§2. Feedback Control of Ignition Access in FFHR

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The feedback control algorithm developed for ignition access in ITER[1] has been applied to FFHR. Here, the heating power is controlled by the H-mode power threshold to keep the H-mode and the fueling rate is controlled by the fusion power to keep it at the desired values.

An external heating power $P_{EXT}(HL)$ to keep an H-mode is given by after rewriting the H-mode power threshold observed in Wenderstein 7-AS as,

$$P_{EXT}(HL)\,[W]=M_{HL0}A_{HL}(t)10^{6}\,\bar{n}[10^{20}m^{-3}]\,B_t[T]\,S_o[m^2] - (\bar{P}_\alpha - \bar{P}_b - \bar{P}_s)\,V_o \quad (1)$$

where M_{HL0} is the set value of H-mode indicator, $\bar{n}$ is the line averaged density, B_t is the magnetic field strength, $\bar{P}_\alpha$ is the alpha heating power density, $\bar{P}_b$ is the bremsstrahlung loss per unit volume, $\bar{P}_s$ is the synchrotron radiation loss per unit volume, V_o is the plasma volume and S_o is the plasma volume.

The temporal evolution of plasma parameters during the ignition access is shown in Fig. 1 for B_o= 10 T, γ_H = 2.5 with hysteresis effect. When the preprogrammed heating power of 70 MW is initially applied, the temperature quickly increases up to 30 keV. After the feedback control is switched on at 10 sec, the heating power gradually decreases and reaches almost zero at 40 sec. The H-mode indicator M_{HL} is initially high and then kept at the set value of M_{HL0} =1.05 by reducing the heating power. Fueling feedback control is switched on at 5 sec, and then the electron density linearly increases to satisfy the desired fusion power and reaches 3.2×10^{20} m^{-3}. To take the hysteresis effect into account, the initial coefficient of the H-mode power threshold of A_{HL} = 0.024 is assumed to start decreasing at 10 sec, and kept constant at A_{HLE} = 0.012 after 40 sec. As the density limit indicator M_{DL} is always larger than 1, the density is within the limit. The alpha ash fraction reaches 6.0 %, the beta value up to ~1.8 %, and the neutron wall loading up to 1.8 MW/m^2. If the hysteresis effect is stronger as A_{HLE} = 0.01, the heating power is completely reduced to zero. Ignition is thus found to be sensitive to the hysteresis effect in FFHR.

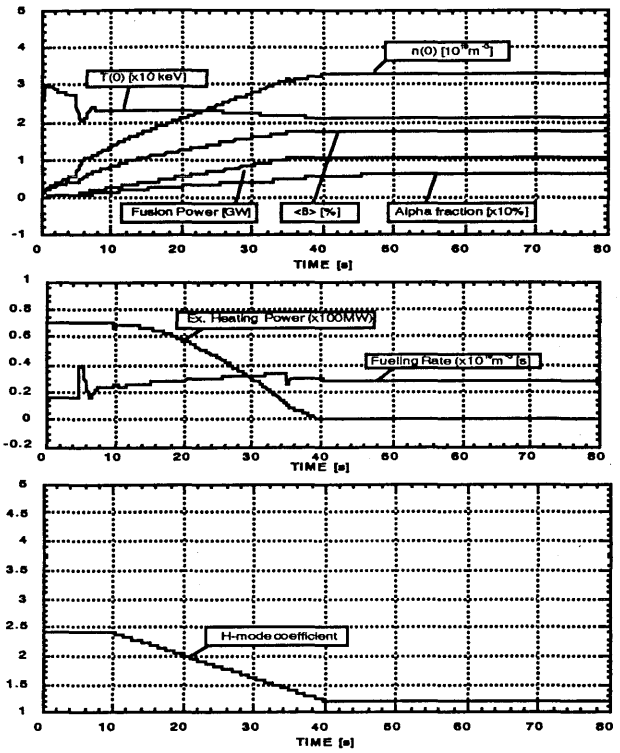

Fig. 1 Temporal evolution of plasma parameters during the ignition access phase with a feedback control in FFHR. The time variable hysteresis is expressed by A_{HLS} = 0.024 and A_{HLE} = 0.012.

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

Major radius:	R = 10 m
Minor radius:	$\bar{a}$ = 1.0 m
Magnetic field:	B_o= 10 T
Fusion power:	P_f = 1 GW
Maximum external heating power:	P_{EXT} = 100 MW
Enhancement factor over LHD scaling :	γ_H = 2.5
Neutron wall loading:	Γ_n = 1.8 MW/m^2
Alpha particle density fraction:	f_α = 6 %
Oxgyn impurity fraction:	f_O = 0.5 %
Effective charge:	Z_{eff} = 1.4
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) O. Mitarai and K. Muraoka. "Ignition burn control and diagnostics in ITER", International Summer School of the Plasma Physics, (Varenna, Italy, Sep. 4- 12, 1997), Diagnostics for International Thermonuclear Experimental Reactor, Plenum Press (1998, December) 93.