Magnetic flux surface mapping system at Chinese First Quasi-axisymmetric Stellarator

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The Chinese First Quasi-axisymmetric Stellarator (CFQS) is developed by the collaboration of Southwest Jiaotong University (SWJTU) in China and National Institute for Fusion Science (NIFS) in Japan [1]. It is designed to have the major radius R_0=1.0 m, the toroidal magnetic field B_t=1.0 T, and the toroidal periodic number N_p=2 [2,3,4]. In August 2024, CFQS-Test (CFQS-T) device has begun commissioning with a magnetic field strength of 0.1 T.

In this work, we designed the CFQS mapping system, which is one of the most important diagnostic tools to validating designed magnetic configuration for stellarators and torsatrons [5,6]. Including an electron gun, a fluorescent mesh, and a high-sensitivity camera, this system enables the visualization of the geometric structure of the magnetic surfaces [7]. Figure 1 shows the schematic of the CFQS mapping system. During mapping experiments, the energy of the electron beam could be adjusted between 20 to 250 eV, emitting from an aperture that is about 1mm in diameter. And the electron gun's drive mechanism is designed to possess three freedoms: horizontal tilt (about ±18 degrees), movement along the radial direction (about 700 mm), and rotation (about ±30 degrees). The first two adjustments allow the electron gun to reach the magnetic axis and different magnetic surfaces, while the latter ensures that the emission direction of the electron beam remains as parallel as possible to the magnetic field lines, thereby minimizing the Larmor radius. As an imaging plane, the movable fluorescent mesh with a transmittance of 0.95 is designed to serve both the coverage of the entire magnetic surface and the periodic motion of the electron beam in the toroidal direction. And the high sensitivity camera is required to have long exposure times under dark conditions to capture the light emitted by the fluorescent agent (ZnO) when electron beam strikes the mesh to obtain the geometric profile of the magnetic surface.

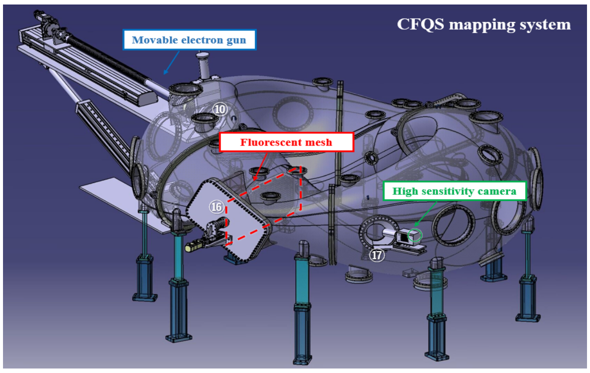

Fig.1. Schematic of the CFQS mapping system

The components of the mapping system have finished tests before the experiments. The electron gun's maximum emission current reached 8 mA, and the displacement accuracy of the electron gun's drive mechanism is about 0.1 mm. This ensures precise determination of the electron gun's actual position for magnetic field line tracing and mapping the entire magnetic surface in both simulations and experiments. The fluorescent agent (ZnO) was tested for luminescence in a dark environment, emitting visible yellow-green light when exposed to blue-violet light. Additionally, the high sensitivity camera, at the designed distance, can clearly capture the grid lines of the fluorescent mesh (~ 0.3 mm).

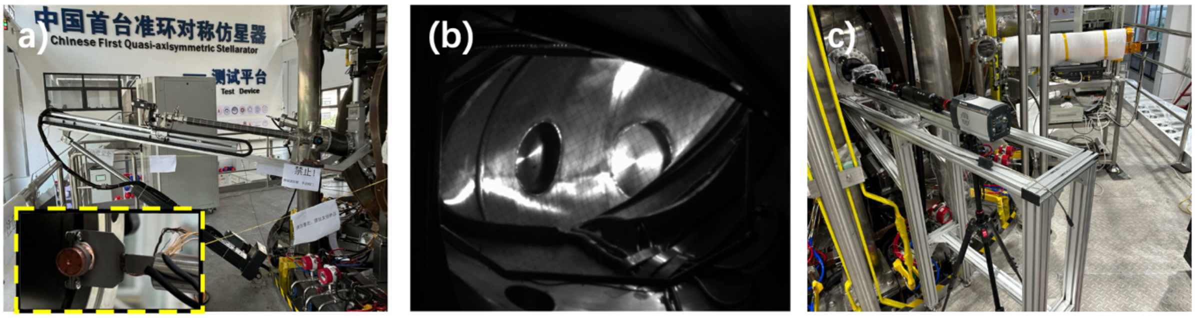

Fig. 2. (a) Photo of the electron gun. (c) Photo of the fluorescent mesh taken by the high sensitivity camera. (c) Photo of the high sensitivity camera.

This mapping system has been successfully developed on CFQS-T and completed the validation of the quasi-axisymmetric magnetic field configuration. Figure 2 shows photos of the components of the mapping system in the CFQS-T. Additionally, we used an optical path to ensure that the high sensitivity camera is as perpendicular as possible to the magnetic surface. Note that the photos of the fluorescent mesh inside the device were taken with the high sensitivity camera. Figure 3 shows an experimental image of one magnetic flux surface measured by this mapping system. The experimental conditions are as follows: the vacuum level is approximately 10^{-5} Pa, the magnetic field strength is 0.1 T, the electron beam energy is around 40 eV, and the exposure time of the high-sensitivity camera is 55 s. Additionally, the position of the electron gun is located near the designed outermost closed magnetic surface.

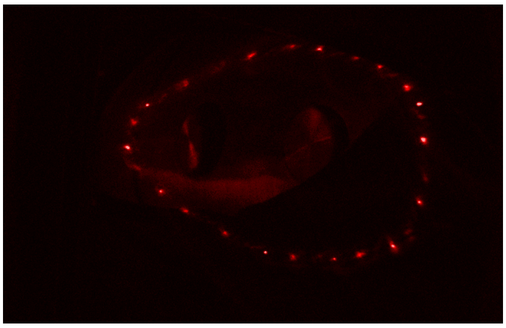

Fig.3. Magnetic flux surface mapping image

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