NIFS-SWJTU joint project for Chinese First Quasi-axisymmetric Stellarator (CFQS)

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1. Introduction

In recent year, helical plasma research has progressed greatly. The deuterium operation of the Large Helical Device (LHD) begun in March, 2017[1] to explore a higher-performance helical plasma and the first plasma was initiated in Wendelstein 7-X in December, 2015[2]. Because a helical plasma based on three-dimensionality is very flexible in a magnetic configuration, continuous efforts to explore advanced configurations must be made steadily. A quasi-axisymmetric stellarator (QAS) is characterized by a tokamak-like axisymmetric magnetic field in the magnetic coordinates as the name suggests [3], and is attractive in terms of having no requirement for inductive plasma current, reduced neoclassical transport, low-toroidal viscosity, magnetic well in an entire region of plasma, and compactness through low-aspect-ratio characteristics. In addition, the QAS offers the drift reversal capability of trapped particles due to weak non-axisymmetric magnetic field components that can potentially suppress micro-instabilities driven by anomalous transport [4]. Physics and engineering design of Compact Helical System (CHS)-qa and National Compact Stellarator Experiment (NCSX) based on a quasi-axisymmetry concept were intensively carried out around 2000 in the National Institute for Fusion Science (NIFS), Japan [5-7] and the Princeton Plasma Physics Laboratory, United States [8,9], respectively. Also, the Evolutive Stellarator of Lorraine (ESTELL) was proposed later in France [10]. However, the experiment device was not realized. In order to explore the potential of expansion of helical plasma confinement, NIFS and Southwest Jiaotong University (SWJTU) in the People's Republic of China have agreed upon construction of Chinese First Quasi-axisymmetric Stellarator (CFQS) with laboratory size but advanced configuration as a joint project.

2. NIFS-SWJTU joint project for CFQS

NIFS and SWJTU have entered into an agreement for international academic cooperation to promote cooperative research in helical fusion plasma research. The signing ceremony was held on July 3, 2017, at SWJTU, as shown in Fig. 1. NIFS and SWJTU, together with implementing a joint project to design and construct a new helical device based upon a quasi-axisymmetry concept, will develop active academic interaction among researchers and students at both institutes. NIFS and SWJTU, while receiving powerful support from the People's Republic of China's fusion research community, will implement design and construction, plasma heating and diagnostics technical development, and plasma experiments, and will introduce the helical device to be called CFQS. These two institutes also will initiate collaborative projects and rigorously cooperate in those projects. NIFS and SWJTU have organized the steering committee for the CFQS that will manage this joint project. This committee consists of members of NIFS and SWJTU. The steering committee organizes subsidiary task forces, and these task forces will discuss specific topics, such as physics, engineering, heating, diagnostics, and other matters.

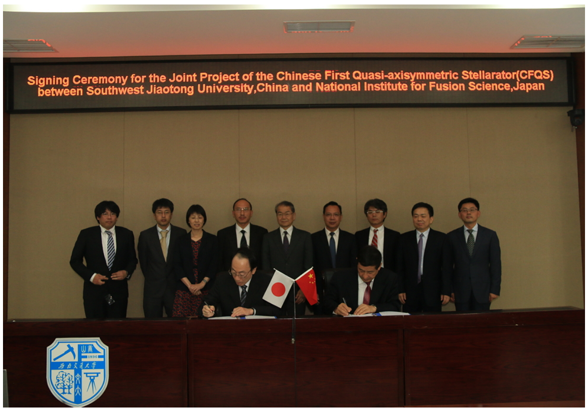

Fig. 1 Signing ceremony for the joint project of the CFQS between NIFS, Japan and SWJTU, China on July 3, 2017.

3. Partial responsibility

Responsibilities of NIFS and SWJTU are as follows. SWJTU prepares the experiment building, basic components of the CFQS, such as magnetic field coils, vacuum chamber, power supply, pure water cooling system, and other components necessary for the CFQS operation at SWJTU. The draft layout for the CFQS and other utilities in the experiment building is schematically depicted on the left of Fig. 2. The interior of the CFQS torus hall is also shown on the left of Fig. 2. The experiment building consists of torus hall (600 m^2), power supply yard (138 m^2), and pure water cooling system yard (168 m^2) placed adjacent to the torus hall. NIFS provides the basic design of the CFQS, such as magnetic field configuration, modular coil geometry, and other design matters, based on experience in physics and engineering design of CHS-qa [5-7]. NIFS also provides experts to support the equipment design and machine construction, and utilizes as many unused CHS apparatuses as possible for the CFQS, such as advanced diagnostics, for example, heavy ion beam probe (HIBP), and 54.5 GHz gyrotron of which maximum power is ~450 kW with pulse duration of 100 ms.

