TEC-FNT # 2835

MACHINE ENHANCEMENT OF TOKAMAK DEVICE FOR THE JT-60SA NEXT OPERATION

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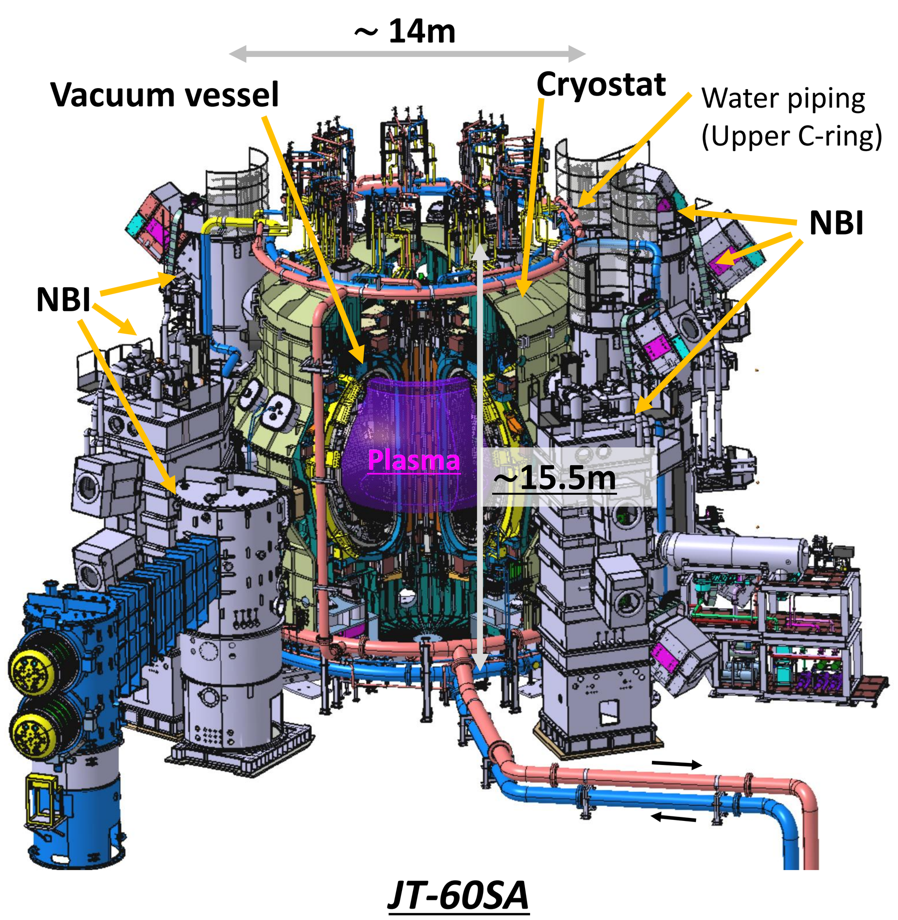
Abstract

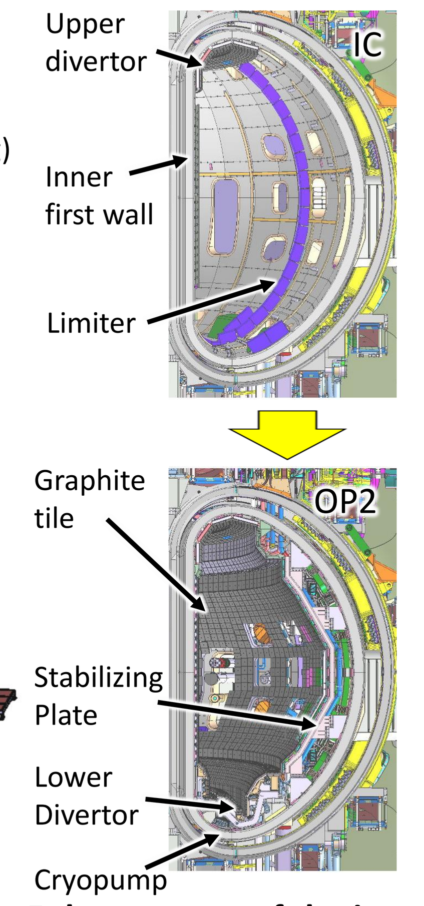
The largest superconducting tokamak device, JT-60SA, achieved the first plasma successfully in the previous Integrated Commissioning (IC) in 2023. In order to achieve high power plasma heating in the next operation, the Maintenance & Enhancement phase 1 (M/E-1) has been started since January 2024. 18 ports are installed to enable high heating power injection with 3 MW ECRH and 23.5 MW Neutral Beam (NB), and to install the diagnostic system. Cooling water circulation system for in-vessel components is developed. The measures for the issues in previous operation will contribute to robust plasma operation on ITER.

