Development of System Code for a Helical Fusion Reactor

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abstract

A System design code for LHD-type heliotron reactors HELIOSCOPE (Heliotron System Design Code for Reactor Performance Evaluation) is developed and design window analyses are carried out. Design windows of an LHD-type heliotron reactor depends strongly on the geometric configuration of helical and vertical field coils. Thus minimum blanket space at the inboard side of the torus is one of the key design parameters. Refinement of the models for the evaluation of engineering and physics constraints are needed to improve reliability of the analysis.

1. Introduction

- Helical systems inherently have suitable properties as a DEMO and a commercial fusion reactor.
- Optimization of the design point and feedback to plasma experiments and engineering R&Ds are needed.

> - Development of a system design code for helical reactors and design window analyses are needed.

2. Analysis models of the system design code

- As the first step, a system design code for LHD (Large Helical Device [1])-type heliotron reactors, HELIOSCOPE (Heliotron System Design Code for Reactor Performance Evaluation), are developed [2].

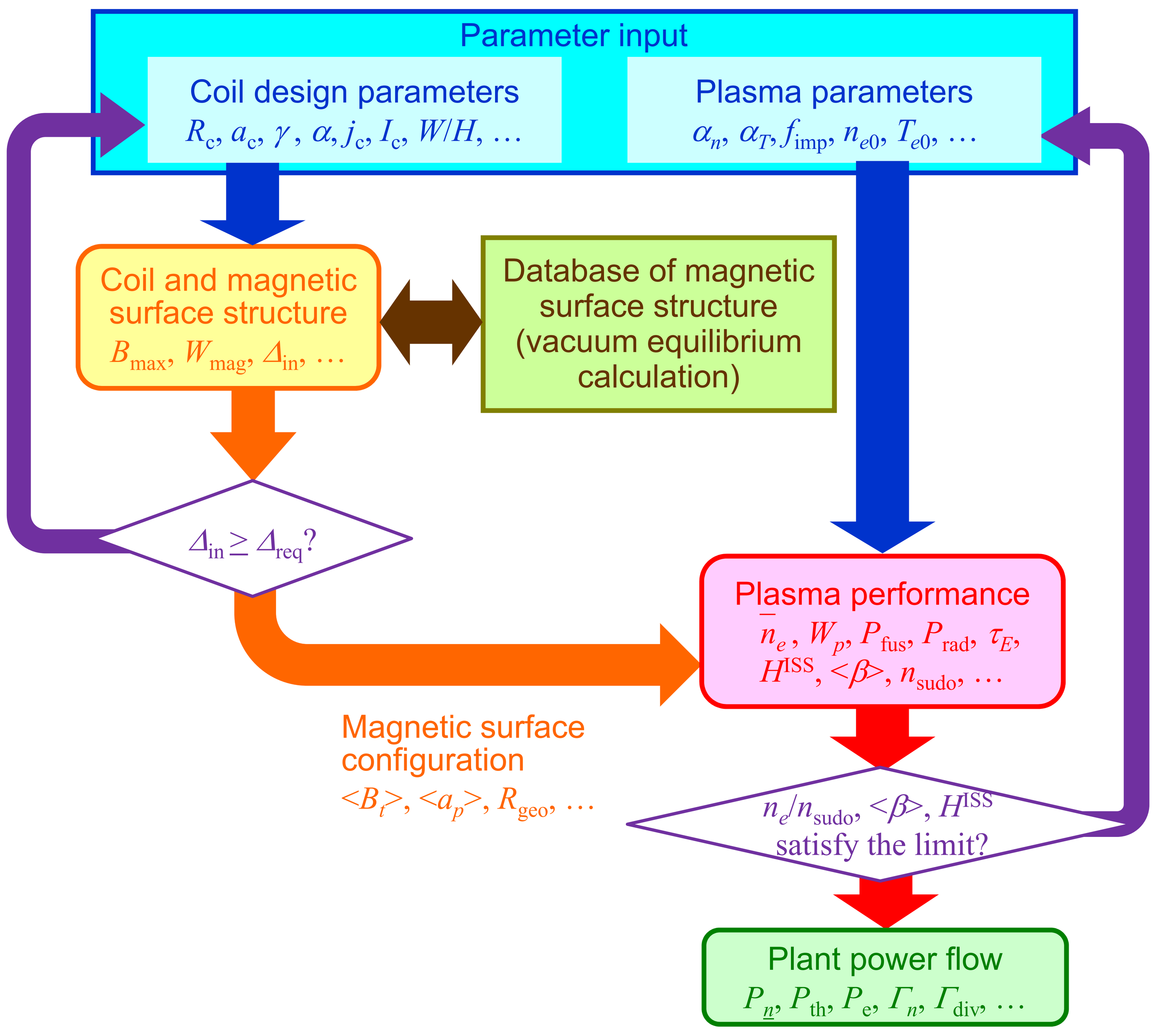

Fig.1 Flowchart of the system design code for heliotron reactors HELIOSCOPE.

- Engineering design by evaluating
  - Maximum magnetic field on helical coil using the scaling law [3] (extension of Yamazaki's scaling[4]):

$$\frac{B_{max}}{\langle B_0 \rangle} = 0.85(1+\alpha)^{-0.117} m^{-0.853} \gamma_c^{0.156} \xi^{0.796} \zeta^{-0.815}$$

  - Stored magnetic energy directly calculated using Neumann's law.

- Plasma performance is evaluated by
  - 0-D power balance model which reflects given density/temperature profiles and the plasma shape base on the vacuum equilibrium:

$$\frac{dW_p}{dt} = -\frac{W_p}{\tau_E} + \eta_\alpha P_\alpha - P_{rad} + P_{aux}$$

  - Sudo density limit [5, 6]:

$$n_{Sudo} = \max\left(0.25\sqrt{\frac{P_{abs}B_{ax}}{a^2 R_{ax}}},\ 0.35\frac{P_{abs}\sqrt{B_{ax}}}{aR_{ax}}\right)$$

  - Confinement property evaluated by ISS (International Stellarator Scaling) [7]:

$$\tau_E^{ISS04v3} = 0.314 f_{ren} a^{2.28} R^{0.64} P^{-0.61} \bar{n}^{0.54} B^{0.84} \iota_{2/3}^{0.41}$$

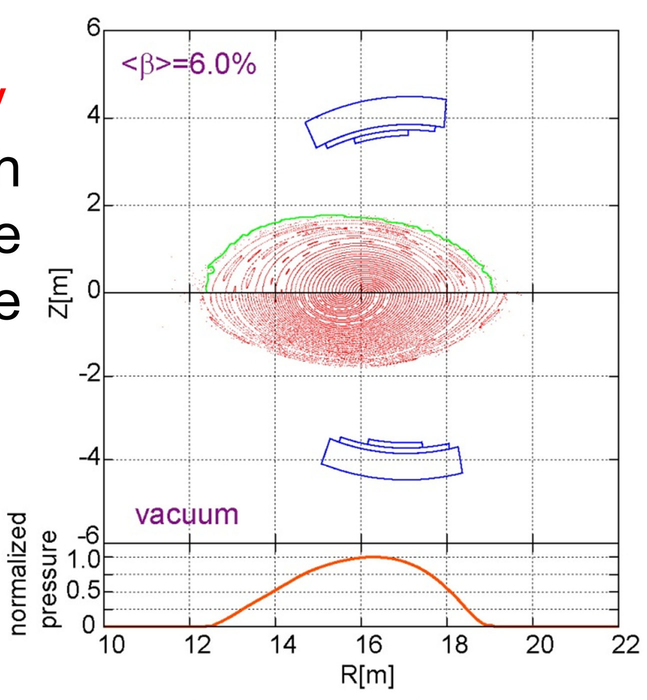

Fig.2: Comparison of the magnetic surface structure in vacuum (lower) and in a high-beta state (6.0% in volume-averaged value) with the adjustment of the vertical field [2].

