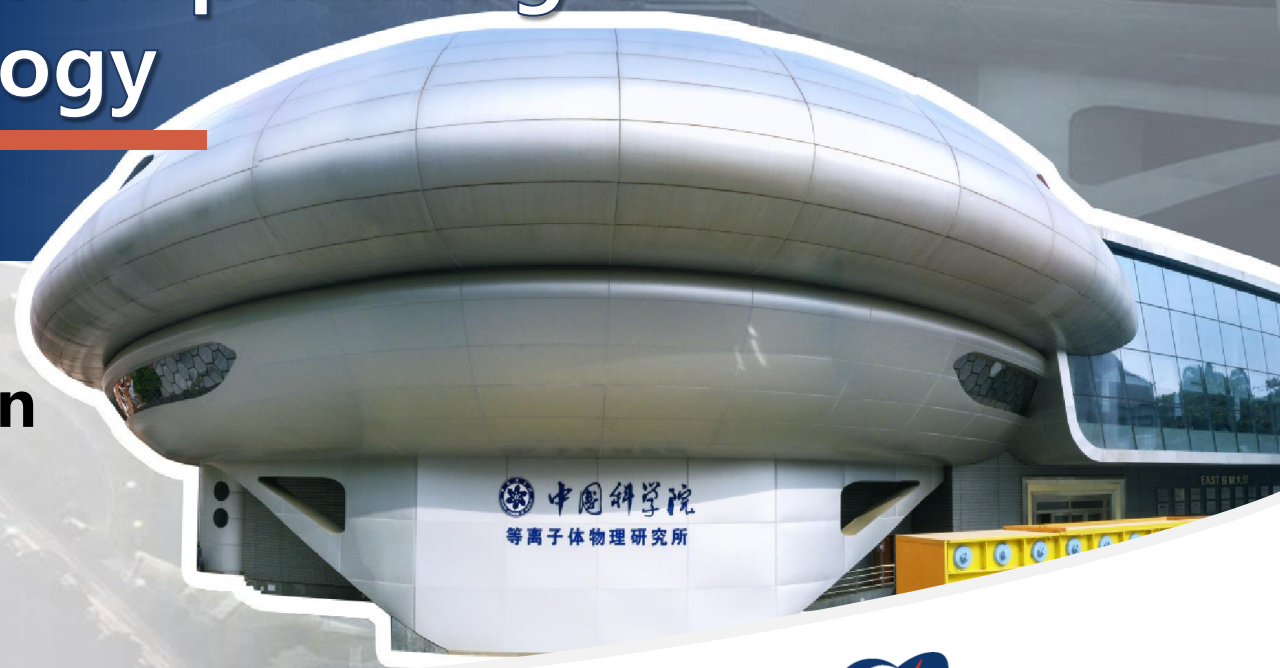


Research status and cooperation planning of remote maintenance technology

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Email: chengyong@ipp.ac.cn

2024.3.21



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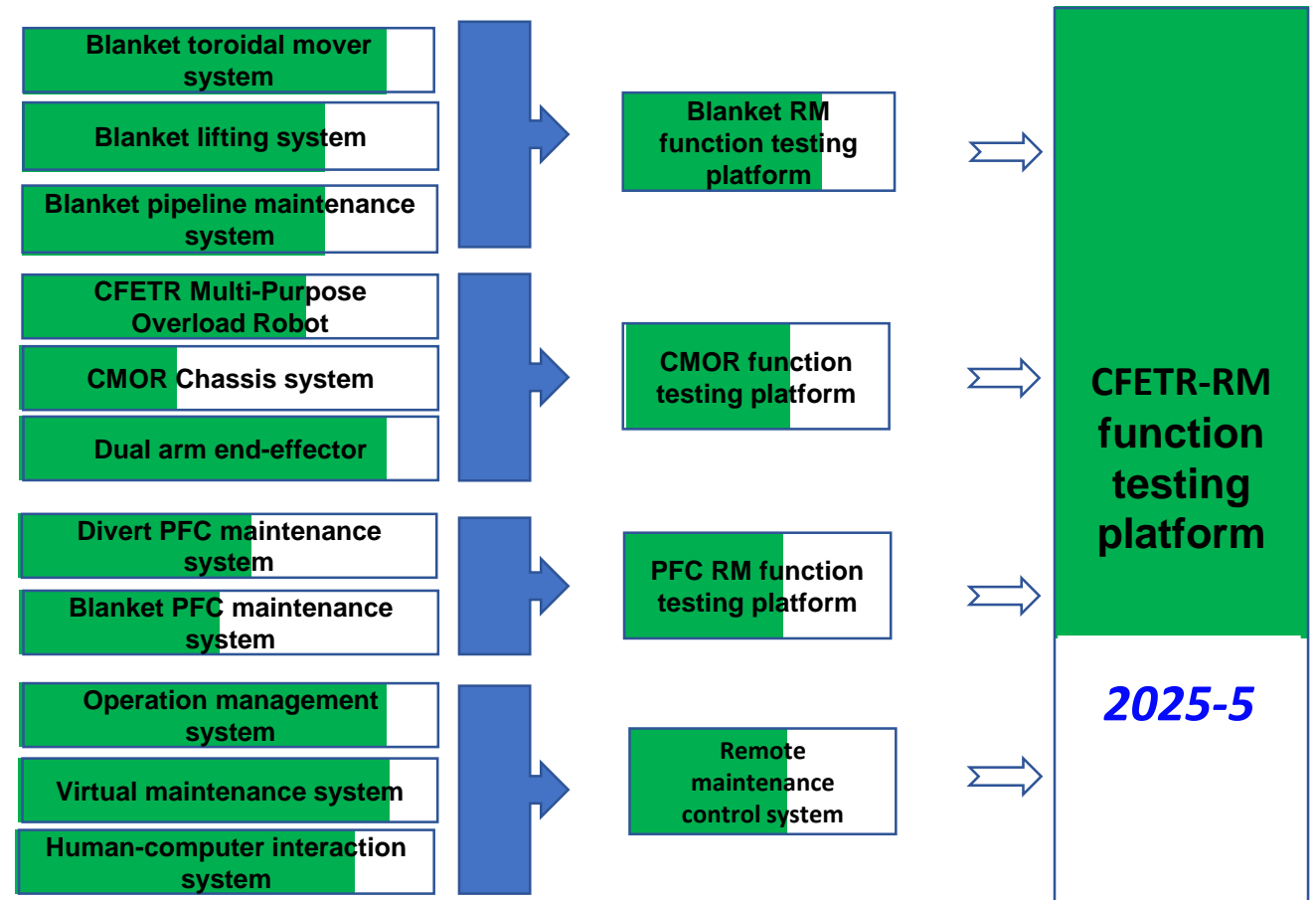


Research status of RM technology



The CFETR-RM function testing platform will be completed in May 2025, and many subsystems have already been constructed.

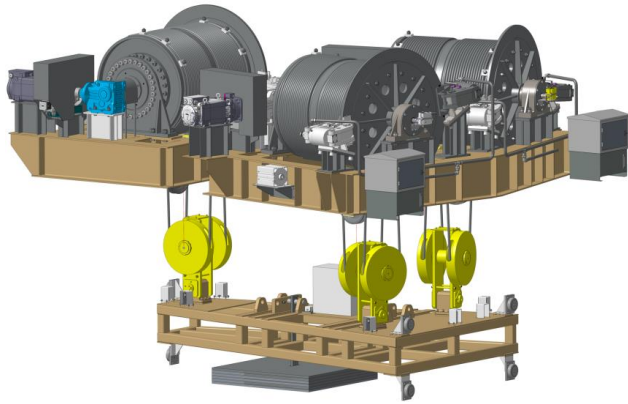
Some remote maintenance function tests have been initiated, Inviting everyone to join us in maintaining validation experiments.



