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ENGINEERING, CONSTRUCTION, AND FLEXIBLE CONTROL OF MAGNETIC FIELD CONFIGURATION OF QUASI-AXISYMMETRIC STELLARATOR CFQS-T

A. SHIMIZU[1,2], M. ISOBE[1,2,3], S. OKAMURA[1], K. OGAWA[1,2], H. TAKAHASHI[1,2], H. YAMAGUCHI[1,2], M. SHOJI[1,2], M. OSAKABE[1,2], L. YANG[2], T. MURASE[1], S. NAKAGAWA[1], H. TANOUE[1], Y. XU[4], H.F. LIU[4], J. CHENG[4], X. ZHANG[4], J. HUAN[4], X. WANG[4], J.F. SHEN[4], H. LAN[4], C. TANG[5], and D. Yin[6].

[1] National Institute for Fusion Science, National Institutes of Natural Sciences, Toki, Japan
[2] The Graduate University for Advanced Studies, SOKENDAI, Toki, Japan
[3] Mahasarakham University, Thailand
[4] Southwest Jiaotong University, Chengdu, China
[5] Sichuan University, Chengdu, China
[6] Anhui Link Future Technology Co., Ltd., China

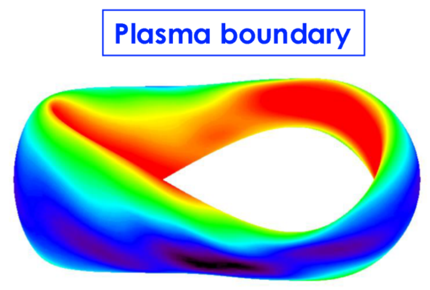
Outline

1. Overview of CFQS quasi-axisymmetric stellarator
2. CFQS engineering
3. CFQS construction
4. Ability of flexible control of CFQS magnetic field configuration
5. Summary

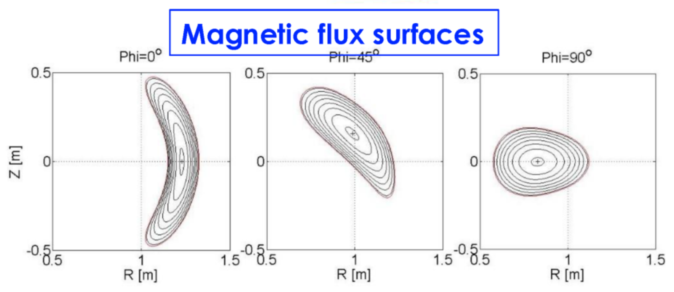
Quasi-axisymmetric configuration of CFQS

The CFQS is designed to combine both advantages of **a stellarator with steady-state operation capability** and **a tokamak with good plasma confinement property**.

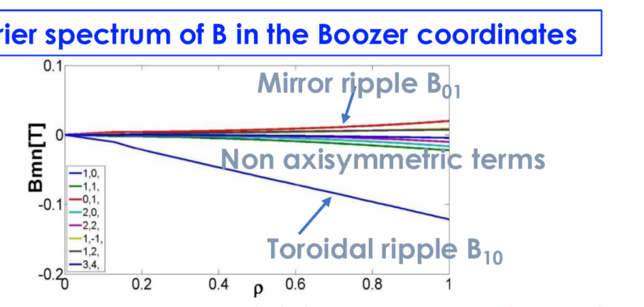
Plasma boundary



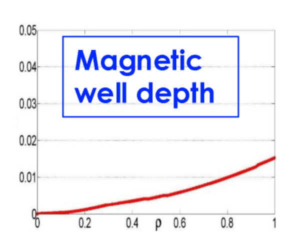
Magnetic flux surfaces



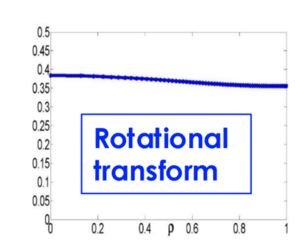
Fourier spectrum of B in the Boozer coordinates



Toroidicity component is dominant.



