power.

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1) O. Mitarai, A. Sagara, et al., Plasma and Fusion Research, Rapid Communication, Vol.2 (2007) 021-1-3
2) O. Mitarai, A. Sagara, et al.,"The high density ignition in FFHR helical reactor by neutral beam injection (NBI) heating " IAEA-FEC-FTP/P6-19 (2010, Daejon)