Research status of RM technology



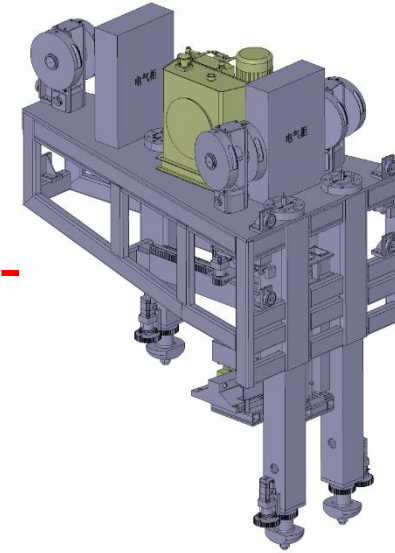
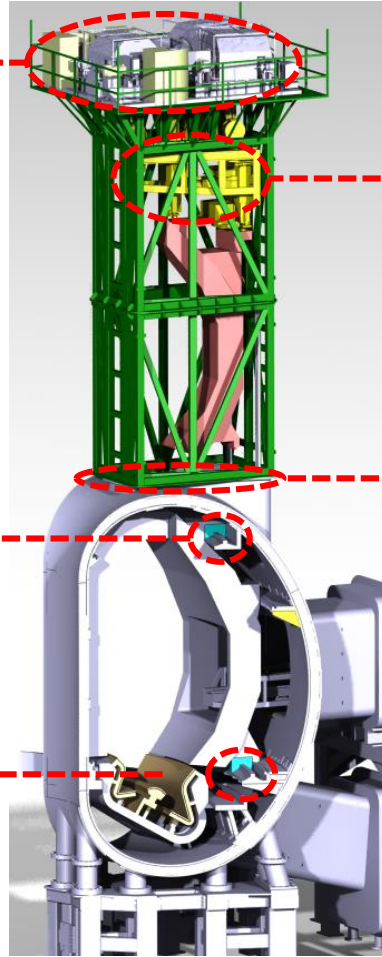
CFETR Blanket Remote Handling System



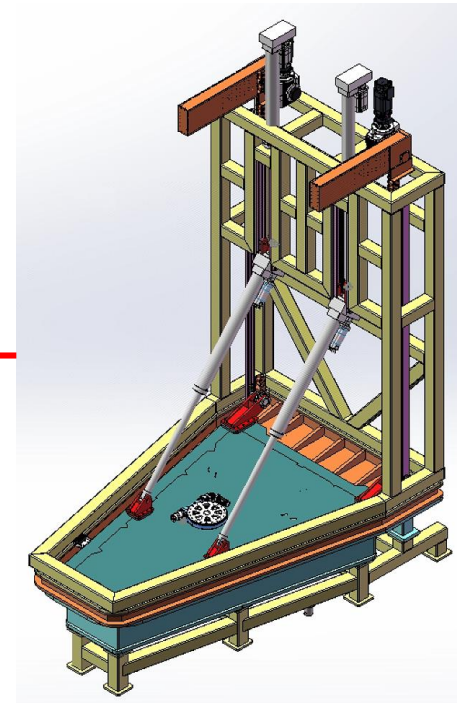
Three cranes work together to lift the blanket segment (60t). The lifting cask frame and crane system were successfully developed in April 2023.



Blanket toroidal Mover system, repositioning accuracy ± 1 mm. Two mover system finish the functional test in June 2023.



Blanket lifting platform to connect/disconnect blanket segment using 3 telescopic booms and twist-lock. The development will be completed in December 2024



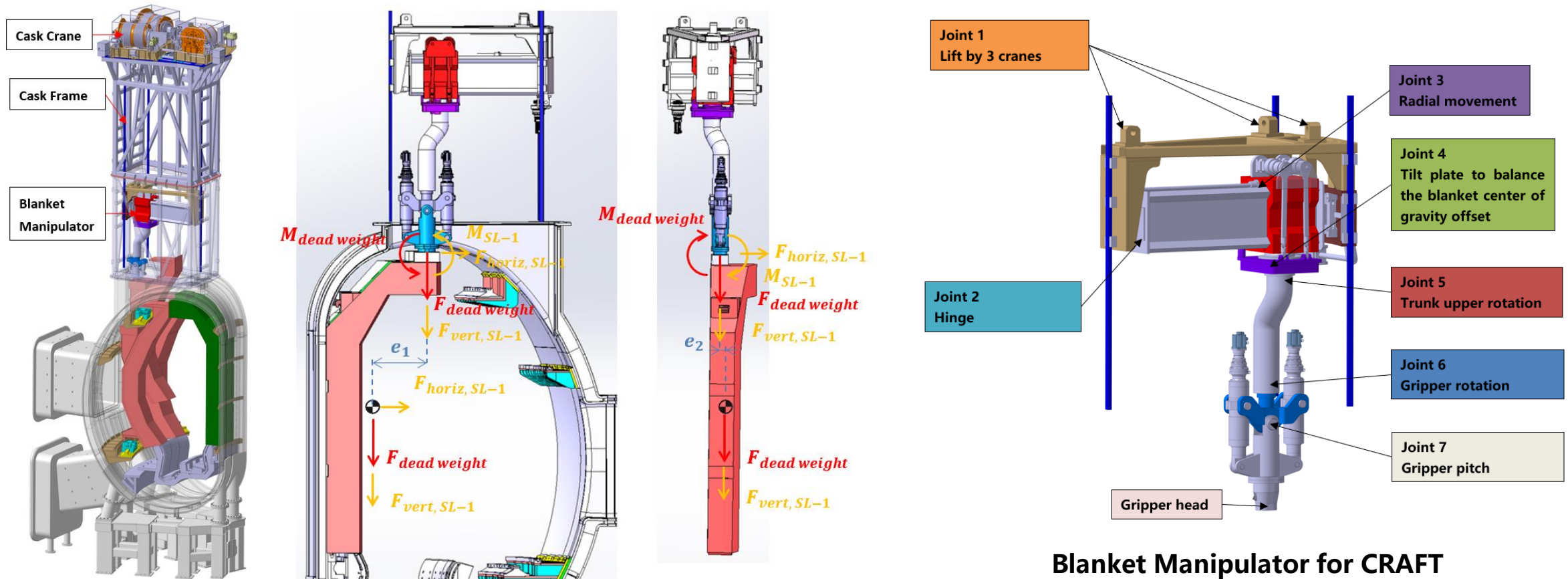
Double door test bench for opening/closing mechanism and leak tightness verification..

Research status of RM technology



EURO fusion Joint Work: blanket manipulator

- ◆ Installation and removal blanket segments using a 7-degree of freedom manipulator system proposed by EU team.
- ◆ We plan to use a virtual maintenance system to validate the functionality of this design solution.

