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Conceptual design of cryogenic system for comprehensive research facility for key fusion reactor core systems

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Abstract. To break the bottlenecks of key components of fusion reactors, the Chinese government have included the construction of a Comprehensive Research Facility for Key Fusion Core System in its recent National Grand Project plans. It encompasses two synergistic research platforms, one for superconductor and magnets capable of a maximum field of 15T, and the other for divertor physics, material and component capable of a maximum plasma particle flux of $10^{24}/m^2s$. The cryogenic system provides the 4.5K, 3K and 1.8K cooling power to all the magnets, superconductor components and cryopumps. The total average cooling capacity is 7.2kW/4.5K (1kW/3K, 250W/1.8K). This paper describes the conceptual design of the system including the helium refrigerators and cryogenic research platform. The features of the cryogenic system and the project schedule are also described.

1. Introduction

To realize fusion energy, the International Thermonuclear Experimental Reactor (ITER) is presently under construction; the Chinese Fusion Engineering Test Reactor (CFETR) research and engineering design are presently in progress; design concepts and technology R&D for fusion DEMO are being pursued worldwide. The cores of these reactors present an environment of extreme conditions, in which key components face bottlenecks of experimental research and engineering development. To break the bottlenecks of key components of fusion reactors, the Chinese government included the construction of a “Comprehensive Research Facility for Key Fusion Core Systems” in its recent National Grand Project plans. It encompasses two synergistic research platforms, one for superconductor and magnets capable of a maximum field of 15T, and the other for divertor physics, material and component capable of a maximum plasma particle flux of $10^{24}/m^2s$. The cryogenic system provides the 4.5K, 3K and 1.8K cooling power to all the superconducting magnets, superconducting components, cryopump and NBI. The total average cooling capacity is about 7.2kW/4.5K (1kW/3K, 250W/1.8K). This paper describes the conceptual design and the features of cryogenic system and cryogenic research platform.

2. Design of cryogenic system

The cryogenic support system is composed of four helium refrigerators (3kW/4.5K, 1kW/4.5K, 200W/4.5K, 250W/1.8K) which satisfy the test requirements of larger scale superconducting magnets, medium and small size superconductor and materials by distribution system. At the same time, it will provide the cooling power to the cryogenic key technology research platform and cryogenic public service platform. The structure of the cryogenic system is shown in figure.1.

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According to the cooling requirements of each system of the device, the system construction scope includes the follows parts:

- 3kW/4.5K (1kW/3K) helium refrigerator unit: it meets the cooling requirements of large scale superconducting magnets, in which the 1kW/3K refrigerating capacity can provide the sub-cooled helium environment for the superconducting magnets.
- 1kW/4.5K helium refrigerator unit: it meets the cooling requirements of the small and medium-sized superconductor research system
- 200W/4.5K helium refrigerator unit: it meets the cooling requirements of the material performance research system.
- 250W/1.8K helium refrigerator unit: it provides the cooling power for the research platform, as well as the cooling requirements of the superconductor in 1.8K cryogenic environments.
- Cryogenic key technology research platform: it will develop and make research on cryogenic systems for future fusion reactors and promote its application in industry.

