§3. Study on the Ignition Access by the Heating Power Control during the Pellet Injection Simulation in FFHR

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i) Introduction

As a feedback control method of the heating power during ignition access to the thermally unstable operation point has been invented for FFHR with continuous fueling [1], the effect of discrete fueling on this control algorithm should be studied to simulate pellet injection. In this annual report, we present the characteristics of this feedback control algorithm for the heating power against the various disturbances during steady state phase [2].

ii) Calculated results on disturbance effect

In Fig.1 is shown the temporal evolution of the various plasma parameters in FFHR2m2 with R=15.7 m, a_{eff}=2.5 m, B_o=4.5 T, P_f=3 GW, γ_{ISS95}=1.43, τ_α^*/τ_E=3, and τ_p^*/τ_E=4 for the discrete fueling. The density profile is α_n=3 and the temperature profile is α_T=1. To access the steady state condition at the thermally unstable regime, the following heating power formula with T_c= 7.5 keV, α_{TC}=0.2 and γ_{TLM} =1.2 has been used.

$$P_{EXT}(T_{LIM}) \ge \left\{\frac{\gamma_{TLM} T(0)}{T_c}\right\}^{\frac{1}{\alpha_{TC}}} \frac{\bar{a}^2 R[m]}{B_o[T]} \times 10^6 - \left(P_\alpha - P_B - P_S\right) \qquad (1)$$

As the actual temperature T(0) approaches the temperature limit T_c, the heating power is applied due to the increase in $T(0)/T_c$. In general when the heating power is applied at the thermally unstable point, the temperature goes down. Thus the temperature is kept lower than the temperature limit T_c and then the thermally unstable regime is accessed. In this calculation, after 75 sec, the temperature limit is set to the reduced value of T_c=5.5 keV for easy application of the heating power to cope with the sudden confinement change and impurity influx.

(a)When the confinement factor is reduced

When the confinement factor is suddenly reduced to γ_{ISS95}=1.3 s at 120 s, the temperature ratio $T(0)/T_c$ is increased and the density is decreased, and then the heating power is automatically applied as shown in Fig.1-(e). When the confinement factor is reset at 130 s again to the previous value, the temperature ratio is decreased and the heating power is switched off. During this smaller confinement factor phase, the fusion power is kept almost constant except for the initial short phase.

The operating path during ignition access and during disturbance is also shown on the POPCON in Fig.1-(f).

(b) When the impurity fraction is increased

When the impurity fraction is increased from 0.75 % to 1.4 % at 110 s, the temperature is increased and the density is decreased due to narrowing the ignition regime. As $T(0)/T_c$ is increased, the heating power is applied. When the impurity fraction is decreased, the temperature is decreased, and the heating power is decreased, returning to the ignition.

It is thus found that the feedback control algorithm for the heating power based on the artificial temperature limit works properly when the parameters change suddenly.

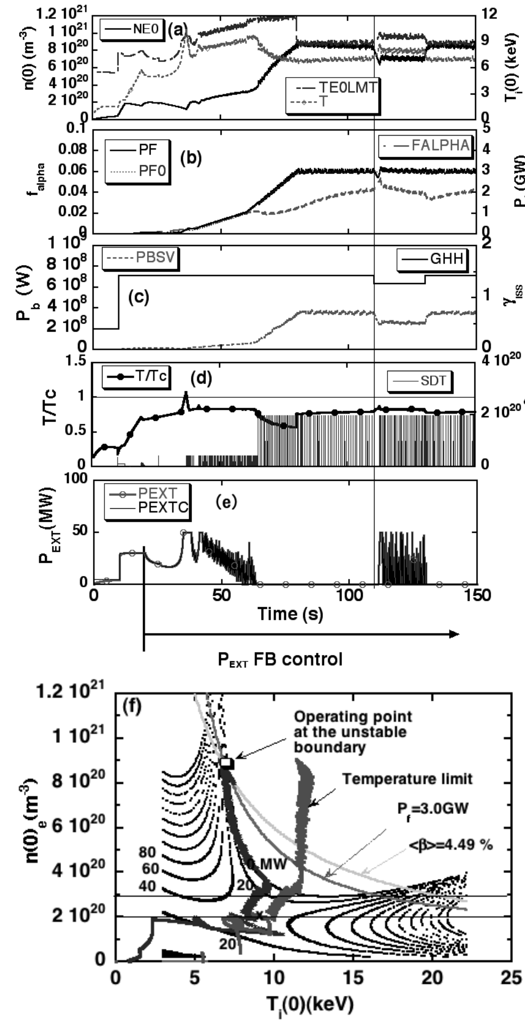

Fig.1. Temporal evolution of the plasma parameters for discrete fueling with the time step of Δt=20 ms. (a) Peak temperature T, temperature limit TE0LMT and peak density NE0, (b) alpha ash fraction FALPHA, fusion power PF and its set value PF0, (c) total bremsstrahlung power PBSV, the confinement factor GHH and (d) D-T pellet fueling rate SDT, and the temperature ratio $T(0)/T_c$, (e) the heating power $P_{EXT} \le$50MW, and (f) the operation path on POPCON

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[1] O. Mitarai, et al., Fusion Engineering and Design, 88 (2013) 1046–1049

[2] O. Mitarai, et al.," Control concept for the high density and low temperature ignition in the FFHR helical reactor", in Chapter 4 in Fusion Energy and Power: Applications, Technologies and Challenges, (2015) Nova publication