Configuration Characteristics of Tokamak-like Stellarator, Chinese First Quasi-axisymmetric Stellarator

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I. Introduction

Southwest Jiaotong University (SWJTU) in China and National Institute for Fusion Science (NIFS) in Japan concluded the official agreement to design and operate collaboratively the Chinese First Quasi-axisymmetric Stellarator (CFQS) based on the CHS-qa configuration, which indicates that the physics and engineering investigation on the advanced stellarator has been carried out in China [1,2]. In recent years, helical systems (stellarators) have made a remarkable progress in magnetic fusion research. In 2015, Wendelstein 7-X at the Greifswald branch of Max Planck Institute for Plasma Physics achieved the first plasma [3], which is the world’s largest fusion device of the stellarator type. In 2017 the deuterium plasma experiment has been executed successfully on the Large Helical Device (LHD). One of the significant achievement is that ion temperature reaches 10 keV [4]. Quasi-axisymmetric stellarators offer novel solutions for confining high-β plasmas by combining best features of advanced tokamaks and optimized stellarators [5,6]. Using the three-dimensional (3-D) shaping freedom available in a stellarator, configurations can be designed that are MHD stable without nearby conducting structure, requiring no current drive at high β and have good orbit confinement. The quasi-axisymmetry gives good orbit and/or neoclassical confinement, equivalent to tokamaks [7]. In this paper, we discuss the configuration characteristics and the design of the modular coil system for the CFQS.

II. Configuration characteristics

The plasma boundary of the CFQS is originated from CHS-qa configuration by shrinking the shape of the plasma boundary of the CHS-qa [8,9]. Via the scan of major radius (1.0 m~1.5 m) and aspect ratio (3-5), the fixed parameters of the CFQS configuration are token in account as follows: toroidal periodic number, aspect ratio, magnetic field strength and major radius are 2, 4.0, 1.0 T and 1.0 m, respectively.

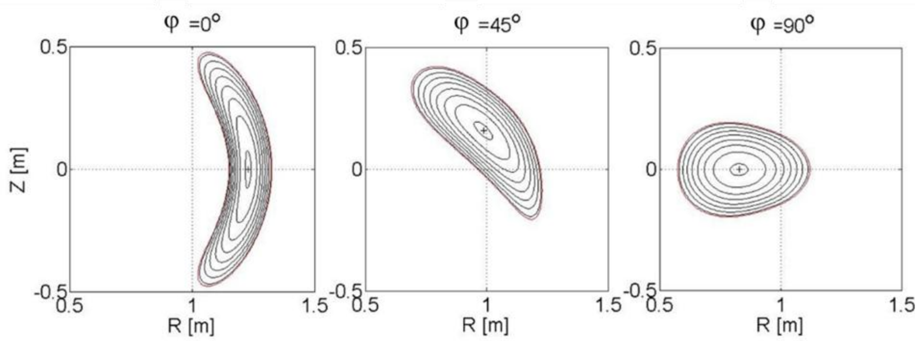

Fig. 1 Magnetic flux surfaces of CFQS at the three different toroidal angles

Figure 1 displays three poloidal cross-sections of the equilibrium magnetic surfaces for the plasma vacuum case. These magnetic flux surfaces indicate large axisymmetric (or toroidal average) crescent, elongation and triangularity. Figure 2(a) shows the rotational transform profile which displays the low magnetic shear exists in the CFQS configuration. The low magnetic shear is beneficial to the emergence of the internal transport barrier. Figure 2(b) shows the profile of magnetic well depth. It can be seen that the well structure is realized in the entire region which leads to the stability of MHD. Figure 2(c) shows the mod-B contour of magnetic field strength at ρ=0.6. The CFQS magnetic field is dominated by B10 indicating a strong axisymmetry-like configuration.

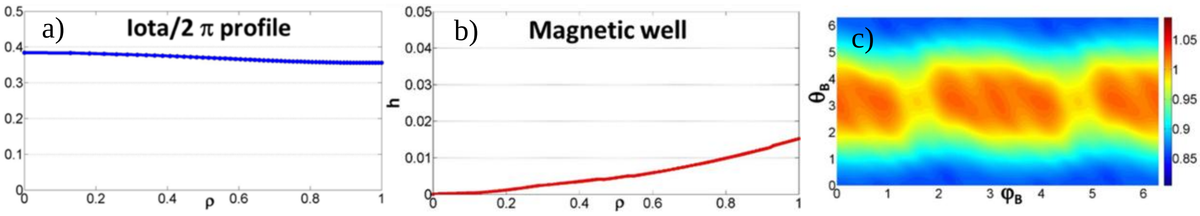

Fig. 2 Rotational transform profile, magnetic well depth profile, and mod-B contour at ρ of 0.6.

