§4. Ignition Study on the Compact FFHR Helical Reactor

Mitarai, O. (Tokai Univ., Kumamoto Campus),
Oda, A. (Yatsushiro National College of Technology),
Sagara, A., Sakamoto, R., Imagawa, S., Goto, T.,
Yanagi, N.

FFHR reactor has been designed in the range of the large major radius of 14~16 m for two operation regimes such as thermally stable and unstable regimes. In the previous studies, a heating system has been assumed to be ideal, and actual system was not considered yet. Although candidate heating method is NBI, it may only work for the low density and high temperature operation. In this report, we demonstrate that tangentially injected NBI with 1.0~1.5 MeV could be used for the high-density operation within the foreseeable technology contrary to expectation.

In the FFHR with R=15m and a=2.5m, 1.5 MeV NBI with 50 MW can be used for the low-density ignited operation with the density of $2x10^{20}$ m^{-3}. On the other hand, in the high-density operation, 1.5 MeV NBI can penetrate into the half minor radius, which is effective for heating, until the peak density of $2\text{-}3x10^{20}$ m^{-3}. Above this density alpha heating takes over and high-density ignition is reached.

In the compact R=9 m experimental reactor with the low density operation, ignition is achieved by injecting NBI with 1 MeV up to $3x10^{20}$ m^{-3}. No special care is needed.

On the other hand in the high-density operation, 1 MeV NBI can penetrate into the half minor radius up to ~$4x10^{20}$ m^{-3}. Above this density, alpha heating takes over to reach ignition. In Fig. 1 is shown the temporal evolution of high-density operation in FFHR-C with the R=9m, a_{eff}=1.5m (3.6m/0.6mx2.5), and B_o=7 T. The fusion power of P_f=1.1 GW, the confinement factor over ISS95 scaling of γ_{ISS}=1.40 (γ_{LHD}=0.87), τ_p^*/τ_E=3, τ_α^*/τ_E=4, and alpha heating efficiency of η_α=100 % have been used. The density profile is assumed to be peaked with α_n=3 and the temperature profile parabolic. The heating power of 25 MW was applied, and then reduced to zero by preprogramming, leading to ignition. In the steady state, the neutron wall loading is 1.5 MW/m^2 and the density is 9.2 $x10^{20}$ m^{-3}, $T_i(0)$=7.9 keV, f_α=3 %, <β>=2.3 %, Z_{eff}=1.49 and the divertor heat flux for 10 cm width at the right angle to the magnetic field line is 11 MW/m^2 in the steady state.

In Fig.2 is shown the operating path on POPCON corresponding to Fig. 1. It can be clearly seen that the operating point proceeds to the low temperature and high-density thermally unstable operating regime.

FFHR-C is 2.5 times larger than the present LHD system. In order to avoid engineering risks to step further to 15m machine, we are surveying the possibility of the medium size machine with the major radius of 9 m with ignition capability. As this is a physics experimental reactor, the blanket is placed only at the outboard side, and only neutron and gamma ray shield is placed in the inboard side of the torus. However, the shield thickness is still thin, the helical coils can be damaged by neutrons. Therefore, as shot number could be limited for DT operation, it is uncertain yet whether enough knowledge can be gained in this machine. Thus, it should be further examined whether such type of machine could be constructed or not for ignition experiment without any risk.

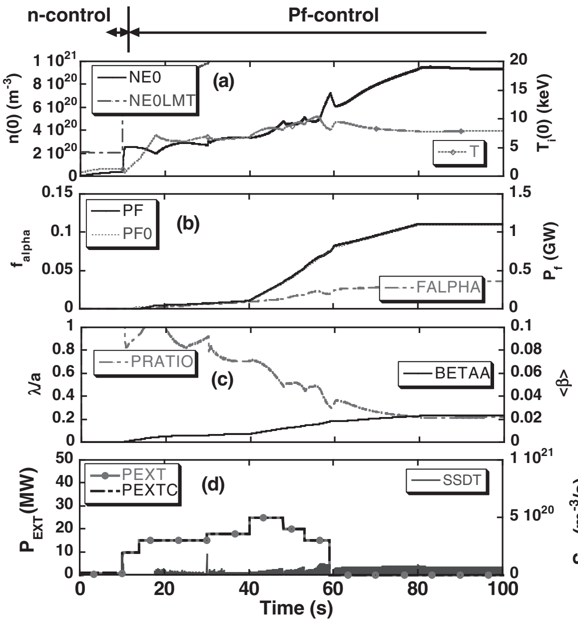

Fig. 1. Temporal evolution of the plasma parameters in FFHR with 9 m. (a) Peak temperature, peak density, density limit, (b) alpha ash fraction, fusion power and its set value, (c) density limit margin, beta value, and (d) D-T fueling rate and the heating power.

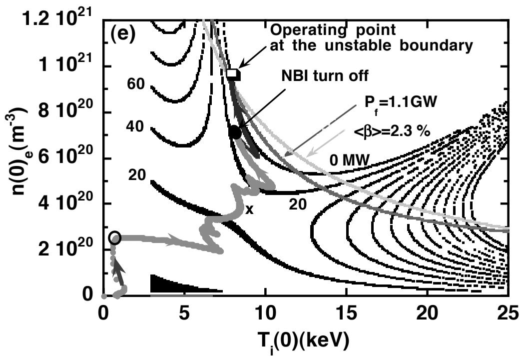

Fig. 2. The operation path to the unstable ignition point on POPCON corresponding to Fig. 1-(a).

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(1) O. Mitarai,A. Sagara, et al.,"Control Algorithm of the Unstable Operating Point in the FFHR Helical Reactor" Fusion Science and Technology **56** (2009) 1495.
(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)