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Performance of JT-60SA Superconducting Magnet Operation in Integrated Commissioning Test

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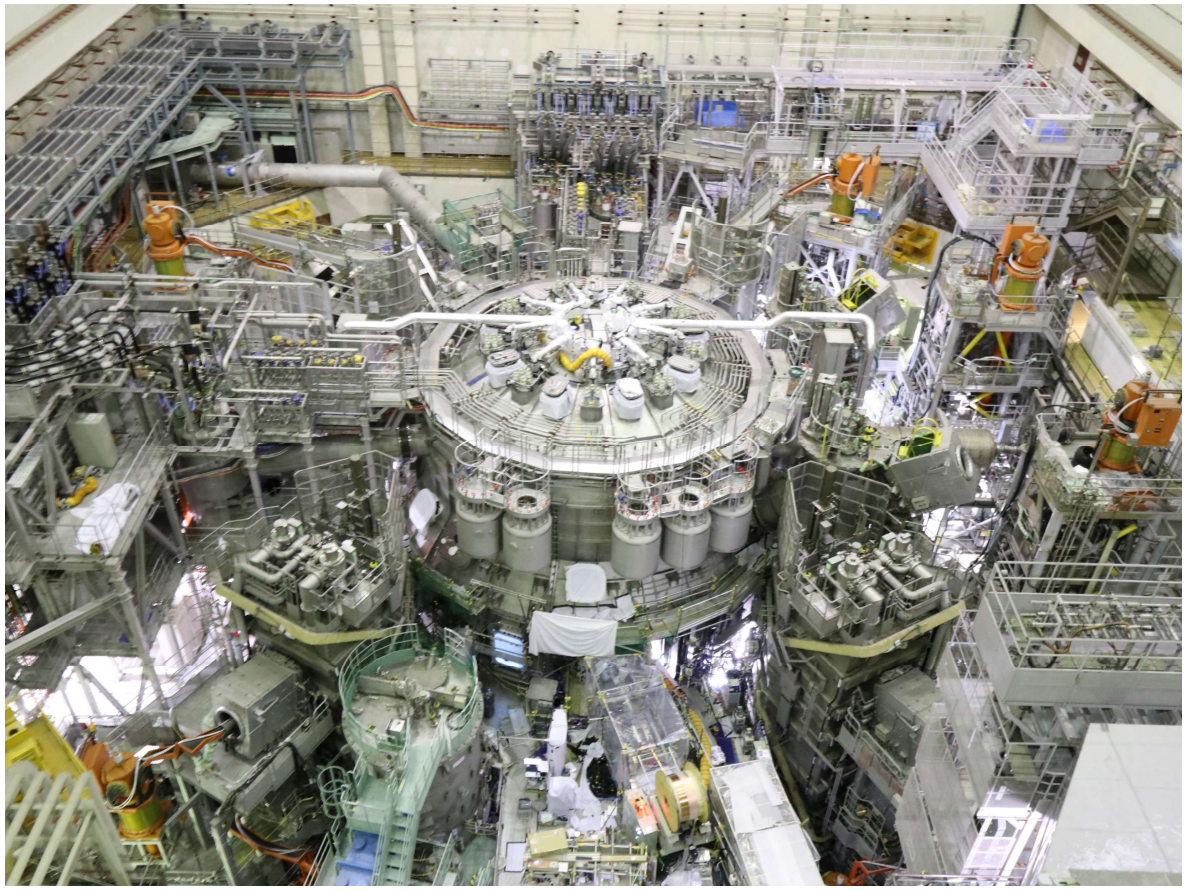
Superconducting Tokamak JT-60SA

- **Largest superconducting tokamak in operation**
  - 2023 October : First plasma produced
- **Satellite of ITER**
  - Supporting ITER program and fostering the next generation of scientists and engineers

2024~ upgrading (mainly installation of the in-vessel components) towards :

