§2. Minimization of the Heating Power during the Fusion Power Rise-up in FFHR

Mitarai, O. (Kyushu Tokai Univ.),
Oda, A. (Yatsushiro National College of Technology),
Sagara, A., Imagawa, S., Watanabe, T., Watanabe, K.,
Motojima, O.

Minimization of the external heating power to access self-ignition is advantageous to increase the reactor design flexibility and to reduce the capital and operating costs of the plasma heating device in a helical reactor. In this work we have found that a larger density limit leads to a smaller value of the required confinement enhancement factor, lower density limit margin reduces the external heating power, and over 300 s of the fusion power rise-up time makes it possible to reach a minimized heating power.

Figure 1 shows the temporal evolution of plasma parameters of FFHR2m with R=14 m, $\bar{a}$ =1.73 m, B_o= 6 T, P_f=1.9 GW, γ_{SUDO}=1.5, γ_{ISS}=1.92 (γ_{LHD}= 1.2) and the helium ash confinement time ratio of $\tau_\alpha*/\tau_E$=3. As the density limit margin is reduced from the value at 29.9s (just before the fusion power rise-up phase) to 1.1 at t=100 s (DLM in Fig. 1-(c)), the external heating power is initially dropped and then increased from the preprogrammed value of 70 MW to 100 MW after the feedback control of the fusion power is switched on at 30 s to adjust it to the preset fusion power. The external heating power is automatically switched off at 100 s, showing self-ignition. The peak density at the steady state is 2.67x10^{20} m^{-3}, the density limit is 27% over the operation density, the ion temperature is 15.8 keV, and the average neutron wall loading is 1.5 MW/m^2. Volume averaged beta value is 3 %.

In the following, the density limit margin is also set to 1.1 at t=100 s. When the fusion power rise-up time is further extended to 300 sec as shown in Fig. 2, where the initial pre-programming power is further reduced to 25 MW, the external heating power is further reduced to 30 MW. In this case, the density limit margin still plays a role to determine the external heating power, because the maximum heating power takes place within 100 s. dW/dt is 3~10 MW during the fusion power rise-up phase.

To separate the density limit margin effect and the dW/dt effect on the heating power, the density limit margin was set to be time constant at 1.1 from t=29.0 s before and during the fusion power rise-up phase. The temporal evolution of the discharge for τ_{rise}=45 s (actual rise time is $\Delta\tau_{rise}$=45-30=15 s) and $P_{EXT\text{-}pre}$=25 MW shows that the heating power becomes the maximum of P_{EXT}=82 MW and the time derivative of the plasma energy is dW/dt=62 MW at t=31.45s, which is the main part of the heating power during the DLM=1.1. This case clearly demonstrates the dW/dt effect on the heating power.

We have thus studied how to reduce the external heating power in a helical reactor. From a different point of view, this reduction means that when the larger external heating power such as 100 MW or more is prepared, any fusion power rise-up time from short to long rise-up time can be achievable. It may provide the flexibility of the machine operation in a helical reactor, because of the short rise-up time for checking the plasma operation without waiting for the long time, and the long rise-up time to reduce the thermal stress in a blanket etc. This type of the flexibility may not be expected in a tokamak reactor because such a shorter fusion power rise-up time is limited in a transformer operation, and the non-inductive current drive operation is possible only at a very long fusion power rise-up time.

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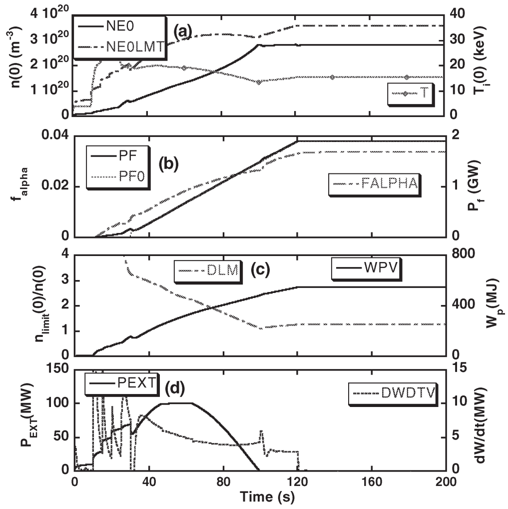

Fig. 1 Temporal evolution of plasma parameters in FFHR2m with the large pre-programming power of $P_{EXT\text{-}pre}$=70 MW and τ_{rise}=120 sec. (a) The peak ion temperature T, the peak density NE0, the density limit NE0LMT, (b) the alpha ash fraction FALPHA, the fusion power PF, its set value PF0, (c) the density limit margin DLM (=NE0LMT/NE0), the plasma energy WPV, and (d) the external heating power PEXT and the time derivative of the plasma energy DWDTV.

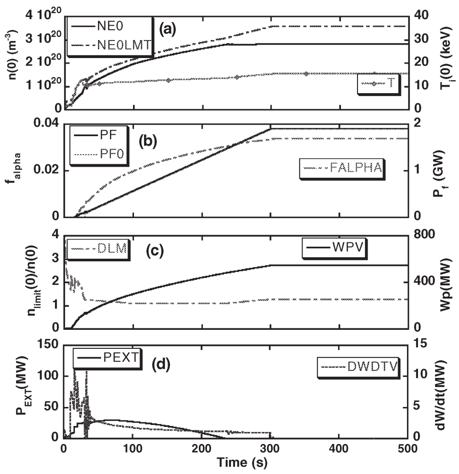

Fig. 2 Temporal evolution of plasma parameters with the pre-programming power of $P_{EXT\text{-}pre}$=25 MW and τ_{rise}=300 sec.