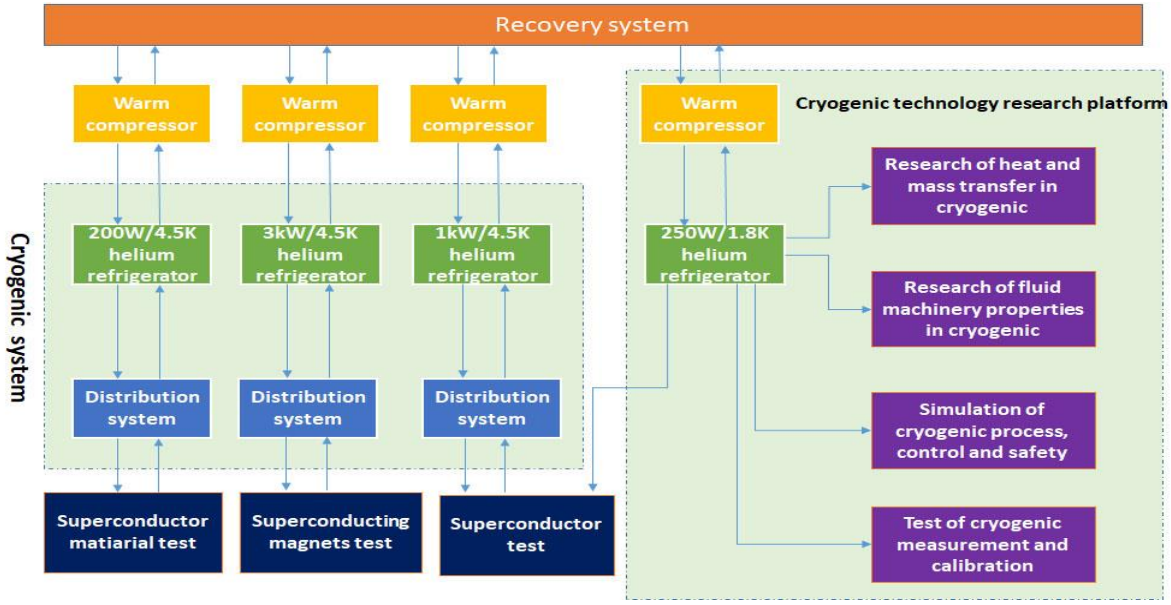

Figure 1. Structure of the cryogenic system

3. Design of cryogenic research platform

The cryogenic key technology research platform is mainly aimed at the engineering requirements of the large scale cryogenic system at 100kW/4.5K level of the fusion reactor in the future. It is intend for research on the heat and mass transfer mechanism of superfluid helium cooling the superconducting magnets and the technology of quench detection and protection. The cryogenic fluid machinery properties will be researched to develop the large-flow turbine expander, cold compressor and helium circulator, and realize the in-house production of key components in large scale helium cryogenic system. The simulator of cryogenic process, control and safety will be built to simulate the periodic impact of the transient pulse load on the cryogenic system, put forward the coordinated control scheme of dynamic response, and evaluate the safety and reliability of the cryogenic system. In addition, the test system of cryogenic measurement and calibration will be built to form the public service platform to satisfy the demand of cryogenics in other fields.

3.1. Heat and mass transfer in cryogenics

The heat and mass transfer of helium in cryogenics from 300k to 1.8K will be explored in order to build the 100kW/4.5K level helium cryogenic system in future fusion. The oil removal test experiment facility will be built to research the compressed helium coalescence separation mechanism and the separation

efficiency of oil and gas under environment temperature, perfecting the database of the dynamic adsorption value of different absorbent. The actual adsorption effect pf adsorbent in cryogenics will be researched by establishing the dynamic absorption database of absorbent under different temperature conditions, and study on the influence of parameters such as the structure, material and flow rate. The heat and mass transfer techniques of helium in cryogenics will be developed, especially on the heat transfer mechanism of sub-atmosphere cryogenic heat exchanger. The mechanism of phase transition of superfluid helium, in the saturated state and subcooled state, and the boiling heat transfer of superfluid helium will be studied. The research on the heat transfer mechanism of superfluid helium flow in micro-channels lays a theoretical foundation for design and application of large scale cryogenic system. Figure 2. Shows the component of the cryogenic flow and heat transfer research platform.

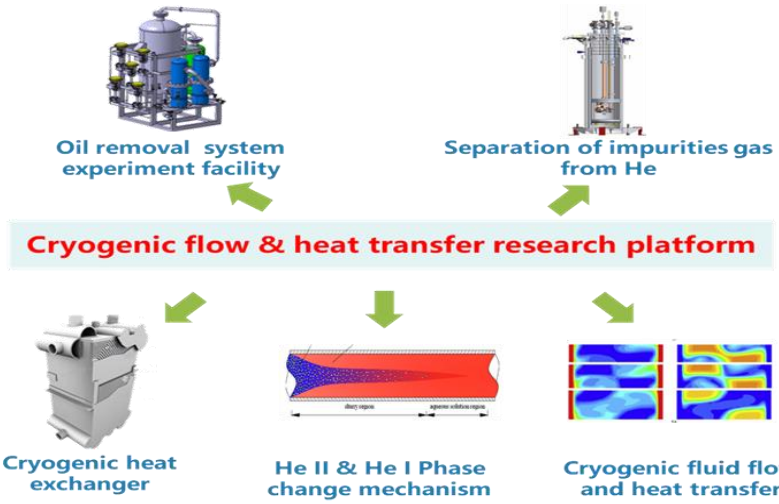

Figure 2. Structure of the cryogenic flow and heat transfer research platform

3.2. Fluid machinery properties in cryogenics

The research of fluid machinery properties in cryogenics focuses on the cold compressor, turbine expander, cryopump, cryogenic valve and mass flow meter in superfluid helium system. The PFD of the test system of the fluid machinery is shown in figure 3. The liquid helium is provided by the 4.5K helium cryogenic system. The test system provides the 1.8K to 3.5K temperature range for the test of single or multi-stage cold compressor. The thermometers and mass flow meters are also calibrated and tested in this platform. The system can also provide the test of performance and efficiency of the key components such as cryogenic circulator, subcooled heat exchanger in cryogenic system, as well as the stability and reliability under long term operation conditions.