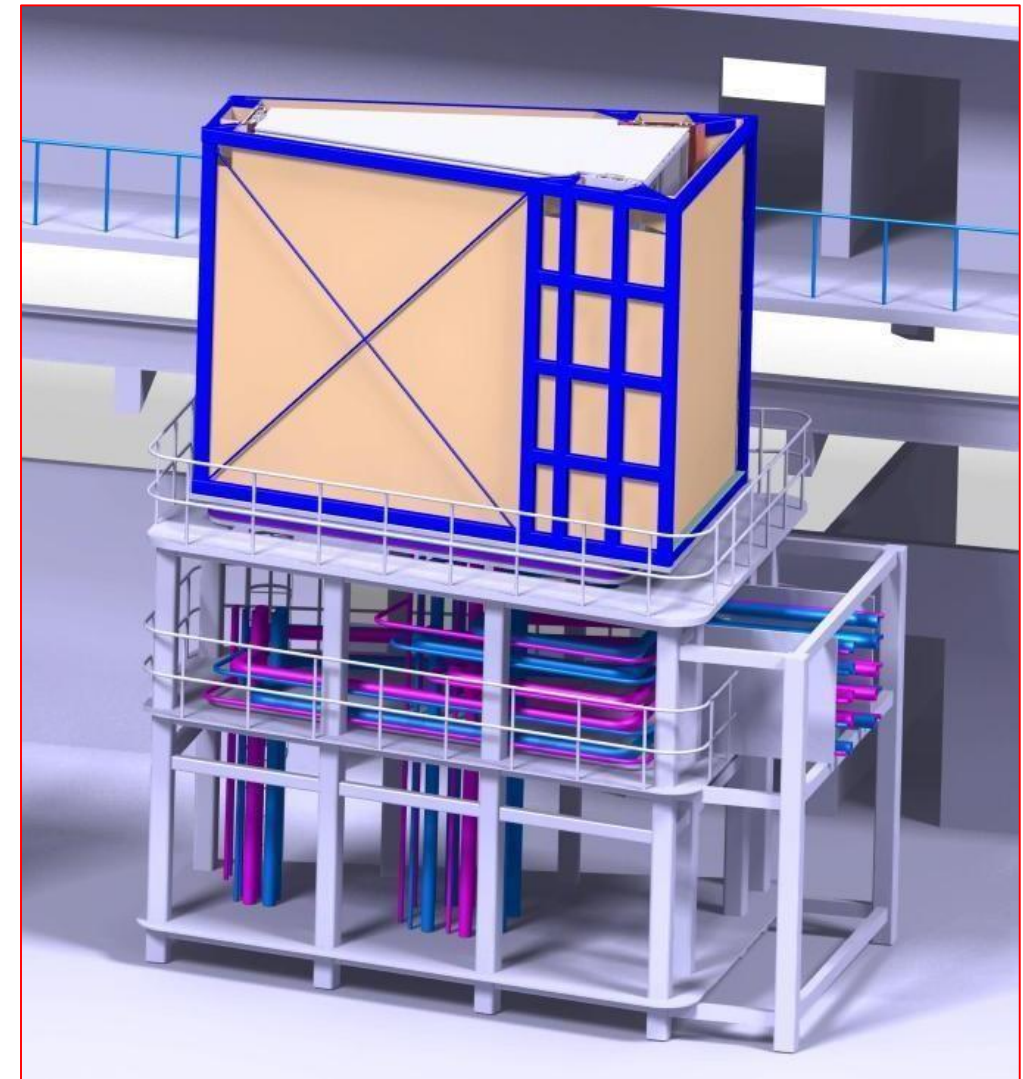
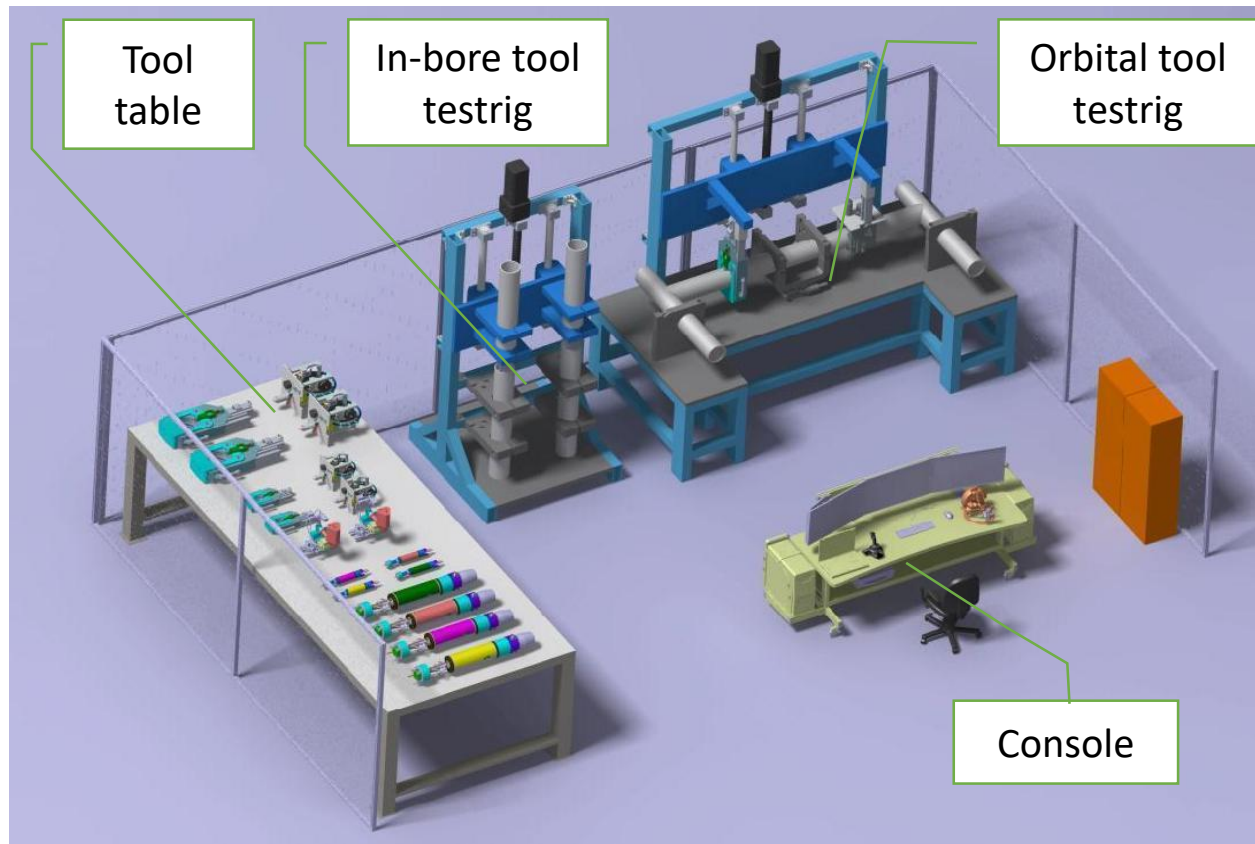


Research status of RM technology



EURO fusion Joint Work: Maintenance of blanket pipelines

- Small mockup is used to find the best tool solution
- Full scale mockup is used to understand the multipipe connection and automation control

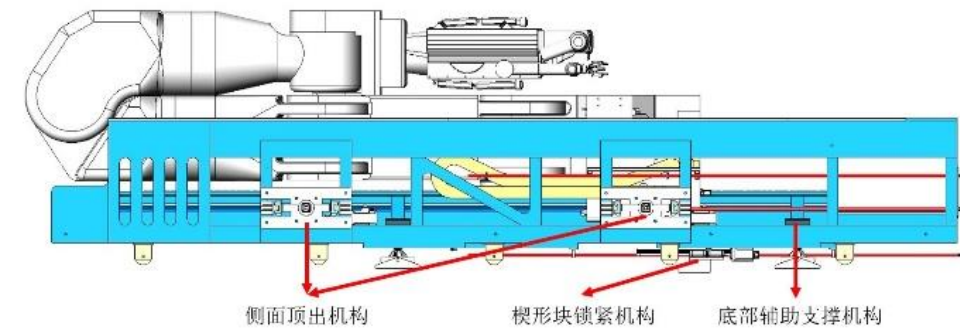


Research status of RM technology



CFETR Multi-Purpose Overload Robot

CMOR is a key device for maintaining in-vessel components like plasma facing component. The development of the robotic arm is about to be completed and will soon enter the assembly and debugging phase.



Based on our development experience with this robotic arm, we are also providing technical services for ITER's ART.

Research status of RM technology

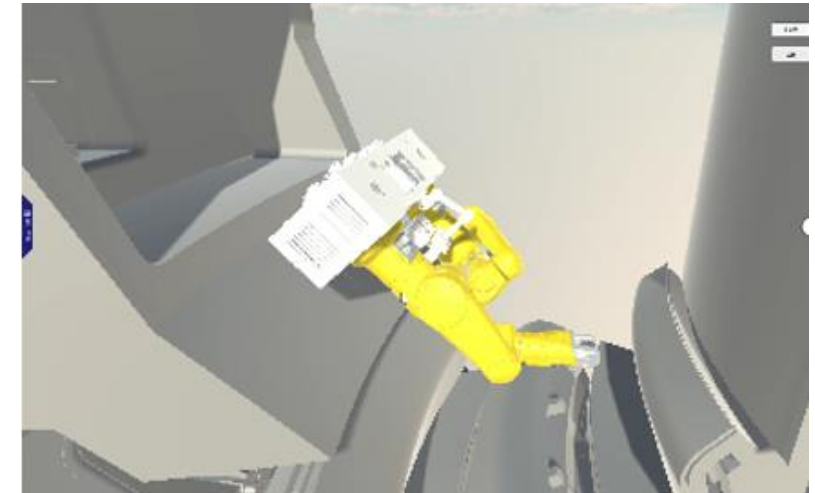


Dual arm end-effector

The final assembly of the robotic arm has been completed and performance testing is underway; The disassembly and installation of the first wall will be verified for functionality through this set of end-effector.