Magnetic well entirely

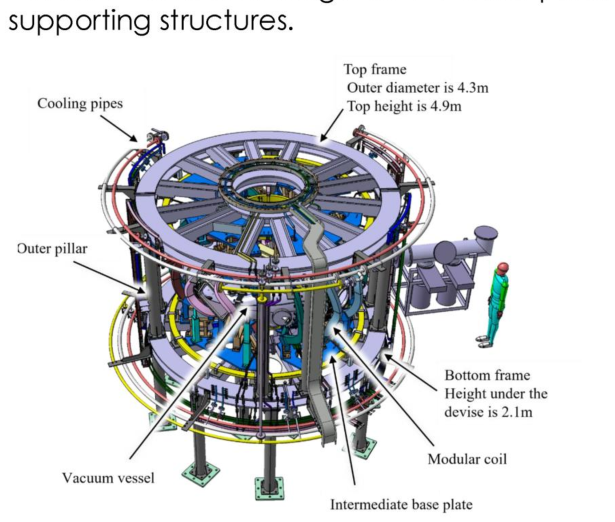


Weak shear profile

A. Shimizu *et al.*, Plasma Fus. Res. **13** (2018) 3403123.

Overview of the CFQS

- B_t = 1 T, R = 1 m, A_p = 4 are selected for CFQS to perform proof of principal experiment of QA stellarator concept.
- The CFQS plasma experiment is divided into two stages: 1st stage of Bt < 0.1 T long pulse operation as "CFQS-T" and 2nd stage of 1 T short pulse operation as "CFQS" after reinforcing the magnetic coil supporting structures.



CFQS-T main body for the 1st stage

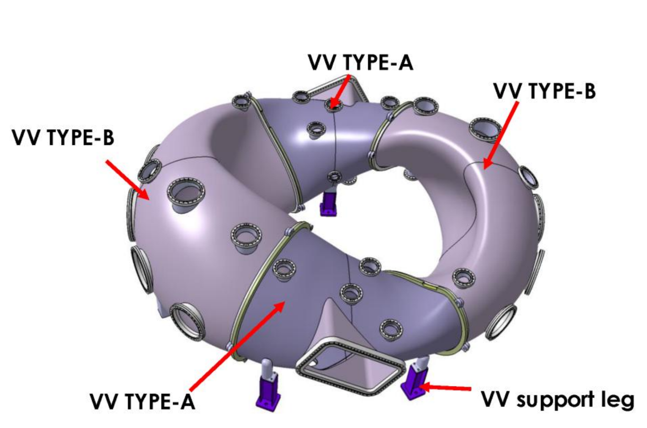
Principal physical properties of CFQS

No	Parameters	CFQS	W7-X	HSX
1	Configuration type	QA	QI	QH
2	Major radius (m)	1.0	5.5	1.2
3	Minor radius (m)	0.25	0.5	0.15
4	Aspect ratio	4	11	8
5	Magnetic field (T)	1	3	1
6	Toroidal periods	2	5	4
7	Rotational transform	0.35~0.38	0.85~1	1~1.1

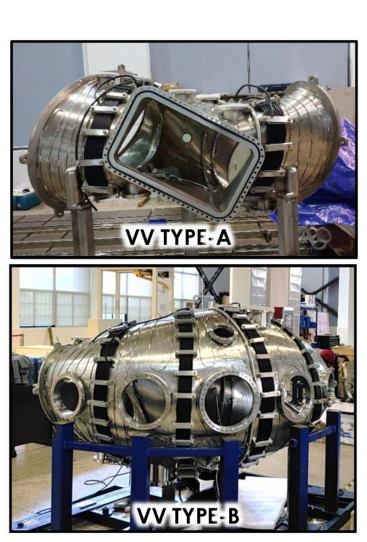
- QA : Quasi-axisymmetric
- QI : Quasi-isodynamic
- QH : Quasi-helical symmetric

Components of CFQS-T main body

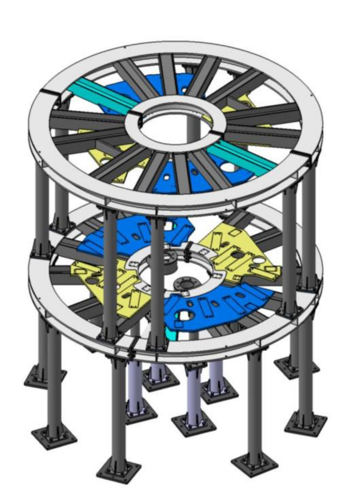
The CFQS-T main body consists of
(1)16 Modular coils,
(2) 4 sectors of vacuum vessel (VV) with 2 types called VV Type-A, VV Type-B
(3) Main body supporting structures.