Summary

- The installation of 18 ports and 5 joints has been completed with high accuracy by dedicated jigs and positioning measurement.
- The cooling water circulation system for the in-vessel components is being maintained and enhanced, enduring electrical isolation and displacement absorption of the Vacuum Vessel (VV), the Cryostat, and the stage.
- Gas ballast system, which dilutes condensable gas, will be enhanced to prevent failure of DRy vacuum Pump (DRP).
- The number of Cold Cathode vacuum Gages (CCG) will be increased to improve coil interlock system redundancy and response speed.



JT-60SA

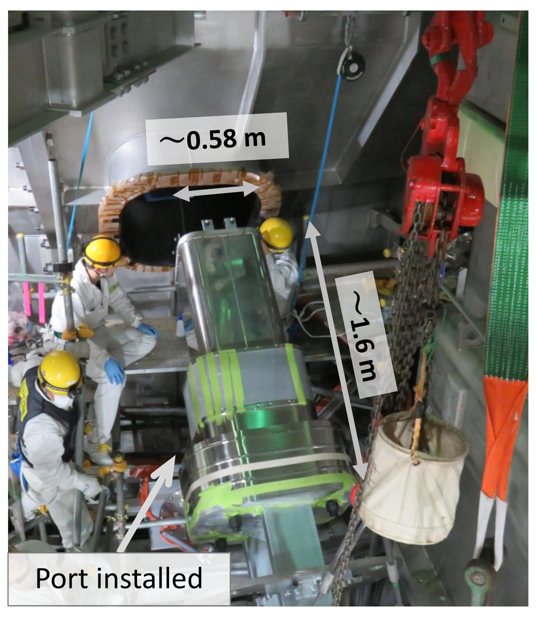


Enhancement of the in-vessel component for OP-2

Preparation for the High-Power Heating

Port Installation for High-Power Plasma Heating Operation

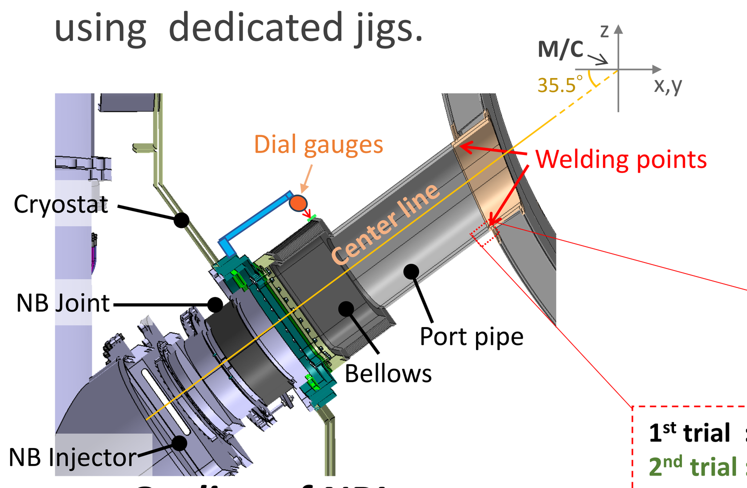
- The VV is required to install ports for new equipment such as NBI and diagnostics.
- The NBI system used in the JT-60U are re-used in JT-60SA with the same locations. Owing to clearance with NBI tanks and cryostat, **tolerance of the NBI port is ±2 mm at its centerline with absolute coordination.**
- Even a small welding distortion can cause major deformation with this large-scale structures (ex. port length: 1.6m).



