Construction Progress of Chinese First Quasi-axisymmetric Stellarator (CFQS) and Preliminary Results in the CFQS-Test Device

Y. Xu[1*], J. Cheng[1], H. F. Liu[1], X. Q. Wang[1], W. M. Xuan[1], J. Huang[1], H. Liu[1], X. Zhang[1], J. F. Shen[1], J. Hu[1], H. Lan[1], Y.C. Li[1], W. Li[1], H. Zhou[1], J. R. Shao[1], A. Shimizu[2,3,] M. Isobe[2,3], S. Okamura[2], M. Shoji[2], K. Ogawa[2,3], H. Takahashi[2,3], H. Yamaguchi[2,3], D. P. Yin[4] and the CFQS team

[1] Institute of Fusion Science, School of Physical Science and Technology, Southwest Jiaotong University, Chengdu 610031, China

[2] National Institute for Fusion Science, National Institutes of Natural Sciences, Toki 509-5292, Japan

[3] The Graduate University for Advanced Studies, SOKENDAI, Toki 509-5292, Japan

[4] Hefei Keye Electro Physical Equipment Manufacturing Co., Ltd, Hefei, China

*Email: xuyuhong@swjtu.edu.cn

The Chinese First Quasi-axisymmetric Stellarator (CFQS) is being constructed as an international joint project between Southwest Jiaotong University (SWJTU, China) and National Institute for Fusion Science (NIFS, Japan), aiming to prove the inherent advantages of the quasi-axisymmetric (QA) magnetic configuration in confining plasmas by substantial reduction of neoclassical transport and stabilizing MHD instabilities by a magnetic well structure, etc [1-3]. The CFQS project is divided into two stages. ***The first one*** focuses on testing of feasibility and accuracy of modular coils for realization of the QA topology, which is conducted on the CFQS-Test (CFQS-T) device and operated at low magnetic field of 0.1 T. ***The second stage*** is scheduled to delve into plasma properties of high parameters at relatively high magnetic field (1 T) in a QA stellarator, for which stronger support structures are needed to withstand large electromagnetic forces. In this presentation, we report the construction progress of CFQS and the preliminary experimental results obtained in the CFQS-T device.

The main parameters of CFQS are: the major/minor radius are 1.0 m/0.25 m, the toroidal periodic number is 2 and the magnetic field strength is 1.0 T [2, 3]. The main body of the CFQS stellarator includes the coil system, vacuum vessel, supporting structure and water cooling pipes [4-7]. The coil system consists of 16 non-planar modular coils (MCs), 4 poloidal field coils (PFCs) and 12 toroidal field coils (TFCs). The MCs of four types (MC1, MC2, MC3, MC4) are designed and manufactured to generate the QA magnetic configuration. The PFCs are used to control the radial movement of the magnetic axis, and the TFCs for adjusting the iota profile and forming the magnetic island divertors [8]. Assembly of CFQS-T device was carried out in several stages, i. e., installation of 2 lower PFCs, MCs and vacuum vessel sections (type A/B) threaded through the 16 MCs, followed by mounting 8 outer pillars, 2 upper PFCs, 12 TFCs and water pipes. In each stage, the positioning of the coils was kept by precision laser tracker. By the end of July 2024, the assembly of CFQS-T was completed with a maximum deviation of ~2.96 mm, meeting the design requirement [5, 9]. Figure 1 shows the picture of CFQS-T installed in the experiment hall in SWJTU. The auxiliary systems, including power supply, vacuum pumping, magnetron (2.45 GHz, 10-30 kW), central control, gas puff and diagnostic systems, have also been installed and commissioned accordingly. For four types of modular coils (MC1-MC4), four

Fig. 1. Photo of CFQS-T in the experiment hall.

individual power supplies are connected separately so that the current ratio between the four MCs can be controlled flexibly [4-7].

In August of 2024, the first QA magnetic configuration was successfully achieved in CFQS-T. Figure 2 illustrates the mapping system used to measure the magnetic topology along with the 2D and

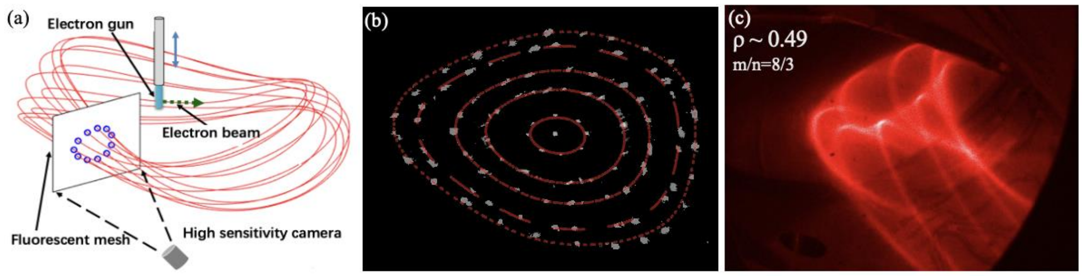

Fig. 2. (a) Schematic of mapping system; (b) 2D Poincare section of closed magnetic surfaces measured by fluorescent mesh and (c) 3D structure of magnetic field lines visualized in argon gas.

3D structures of the magnetic surfaces. Figure 2(a) shows that the mapping diagnostic mainly consists of three elements: an electron gun (energy range: 20-250 eV), a fluorescent mesh (grid size: 2 cm × 2 cm) and a high-sensitivity camera (exposure time: ~ 60 s) [10]. The electron beam emitted from the electron gun at a fixed radial position travels along the magnetic field lines. When it strikes the fluorescent mesh, the latter will light up. The illuminated pattern is continuously recorded by the high-sensitivity camera. By emitting the electron beam at different radii, various magnetic surfaces can be visualized. The mapping results are shown in Fig. 2(b), where the white light points clearly show Poincare section of nested and closed flux surfaces, and in good agreement with the simulated values (red curves) [6, 7]. The electron beam alone could also visualize the 3D structure of field lines via collisional excitation of argon gas, as shown in Fig. 2(c) with a striking image of the m/n = 8/3 modes. Using the method proposed by Boozer [11], the error field of intrinsic 5/2 island is evaluated to be ~ 5.6×10^{-5}, meeting our design request. In such a precise QA configuration, the neoclassical transport has been estimated with experimentally measured density and temperature profiles, and the value is about 1-2 orders lower than that in a conventional stellarator.

The above results, **for the first time**, validate the accurate QA magnetic topology in the CFQS-T stellarator with modular coils **in the world**, and demonstrate the capability of the optimized QA configuration in trimming down the neoclassical transport. Further analyses of plasma properties, such as turbulent transport and MHD activities, are underway.

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