Vacuum vessel and its sector



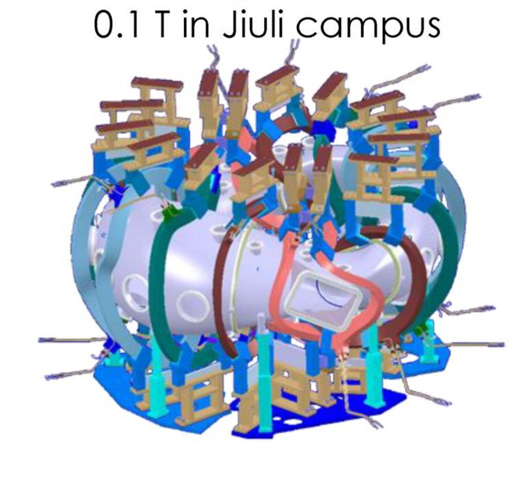
Assembled VV sectors



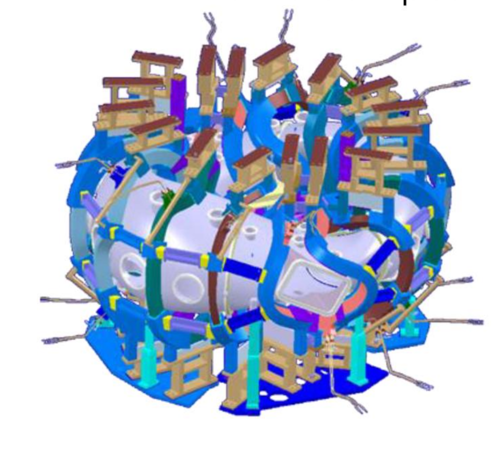
Main body support structure

Supporting structure design

1st stage: CFQS-T
0.1 T in Jiuli campus



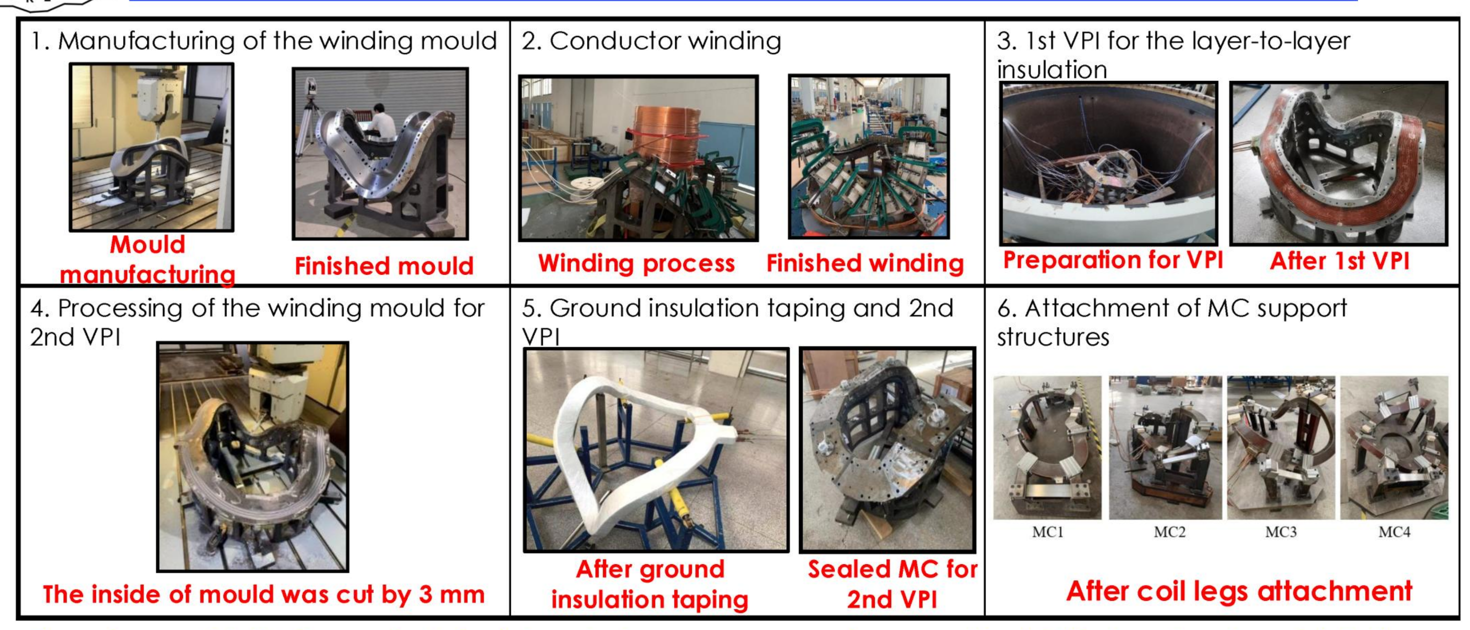
2nd stage: CFQS
1 T in Tianfu campus



Center pole

The 1st stage machine, i.e., CFQS-T for 0.1 T operation is not equipped with coil cases, full specification of supporting structures, and center pole to withstand electromagnetic force.

