Design activity of a flexible stellarator at the National Institute for Fusion Science

H. Yamaguchi

National Institute for Fusion Science, National Institutes of Natural Sciences, Toki-city, Japan

The Graduate University for Advanced Studies, SOKENDAI, Toki-city, Japan

A stellarator is a type of magnetic confinement device for nuclear fusion that uses fully three-dimensional magnetic fields to confine high-temperature plasma without relying on a large plasma current. Designing stellarators with high performance requires computational optimization of magnetic configurations involving multiple physical objectives, as well as engineering feasibility. Conventional optimization typically targets a single plasma condition, such as a fixed beta value (the ratio of plasma pressure to magnetic pressure), and searches for configurations with good stability and transport properties. However, an actual fusion reactor must operate over a wide range of plasma parameters, from low-beta startup to high-beta steady-state operation. Therefore, it is essential to develop optimization frameworks that explicitly account for multiple operational modes and parameter regimes. Such approaches also provide an important basis for the precision design of experimental devices with magnetic flexibility, which is valuable for systematic physics studies and for validating optimization objectives.

We have developed a stellarator optimization framework, OPTHECS, that directly treats coil shapes and currents as design variables. OPTHECS performs a sequence of physics simulations in parallel, including vacuum magnetic field computation based on the Biot–Savart law, field-line tracing, MHD equilibrium calculations, neoclassical transport, and particle orbit analysis, evaluating both plasma performance and coil engineering properties in an integrated manner. Over the past two years, using OPTHECS, we have obtained a new experimental stellarator design concept capable of realizing multiple types of quasi-symmetry, a key physical property for improved plasma confinement in stellarators. Building on this achievement, we are extending OPTHECS to incorporate simultaneous optimization over multiple magnetic configuration modes and plasma beta values, further advancing the capability for comprehensive stellarator design.