> - Fast calculation (< 1sec for one parameter set) for the application to parametric scans over a wide design space with a reasonable accuracy can be achieved.

3. Example of a system analysis

- Design windows of an LHD-type heliotron reactor depends strongly on the geometric configuration of the helical and the vertical field coils.

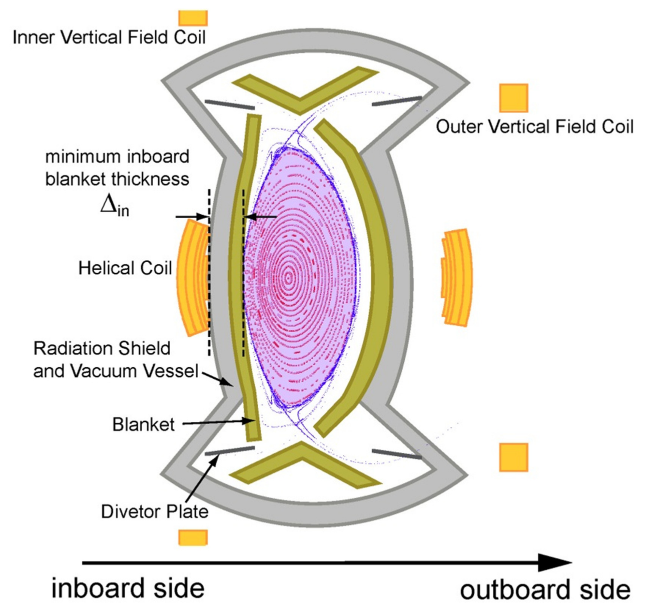

Fig.3: Cross-sectional view of an LHD-type heliotron reactor on the vertically elongated poloidal cross-section.

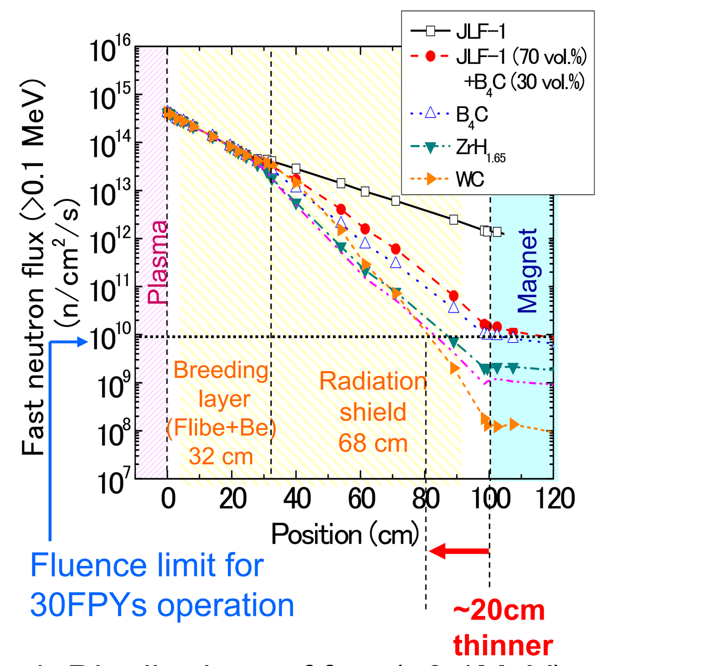

Fig.4: Distributions of fast (>0.1MeV) neutron flux in the FFHR blanket system[8] with different materials composition in radiation shield.