- D-D plasma with Ip=5.5MA
- Current drive with NB and RF



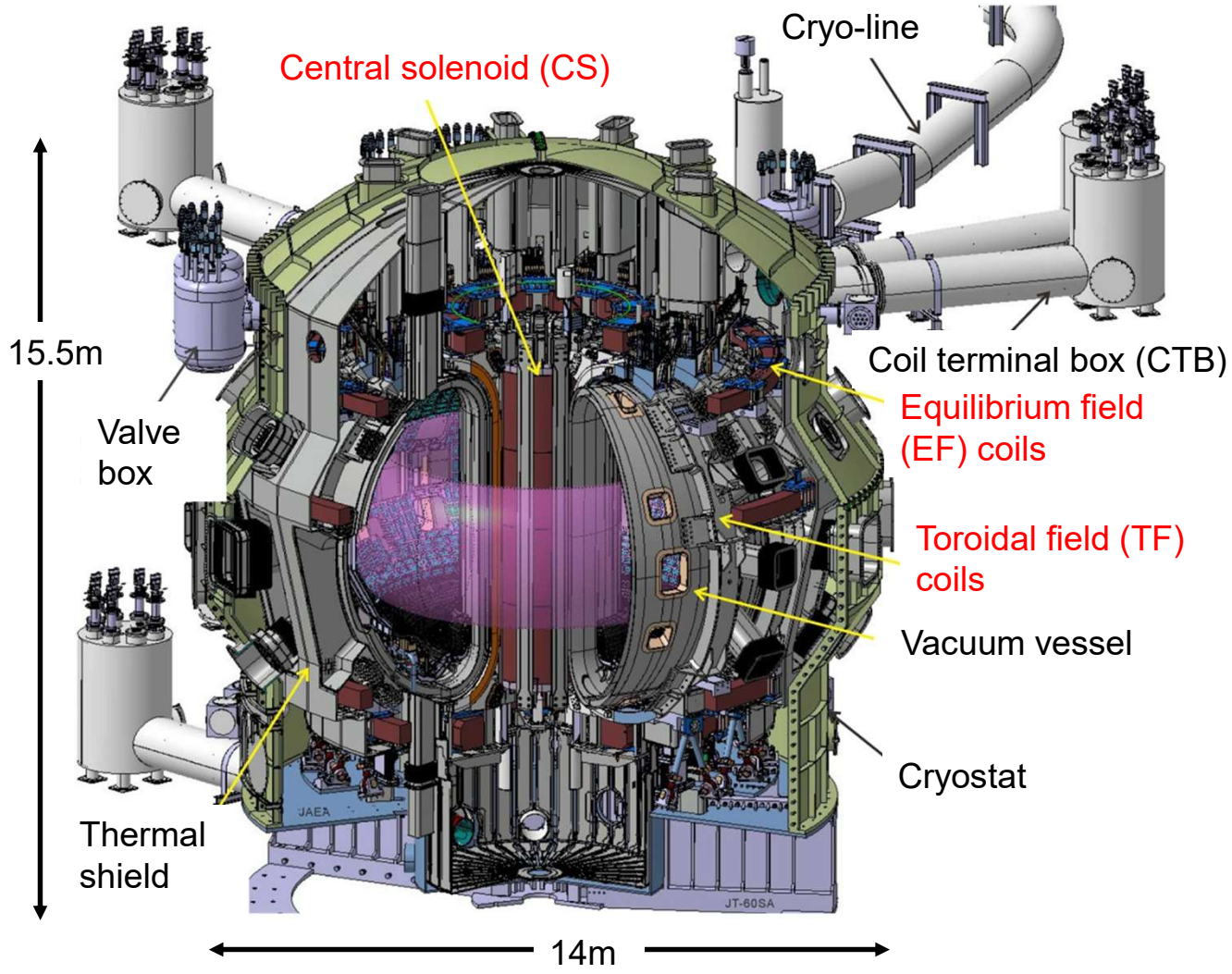
JT-60SA was jointly constructed and is jointly funded and exploited under the Broader Approach Agreement between Japan and EURATOM

Superconducting Magnet system

Fully superconductive magnet system

- 18 Toroidal Field coils (NbTi)
- 6 Equilibrium Field coils (NbTi)
- 4 Central solenoid modules (Nb_3Sn)

	Nominal current	Magnetic field	Weight
TF	**25.7kA**	**5.65T**	**400t**
CS	**20kA**	**8.9T**	**100t**
EF1	**20kA**	**4.8T**	**160t**
EF2	**20kA**	**4.8T**	
EF3	**20kA**	**6.2T**	
EF4	**20kA**	**6.2T**	
EF5	**20kA**	**4.8T**	
EF6	**20kA**	**4.8T**	



The JT-60SA experiment

- 2020

  Integrated commissioning was started :

  - TF coil successfully operated with the nominal current (25.7kA).
  - In March 2021, EF1 short-circuit incident occurred.
    => Insulation reinforcement and HV tests were done.

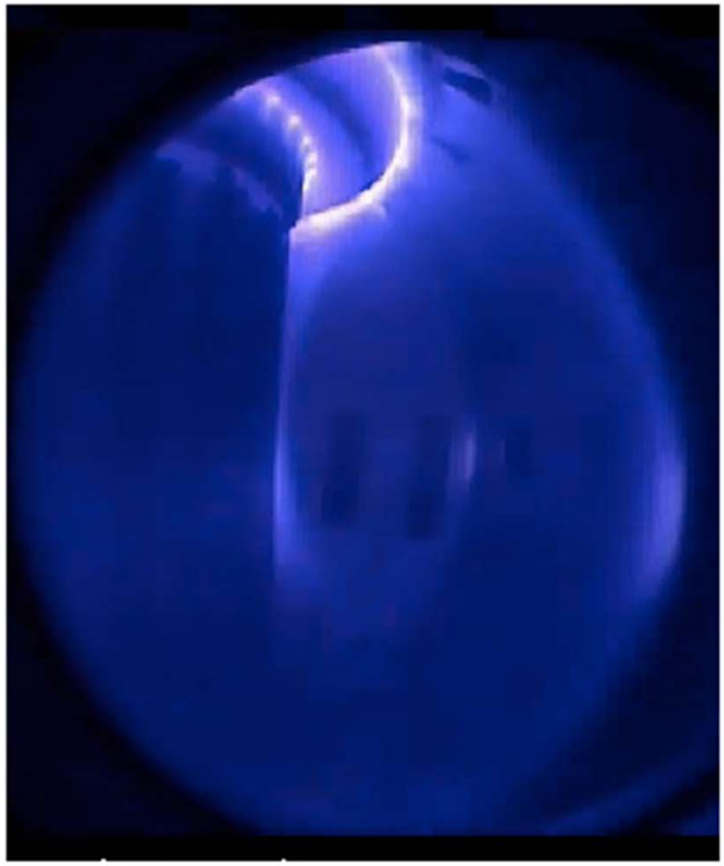
- 2023

  Integrated commissioning was resumed.

  - Single PF operation: 10kA
  - TF 100% current, PF coil current < 5kA
    - First plasma was achieved.
    - MA-class plasma (maximum Ip=1.2MA) was operated.

