§13. Gyro-Bohm-Based Extrapolation of Radial Profiles in LHD to a Reactor Condition

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A reliable method to extrapolate measured radial profiles to a reactor condition has been proposed. This method assumes a gyro-Bohm type relation [1] between the local electron pressure, $p_e(\rho)$, and the local electron density, $n_e(\rho)$, as below,

$$p_e(\rho) \propto a^{2.4} R^{0.6} B^{0.8} P_H^{0.4} n_e(\rho)^{0.6}, \quad (1)$$

where a, R, B, and P_H are the averaged plasma minor radius, the major radius of magnetic axis, the magnetic field strength on the magnetic axis, and the total heating power, respectively (a, R, and B are those in vacuum). Here, the temperature and the density of ions are assumed to be identical to those of electrons. This model basically assumes that R/a, n_e, and the plasma beta, $\beta \propto n_e T_e / B^2$, are fixed. Then, the local electron temperature, $T_e(\rho)$ should increase with B^2, when B is increased. According to this assumption together with Eq. (1), the P_H should be also increased with B^3. If B is 10 T in a reactor condition, for instance, $T_e(\rho)$ there will be $(10/2.64)^2 \sim 14$ times higher than that observed in LHD with 2.64 T.

Two examples of extrapolation are shown in Fig. 1, where time slices of a standard internal diffusion barrier (IDB) plasma of R = 3.75 m and an inward-shifted IDB plasma of R = 3.60 m are used. Once $n_e(\rho)$ and $T_e(\rho)$ are given, one can estimate the fusion reaction occurring in the plasma. In Fig. 1(d), radial profiles of the alpha heating power per volume, $P_\alpha'(\rho)$, generated by DT fusion reaction are shown, where $n_D/n_T = 1$ and $Z_{eff} = 1$ are assumed. The total heating power is evaluated integrating $P_\alpha'(\rho) - P_B'(\rho)$, where $P_B'(\rho)$ is the Bremsstrahrung loss per volume, with the plasma volume, V_p, using $dV_p/d\rho$ of the best equilibrium calculated by the VMEC code for the given β profile. In Fig. 1, it is assumed that R is increased to 15 m in the reactor. Then, the V_p is increased to ~1600 m^3 from ~25 m^3 in LHD (Fig. 1(e)). The total heating power is ~900 MW in the standard IDB and is higher than ~400 MW in the inward-shifted IDB (Fig. 1(f)). The high central density in the standard IDB plasma is preferable in the reactor. The P_H needed to achieve the plasma is also shown in Fig. 1(f). In the case of standard IDB, the alpha heating is enough ($P_\alpha - P_B > P_H$) and therefore a smaller R is acceptable, while it is not enough ($P_\alpha - P_B < P_H$) and a larger R is necessary for the case of inward-shifted IDB.

Using this method, one can estimate the devise size of reactor needed to achieve the self-ignition condition of $P_\alpha - P_B > P_H$ for a given B. Examples of the relation between R and B are shown in Fig. 2. In the future experiment, it will be important to obtain the profile data to minimize R and B in the self-ignited reactor given by this method.

1) Miyazawa, J. et al.: Plasma Fusion Res., *to be printed*.

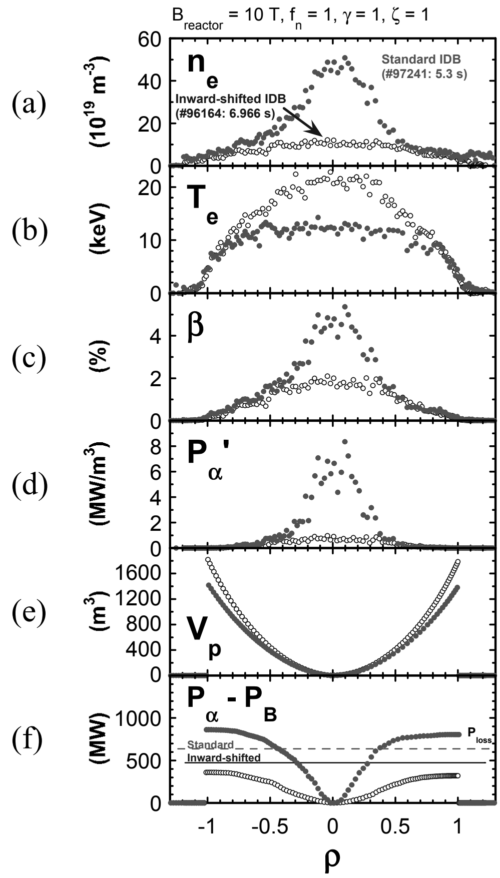

Fig. 1. Examples of radial profiles extrapolated from LHD to a reactor of R = 15 m and B = 10 T, where (a) the electron density, (b) the electron temperature, (c) the plasma beta, (d) the alpha heating power per volume, (e) the plasma volume inside the ρ, and (f) the heating power $P_\alpha - P_B$ passing through the magnetic flux surface at ρ together with the extrapolated total heating power of P_H (straight lines) are shown from top to bottom. The aspect ratio, the plasma density, and the plasma beta are fixed ($f_{R/a} = f_n = f_\beta = 1$). No confinement improvement ($\gamma = 1$), no direct loss of alpha particles ($\eta = 1$), $n_D/n_T = 1$ and $Z_{eff} = 1$ are also assumed.

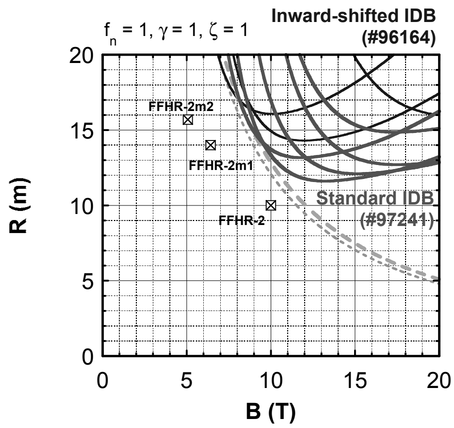

Fig. 2. The plasma major radius in the fusion reactor needed for self-ignition as a function of the magnetic field strength on the magnetic axis.