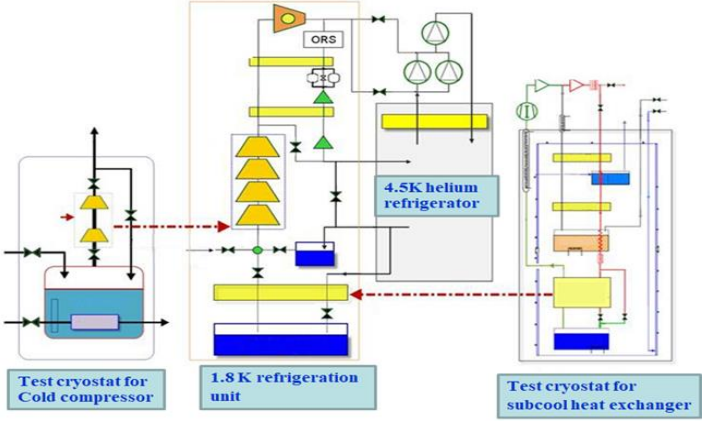

Figure 3. Test system of the fluid machinery properties in cryogenic

3.3. Simulation of cryogenic process, control and safety

The dynamic simulator will be built for the cryogenic process and control simulation. The cryogenic system model is based on the EcosimPro and Cryolib and will be used to replace the real cryogenic system to provide the simulated I/O signals and the controlled object for the control system. The control system architecture is based on the EPICS shown in figure 4. EPICS is a set of open source software tools, libraries and applications developed by an international collaboration. The open source software CSS（Control System Studio）is to provide I/O module configuration, database, control module and HMI. The communication between CSS software and cryogenic system model is realized based on OPC interface. This simulator can be used for different purpose such as operator training, test of the new control strategies and the optimization of cryogenic system.

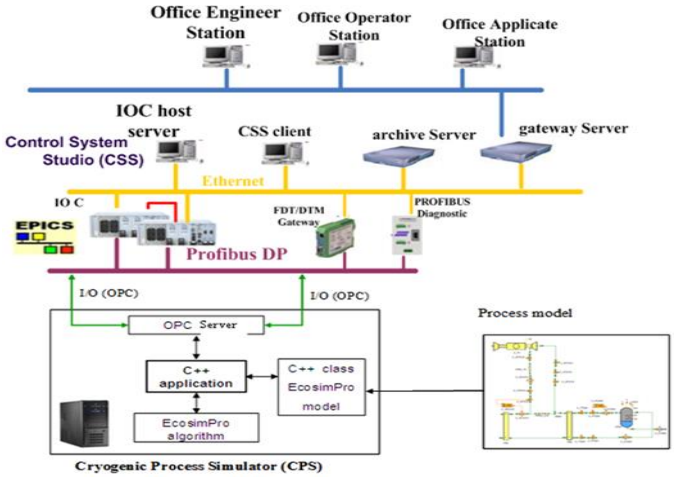

Figure 4. Structure of the simulator of cryogenic process, control and safety

3.4. Test of cryogenic measurement and calibration

Three large helium refrigerators and a GM refrigerator built for superconducting magnet testing provide a high-precision temperature control and high-vacuum testing environment with 1W ~ 7.2kW refrigerating capacity and a temperature range of 1.8K ~ 873K. The 1.8K superfluid helium test can be obtained by the 1.8K helium refrigeration system and stored in the superfluid helium cryostat for different test requirements. The structure of the test platform is shown in figure. 5. The service platform of cryogenic precision measurement calibration and performance testing is established for calibration and testing of cryogenic precision measurement instruments, high-voltage insulation performance, insulating materials under 1.8k, and cryogenic performance testing of sealing materials and sealing structures, flow characteristics, sealing characteristics and heat leakage characteristics of cryogenic valves.

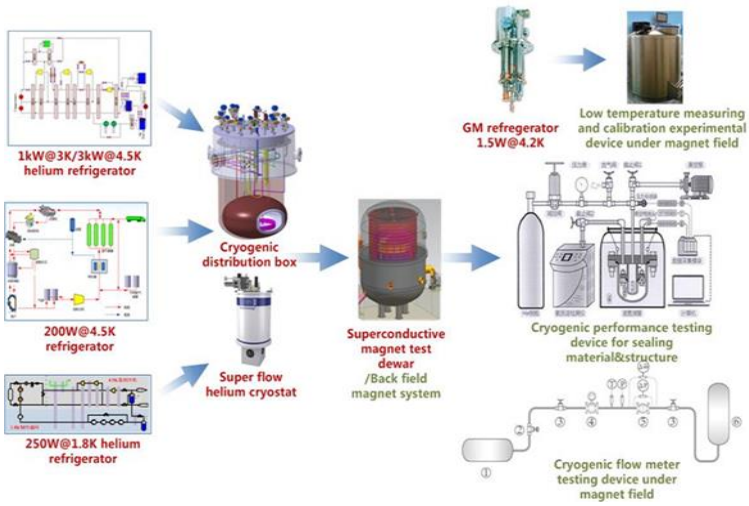

Figure 5. Structure of test of cryogenic measurement and calibration

4. Conclusion

The conceptual design of the cryogenic system is complete and preliminary design is well underway. The helium refrigerators will be designed, manufactured and integrated by ASIPP. The detailed design of the cryogenic distribution system will also start this year. The completed cryogenics system is scheduled to be completed within four years.

Acknowledgements

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References

[1] Y.X. Wan, Mission of CFETR, in ITER Training Forum & Second Workshop on MFE Development Strategy, Sep. 6, Hefei, 2012.
[2] Y.T. Song, S.T. Wu, J.G. Li, B.N. Wan, Y.X. Wan, P. Fu, et al., Concept design of CFETR tokamak machine, IEEE Trans. Plasma Sci, 42:503-509, 2014.
[3] E. Agrupados. EcosimPro: modeling and simulation software, 2016.
[4] E. Agrupados. CRYOLIB Library v1.2.7 User Manual, 2016.