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Conceptual Design Study of an Advenaced Divertor, Short Super-X Divertor
原型炉における先進ダイバータshort super-X divertorの概念設計研究

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A short super-X divertor is proposed as a new option for fusion divertor, which can be incorporated in a similar size of conventional divertor cassette, and the field line length from the divertor null to the outer target is largely increased (two times). Physics and engineering design studies have progressed. Minimal number of the divertor coils were installed inside the toroidal field coil, i.e. interlink-winding (interlink). Arrangement of the poloidal field coils and their currents were determined, taking into account of the engineering design such as vacuum vessel and the neutron shield structures, and maintenance scenario of the divertor. Divertor plasma simulation showed that large radiation region is produced between the super-X null and the target, and the plasma temperature becomes low (1 eV) both at the inner and outer divertors, i.e. fully detached plasma was obtained efficiently.

1. Introduction

Magnetic configurations of advanced divertor were recently proposed in order to handle large exhausted power for the tokamak reactor, and two concepts of “super-X divertor (SXD)” and “snowflake divertor (SFD)” were proposed, which have advantages to increase both the field line length in the divertor and magnetic flux expansion in the divertor. The radiation power and detachment in the divertor expect to be enhanced, comparing to the conventional divertor. SXD and SFD concepts have been investigated [1] for an ITER-size compact Demo reactor of SlimCS (I_p = 16.7 MA, B_t = 6.0 T, R_p = 5.5 m, a_p = 2.1 m, and the fusion power of 3 GW level) [2], as new options of the Demo divertor design. Advanced divertor configurations are produced with reversing one or some of the divertor coil currents to produce another magnetic null or snowflake-null. Interlink coils are necessary to design appropriate coil current (less than I_p) since large divertor coil current such as 100-300 MAT is required for installation outside TFC.

For the application to Demo reactor, we think some disadvantages in SFD: larger interlink-coil currents were necessary, control of the SF-null and plasma shaping is difficult by a few interlink coils, and further open divertor geometry is a disadvantage for particle and impurity retention in the divertor chamber. Proposal of a short SXD has advantages in these viewpoints, and it can be incorporated in a similar size of conventional divertor cassette. For their applications to the fusion reactor, both the plasma performance and engineering design should be investigated.

2. Design Concept of Short Super-X Divertor

Arrangement of 9 PFCs with including two interlink divertor coils and the current distribution

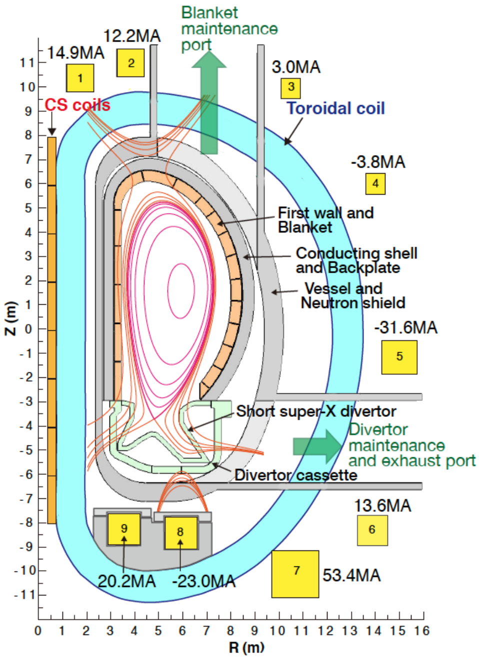

Fig. 1 Arrangement of short SXD and PFCs, where two interlink divertor coils are incorporated. Plasma equilibrium with f_{SX} = 0.99 and current distribution for SlimCS Demo reactor. Structures image of blanket modules, vacuum vessel, neutron shield and maintenance ports are also shown.

were determined by the plasma equilibrium calculation (Fig.1): it takes into account of structures such as divertor cassette, neutron shield (50 cm thick) and vacuum vessel (30 cm thick), maintenance ports for the divertor. Interlink coils (PFC-8 and -9) are designed by Nb_3Al superconductors, based on ITER poloidal coil technology, and they will be inserted between TFCs, winded on the bobbin toroidally, and installed at the bottom. Their currents are minimized to -23 MAT and +20 MAT, respectively, which are slightly larger than the plasma current. The coil size is 1.6 m for 25 MAT, and stress analysis result (lower than 250 MPa) showed lower load ratio (lower then 50%) of allowable stress (500 MPa).