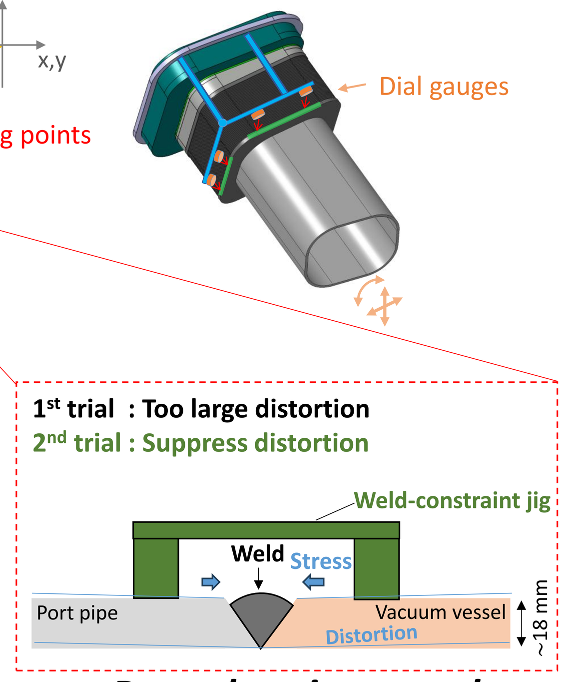
Port installed

Welding procedure to achieve high precision

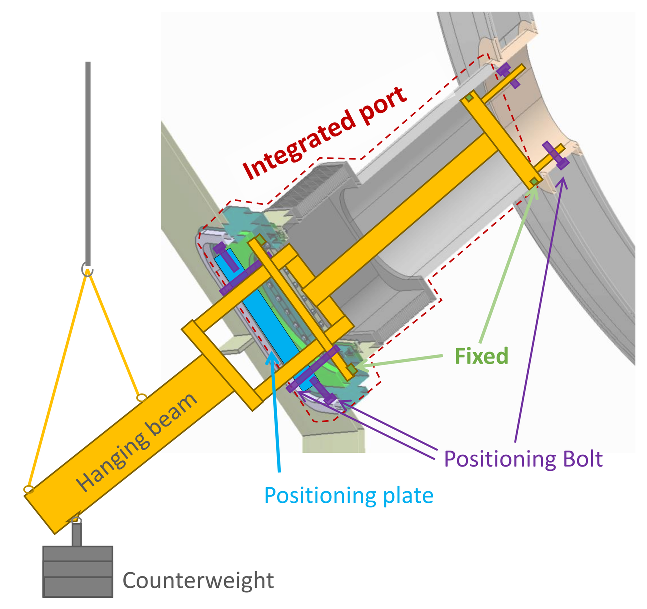
- Position measurement: dial gauges and laser trackers.
- Procedure was improved through test, and trial & error.
- Port comportment such as bellows and port pipe are combined as Integrated Port, and installed using dedicated jigs.



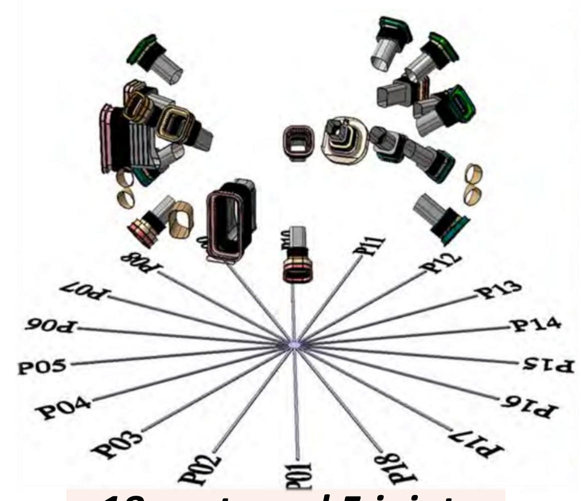
Outline of NBI port



Procedure improved



Lifting and positioning



18 ports and 5 joints

Installation of all the 18 ports and 5 joints have been completed.