Load and deformation testing



Robot Control Experiment Based on Virtual Scene



Diverter PFC Maintenance Test Platform

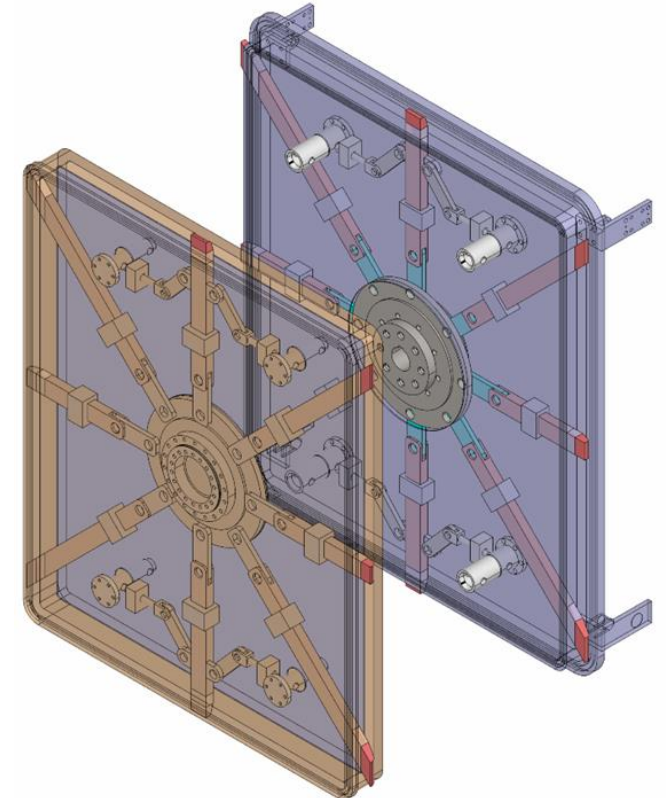
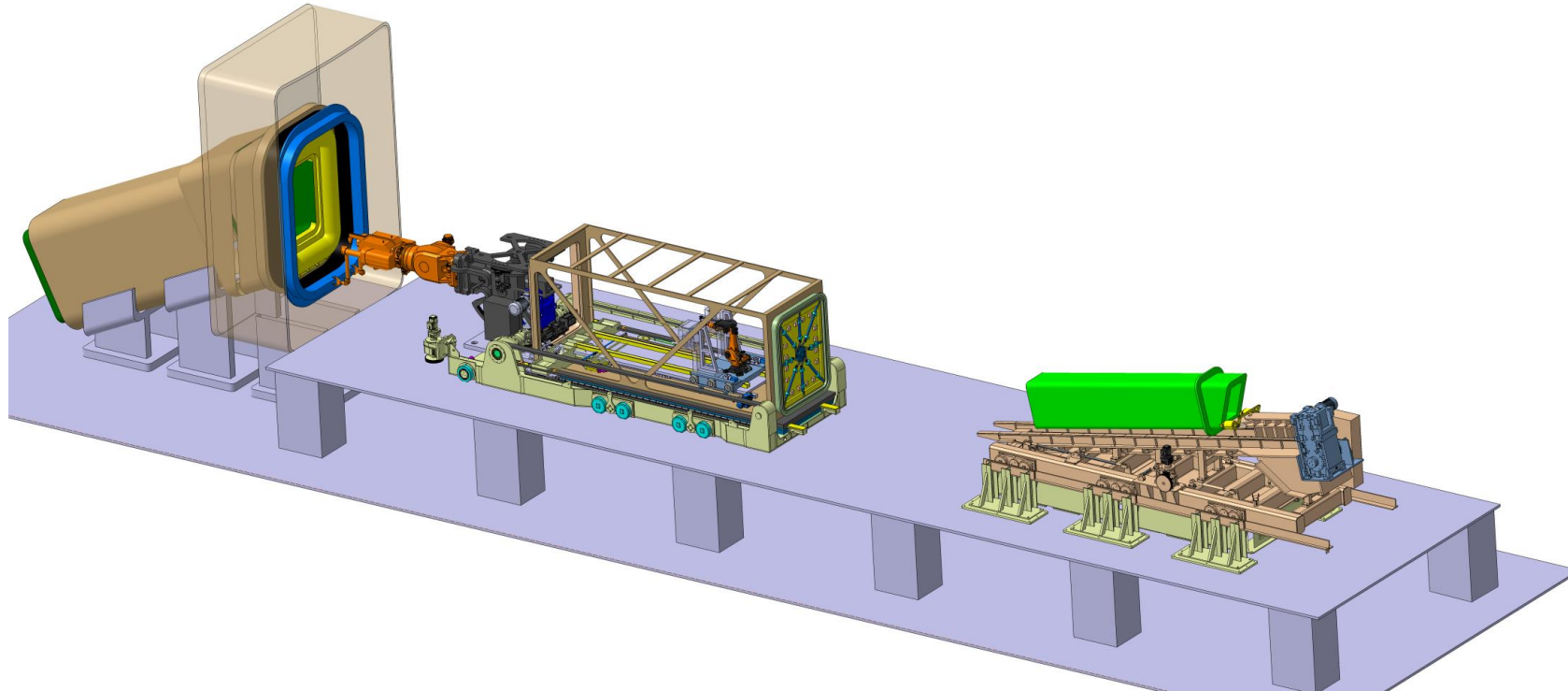
- In-bore cutting tool is delivered and tested. Cut the pip from inside without lubricant and debris.
- Divertor grasping tool is delivered and tested
- TIG based in-bore welding tool is in manufacturing. Bolting tool and cap cutting tool will be manufactured this year





Port-plug Maintenance Test Platform

- The construction of the double sealing door testing platform has been initiated, Sealing performance and opening/closing action reliability will be tested.
- We will also conduct validation experiments on the entire maintenance process of the port plugin.

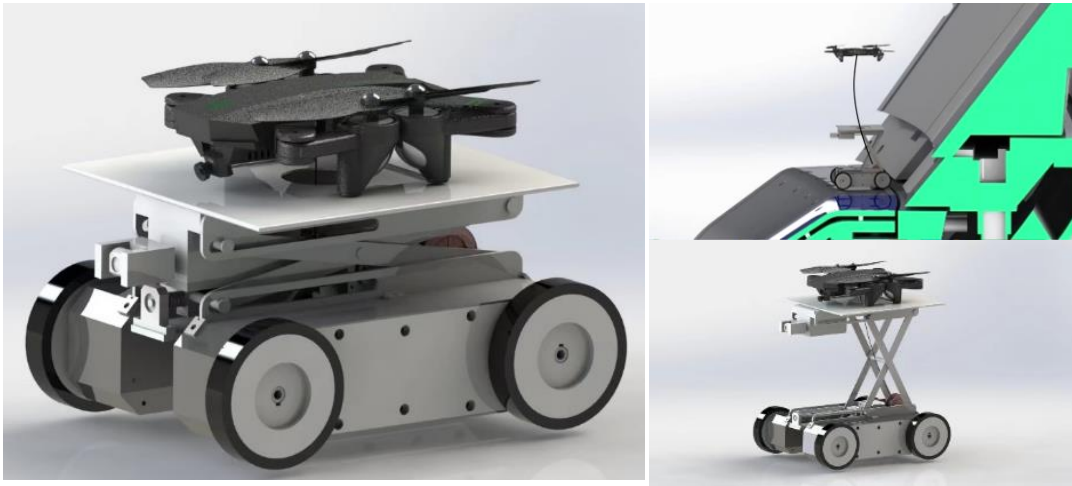


Research status of RM technology



Functional validation of the drone observation

- Last year's October, a drone observation experiment was completed inside a simulated vacuum chamber, Basic functions have been verified.
- We plan to implement observation experiments in the EAST environment this year.



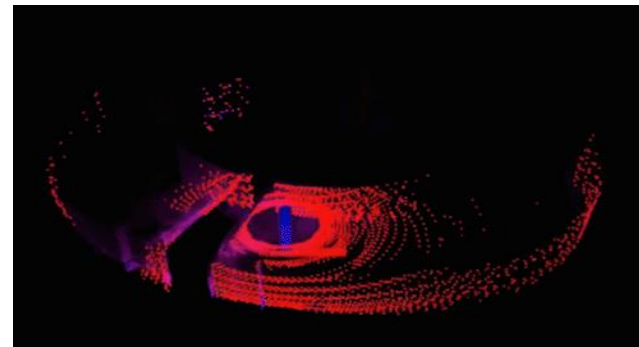
Air-Ground separation inspection drone design



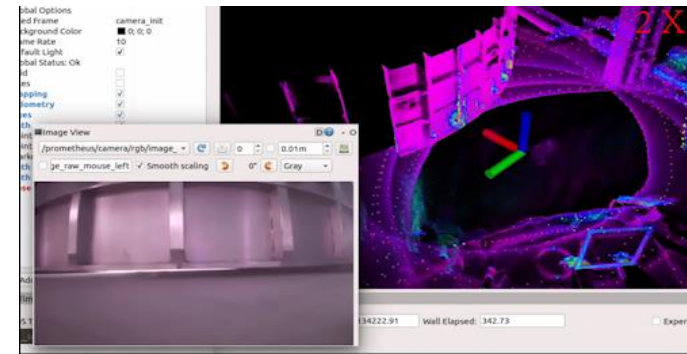
First-generation drone prototype



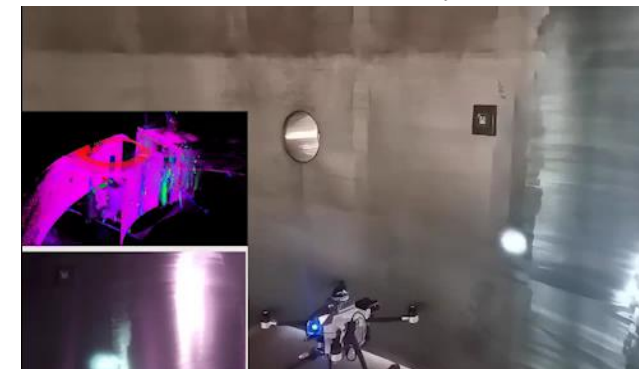
test site



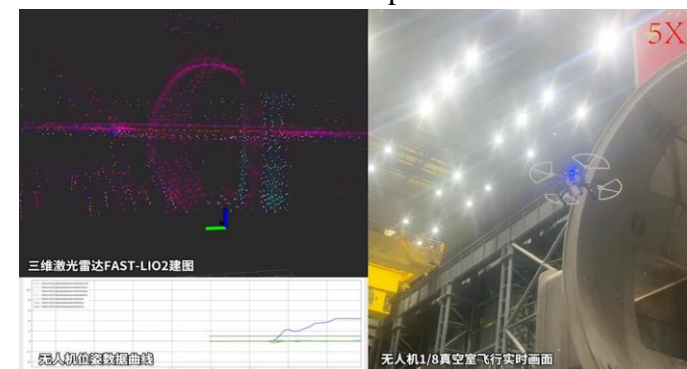
shell 3D reconstruction/accuracy measurement



