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Design of Cryogenic Distribution System for CFETR CS model coil

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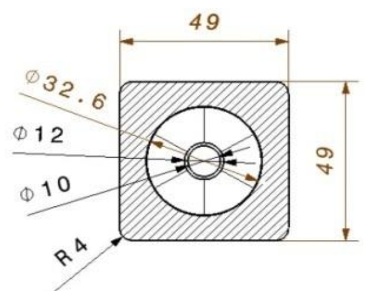
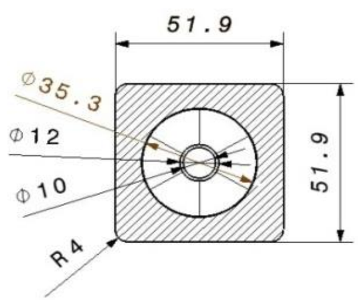
Introduction

Superconducting magnet of Central Solenoid (CS) model coil of China Fusion Engineering Test Reactor (CFETR) is operated by forced-flow cooling with a large amount of supercritical helium. The cryogenic circulation pump can be effective to achieve the supercritical helium (SHe) circulation to the forced-flow cooled (FFC) cable-in-conduit conductor (CICC) magnet.

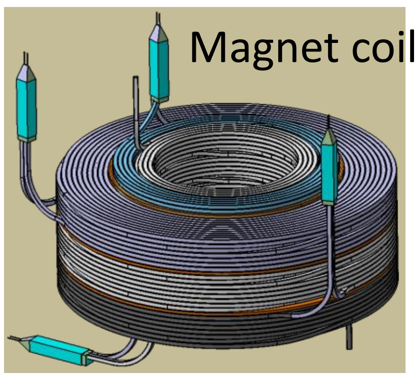
The CFETR CS model coil has a total cold mass of about 200 tons, and are wound with Nb3Sn cable-in-conduit conductor (CICC) and NbTi CICC.

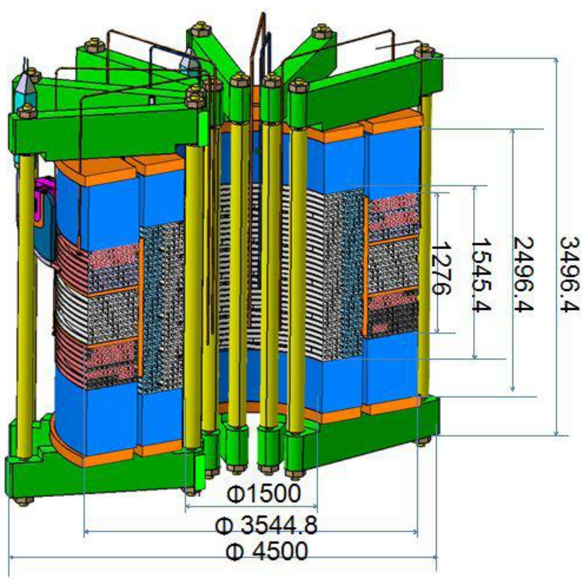


Length of Nb_3Sn Coil : 1400 m



Length of NbTi Coil : 2235 m





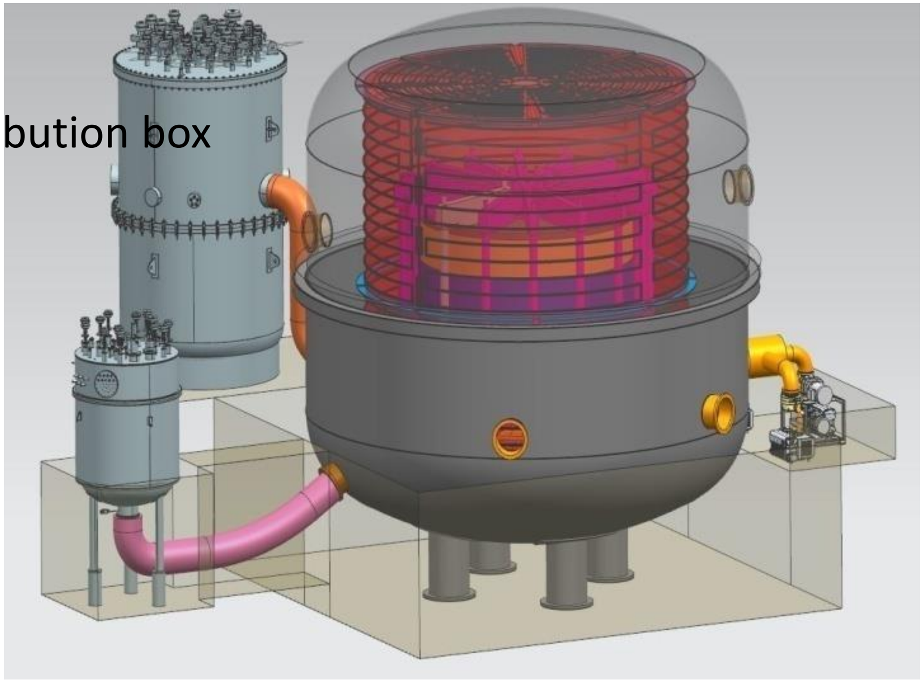
CFETR CS model coil

Introduction

In order to cool the model coil and comply with the test parameters such as temperature, pressure, mass flow rate of the magnet coils, a cryogenic distribution system will be designed and constructed, which distributes refrigerant to all of the cold components of model coil.