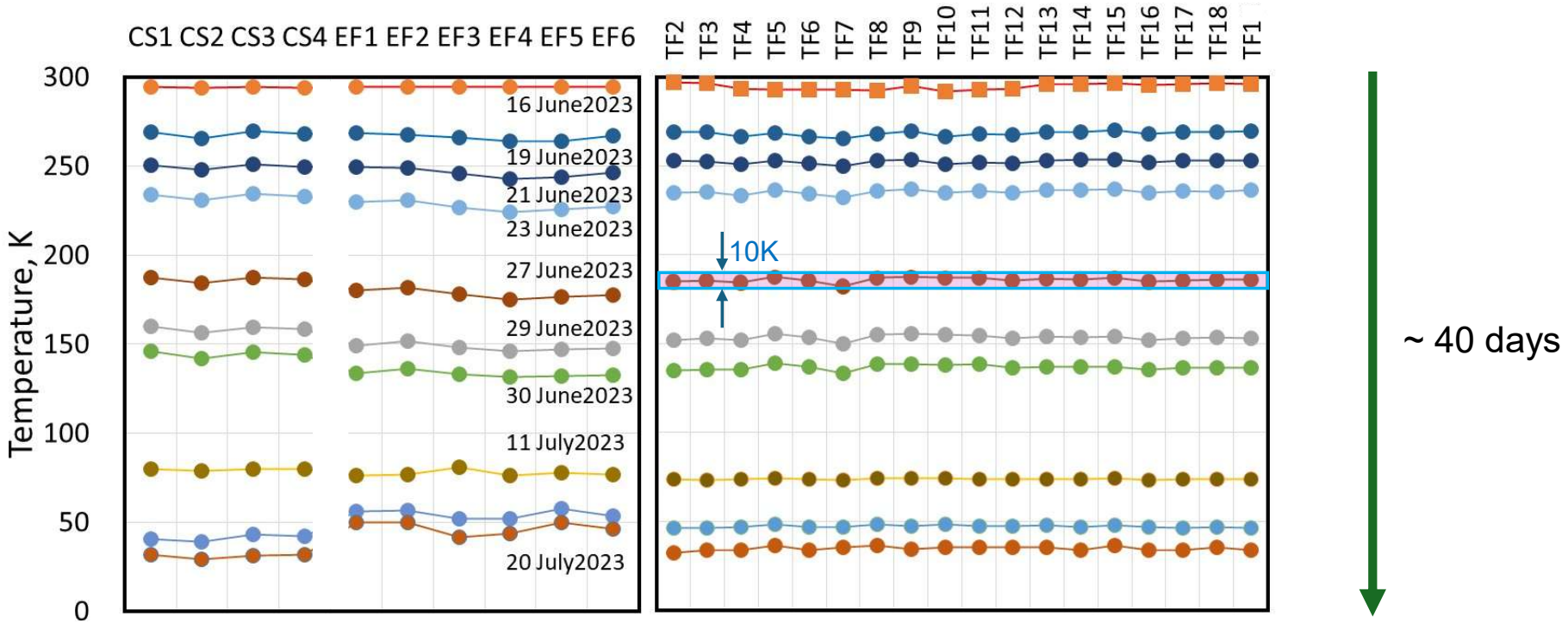
- 2024 ~

  Aiming to 20 kA operation for PF coils, improvement of insulation, reduction of operation voltage and cryostat vacuum monitoring system were applied to avoid discharge.



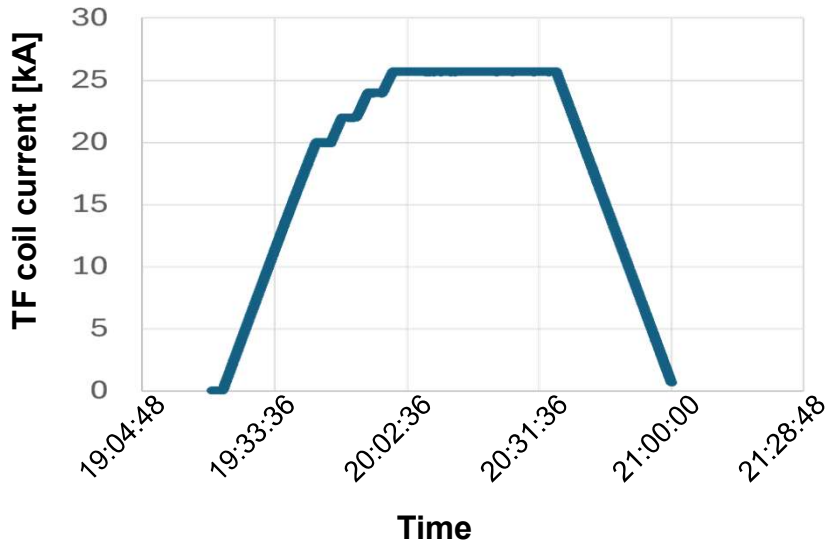
Integrated commissioning results
Cooling down