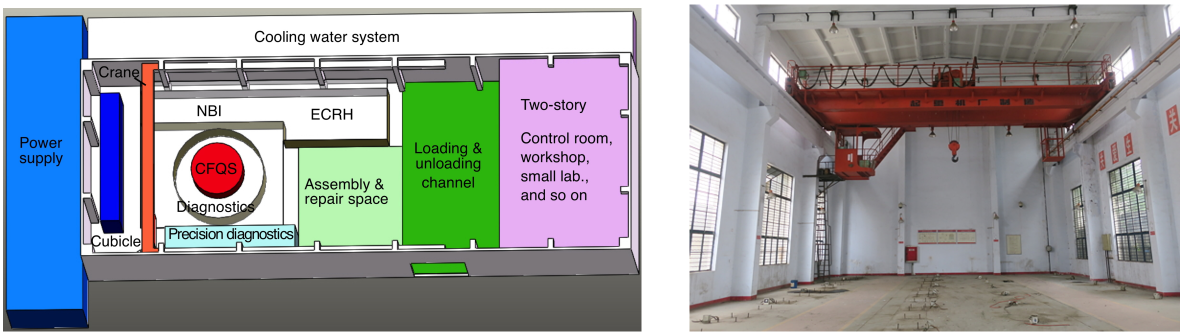

Fig. 2 Left: Draft layout of CFQS and facilities in the experiment building. The size of the torus hall is 42 m x 15 m, and 10 m in height. Right: CFQS torus hall at SWJTU. The floor area of the torus hall is 600 m^2. The torus hall is equipped with a 10-ton crane.

4. Status of physics and engineering design

Physics design of the CFQS was intensively performed as a collaborative work between NIFS and SWJTU in 2017. Fundamental properties of CFQS, such as Fourier spectrum of magnetic field strength, mod-B contour, and profiles of rotational transform and magnetic well depth are available in Ref. 11-13. A feasible divertor study is also ongoing[14]. Primary device parameters of CFQS were decided on May 30, 2018, through discussion in the steering committee meeting of the NIFS-SWJTU joint project as follows : major radius of 1 m, number of toroidal periods of 2, aspect ratio (A_p) of 4, maximum toroidal magnetic field strength of 1 T, and 16 modular coils made of water-cooled hollow copper conductors [7]. Although CHS-qa was designed with A_p of 3.2, we chose A_p of 4 for CFQS to avoid difficult technical challenges in the machine design and construction. Engineering design, for example, evaluation

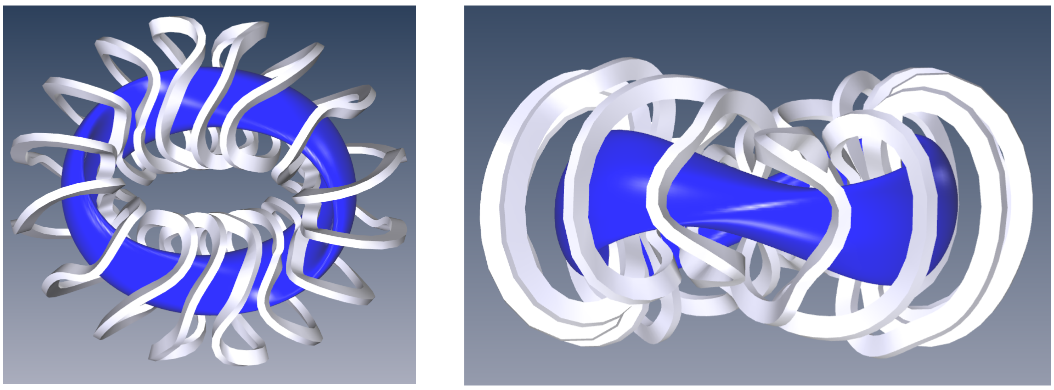

Fig. 3 Three-dimensional computer-aided drawing of modular coils and last closed magnetic flux surface of CFQS. The CFQS has a major radius of 1 m, aspect ratio of 4, and toroidal periods of 2. The toroidal magnetic field strength will be increased up to 1 T.

of electromagnetic force for each coil, design of support structure, vacuum vessel, power supply system, and other issues, is now being performed at Hefei Keye Electro Physical Equipment Manufacturing Co., Ltd. (Keye), SWJTU, and NIFS. Fabrication of a mock-up of the modular coil will be initiated at Keye in 2018. The planned time line of this project is classified into four phases. In Phase I, physics design, such as magnetic configuration, neoclassical transport property, MHD stability, and engineering design for modular coils, vacuum vessel, supporting structure, power supply for modular coils, etc. are performed. The project is now in Phase I. In Phase II (September, 2018~), fabrication of CFQS and transfer of heating and advanced diagnostic systems from NIFS to SWJTU, such as gyrotron and HIBP, will be performed. In Phase III (January, 2021~), after verification of the accuracy of CFQS and commissioning are completed, the first plasma of CFQS will be achieved. In Phase IV (July, 2021~), physics experiments will begin.

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