§9. Pellet Fueling Requirements to Allow Self-burning on Helical Type Fusion Reactor

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Pellet refueling conditions to sustain self-burning plasma has been investigated by extrapolating confinement property of the LHD plasma which appear to be governed by gyro-Bohm type confinement property. A power balance of burning plasma is calculated taking into account the profile change with the pellet deposition and subsequent density relaxation. Self-burning plasma is achieved within the scope of conventional pellet injection technology. However, very small burn-up rate as 0.18 % is predicted.

A power-balance analysis has been performed according to the following conditions. (1) Only pellet injection is considered for the fueling and a particle deposition profile is estimated using a conventional neutral gas shielding (NGS) model. (2) Density profile relaxation process after the pellet fueling is calculated by assuming particle transport coefficients which are extrapolated from the LHD experiment. (3) Temperature profile change is calculated by using the direct profile extrapolation (DPE) method1) in which the normalized plasma pressure profile obtained from the LHD experiment is directly extrapolated into a burning plasma by assuming gyro-Bohm type parameter dependence.

To characterize the particle transport property of the pellet fueled high density plasmas in LHD, density profile changes were fitted into one-dimensional diffusion equation with cylindrical approximation,

$$\frac{\partial n}{\partial t} = D\frac{\partial^2 n}{\partial r^2} + \left(\frac{D}{r} + \frac{\partial D}{\partial r} - V\right)\frac{\partial n}{\partial r} - \left(\frac{V}{r} + \frac{\partial V}{\partial r}\right)n + S, \quad (1)$$

where n, r and S denote the plasma density, minor radius and particle source profile, respectively. It is assumed that the particle flux is consist of diffusion term; D and convection term; V. In regard to a thermal transport property, pressure profile which is typically observed in LHD experiment is directly extrapolated to burning plasma condition assuming the gyro-Bohm type thermal transport property, namely, following relationship is formed between LHD plasma (subfix exp) and burning plasma (subfix bp).

$$p_{\mathrm{nor}}(\rho) = \frac{p_{\mathrm{exp}}(\rho)}{P_{\mathrm{exp}}^{0.4} n_{\mathrm{exp}}(\rho)^{0.6} B_{\mathrm{exp}}^{0.8}} = \frac{p_{\mathrm{bp}}(\rho)}{P_{\mathrm{bp}}^{0.4} n_{\mathrm{bp}}(\rho)^{0.6} B_{\mathrm{bp}}^{0.8}} \quad (2)$$

where p^{nor} is normalized pressure profile. p, P and B denote pressure profile, heating power and field strength. Temperature profile change can be expressed as follows in consideration of an energy confinement time τ_{E},

$$\frac{\partial T}{\partial t} = \frac{1}{\tau_{\mathrm{E}}}\left(\left(\frac{P_{\mathrm{bp}}}{n}\right)^{0.4} B_{\mathrm{bp}}^{0.8} p_{\mathrm{nor}} - T\right). \quad (3)$$

Long duration sustainability of pellet fueled burning plasmas have been investigated taking into account the above mentioned plasma confinement properties. Figure shows waveforms of typical plasma parameters and fusion output in the case of 7.1 mm pellet injection at a velocity of 1.2 km/s. Though there is a fluctuation of the fusion output due to a drastic profile change by pellet fueling in the initial phase, quasi steady-state burning plasma is sustained after termination of auxiliary heating if the pellet injection interval is shorter than 75 ms. The minimum fusion output to sustain self-burning quasi steady-state plasma is about 3.1 GW and the fusion output at the quasi steady-state phase increases as the injection interval shortens. The fusion output fluctuation due to pellet refueling is ±34 MW and this value is sufficiently small as compared with the averaged fusion output of 3.1 GW. On the other hand, self-burning plasma sustainment cannot be achieved with the longer pellet injection interval above 80 ms. The fusion output gradually declines after termination of auxiliary heating and the plasma finally collapse due to losing a heat balance. In order to sustain a self-burning plasma, adequately short pellet injection interval is required and minimum required DT particles are 1.2×10^{24} DT particles per second in the case of 7.1 mm pellet injection at 1.2 km/s. These parameters can be accomplished within the scope of present-day technology. Since a net DT fuel consumption rate at 3.1 GW fusion output is 2.2×10^{21} /s, a burn-up ratio which is defined by fusion reacted particle to injected fuel particles is only 0.18 %.

1) Miyazawa J. *et al* 2011 *Fusion Eng. Design* **86** 2879