§17. ICRF Sustained LHD Type Proton-Boron Reaction

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The drastically improved performance for the plasma heating by the ion cyclotron range of frequency (ICRF) is shown in the Large Helical Device (LHD) experiments in 1999. It is observed that the high energy ion-tail extends to 300keV and that the electron temperature is raised with the electron-drag relaxation process of the directly heated protons. It is also found that protons are heated to the order of $1MeV$ and that they are well confined, through the numerical computations of particle orbits under the ICRF heating of LHD. Stimulated by these results, we have studied p-^{11}B fusion reaction in a ICRF heated plasma confined in the same magnetic configuration to LHD.

The p-^{11}B reaction,

$$\mathrm{p} + ^{11}\mathrm{B} \rightarrow 3\,^{4}\mathrm{He} + Q_{\mathrm{F}}, \quad (Q_{\mathrm{F}} \simeq 8.7\mathrm{MeV}), \qquad (1)$$

has the advantages as follows:

- Only few neutrons are produced by side reactions at low energy level ($\leq$ 1MeV). So it is not need to consider the neutron wall loading, the severe radiation damage and the radioactivity in structural materials. The blanket is not also needed.
- A large amount of hydrogen and boron are ubiquitous on the earth.

The possibility of the p-^{11}B fusion reactor has been investigated several authors. It is pointed out that the economical p-^{11}B reactor would be unlikely since the bremsstrahlung power loss exceeds the fusion output power. In such investigations, protons are injected as the neutral beam into the reactor in which the boron plasma is sustained in a steady state. As a basis for the study, we consider an ICRF sustained p-^{11}B reaction shown in Fig. 1 for the simplest energy flow analysis. The output power from the fusion plasma is converted into the electric power with an efficiency η_{PP}. Since a part of the electric power is needed for the RF oscillator, we can get the net output power (=P_{NET}) reduced to

$$P_{\mathrm{NET}} = \eta_{\mathrm{PP}}(P_{\mathrm{RF}} + P_{\mathrm{F}}) - \frac{P_{\mathrm{RF}}}{\eta_{\mathrm{RF}}} > 0.$$

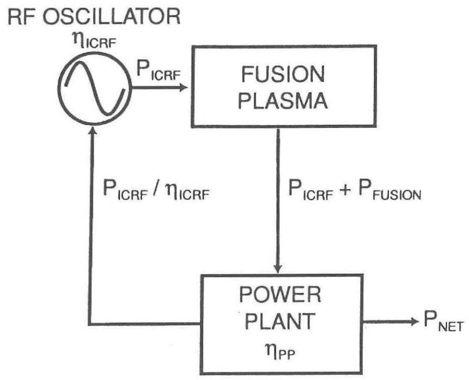

Fig. 1: Simplest model of energy flow in the ICRF sustained p-^{11}B fusion reaction.

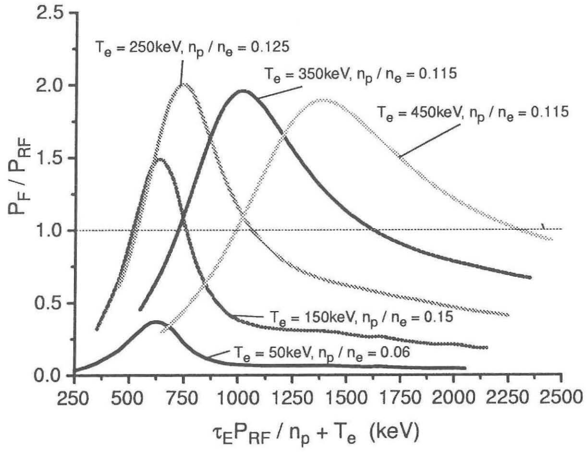

Fig. 2: Relationship between $P_{\mathrm{F}}/P_{\mathrm{RF}}$, τ_{E}, and T_{e}. $n_{\mathrm{p}}/n_{\mathrm{e}}$ is set to the optimal value for the maximum $P_{\mathrm{F}}/P_{\mathrm{RF}}$. The line of $P_{\mathrm{F}}/P_{\mathrm{RF}} = 1$ is shown for reference.

From this relation, it is found that the ICRF sustained p-^{11}B reactor needs

$$P_{\mathrm{F}}/P_{\mathrm{RF}} > \frac{1 - \eta_{\mathrm{PP}}\,\eta_{\mathrm{RF}}}{\eta_{\mathrm{PP}}\,\eta_{\mathrm{RF}}} \simeq 1.22 \text{ (for } \eta_{\mathrm{PP}} \simeq 0.5).$$

We use the simplest one proton model to evaluate amplification factor $P_{\mathrm{F}}/P_{\mathrm{RF}}$ of the ICRF sustained p-^{11}B reaction. Protons are heated by ICRF under the electron-drag. Figure 2 shows the relationship between $P_{\mathrm{F}}/P_{\mathrm{RF}}$, P_{RF}, τ_{E} (electron-drag time), and T_{e}. This figure shows that the optimal ICRF power for the $P_{\mathrm{F}}/P_{\mathrm{RF}}$ value ($\simeq 2$) is nearly equal to $0.32MW/m^3$ when $n_e = 5 \times 10^{20} m^{-3}$, $n_p = n_e/8$ and $T_e = 250keV$.

We have also proposed an active peripheral potential control method and an active ^{4}He ash exhaust scheme with ICRF.