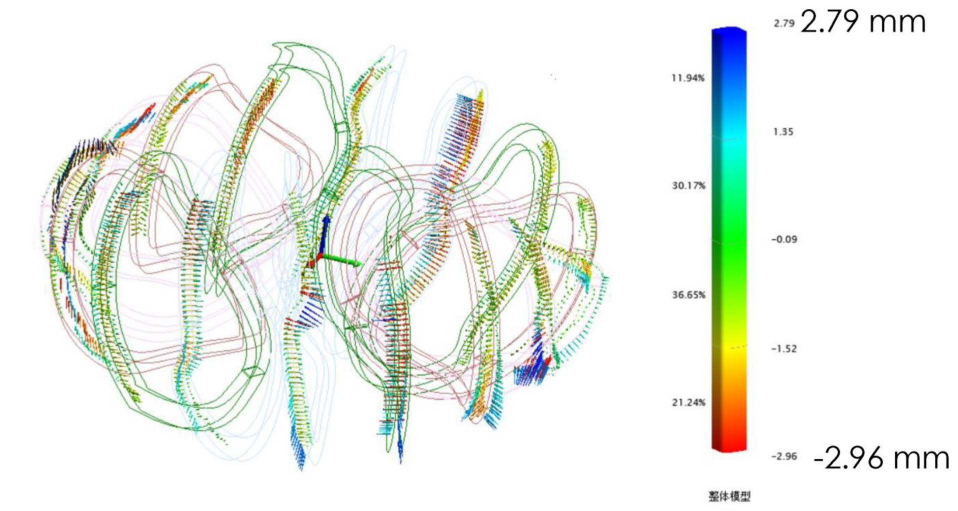
Establishment of manufacturing method of MCs



- The unique point of MC manufacturing is to adopt vacuum pressure impregnation (VPI) in two steps to maintain the shape of MC winding packs during ground insulation taping without the winding mould.
- All MCs have passed final inspections. They have been manufactured with less than 2 mm dimensional deviation.

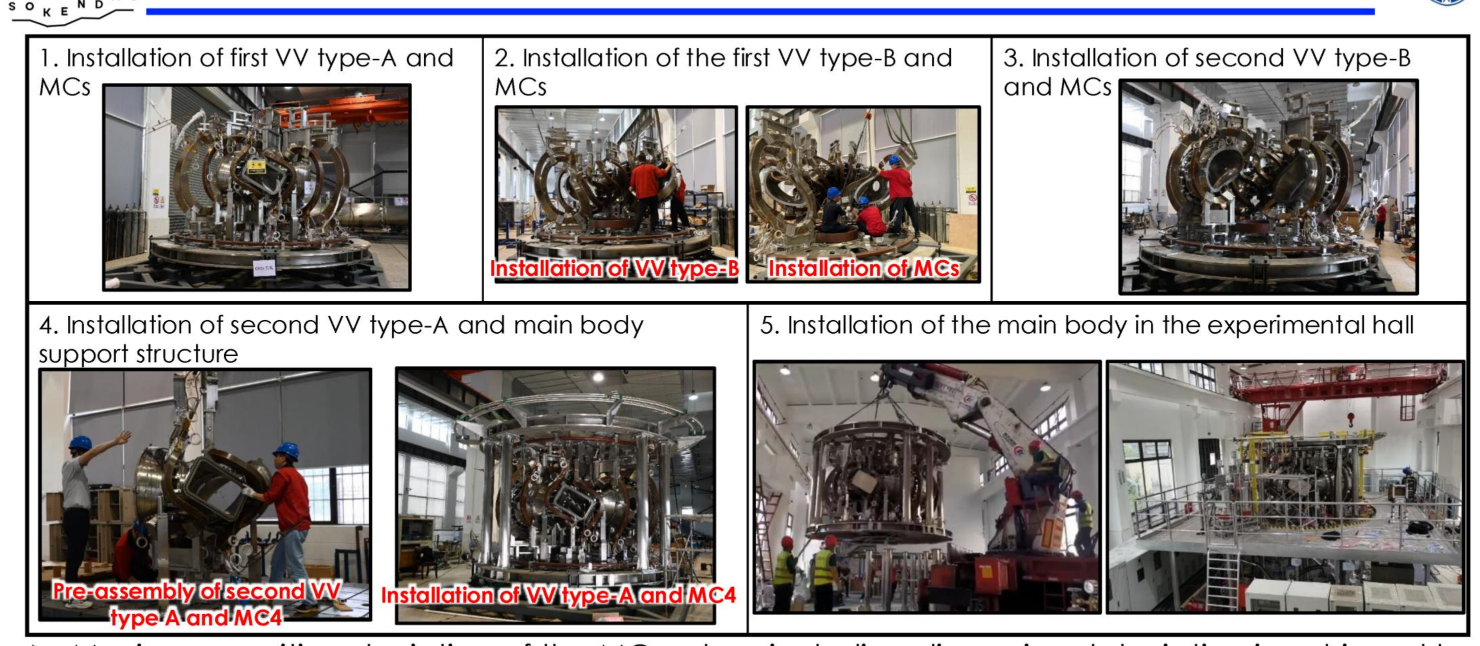
Position error of MCs after assembling process

