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Development of a Real-time Simulation Tool towards Self-consistent Scenario of Plasma Start-up and Sustainment on Helical Fusion Reactor FFHR-d1

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In a heliotron type system like LHD, compatibility between MHD stability and good confinement is recognized as one of the crucial issues. This paper reports the world's first attempt of the close investigation of self-consistent solution of plasma operation scenario in view of MHD stability, anomalous transport, alpha energy loss and impurity effect in addition to MHD equilibrium and neo-classical transport. Using a 1-D calculation model which can reproduce typical pellet discharges of LHD experiment, plasma operation regime of the LHD-type helical reactor FFHR-d1 was examined. It was found that a steady-state, sub-ignition operation with fusion gain Q at least 5 can be attained with the plasma parameters established in the previous study: the same reference profile of gyro-Bohm normalized pressure, magnetic configuration with inward-shifted vacuum magnetic axis position (the ratio between the magnetic axis position and the major radius is 3.5/3.9) and alpha energy loss fraction of 15%. It is the first result to give the operation scenario of FFHR-d1 within the parameter regime that has already been confirmed in LHD experiment: edge electron density below Sudo density limit, Mercier index at the m/n = 1/1 rational surface below 0.25, the energy loss by anomalous transport twice larger than that by neo-classical transport. Operation with further larger fusion gain is achievable by optimization of the plasma and engineering design parameters. Because real time calculations are possible by utilizing the model or scaling established by the detailed analysis codes, systematic analysis of different design parameters can be easily obtained. This study clarified the effect of the plasma and engineering design parameters (e.g., magnetic field configuration and plasma radial profile) on self-consistent plasma operation regime of the helical reactor FFHR-d1. Although further detailed analysis including the effect of boot-strap current, temperature inequality, edge neutral particles and deposition profile of heating power is needed, this study provides the design conditions of the plasma control system and contributes to the plant system design of FFHR-d1. The developed calculation tool can be a base and guidelines of the real-time predictive simulation tool of the core plasma which aids the plasma operation control of future fusion power plants.

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