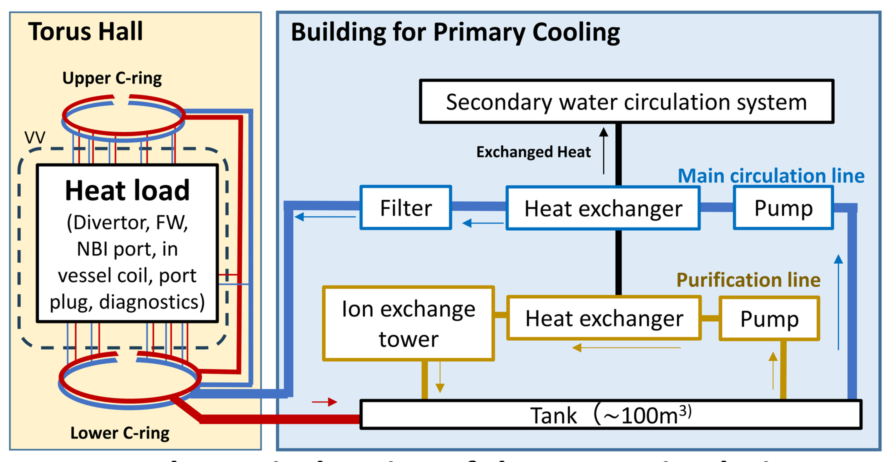
- In addition to 55 ports already installed before first plasma, installation of all 73 ports, which is JT-60SA device design, has finely completed.

Cooling Water Circulation System for Long-Pulse Plasma Operation

- In the Operation Phase 2, high heat flux of several seconds will be applied to in-vessel components.
  - e.g., 10 MW m^{-2} for 7.5 s and 15 MW m^{-2} for 5 s on the lower divertor are planned [1].
- Water circulation system in the JT-60 is maintained for early supply of water-cooling in the JT-60SA.
  - Maintenance of equipment, such as pumps and heat exchanger, is completed.
  - Parts of water piping are being installed.

Enhancement plan of the cooling water circulation system

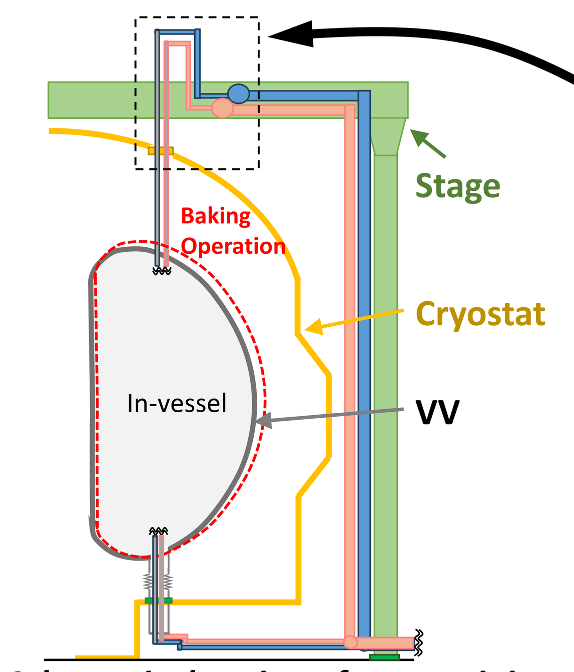
Research phase	Initial research phase		Integrated research phase
Operation Phase	OP-1	**OP-2 to OP-4**	TBD
Piping	None	**Enhanced**	Used (partially enhanced)
Water circulation system	Not maintained	**Re-use of JT-60U (~ 500m^3/h , ~1.4MPa at pump)**	Enhanced to full specification (~3000m^3/h, >2MPa)



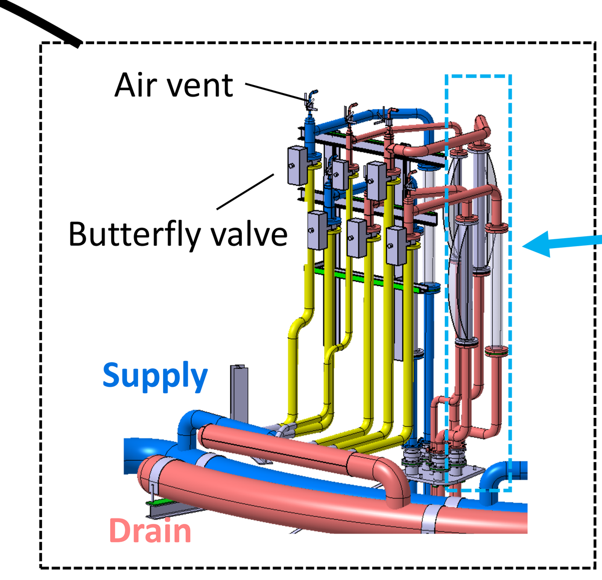
Schematic drawing of the water circulation system during the Initial Research Phase

- The cooling water is required to pass through three different components; **the VV, the Cryostat, and the stage.** Each components have different electrical grounding and movement in baking operation and seismic event.