- Dimension measurement of MC position was performed.
- Position error of realized MCs from 3-D CAD design was measured by laser tracker.



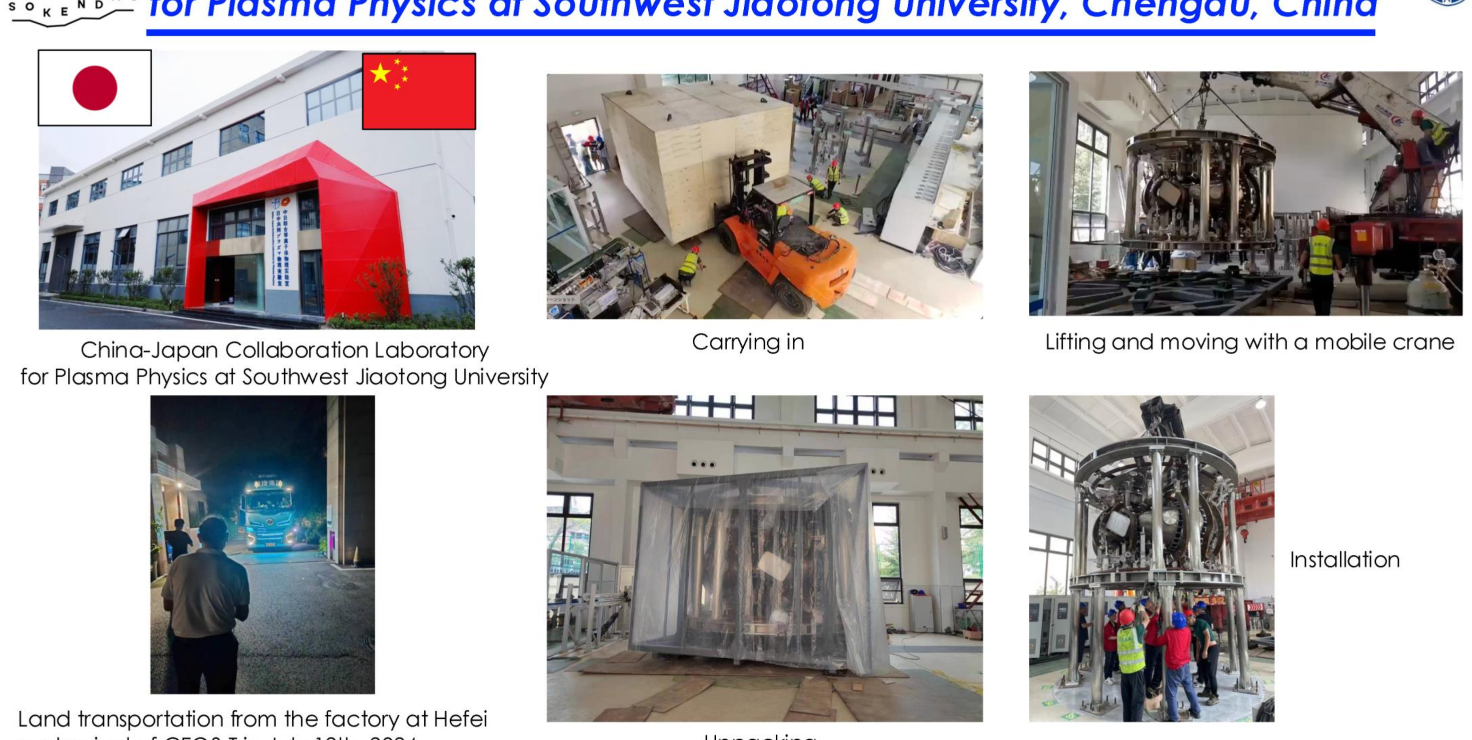
The final deviation of MC assembling is -2.96~2.79 mm.