III. Design of the modular coil system

Vacuum equilibrium properties of a toroidal configuration are determined by the shape of the outermost closed flux surface. Generally, considering the nested magnetic flux surfaces, the VMEC code enables to solve the three-dimensional MHD equilibrium accurately and efficiently.

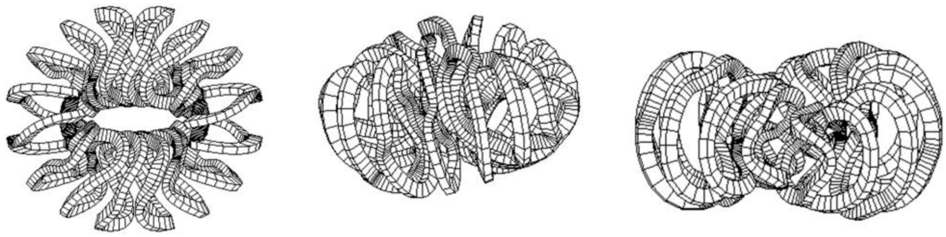

Fig. 3 Modular coils of the CFQS. The top view, side views at toroidal angle=0^o (vertically elongated cross section), and 90^o (horizontally elongated cross section). The coil system comprises of four different shape coils.

In order to achieve the target magnetic configuration, a modular coil system has to be designed to reproduce the plasma boundary. Due to the Neumann boundary condition, the accuracy of the magnetic configuration induced by the coil system is dependent on the normal component of the magnetic field on the plasma boundary. Via the minimization of it on the plasma boundary, the modular coil geometry is optimized. Meanwhile, the engineering constraints are taken into account which are the minimum interval between adjacent coils and maximum curvature. This

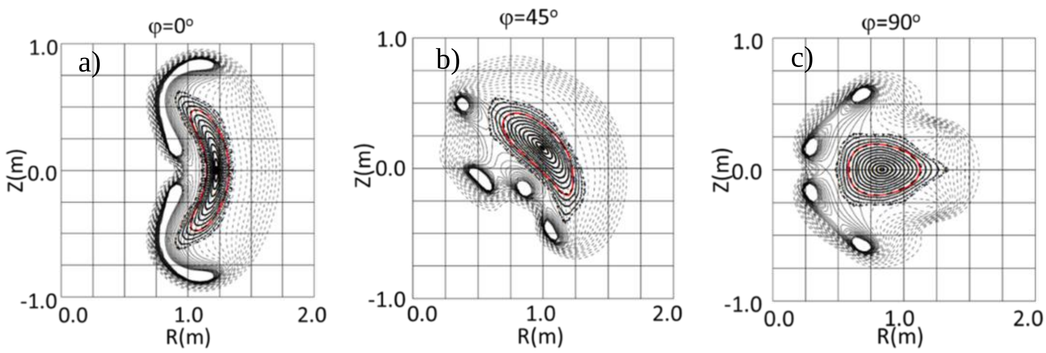

Fig. 4. Poincaré plots of magnetic flux surfaces at the toroidal angle =0^o, 45^o, and 90^o for (a)-(c), respectively. The red curve represents the target plasma boundary.

optimization process is accomplished by the NESCOIL code [10]. In the design of the coil system for the CFQS, the coil numbers have been scanned to achieve an optimum modular coil system. The following figure gives the 16-modular coil system, the optimum design. The coil system possesses four different shaped modular coils. In Fig. 4, poloidal cross sections at the toroidal angle= 0^o, 45^o, and 90^o are displayed. The average of $\mathbf{B}\cdot\mathbf{n}/|\mathbf{B}|$ on the plasma boundary is below 1%, which cannot be reduced from the viewpoint of the engineering. In Figs. 4(a)-(c), a good coincidence in the shapes of a magnetic flux surface and that of target plasma boundary can be seen. The outermost flux surface produced by modular coils is larger than that of target plasma boundary, which is beneficial to raise (or control) the plasma volume by movable limiters. On the basis of above analyzation, the designed 16-coil system is well workable.

IV. Conclusion

The CFQS design has been conducted as an international joint work between SWJTU and NIFS. In this paper, the modular coil system for the CFQS is designed successfully to achieve the quasi-axisymmetry. The parameters of CFQS are that the toroidal periodic number=2, aspect ratio=4.0, magnetic field strength=1.0 T, and major radius=1.0 m. In order to fabricate the modular coil system, firstly considering the physics constraint, $\mathbf{B}\cdot\mathbf{n}/|\mathbf{B}|$ at the plasma boundary, and the fabrication constraints including the radius of coil curvature and distance between adjacent coils, the discrete coils are generated by NESCOIL code. Secondly via the comparison between properties of the coils induced magnetic configuration and target configuration, the accuracy of the coil system is evaluated to guarantee that the target configuration can be reproduced by the designed coil system.

Acknowledgments

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