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Conceptual Design of a Compact Helical Fusion Reactor FFHR-c1 for the Early Demonstration of a Year-long Electric Power Generation

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Conceptual design of a compact LHD-type helical fusion reactor FFHR-c1 has been conducted. This design focuses on a year-long electric power generation with as small a reactor size as possible by adopting the operation with auxiliary heating and innovative ideas for the design of engineering system. This design ensures the path to helical commercial power plants through the examination of confinement scaling and steady-state operation test of engineering components. Though intensive R&Ds are needed, the innovative ideas provide more options and increase the probability of solving critical issues of fusion reactors: accommodation of high heat and particle load on the divertor, construction and maintenance within a reasonable period.
The candidate design point of FFHR-c1 has been identified using the systems code HELIOSCOPE. A smaller reactor with the same plasma confinement property can be realised by increasing the magnetic field. However, the size reduction is limited by the decrease of the thickness of the neutron shield in the blanket system. In this regard, the adoption of supplementary helical coils can increase the blanket space by $\sim$ 15%. Finally, the design point with the major radius of 10.92 m, the magnetic field on the helical coil winding centre of 7.3 T and the fusion gain $Q \sim 10$, which can achieve positive net electric power with a minimum reactor size, have been selected.
To confirm the feasibility of the core plasma design, integrated physics analysis has been conducted. The magnetic configuration with a high aspect ratio and inward-shifted magnetic axis position was assumed. As a result, $Q \sim 15$ can be achieved within the operation regime that has already been confirmed in the LHD experiment: the Mercier index D_I < 0.3 at the n/m = 1/1 rational surface and the neoclassical energy loss lower than a half of the total absorbed power.
Although there are some issues to be solved (e.g., design of the helical coils with a current density of > 40 A/mm^2, achievement of the peak beta value of $\sim$ 3% with an inward-shifted configuration), this comprehensive study has shown the design feasibility of a compact LHD-type helical reactor that can satisfy the requirements on Japanese fusion DEMO: steady-state electricity generation above several hundred MW, tritium fuel self-sufficiency and practical availability.

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Author: Dr GOTO, Takuya (National Institute for Fusion Science)

Co-authors: Prof. SAGARA, Akio (National Institute for Fusion Science); Dr SUZUKI, Chihiro (National Institute for Fusion Science); Dr TAMURA, Hitoshi (National Institute for Fusion Science); Dr MIYAZAWA, Junichi (National Institute for Fusion Science); Prof. YOKOYAMA, MASAYUKI (National Institute for Fusion Science); Dr NUNAMI, Masanori (National Institute for Fusion Science); Dr YANAGI, Nagato (National Institute for Fusion Science); Dr SEKI, Ryosuke (National Institute for Fusion Science); Prof. SAKAMOTO, Ryuichi (National Institute for Fusion Science); Dr SATAKE, Shinsuke (National Institute for Fusion Science, Japan); Dr TANAKA, Teruya (National Institute for Fusion Science)

Presenter: Dr GOTO, Takuya (National Institute for Fusion Science)

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