Assembly procedure of the CFQS-T main body



- Maximum position deviation of the MC system including dimensional deviation is achieved to be less than ±3 mm measured by a laser tracker. It will not significantly affect the magnetic field configuration*. *G. Xiong *et al.*, Plasma Phys. Control. Fusion 65 (2023) 035020.

Installation of CFQS-T into the China-Japan Collaboration Laboratory for Plasma Physics at Southwest Jiaotong University, Chengdu, China

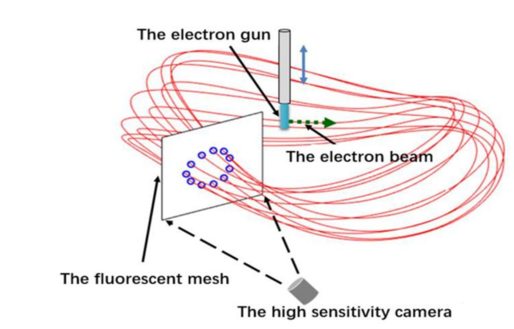


Overview picture of CFQS-T

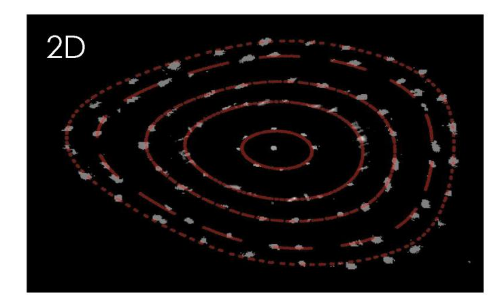
- The first plasma of CFQS-T was achieved in August 31st, 2024.
- The CFQS-T campaign was ended in May 2025, and transferred to the factory in Hefei to upgrade to CFQS for 1 T operation.