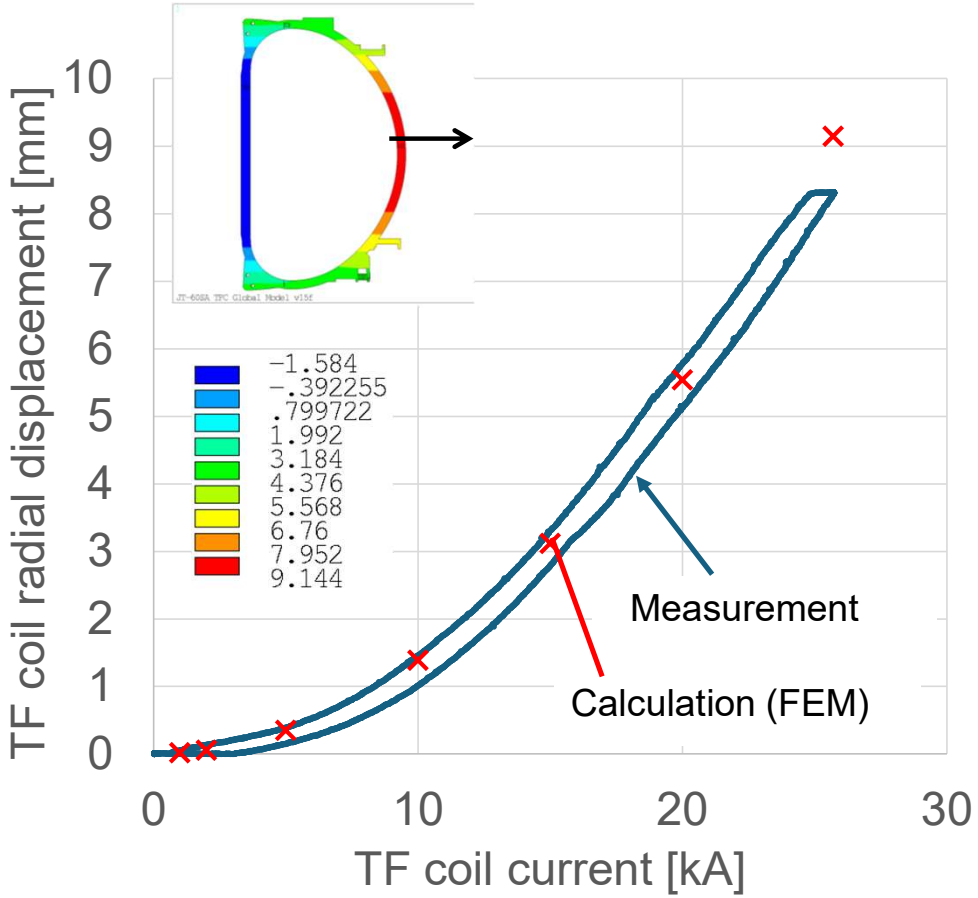
- In about 40days, cool-down operation of 660-ton magnet system was completed under the temperature control.
- During cool-down (from 300 to 80K), the differential of temperature between CS1~4, EF1~6 and all TFs were controlled within the allowable range (<10K).



In-plane deformation of TF coil

TF coil was successfully operated with nominal current (25.7kA) .



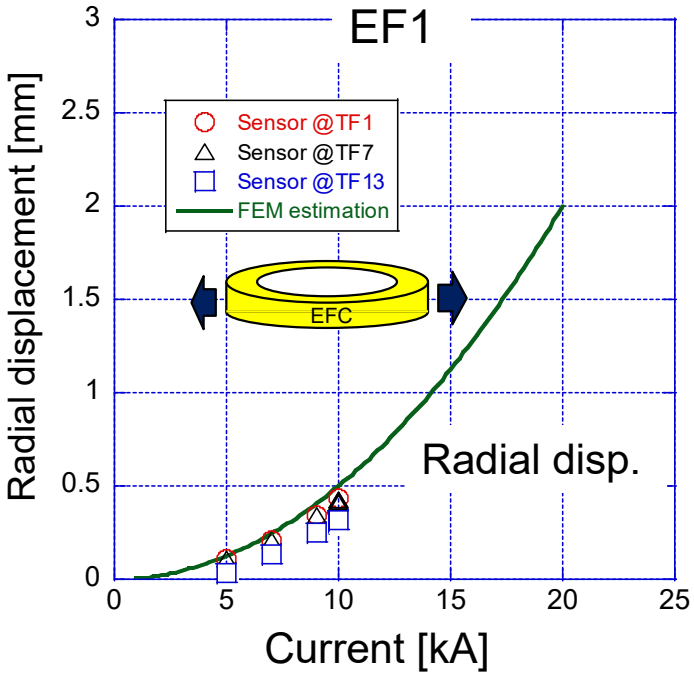


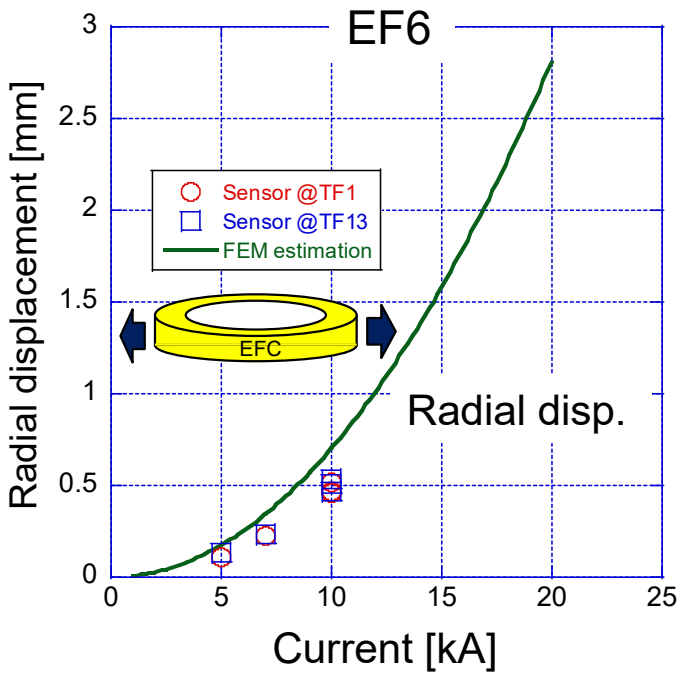
The displacement of TF coil was good agreement with the result by the calculation.