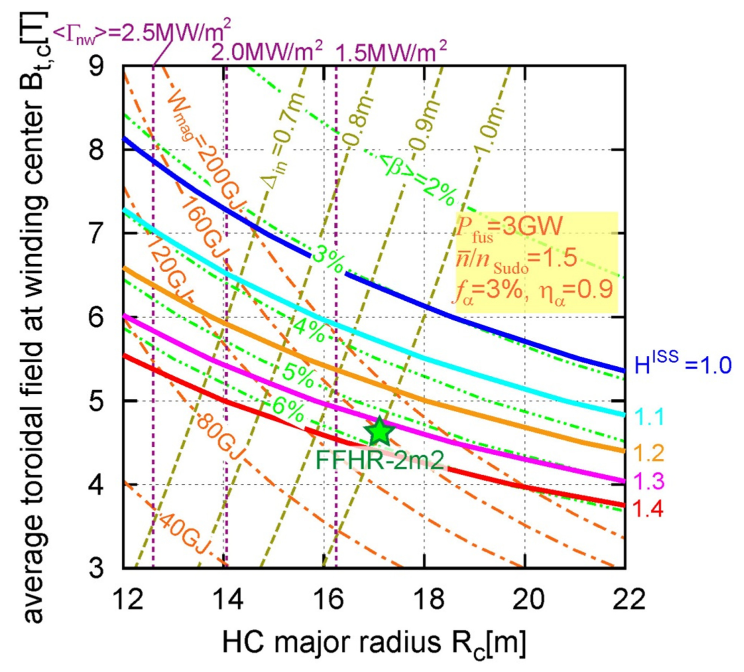

Fig.5: An example of a design window analysis for an LHD-type heliotron reactor with helical pitch parameter of γ_c=1.20 ($\gamma_c = ma_c/(lR_c)$).

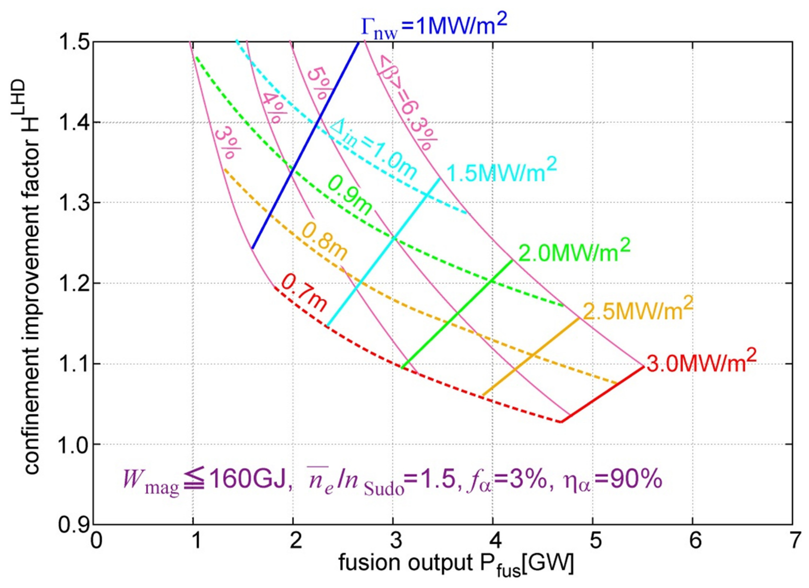

Fig.6: Relation between the fusion output and the required confinement improvement relative to the LHD experimental results with a constant stored magnetic energy.

> - A reduction in the minimum blanket thickness at the inboard side of the torus can moderate both physics and engineering requirements.

4. Summary and future work

- A system design code for LHD-type heliotron reactors is developed and design window analyses are carried out.
- Design windows of an LHD-type heliotron reactor depends strongly on the geometric configuration. Thus the minimum blanket space is one of the key design parameters.
- Refinement of the calculation models by reflecting the latest physics/ engineering models and the result of the detailed configuration optimization studies are planned to improve reliability of the analysis.
- Parametric scans of the model parameters themselves are effective to secure the robustness of the design window.

Acknowledgements

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