shell external fixed-point observation



shell internal fixed-point observation



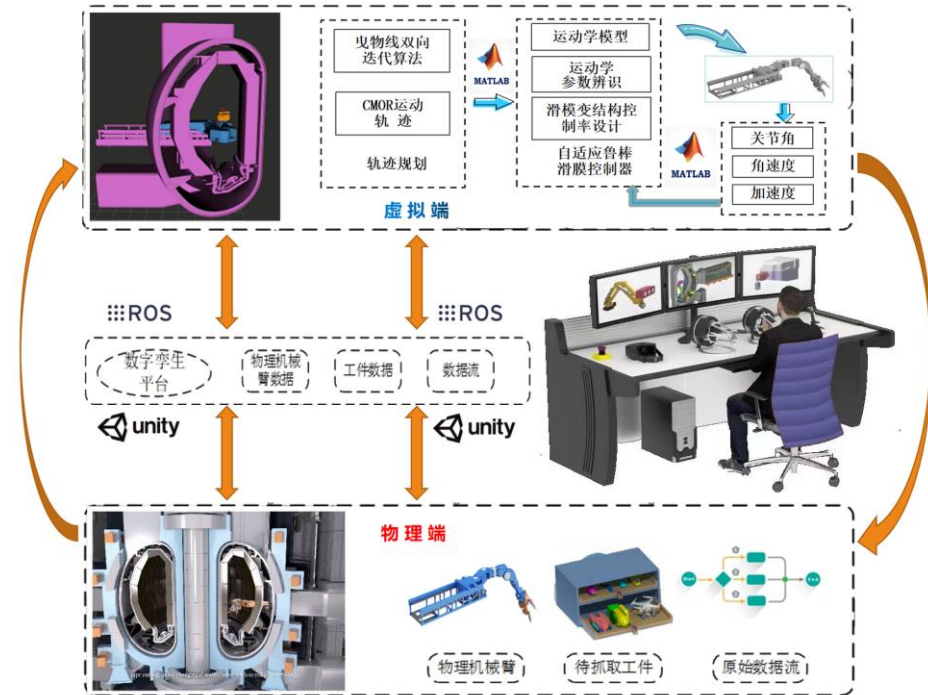
1/8 VV 3D reconstruction/accuracy measurement

Research status of RM technology



Virtual RH Maintenance platform is developed on the Unity-3D, simulating all RH maintenance operations.

- Simulate the robot's behavior using robot physics engine, including collisions, object grasping, force feedback, and sensor data.
- Establish a mapping between the real system and virtual devices to achieve data collection, simulation of operations, motion planning, and decision-making



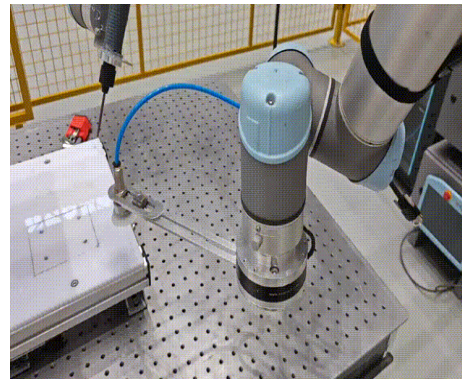
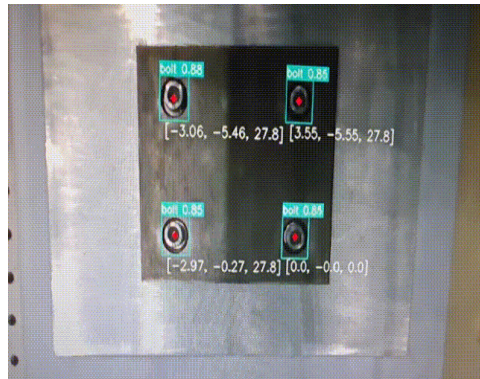
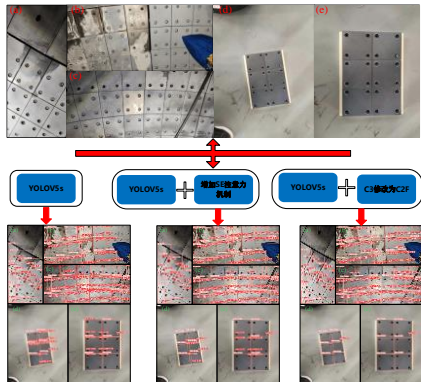
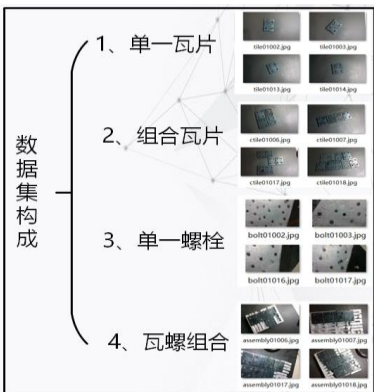
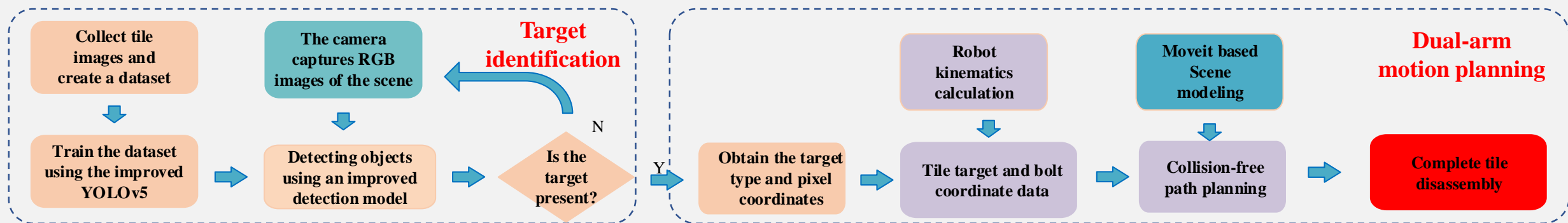
virtual-to-physical interaction
information mapping control for RH

Research status of RM technology



Dual-arm Experimental Platform for Tile maintenance

For the requirement of the internal components of the Tokamak, we have made some progress for the tile maintenance based on dual-arm platform: such as precise tile recognition based on **vision and deep learning**, **active compliant** control and robot **path planning**.



Train the dataset using YOLOv5

Target identification

Active compliant control

Tile disassembly experiment

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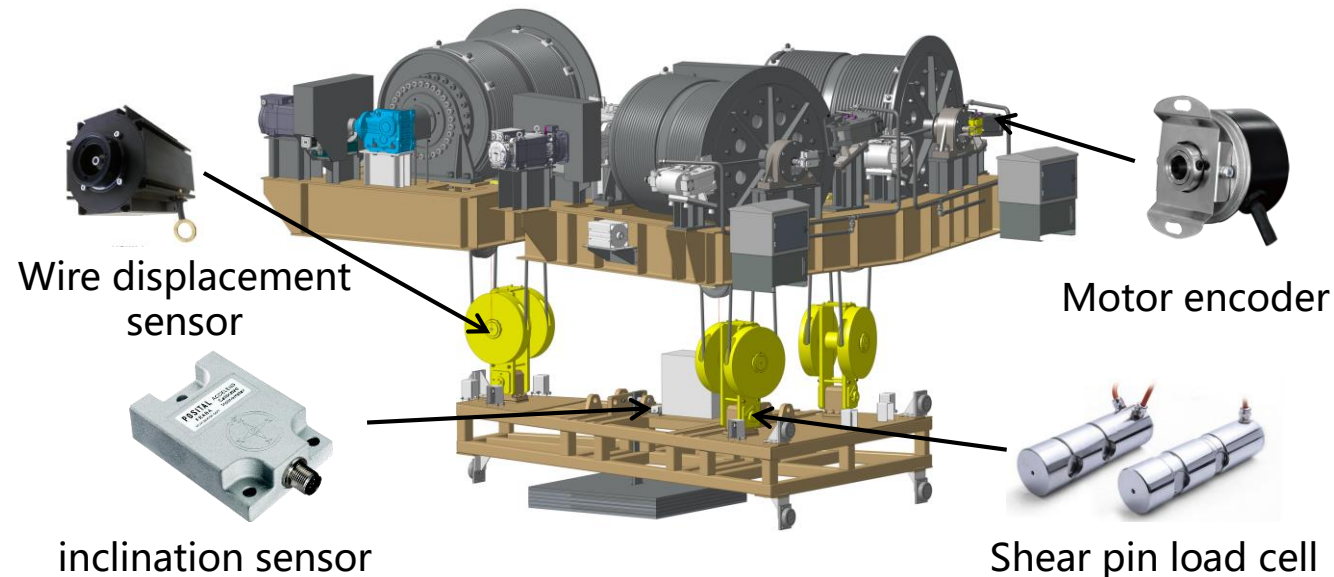