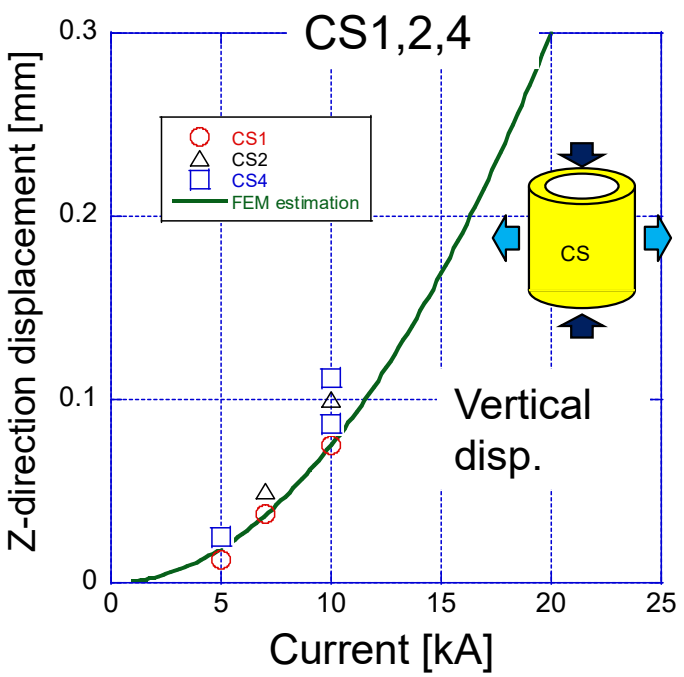
The mechanical design of the TF coil was as expected.

Deformation of PF coils

In the single coil energization tests, PF coil were successfully operated with 10kA in maximum. (except EF2 and CS3)





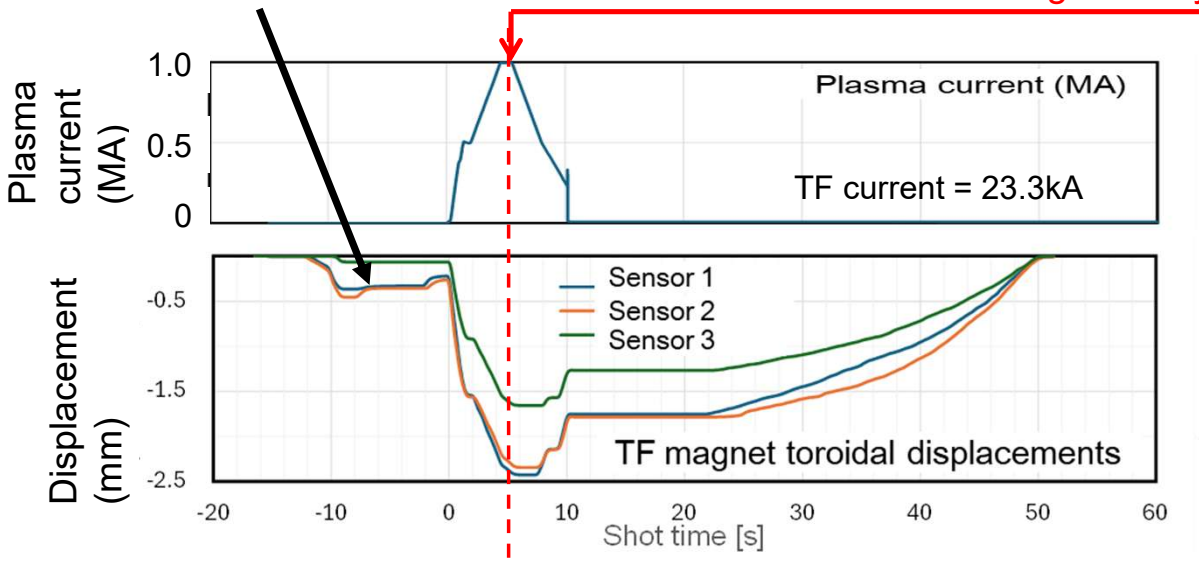


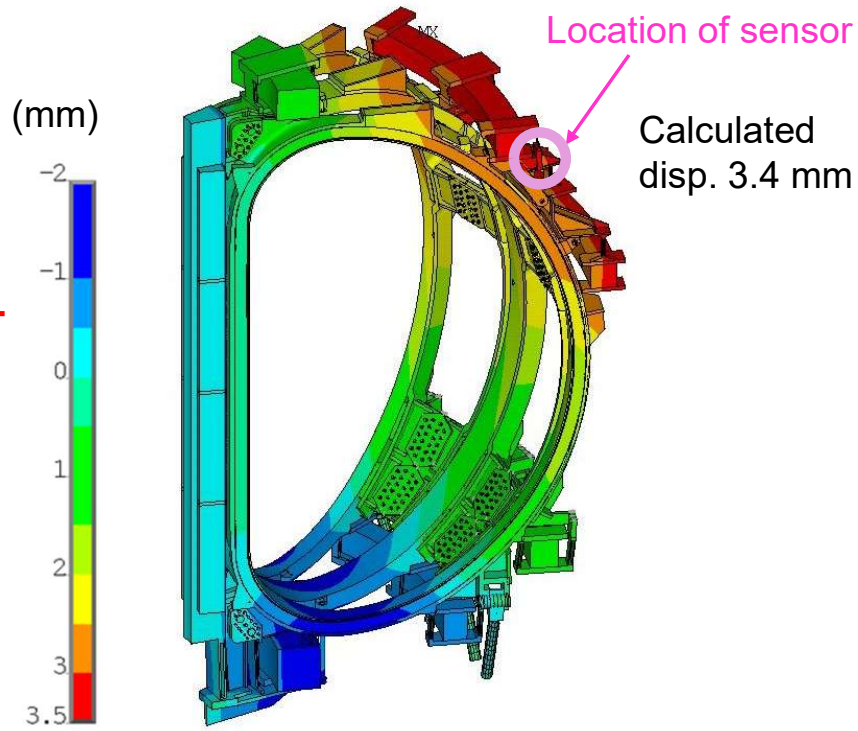
The measured displacement of the EF and CS coils are proportional to the square of the current as expected.

Out-of-plane deformation in the plasma operation

Production of 1st plasma, and MA class plasmas were also successfully produced by simultaneously operation of all magnets.

Toroidal (out-of-plane) displacement of TF coils induced by over-turning force was measured.