Super-X (SX) null can be controlled in the outer divertor, Fig. 2 (a), by introducing location of the SX null (R_{SX}, Z_{SX}) and a ratio of the poloidal flux at the SX null to that at the separatrix ($f_{SX} = [\psi_{SX}-\psi_{ax}]/[\psi_{sep}-\psi_{ax}]$, where the separatrix extending outboard for $f_{SX} < 1$). The divertor bottom is the same as the SlimCS divertor, and the outer divertor target is shifted to R_{div} = 6.6 m. Figure 2(b) compares the connection length from the divertor null ($L_{//}$) and the flux expansion (f_{exp}) just outer the separatrix as a function of the poloidal length from the divertor null (L_p). For the short SXD, both $L_{//}$ and f_{exp} increase in the divertor, which are particularly enhanced near the SX-null (L_p = 1.4 – 2.0 m) for f_{sx}. = 0.99. Consequently, $L_{//}^{div}$ is 1.75–2.3 times longer than the reference divertor, while increment in $L_{//}^{div}$ for the long-leg divertor [3] is 1.14 times.

3. Plasma and Radiation in Super-X Divertor

Impurity radiation and plasma detachment in the short SXD has been simulated, using SONIC code with Ar impurity seeding, where the input parameters were, the same as the conventional divertor studies for the SlimCS [3]: P_{out} = 500 MW, $n_i = 7\times10^{19}$ m^{-3} at the core-edge boundary of r/a = 0.95, and $\chi_i = \chi_e = 1$ m^{2}s^{-1}, D = 0.3 m^{2}s^{-1}. Calculation mesh for the short SXD is shown in Fig. 3(a). Result for the large radiation fraction of P_{rad}/P_{out} (f_{rad}) = 0.92 was obtained. In the outer divertor, radiation is enhanced near the SX-null, i.e. further upstream of the target, while high temperature plasma is maintained upstream of the large radiative region. It is found that large radiative region is narrow in the poloidal direction due to long fieldline length near the SX-null. Plasma temperatures become low (1 eV) both at the inner and outer divertors. Fully detached plasma is produced, while partially detached divertor was seen in the conventional divertor [3]. Plasma heat and radiation loadings decrease near the separatrix significantly, and surface recombination increases since significant ion flux to the target. Peak heat load is 10 MWm^{-2} at target in full detached divertor.

References

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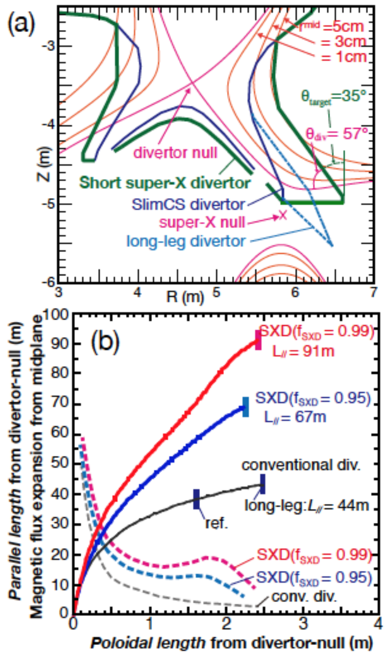

Fig. 2 (a) Plasma equilibriums in the short super-X divertor for f_{SX} = 0.99. (b) Connection length along the field line from the divertor null and flux expansion for f_{SX} = 0.95 and 0.99 as a function of poloidal length.

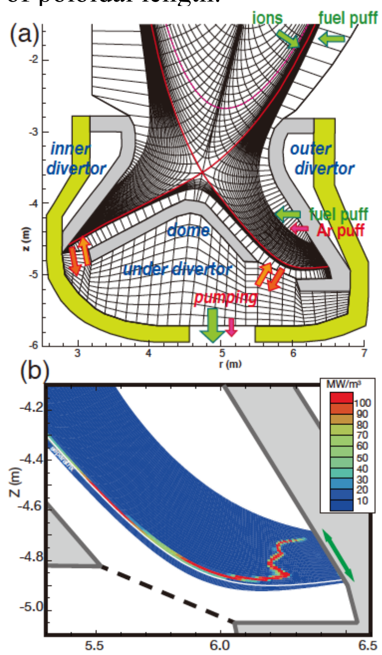

Fig. 3 (a) Divertor geometry and calculation mesh (lower half) for SlimCS short super-X divertor. Locations of Ar impurity and fuel gas injections and exhaust route are shown. (b) Radiation distribution in the short SXD.