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磁場配位最適化ヘリカルコイルの電磁力と機械的挙動

Electromagnetic force and mechanical behavior of a helical coil with optimized magnetic field configuration

田村仁[1,2]、山口裕之[1,2]、後藤拓也[1,2]、柳長門[1,2]、佐竹真介[1,2]、市口勝治[1,2]

TAMURA Hitoshi[1,2], YAMAGUCHI Hiroyuk[1,2], GOTO Takuya[1,2], YANAGI Nagato[1,2], SATAKE Shinsuke[1,2], ICHIGUCHI Katsuj[1,2]

1) 核融合研、2) 総研大

1) NIFS, 2) SOKENDAI

In the conceptual design of the helical fusion reactor, each coil has been assumed to have a similar shape to that of LHD. Recently, research has progressed to aim for better plasma confinement and larger blanket space, and optimization by flexibly changing the winding parameters and winding law itself has been attempted [1,2]. On the other hand, even if a coil current center trajectory that generates an ideal magnetic field distribution is found, it is necessary to verify the soundness of the system from various aspects to make it a practical device. Therefore, we are concurrently studying what happens to the electromagnetic (EM) force and mechanical behavior generated by changes in the coil trajectory.

The current center trajectory of the helical coil of the LHD is determined by the winding trajectory formula including the pitch modulation parameter α, the relationship between the toroidal angle φ and the poloidal angle with respect to the pseudo toroidal coordinates. For LHD, α=0.1, the helical coils are inclined vertically on the outboard of the torus and horizontally on the inboard of the torus. The opposite is true when α is negative. For optimization by winding law variation, α=0 is a candidate. In the optimization search by introducing B-spline curves, the trajectory is varied using the LHD coil geometry as a starting point, and configurations with potential for performance improvement are proposed. Fig. 1 compares a helical coil with the same winding rule as LHD (LHD-type α=0.1) and optimization by spline curve (Spline optimized). Spline-optimized-type differs from the LHD-type in the size of the part corresponding to the minor radius and the degree of inclination in the cross-sectional width direction of the coil. Although these differences are slight in appearance, the difference appears in the generated EM force due to the synergy with the vertical field coils.

The EM field analysis assuming a major radius of 7.8 m and a plasma center field of 6.6 T shows that the maximum magnetic field in the coil is 19.5 T for the spline optimized case, and the EM force acting on the helical coil is 80.7 MN/m for the LHD-type, α = 0.1. In the Spline optimized case, the hoop force acting on the vertical field coil was 113 MN/m, both of which are very severe values.

A structure to support the strong EM forces is essential, but the design must consider not only the plasma space but also the layout of the in-vessel components and their maintenance. Therefore, a topology optimization method (Fig. 2), which can create an appropriate shape from a rough initial shape, was applied to each coil system to verify the outline of the support structure and its mechanical behavior.

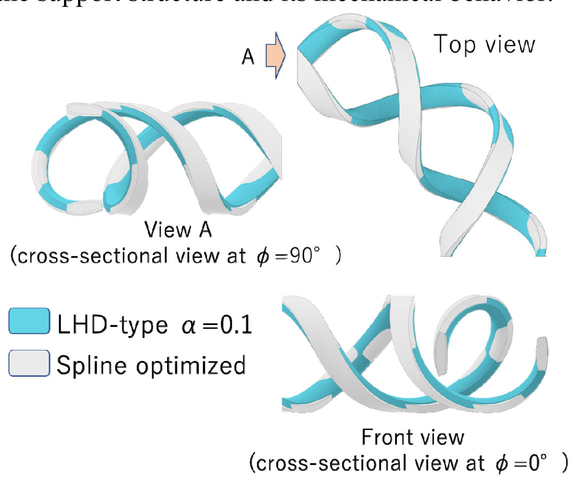

Fig. 1 Comparison of 3D shape of helical coil.

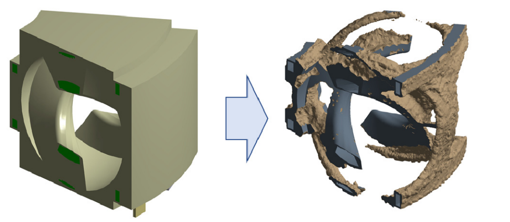

Fig. 2 Example of a design method using topology optimization. [3].

References

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