Measured deformations of TF and PF coils are consistent of the deign.
=> There was no problem with the mechanical stiffness of the magnet system.

Aiming to 20kA operation of PF coils

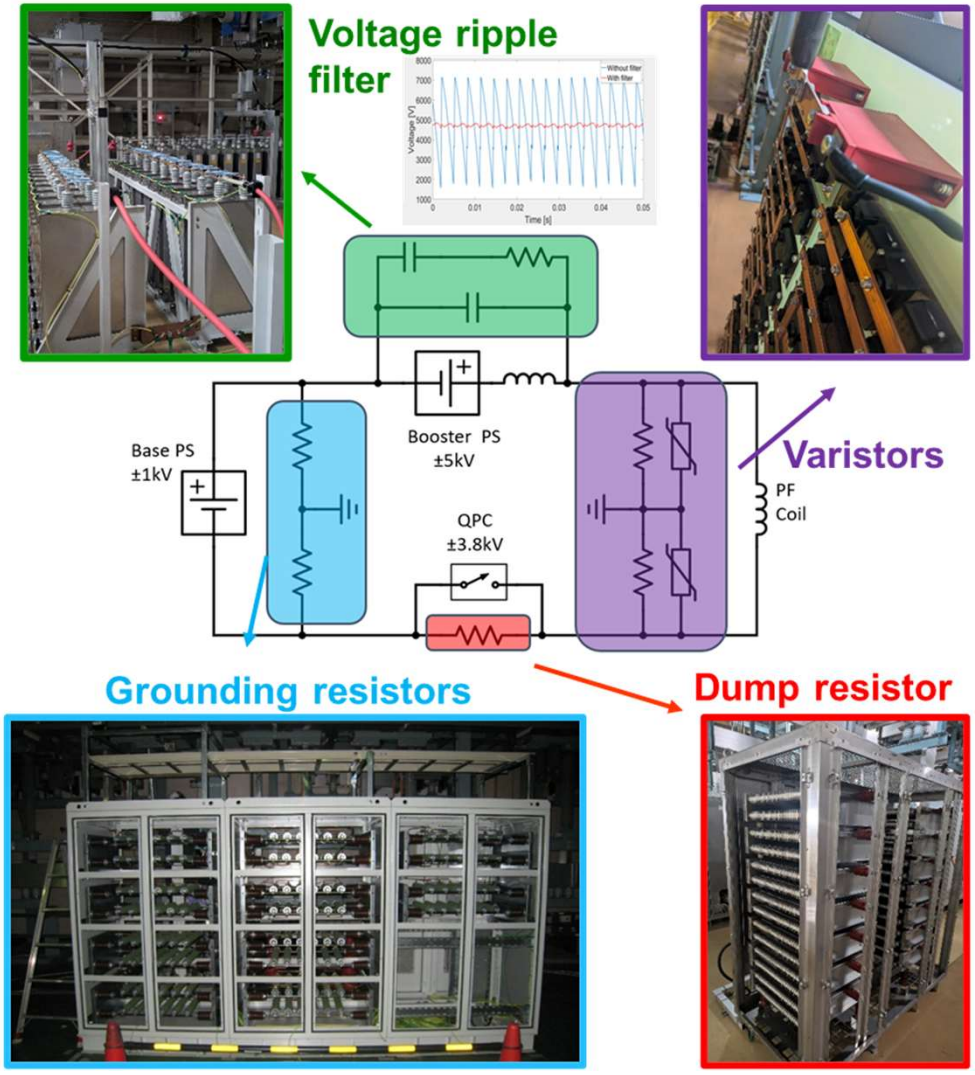
Issues to be solved for OP-2 :

1. Improvement of magnet withstand voltage capability
   - Insulation reinforcement
   - reduction of CS dump resistor of fast discharge unit.
   - PS spike noise reduction

2. Noise reduction on the quench detection system

3. Enhancement of vacuum monitoring system
   Installation of vacuum sensor to detect degradation of vacuum to avoid Paschen discharge.

1. Improvement of magnet withstand voltage capability ~ PS spike noise reduction~



Transient voltage is tried to be mitigated according to increasing PF coil current.

Toward OP-2, several upgrades in the power supplies, CS dump resistors, and grounding scheme will be applied.

Due to decrease the spikes of the voltage, the safety of magnet system will be improved.

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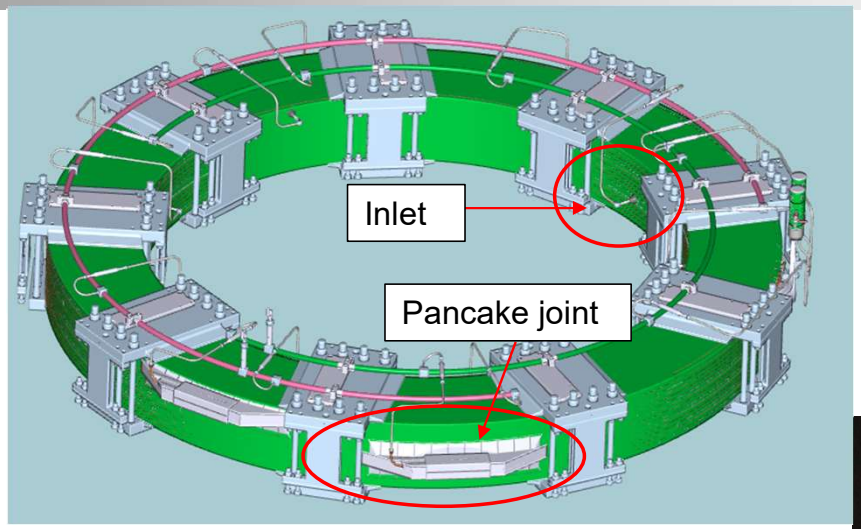
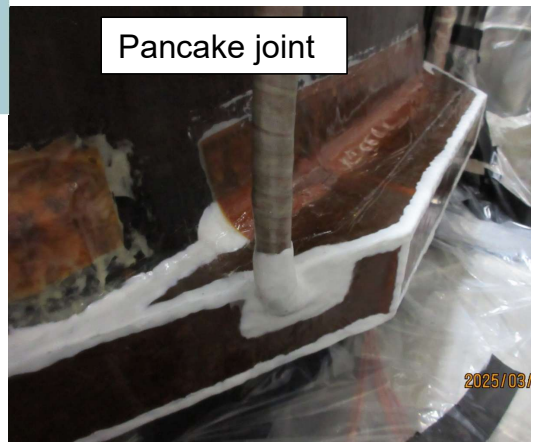
1. Improvement of magnet withstand voltage capability ~ Insulation reinforcement ~

