# §17. The High-density and Low Temperature Ignited Operation in the FFHR Helical Reactor

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Recently a high-density plasma up to $1.2\times10^{21}$ $m^{-3}$ has been observed in Large Helical Device (LHD) experiments. From these experimental results, the high-density and low-temperature operation may be a promising scenario to realize a helical reactor. However, in such a situation the ignited operation usually faces thermal instability. So far we have developed ignition scenario using continuous fueling. However, in actual LHD experiments SDC discharge is achieved by the pellet injection. Therefore, the ignition study should be extended to the pellet injected operation. By pellet injected operation, the density and temperature vary. Interesting problem is how much density variation can be tolerated to maintain the ignition at the thermally unstable regime in FFHR.

In the D-T particle balance equation, pellet injection fueling $S_{DTpellet}$ is controlled by PID (proportional-integration-derivative) of the error of the fusion power as

$$Error(P_f) = \left\{ e_{DT}(P_f) + \frac{1}{T_{int}}\int_0^t e_{DT}(P_f)dt + T_d \frac{de_{DT}(P_f)}{dt} \right\} \quad (1)$$

$$\begin{cases} S_{DT}(t) = S_{DTpellet} & for\ Error(P_f) > 0 \\ S_{DT}(t) = 0 & for\ Error(P_f) \le 0 \end{cases} \quad (2)$$

where $T_{int}$ is the integration time, $T_d$ is the derivative time, and the error of the fusion power is $e_{DT}(P_f) = -(1- P_f / P_{fo})$. $P_{fo}$ the fusion power set value and $P_f$ the calculated fusion power. 0-dimensional particle and power balance equations have been used in this study. The alpha ash confinement time ratio of $\tau_\alpha{}^*/\tau_E=3$ and the confinement enhancement factors over the ISS95 scaling $\gamma_{ISS}=1.6$ are assumed. We have used the parameters of the FFHR ($R$=14m, $a$=1.73m, $B_o$=6T, $P_f$=1.9 GW, and the box type density and broad temperature profiles.

The temporal evolutions is shown in Fig. 1 where the pellets with the size of $L_p$=14 mm (corresponding to $S_{DTpell}=1.57\times10^{20}$ $m^{-3}$/(1 pellet train) are injected in FFHR. When the density is increased by pellet injection, the temperature is dropped and the density variation is $\Delta n(0)\sim 2.5\times10^{19}$ $m^{-3}$ ($\Delta n(0)/n(0)\sim2.5$ %). Their density and temperature variations are out of phase due to adiabatic process in a short time.

The operating path corresponding to Fig. 1 is plotted on POPCON in Fig. 2. It can be clearly seen that the operating point proceeds to the thermally unstable operating point at the temperature of $T_i(0)\sim6.4$ keV, the peak density is $n(0)=9.62\times10^{20}$ $m^{-3}$, the volume averaged beta value is $<\beta>\sim$ 2.5 %, the alpha ash fraction is $f_\alpha\sim5.4$ %, and the effective charge is $Z_{eff}\sim1.52$,

When the pellet size is increased to 16 mm, the density variation increases up to $\Delta n(0)/n(0)\sim8$ %, but ignition can be maintained. If the pellet size is further increased to 17 mm, the ignition is terminated, when the density and temperature variation are out of phase.

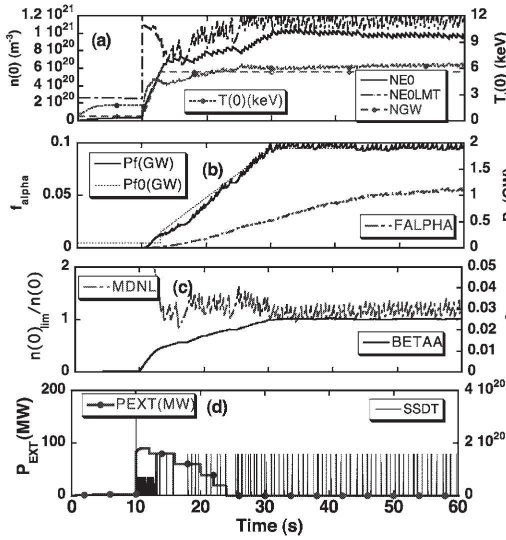


Fig. 1. Temporal evolution of the plasma parameters with 14 mm pellet injection (a) Peak temperature, peak density, density limit, (b) alpha ash fraction, fusion power and its set value, (c) density limit margin, beta value, and (d) D-T pellet fueling rate, and the heating power. $T_d$=0.26 s and $T_{int}$=8 s.

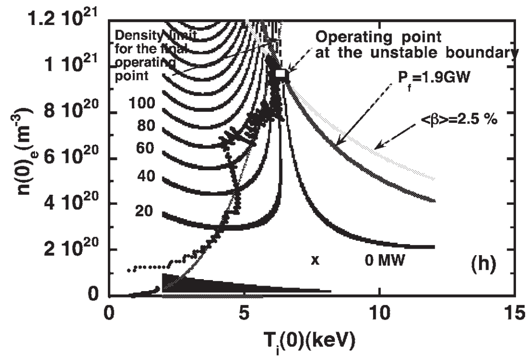


Fig. 2. The operation path to the unstable ignition point on POPCON corresponding to Fig. 1-(a).

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