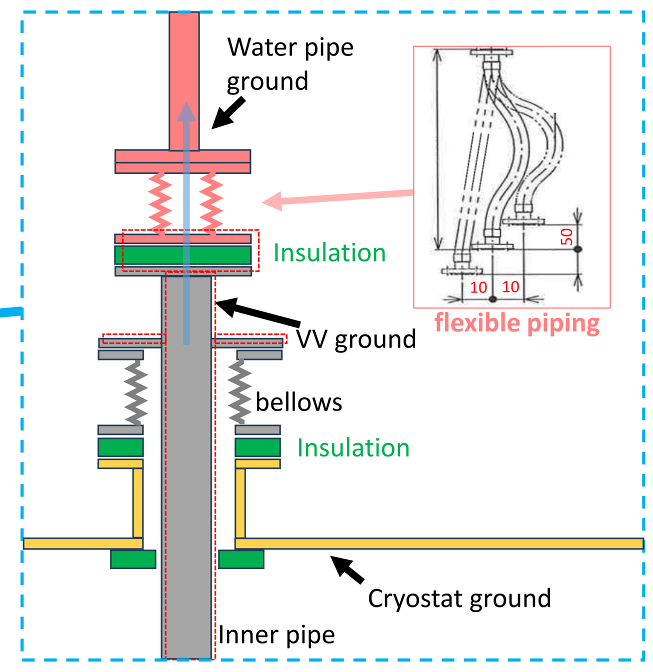
→Flexible piping is designed to absorb displacement of 50 mm in vertical and 10mm in horizontal.



Schematic drawing of water piping pass around tokamak



Water piping (Upper C-ring)



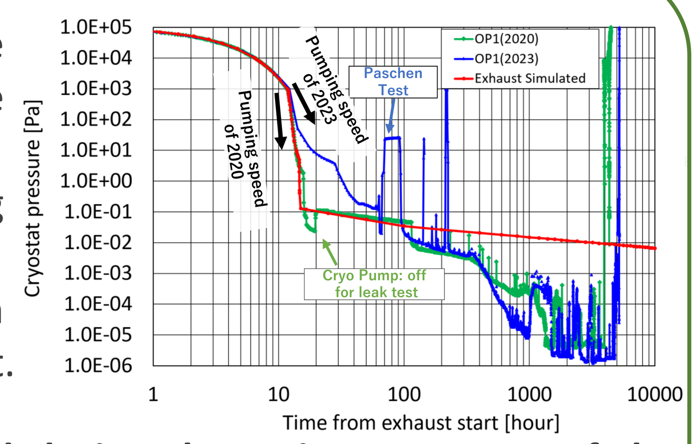
Piping design to satisfy electrical insulation and thermal stress

Improvements in Vacuum Pumping System and Vacuum Interlock System

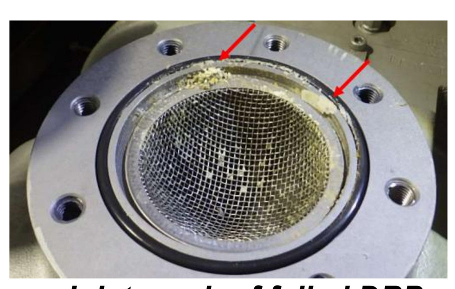
Improvement in Cryostat Vacuum Pumping System

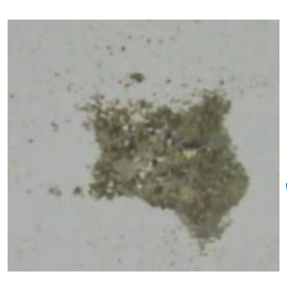
- Vacuum pumping of the cryostat is carried out under severe conditions, owing to carbon compounds such as polyimide and polyester which constitute multi-layer insulation (MLI).
- In addition, the electrical insulation of the superconducting coil terminal had been reinforced with resin [1].

➢ Speed of vacuum pumping downed due to outgassing from carbon compounds, brought by the insulation reinforcement.