After OP-1, additional insulation enhancement for PF coils is on-going.



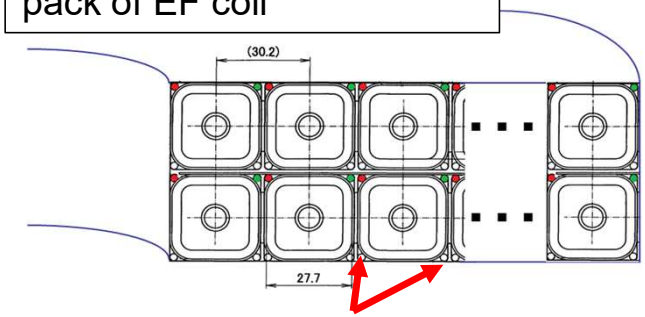


- He inlets for EF1~EF4 coils.
- Pancake joints for EF1~EF3 coils.
- He inlets/outlets and wire extractions for all CS modules.

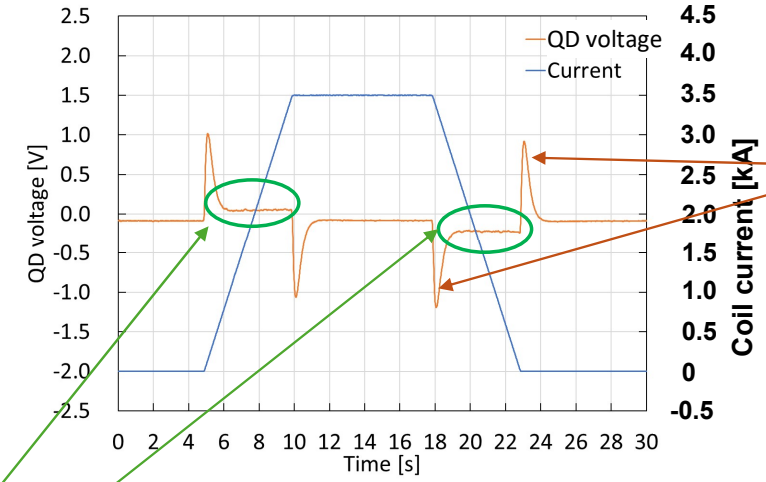
After the work for each location, it was confirmed that the target has enough performance of insulation by the Paschen test in 7kV DC.

2. Noise reduction on the quench detection system

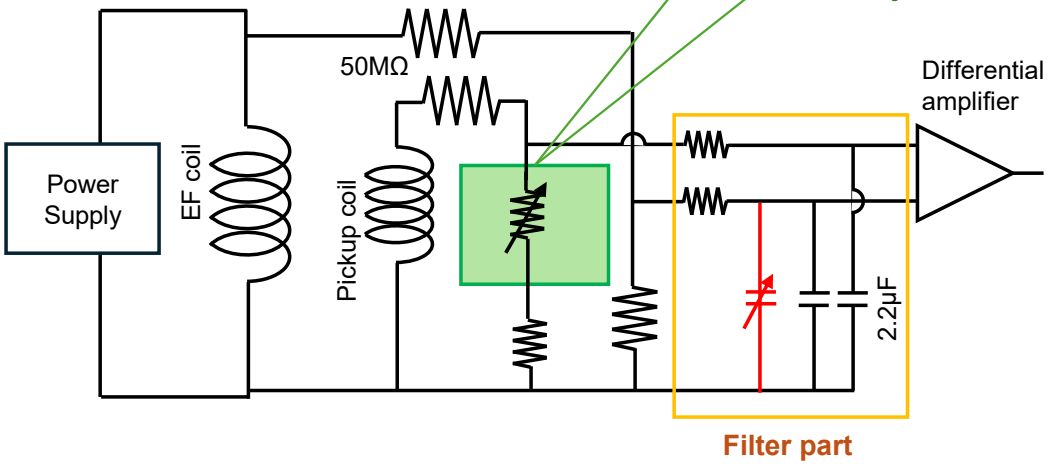
Cross section of winding pack of EF coil



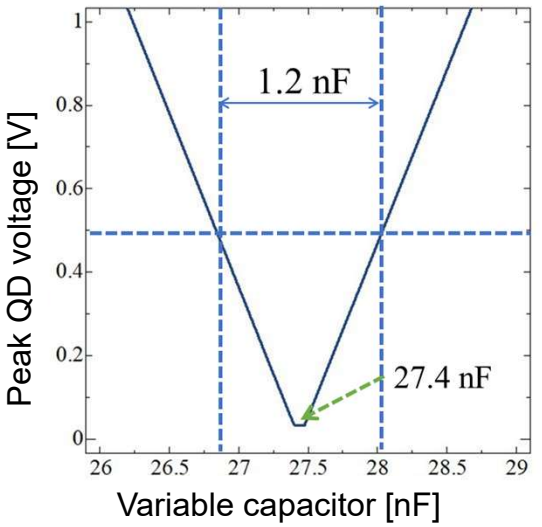
Voltage difference between the coil and the pickup coil must be zero.



