# §1. Design Integration towards Size-Optimization of LHD-type Fusion Energy Reactor FFHR

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On optimizing the reactor size of FFHR, one of main issues is the structural compatibility between blanket and divertor configurations. In particular, as shown for FFHR2m1 in Fig.1, the blanket space at the inboard side is still insufficient due to the interference between the first walls and the ergodic layers surrounding the last closed flux surface.

From the point of view of α-heating efficiency over 0.95, the importance of the ergodic layers has been found by collision-less orbits simulation of 3.52MeV alpha particles [1]. Therefore, the reactor size is increased as shown in Fig.1 and Table1, and the design is improved as FFHR2m2, in which the helical pitch parameter $\gamma$=1.20 is selected with inward shifted magnetic axis as shown in Fig.2. In this case, it is found that there is the optimum major radius of plasma around 16 m with a central toroidal field of about 5 T by taking into account the neutron wall loading kept below 2MW/m$^2$, cost analyses based on the ITER (2003) design and engineering feasibility on large scaled magnets. The magnetic stored energy is reduced by selecting the location of poloidal coils as shown in Fig.2, then it is about three times as large as ITER but the maximum magnetic field and mechanical stress can be comparable.

For continuously wound large superconducting magnet systems under the maximum nuclear heating of 200W/m$^3$, cable-in conduit conductor (CICC) of current 90 kA with $Nb_3Al$ are proposed with quench protection candidates and with a robust design of LHD-type cryogenic support posts. In this concept, react and wind method is preferred to use conventional insulator and to prevent huge thermal stress. The maximum length of a cooling path is about 500 m [2].

The blanket designs have been improved to obtain the total TBR over 1.05 for the standard design of Flibe + Be/JLF-1 and long-life design of Spectral-shifter and Tritium Breeding (STB) blanket with the blanket cover rate over 90%, which is effectively possible by a new proposal of Discrete Pumping with Semi-closed Shield (DPSS) concept [1] and is very important not only to increase the total TBR over 1.2 but also to reduce the radiation effects on magnets [3].

For the new ignition regime in a super dense core (SDC) plasma found in LHD, a new proportional - integration - derivative (PID) control of the pellet fueling can handle the thermally unstable plasma at high and low temperature operation, which is generally advantageous to reduce the divertor heat flux due to an enhanced radiation loss rate as shown in Table1.

[1] A. Sagara et al., Fusion Eng. Des., 83 (2008) 1690-1695.
[2] S. Imagawa et al., Nucl. Fusion 49 (2009) 075017.
[3] T. Tanaka et al., Nucl. Fusion 48 (2008) 035005.

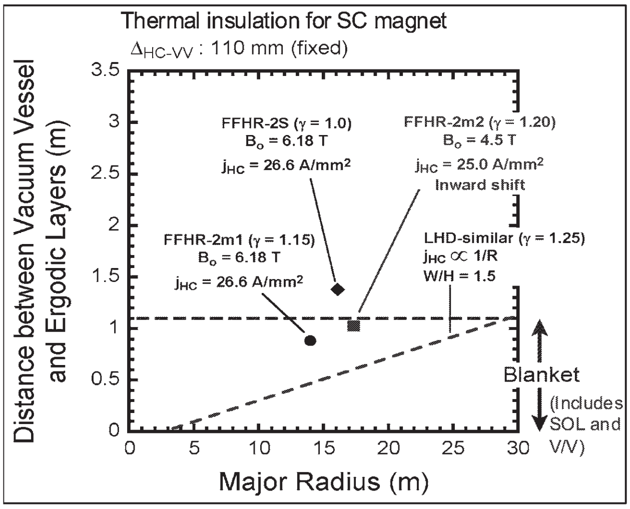


Fig.1 Rc dependence of blanket space

Table 1 FFHR design parameters

| Design parameters | | | LHD | FFHR2 | FFHR2m1 | FFHR2m2 | SDC |
|---|---|---|---|---|---|---|---|
| Polarity | l | | 2 | 2 | 2 | 2 | |
| Field periods | m | | 10 | 10 | 10 | 10 | |
| Coil pitch parameter | $\gamma$ | | 1.25 | 1.15 | 1.15 | 1.20 | |
| Coil major Radius | $R_c$ | m | 3.9 | 10 | 14.0 | 17.3 | |
| Coil minor radius | $a_c$ | m | 0.98 | 2.3 | 3.22 | 4.16 | |
| Plasma major radius | $R_p$ | m | 3.75 | 10 | 14.0 | 16.0 | |
| Plasma radius | $\langle a_p \rangle$ | m | 0.61 | 1.24 | 1.73 | 2.35 | |
| Plasma volume | Vp | $m^3$ | 30 | 303 | 827 | 1744 | |
| Blanket space | Δ | m | 0.12 | 0.7 | 1.1 | 1.05 | |
| Magnetic field | $B_0$ | T | 4 | 10 | 6.18 | 4.84 | |
| Max. field on coils | $B_{max}$ | T | 9.2 | 14.8 | 13.3 | 11.9 | |
| Coil current density | j | $MA/m^2$ | 53 | 25 | 26.6 | 26 | |
| Magnetic energy | | GJ | 1.64 | 147 | 133 | | |
| Fusion power | $P_F$ | GW | | 1 | 1.9 | 3 | |
| Neutron wall load | $\Gamma_n$ | $MW/m^2$ | | 1.5 | 1.5 | 1.5 | |
| External heating pow | $P_{ext}$ | MW | | 70 | 80 | 43 | 100 |
| α heating efficiency | $\eta_\alpha$ | | | 0.7 | 0.9 | 0.9 | 0.9 |
| Density lim. improvement | | | | 1 | 1.5 | 1.5 | 7.5 |
| H factor of ISS95 | | | | 2.40 | 1.92 | 1.92 | 1.60 |
| Effective ion charge | $Z_{eff}$ | | | 1.40 | 1.34 | 1.48 | 1.55 |
| Electron density | $n_e(0)$ | 10^19 $m^{-3}$ | | 27.4 | 26.7 | 17.9 | 83.0 |
| Temperature | $T_i(0)$ | keV | | 21 | 15.8 | 18 | 6.33 |
| Plasma beta | $\langle\beta\rangle$ | % | | 1.6 | 3.0 | 4.40 | 3.35 |
| Plasma conduction lo | $P_L$ | MW | | | 290 | 453 | 115 |
| Diverter heat load | $\Gamma_{div}$ | $MW/m^2$ | | | 1.6 | 2.3 | 0.6 |
| Total capital cost | | G$(2003) | | 4.6 | 5.6 | 7.0 | |
| COE | | mill/kWh | | 155 | 106 | 93 | |

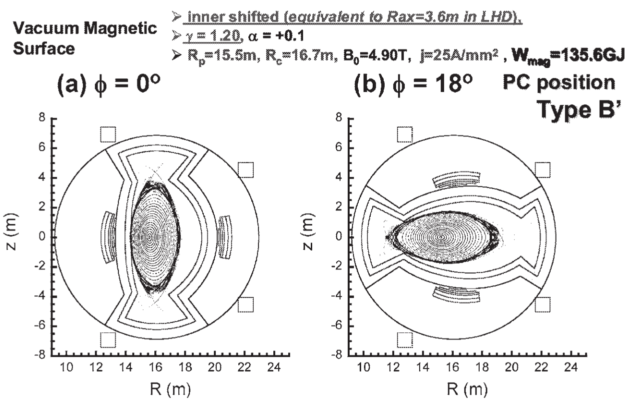


Fig.2 Poloidal cross sections of magnetic surface and blanket with HC and PC magnets.