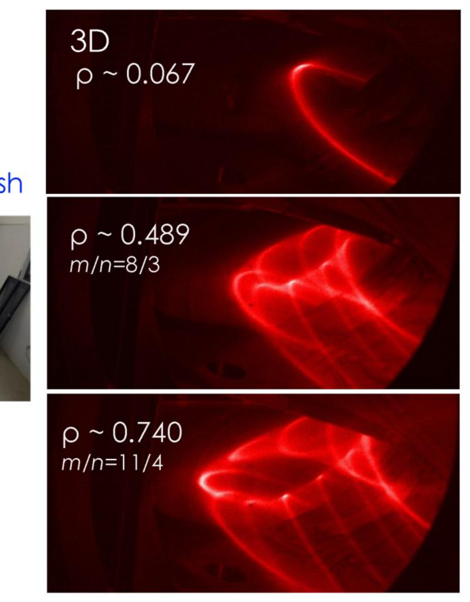
Magnetic field mapping experiment

Experimental setup for mapping



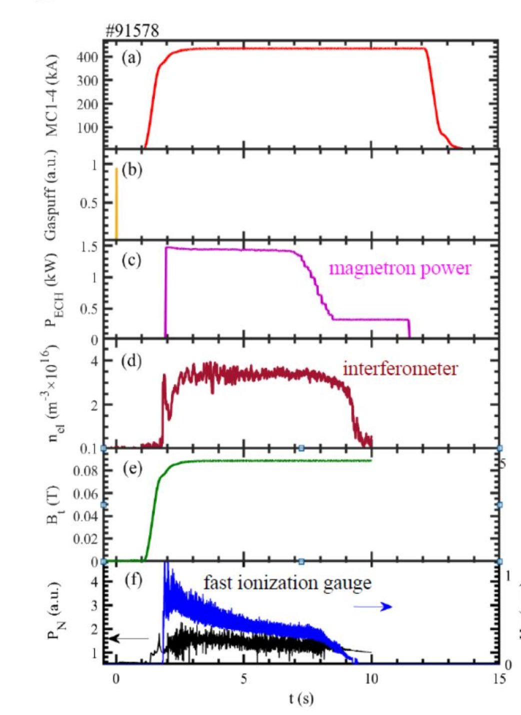
Fluorescent mesh





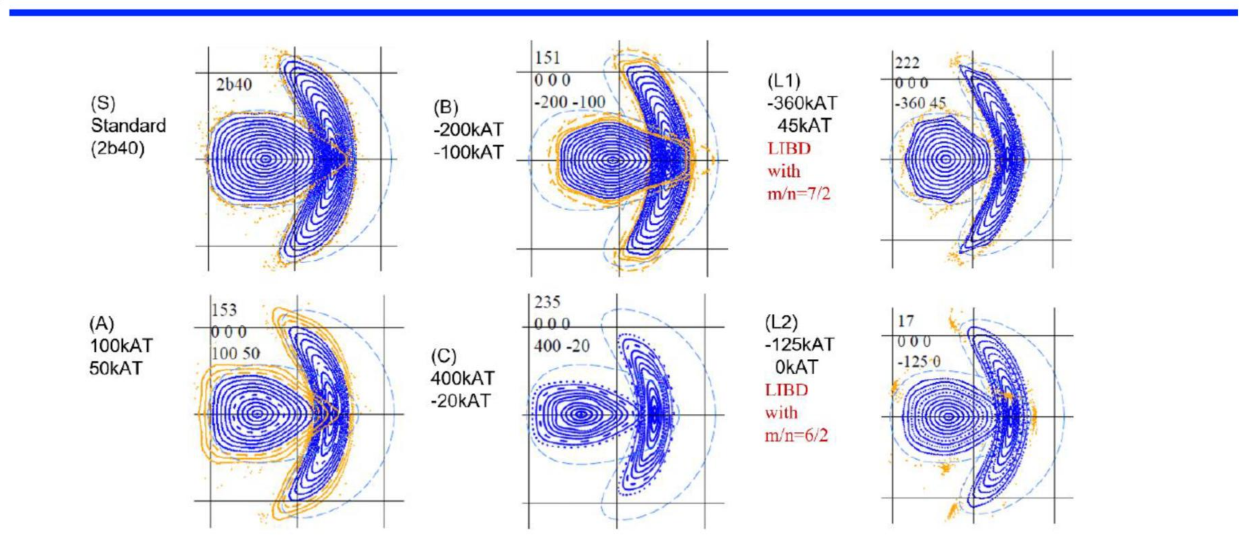
- The mapping experiment shows the good magnetic surfaces.
- Experiment results match the simulated magnetic surfaces.

A typical plasma discharge in CFQS-T



- The CFQS-T plasma is produced by 2.45 GHz magnetron.
- P_{ECRH} < 5 kW.

Control capability for magnetic field configuration



- The rotational transform can be controlled with TFCs, the , by which the divertor configuration can be produced with m/n = 2/5 islands structure in the peripheral region.
- Although the QA-ness is slightly deteriorated by this control, effective helical ripple can be kept lower level than that of W7-X.
- By using PFCs, position of the magnetic axis can be shifted.
- By adjusting the current ratio of IV coil to OV coil, rotational transform also can be controlled.

Summary

- The CFQS is a quasi-axisymmetric stellarator having R of 1 m, A_p of 4.
- The CFQS project is performed in two steps, 1st phase: CFQS-T for 0.1 T operation, 2nd phase: CFQS for 1 T operation.
- Construction of CFQS-T was successfully completed in May 2024, and the first plasma was achieved in Aug. 31st 2024.
- Maximum position deviation of the MC system including dimensional deviation is achieved to be less than ±3 mm measured by a laser tracker. It will not significantly affect the magnetic field configuration
- Magnetic field mapping experiment was performed. Good magnetic surfaces were obtained as we expected, matching the simulation results
- The CFQS for 1 T operation will be started in the end of 2026.