By the variable resistance, adjustment was successfully done.



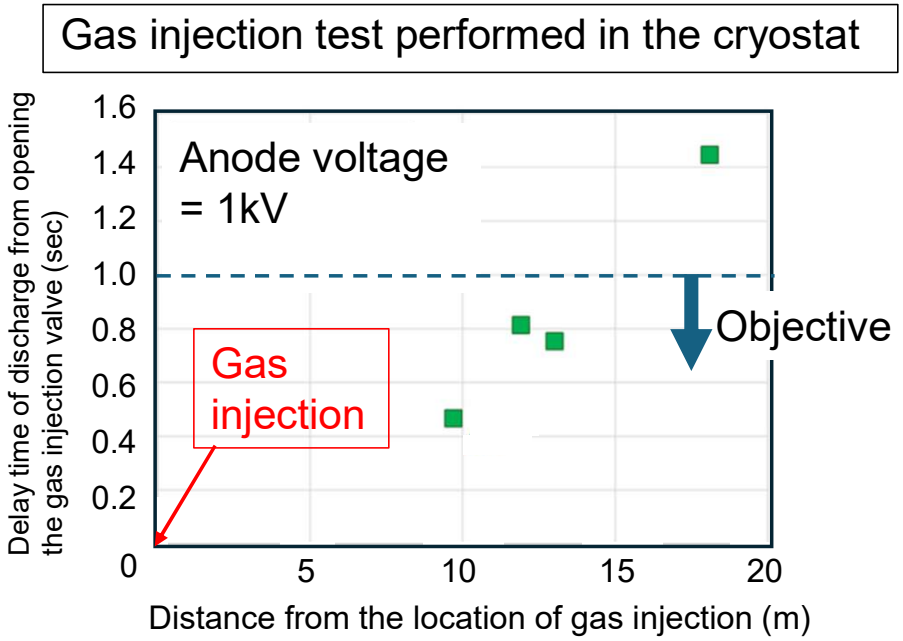
To reduce the spike noise, variable capacitors are added at filter part.



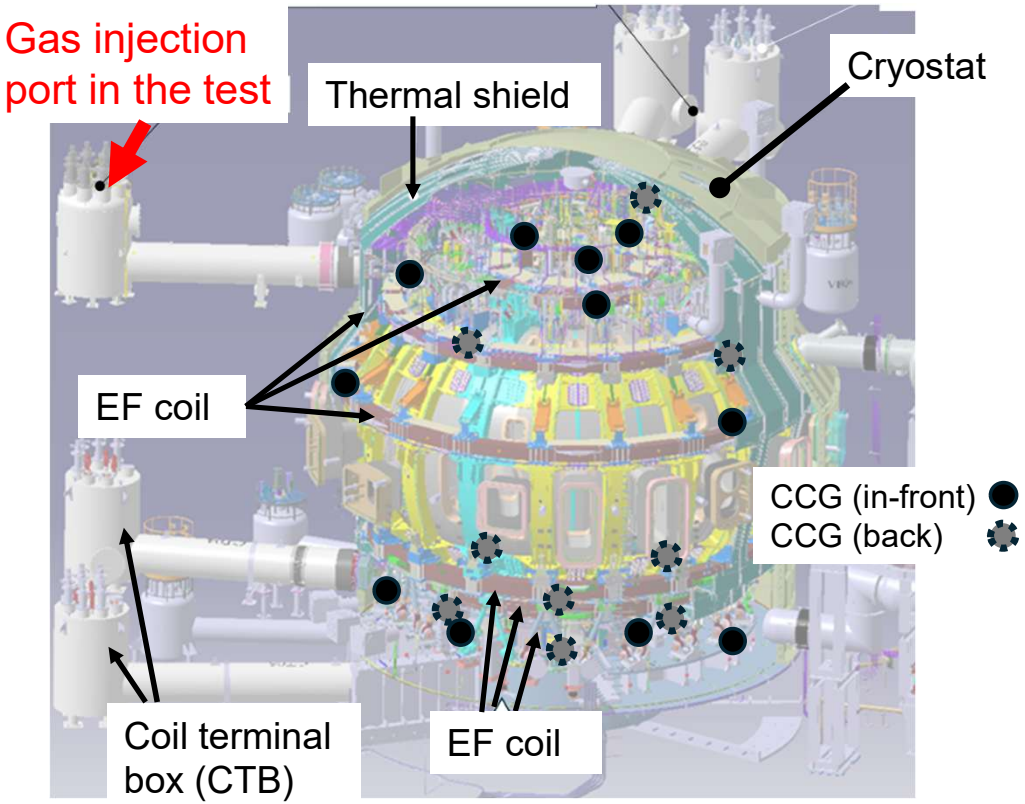
For the circuit model, the noise was able to be canceled.

3. Enhancement of vacuum monitoring system

As a coil protection system, cold cathode gauges (CCG) are installed around EF coils.



CCG should be installed within 15m from the gas source.



CCG will be also installed in all CTB from OP-2.

Coil operation is possible to stop before the peripheral pressure becomes Paschen condition.

Summary

- The first plasma in JT-60SA was successfully achieved in 2023. Most of PF coils was successfully operated with 10kA in maximum.
- It was confirmed that there were no problem in terms of the mechanical stiffness of TF and PF coils.
- Aiming to the nominal current (20kA) operation for PF coils, the following actions are being performed :

  - As the countermeasure of operation voltage, insulation enhancement and revising PS equipment are in progress.

  - QD and CCG systems are improved to increase the performance of coil protection.

These actions will contribute to the high performance plasma operation in OP-2.

谢谢您的关注！

Thank you for your attention !