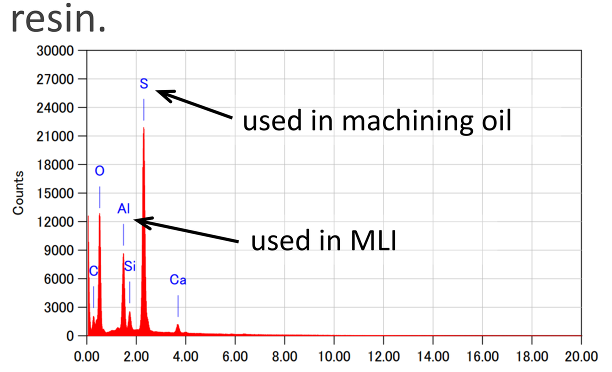


- **Two DRy vacuum Pump (DRP) for cryostat pumping failed during the IC in 2023. One of the cause is damage to the bearings by solidified impurities.**
- Impurities are assumed to originate from MLI ,machining oil and resin.


Inlet mesh of failed DRP


Solidified impurity materials

Elemental analysis



Energy-dispersive X-ray spectroscopy

●Non-condensation condition at compression zone in pump

$$x_{cond} < \frac{p_{cond,sat}(T_{comp})}{P_{comp}}$$

$p_{cond,sat}(T)$: saturation pressure of condensable gas
P_{comp} : total pressure at compressed zone
T_{comp} : temperature at compressed zone
x_{cond} : mole fraction

- To prevent condensation, a gas ballast system will be employed.
  - Inject dry air to decrease the mole ratio of condensable gas before compression.
- Dilution ratio > 10 is assumed.

→ Robust operation in the next vacuum pumping

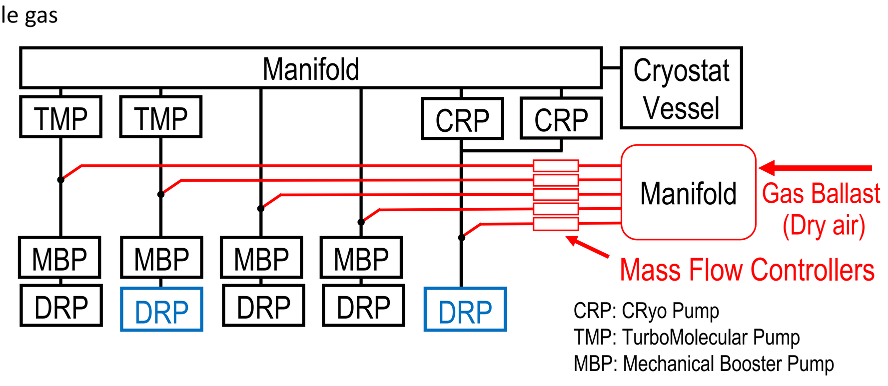


Diagram of the cryostat vacuum pumping and gas ballast system

Vacuum Interlock Gauges for Reliable Superconducting Coil Protection

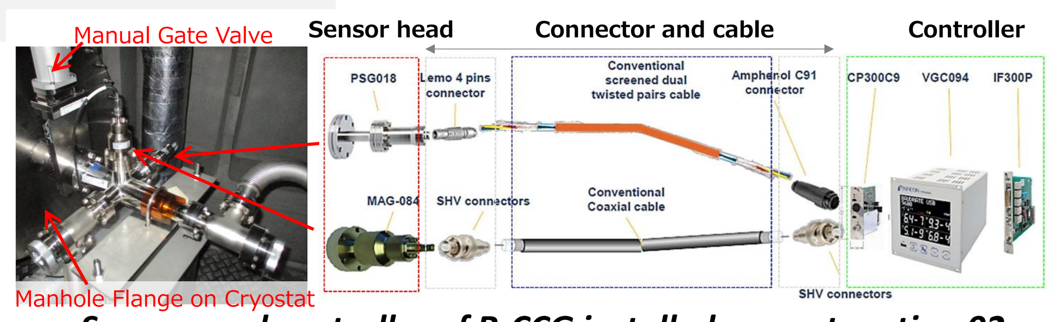
- Superconducting Coil protective I/L system, that rapidly detects abnormal vacuum degradation and achieve safety termination of the coils, has been constructed from the Operation Phase 1 (OP-1).

