(2) Helical Reactor Design

Due to inherent current-less plasma and intrinsic diverter configuration, helical reactors have attractive advantages, such as steady operation and no dangerous current disruption. In particular, in the LHD-type reactor design, the coil pitch parameter γ of continuous helical winding can be adjusted beneficially to reduce the magnetic hoop force (Force Free Helical Reactor: FFHR) while expanding the blanket space.

On the basis of physics and engineering results established in the LHD project, the LHD-type D-T reactors have been studied with collaboration works in wide research areas on fusion science and engineering in the Fusion Research Network in Japan, because there are a lot of common issues to be developed for magnetic fusion energy MFE systems and inertia fusion energy IFE systems. The main purpose is to make clear the key issues required for the core plasma physics and the power plant engineering, by introducing innovative concepts expected to be available in this coming decades.

Reactor design activities on international collaborations are also increasing in many aspects and wide areas of physics and engineering in order to advance the reactor design studies. Results are presented in many international workshops and conferences.

Since 1993, collaboration works have made great progress in design studies, which was started as the Phase-1 for the concept definition prior to the present-day Phase-2 for the concept optimization and the cost estimation. There are two types of reference designs: the large size reactor FFHR-1 (l=3, m=18) with the major radius R of 20m and a reduced size reactor of FFHR-2 (l=2, m=10). The design studies on the compact reactor FFHR2 was reported in the 17th IAEA Conference on Fusion Energy in 1998. Design studies on modified FFHR2m1 and 2m2 in the Phase 2 has been reported in the 20th IAEA in 2004, and improved ignition access, 3D neutronics design in the 21th IAEA in 2006, and magnet system concept, cost evaluation in the 22th IAEA Conference on Fusion Energy in 2008.

These FFHR designs have been studied from both aspects of physics and engineering: MHD equilibrium and stability analysis, alpha-particle confinement analysis, ignition access analysis using the simplest control algorithm, 3-D SC supporting structure analysis, SC magnet system design, advanced blanket and energy transfer system design, and system safety analysis. As for the blanket system, molten-salt Flibe has been selected as a self-cooling tritium breeder from the main reason of inherent safety.

In the series of FFHR-1, 2, 2m1 and 2m2 designs, the coil pitch parameter of continuous helical winding and the major radius R with poloidal coil positions have been optimized to reduce the magnetic stored energy below 150 GJ while expanding the blanket space, and a self-cooled Flibe blanket has been proposed as a long-life blanket under neutron wall loading less than 2 MW/m^2. Recent discovery of the super dense core (SDC) plasma up to 1.1x10^{21}m^{-3} in LHD has led the new operation regime, in which the high-density ignition scenario has been proposed with drastically reducing divertor heat load by newly proposing a thermal instability control method. Large-size superconducting helical coil is shown conceptually feasible. Divertor design, external heating design and unscheduled blanket replacement are engineering key issues.

In this fiscal year, design studies in wide areas of collaboration have been carried out on key issues and important subjects for the system integration of reactor design as follows:

1. Design Integration towards Size-Optimization of LHD-type Fusion Energy Reactor FFHR
2. Ignition study on the compact FFHR helical reactor
3. Design window analysis and Core Plasma Design of a Heliotron Reactor
4. A Conceptual Design of Helical Coils for Heliotron DEMO Plant
5. Design Progress on the High-Temperature Superconducting Coil Option for FFHR
6. Heat Flux Reduction by Helical Divertor Coils in the Heliotron Fusion Energy Reactor
7. Rigidity evaluation method of LHD-type superconducting helical coil
8. FFHR magnetic field configuration by low helical pitch parameter, flat-type helical coils
9. Neutronics investigation for reduction of radiation shield thickness
10. Investigation of feasibility of remountable superconducting magnet for helical reactor
11. Study on standardization for fusion reactor designs and construction of an unified system design code
12. Study on heat transfer mechanism under magnetic field in a liquid blanket
13. Experimental study of counter-current extraction tower for tritium recovery in Flibe blanket of fusion reactor
14. Economic and Environmental Assessment of Helical and Tokamak Reactors
15. Development of hybrid-porous evaporator for FFHR divertor cooling
16. Development of Thermal Analysis Code for Peltier Current Lead

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