Research on Vertical Lifting of Blanket Module

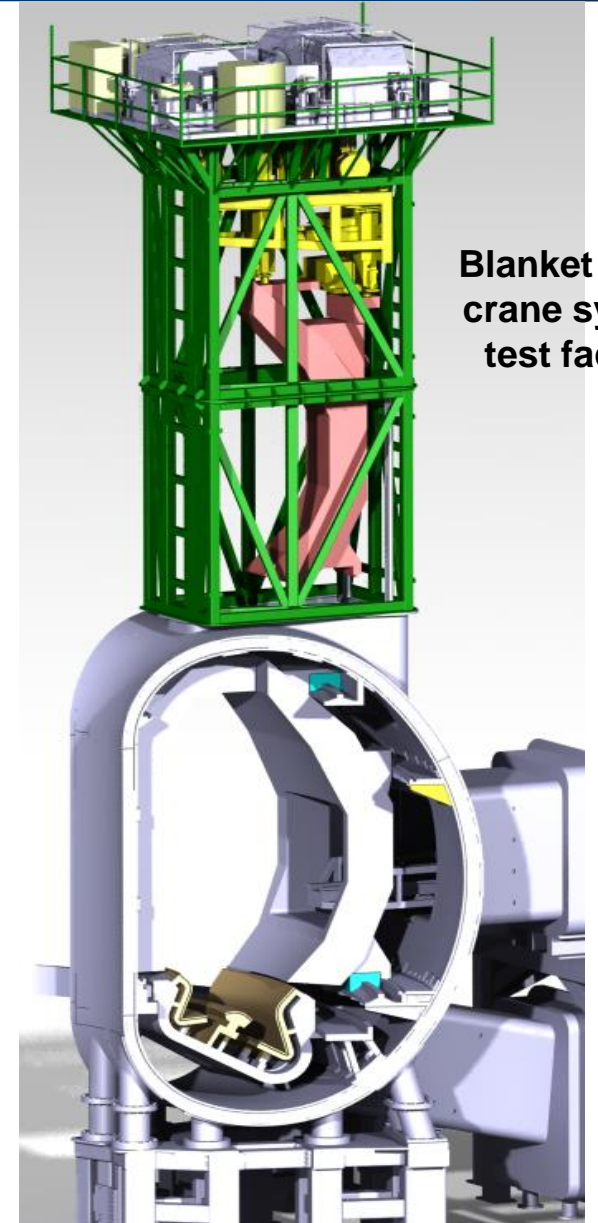
Technical challenge: high-precision and stable lifting of heavy components in a narrow working space (100mm gap)

Motion control: Propose a multi-sensor fusion scheme (measuring tension, displacement, velocity, and inclination angle), using a position + velocity + force feedforward control strategy to ensure the safety, stability, and reliability of the lifting motion control

Key parameter: The load (70 tons), lifting accuracy ($\pm 20\text{mm}$), and stability (inclination angle change $< 0.6^\circ$)



Three cranes synchronization by multi-sensor fusion control scheme



Blanket lifting crane system test facility

Research plans of RM technology

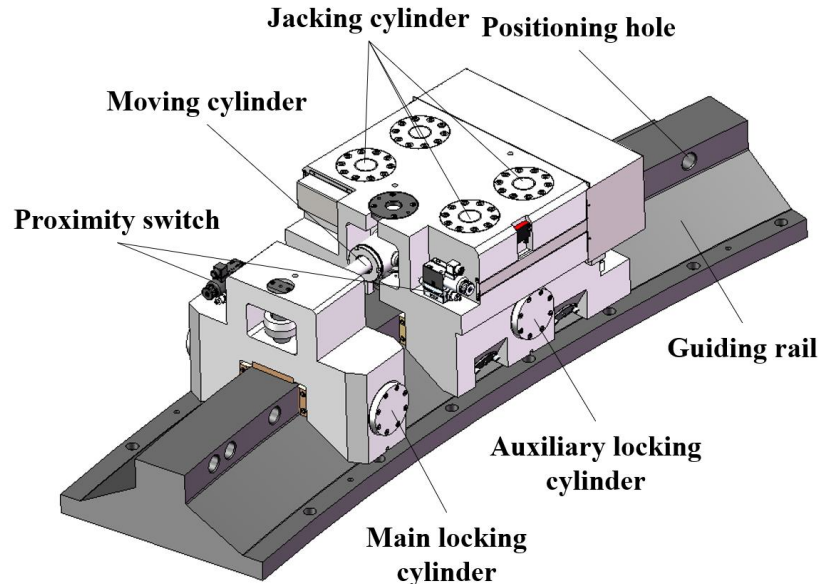


Research on toroidal movement of blanket modules

Compact and heavy load: compact and stable hydraulic toroidal drive device --- Dual Mover system to carry the blanket from the bottom and top

Synchronization motion control: Through the control strategy of cylinder pressure adaptive control, position closed-loop + speed feedforward, the dual Mover synchronous motion control will be achieved

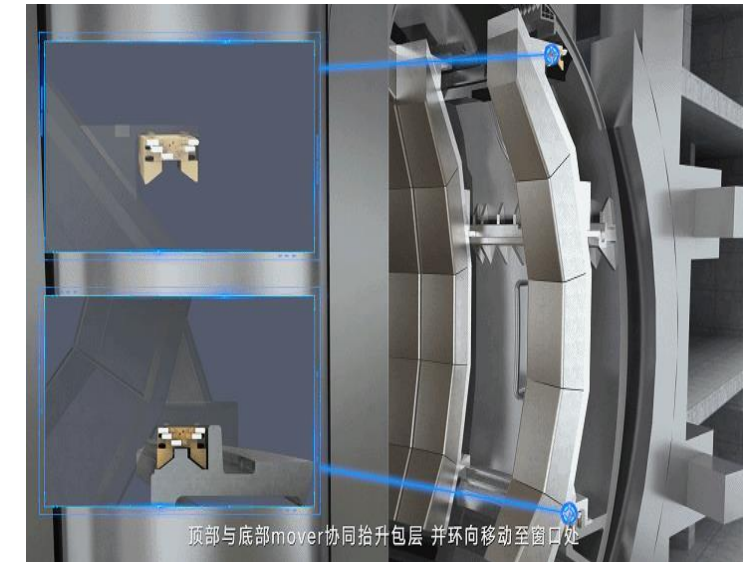
Key parameter: Load capacity (60 tons), repeated positioning accuracy ($\pm 2.5\text{mm}$), dual Mover toroidal motion synchronization accuracy ($\pm 0.04^\circ$)



Hydraulic toroidal Mover system



Dual Mover motion synchronization test facility



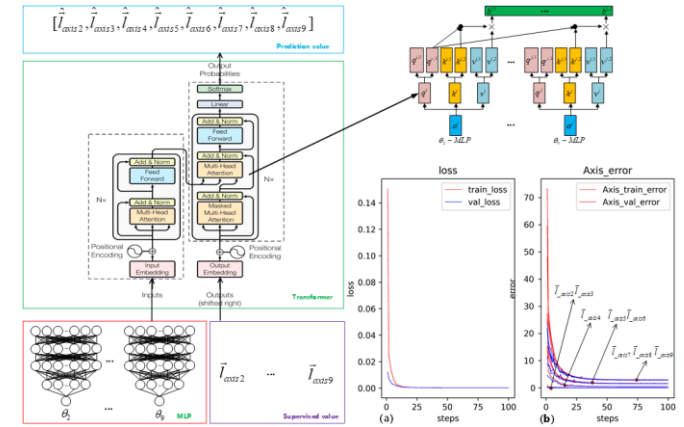
Dual Mover motion demonstration inside VV