Commercial type Cold Cathode vacuum Gauge(CCG)
- used in a relatively low magnetic field environment of Room temperature **(called R-CCG).**

→ **Aiming at higher reliability**

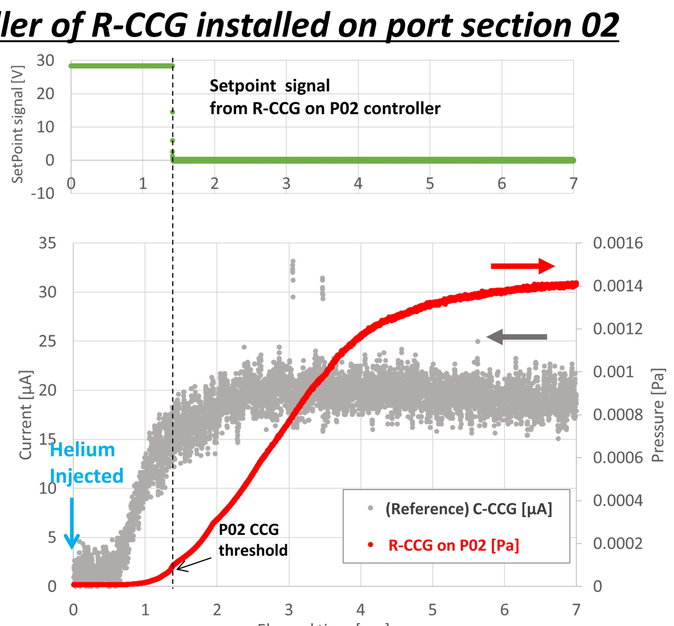
C-CCG (self-product) [2,3]
- installed on SC coil at cryogenic temperature.

Interlock system response time
- Time of coil current start decreasing after CCG send the setpoint signal.
  - total 73 ms for the EF/CS coil.
  - total about 500 ms for the TF coil.



Sensors and controller of R-CCG installed on port section 02

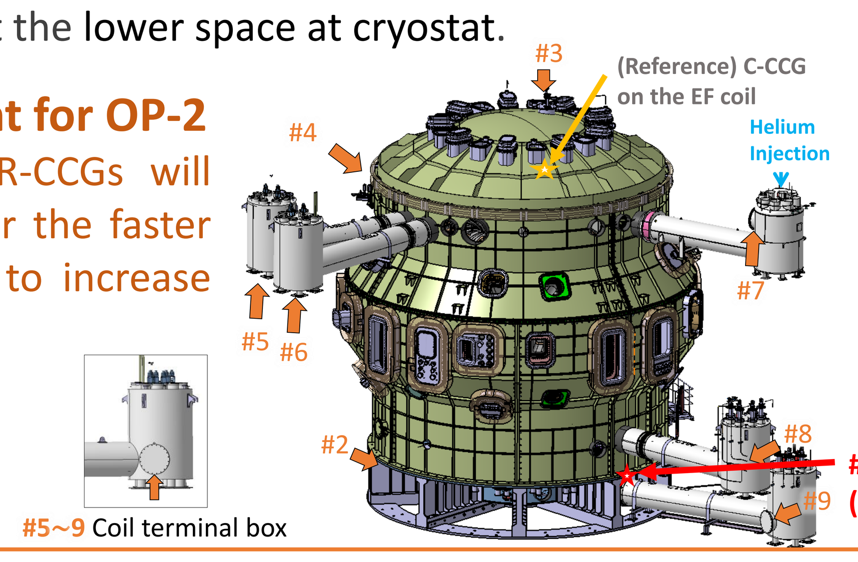
Test onsite on OP-1
- Controller of the CCG output setpoint signals at 1.41 s after injection of Helium gas about 25 Pam^3.
- C-CCG detect pressure increases about 0.5 s earlier than the R-CCG at the lower space at cryostat.



CCG and setpoint signal at test onsite

Improvement for OP-2

Additional 8 R-CCGs will be installed for the faster response and to increase redundancy.



[1] H. Shirai, et al., Nucl. Fusion. 64 (2024) 112008. [2]K. Fukui, et al., IEEE Trans. Appl. Supercond. 35 (2025) 4202005 [3] K. Tsuchiya., et al., This Conf. [ID: 2727 & 3492]