§1. Sub-ignition Controlled by Pellet Injection in FFHR

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In LHD experiments, the high density over 0.5×10^{20} m^{-3} can only be achieved by repetitive pellet injections. Therefore, it is important to develop the pellet fueling control algorithm for regulating the fusion power through the electron density in FFHR helical reactor. In general, the plasma parameters, such as the fusion power, oscillate by repetitive pellet injections. This oscillation must be reduced as small as possible. In this study, we demonstrate the fusion power evolution without oscillation by repetitive pellet injections.

As the clear L to H transition has not been observed in LHD experiments, we have used the alternative control algorithm for the heating power based on the density limit scaling[(3)]. The heating power is applied so as to keep the density limit over the operating density. We have also assumed the confinement factor of $\gamma_H = 1.6$ over the ISS95 scaling.

Hence, the heating power is given by

$$P_{EXT}(DL)\,[W] = \left(\frac{\gamma_{DL0}\gamma_{pr} n(0)\,[m^{-3}]}{0.25\times10^{20}}\right)^2 \frac{R\,a^2}{B_o[T]} \times10^6 - (P_\alpha - P_B - P_S)$$

where γ_{DL0} is the set value of the density limit factor (= 1.1), γ_{pr} is the profile factor (= 2/3 for the parabolic density profile), n(0) is the peak density, B_o is the magnetic field strength, P_α is the total alpha heating power density, P_B is the total bremsstrahlung loss, and P_S is the total synchrotron radiation loss.

The repetitive pellet pulses are simulated by the pulse train of the square waves based on the time step of the calculation, which is controlled by the proportional (P) error signal of the fusion power. When the error signal of $e_{DT}=\{1-P_f/P_{fo}\}$ is negative ($P_f > P_{fo}$), the pulse train is turned off to decrease the fusion power. In this study, both the gas puffing and the pellet injection are used and controlled by the same error signal of the fusion power to reduce the fusion power oscillations. On the other hand, gas puffing is regulated by PI-control with the delay time of 20 sec.

The temporal evolution of plasma parameters during the sub-ignition access is shown in Fig. 1 for B_o= 10 T, γ_H = 1.6 and every 1 sec repetitive pellet injections. The preprogrammed heating power of 40 MW is initially applied. When the density reaches 2×10^{20} m^{-3}, the repetitive pellets are injected. The fusion power increases linearly with pellet injection ("Pellet") and gas puffing ("SSDTL"), and 1 GW is obtained without oscillations. The temperature is around ~11 keV and the density reaches 5×10^{20} m^{-3}, which are both oscillating with small amplitude. The average and oscillating component of the heating power are to keep the density limit factor of 1.1 and to suppress the fusion power oscillation, respectively. The maximum heating power is taken as 120 MW.

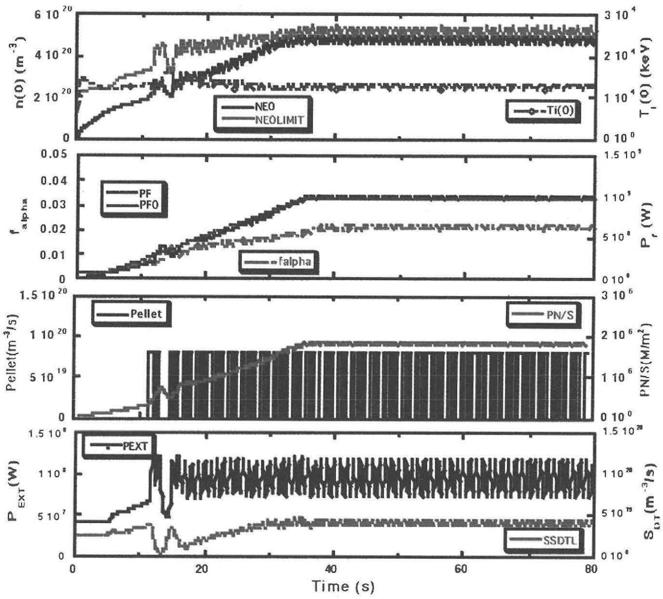

Fig. 1　ＦＦＨＲのペレット入射制御によるサブイグニッション接近

Fig. 1　Temporal evolution of plasma parameters during the sub-ignition access with pellet fueling feedback control in FFHR.

Table 1.　Machine and plasma parameters for the compact size of FFHR.

Major radius:	R = 10 m
Minor radius:	a = 1.0 m
Magnetic field:	B_o= 10 T
Fusion power:	P_f = 1 GW
Maximum external heating power:	P_{EXT} = 120 MW
Enhancement factor over ISS95 scaling :	γ_H = 1.6
Neutron wall loading:	Γ_n = 1.8 MW/m^2
Alpha particle density fraction:	f_α= 2.1 %
Oxgyn impurity fraction:	f_O = 0.5 %
Effective charge:	Z_{eff} = 1.32
Alpha confinement time ratio:	τ_α^*/τ_E = 3
Temperature ratio:	T_i/T_e = 1
Fuel ratio:	n_D/n_T = 1
Alpha particle heating efficiency:	η_α = 0.7
Wall reflectivity:	R_{eff} = 0.9
Hole fraction:	f_H = 0.1
Density profile:	α_n = 1.0
Temperature profile:	α_T = 1.0

References

(1) R.Sakamoto, et al., Nucl. Fusion, 41 (2001) 381.
(2) S. Sudo, et al., Nucl. Fusion, 30 (1990) 11.