Research plans of RM technology

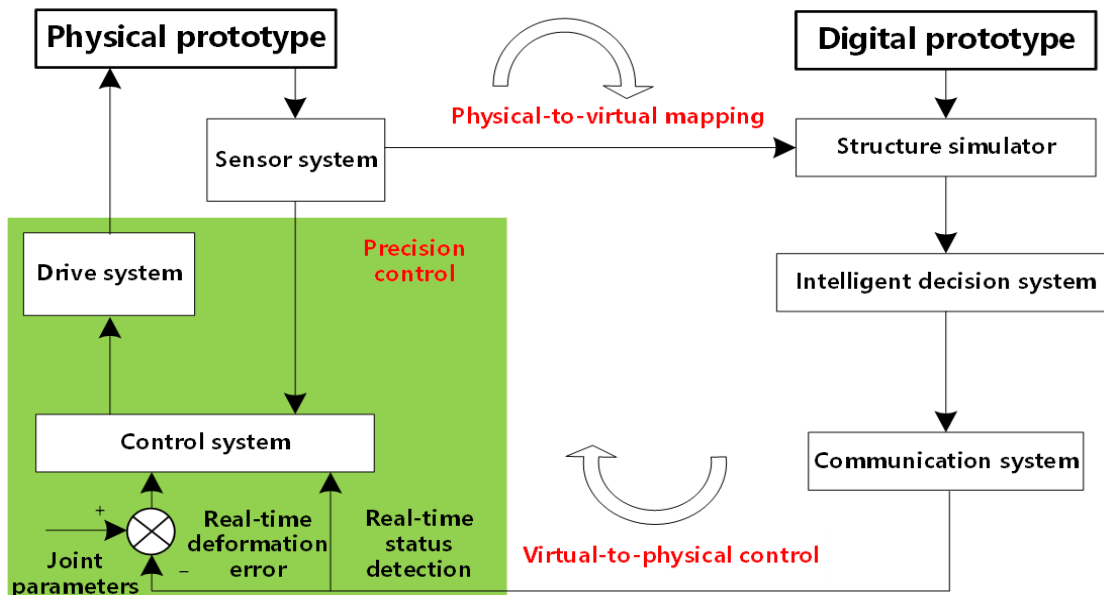


Digital twin based real-time precision control of CMOR

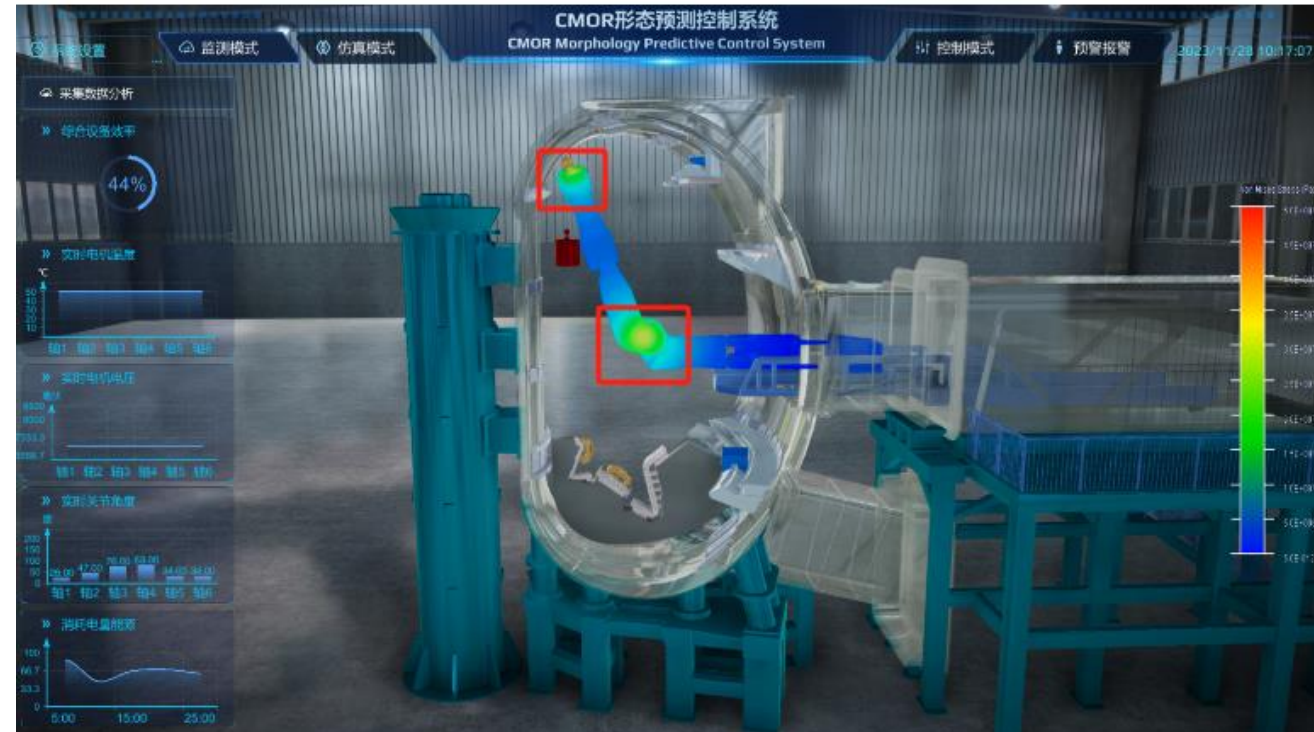
- Problem: Low accuracy operation
- Proposal
 - Build a deformation prediction model
 - Build a Digital twin system with deformation prediction model
 - Real-time deformation error compensation and verification



The deformation prediction neural network

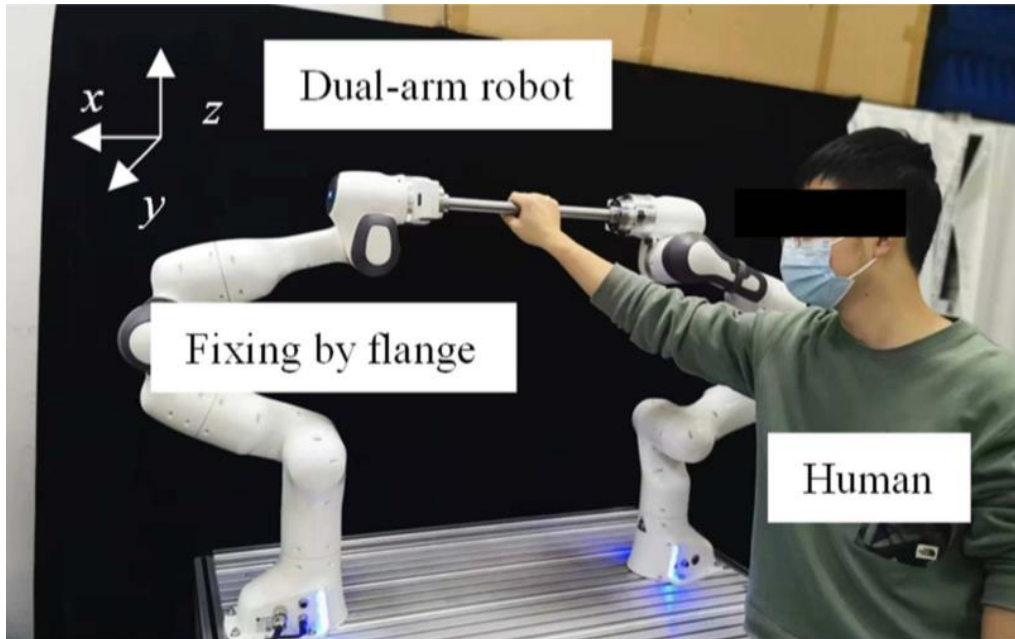


The digital twin based real-time precision control



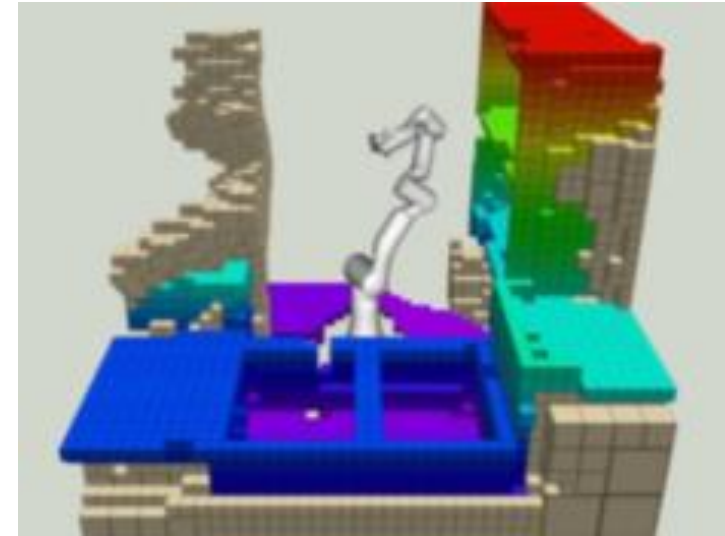
Dual-arm Experimental Platform for PFC maintenance

➤ Compliant control for dual-arm cooperation



For the task of first-wall maintenance based on the dual-arm, Sometimes we need dual arms to work together to complete complex maintenance tasks. This requires controlling the dual arms based on compliant algorithms to achieve coordinated work between the two arms.

➤ Autonomous workspace reconstruction based on environment perception



manipulator autonomously maps unknown environment

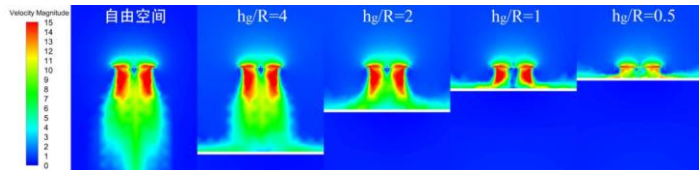
To improve the quality and efficiency of the reconstruction, different strategies are applied to different geometric primitives.

The field of view of the sensor and the collision model of the environment are considered simultaneously in the planning of the sensor's viewpoint.

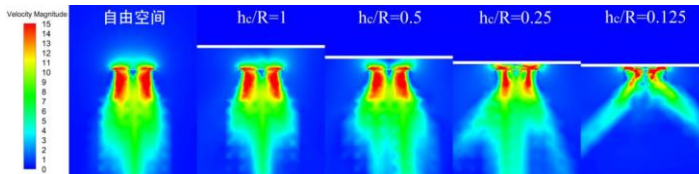


The EAST First Wall observation experiment

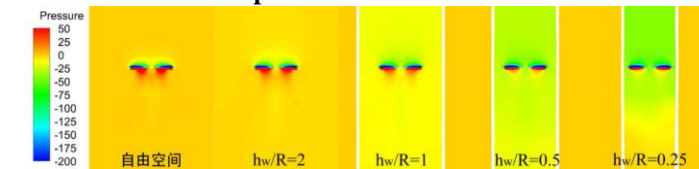
- Optimized design of near-wall stability control for drones
- Drone autonomous inspection planning and defect information recognition experiments
- Drone emergency recovery, rescue experiment
- Drone flight test in 1:1 simulated EAST environment



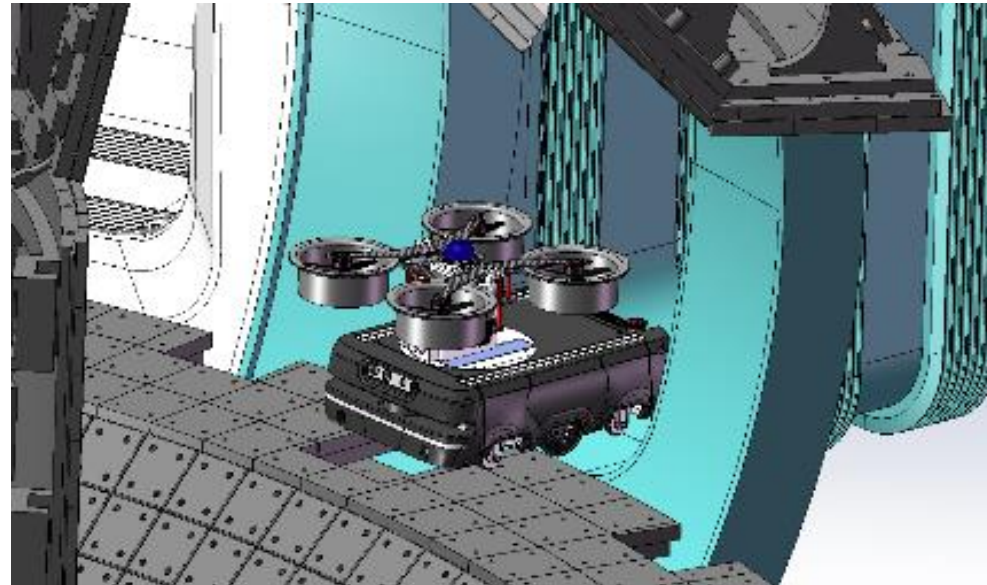
Ground effects on drones



Top surface effects on drones



Ring surface impacts of drones



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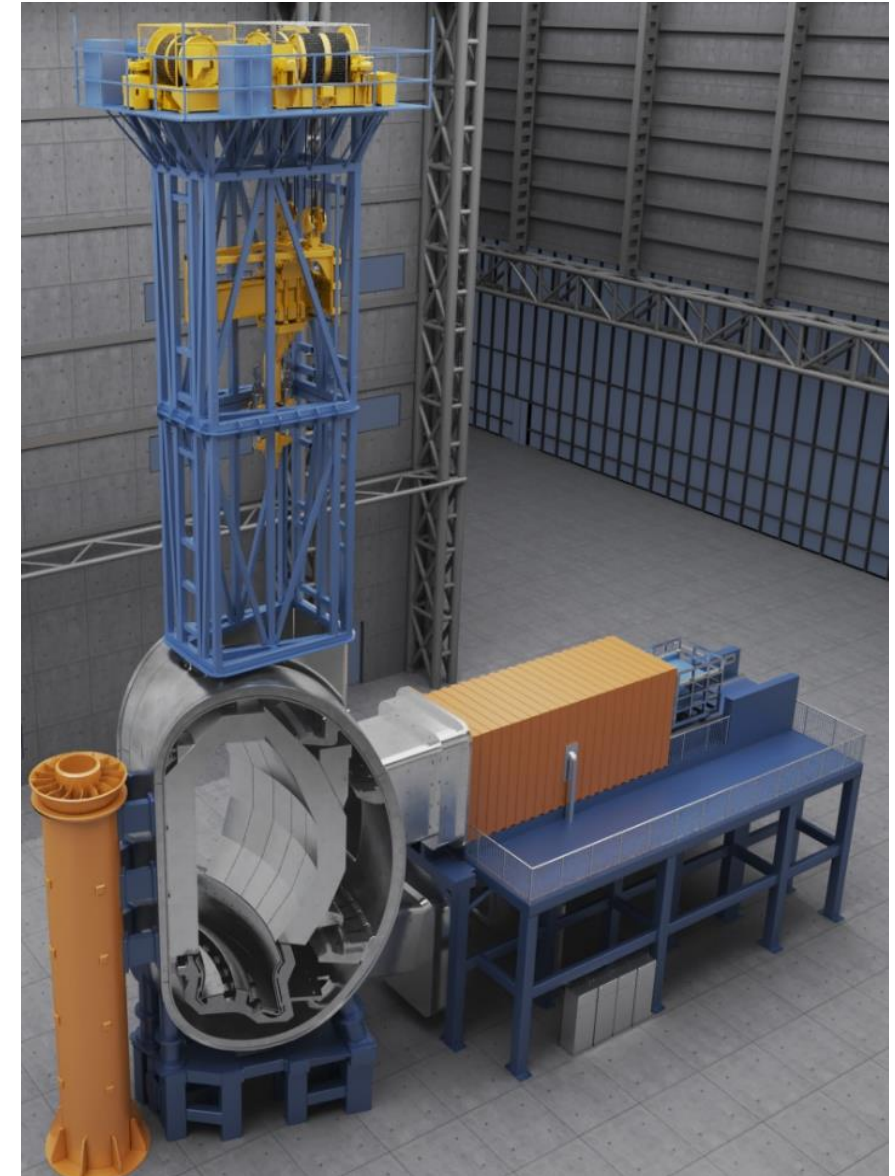
Cooperation needs of CN-EU



It is expected that **extensive and deeper international cooperation** will play an important role in accelerating the development process.

Joint experimental

- ◆ Dual-arm Experimental Platform for PFC maintenance **2024-06**
- ◆ Research on toroidal movement of blanket modules **2024-08**
- ◆ The EAST First Wall observation experiment **2024-10**
- ◆ Research on Vertical Lifting of Blanket Module **2025-03**
- ◆ Digital twin based real-time precision control of CMOR **2025-05**



The CFETR-RM function testing platform



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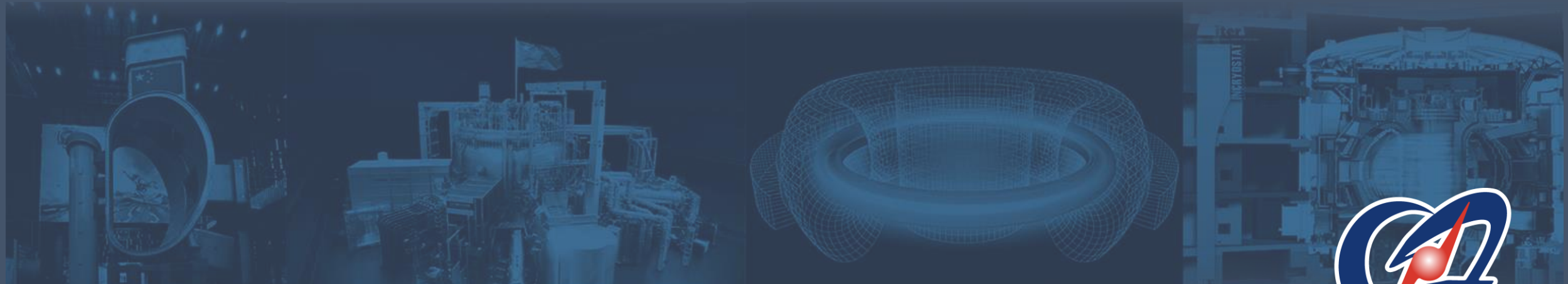
Summary



Summary



- **The CFETR-RM function testing platform will be completed in May 2025, and many subsystems have already been constructed.**
- **Many remote maintenance function tests have been initiated, Inviting everyone to join us in maintaining validation experiments;**
- **The conceptual design of the BEST RH system has been basically determined, and the development of some key components will also be gradually carried out this year.**
- **The joint together for the ITER or BEST RH task and exchange of researchers will be the direction for us to increase our cooperation efforts.**



Thanks for your attention!

ASIPP