The cryogenic distribution system consists of vacuum vessel, cryogenic control valves, cryogenic vessels, SHe circulation pump, thermal shield, heat exchangers and other apparatus.

distribution box



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Introduction

➢The heat loads of the CFETR CS model coil consist:

heat radiation	21W	Joule heat in the joints	36W
residual gas conduction	14W	alternating current losses	400W
heat conduction from supports	59W	heat loss from the pump	550W
losses in the helium transfer line, the heat loss from the valves and current leads			

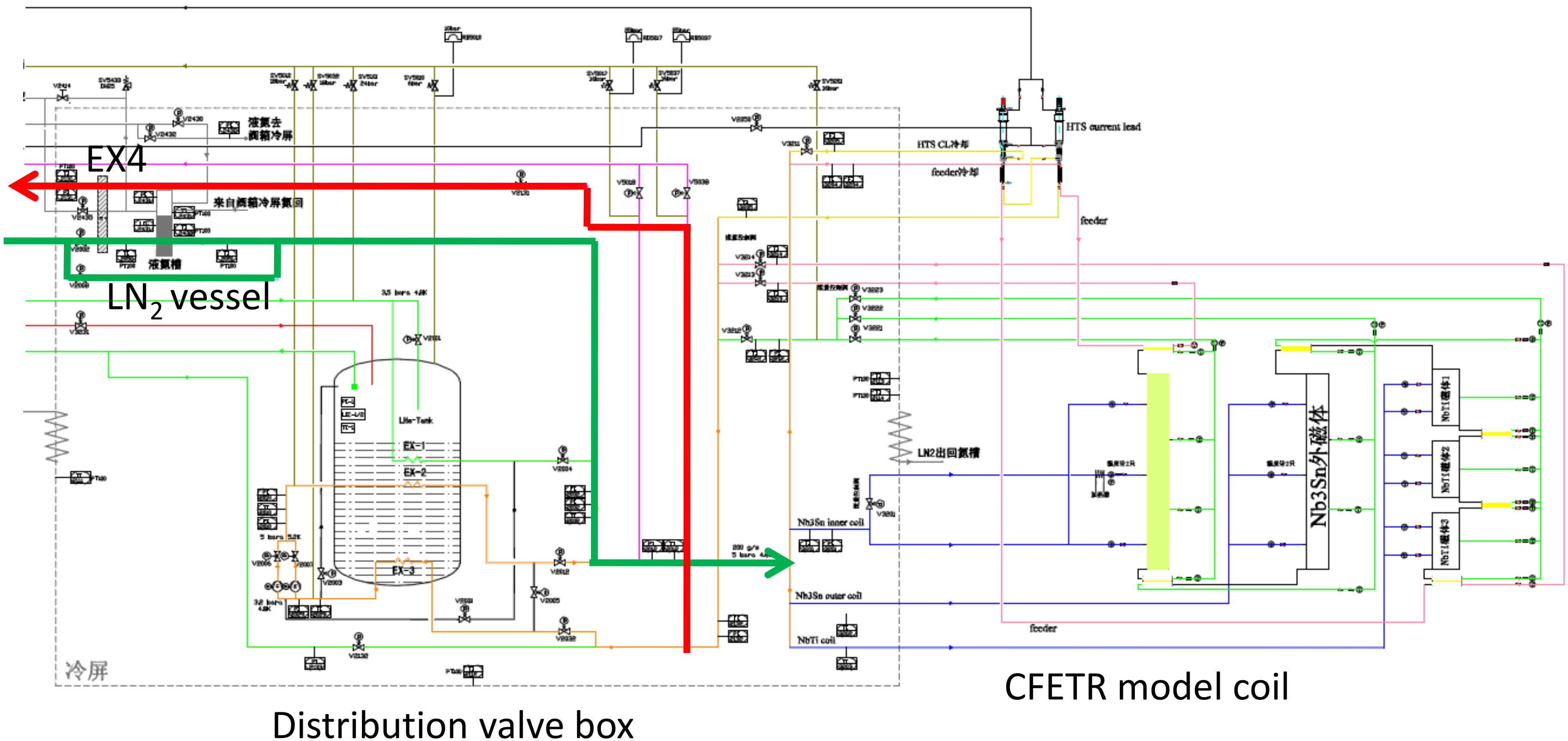
➢The parameters for cooling the CFETR CS model coil:

Mass flow rate (g/s)	200	Pressure drop through the magnet (MPa)	≤ 0.07
Inlet temperature (K)	4.5	Outlet temperature (K)	≤ 6
Inter pressure (MPa)	0.5		

➢The process flow of cryogenic distribution box mainly includes the following cooling loops

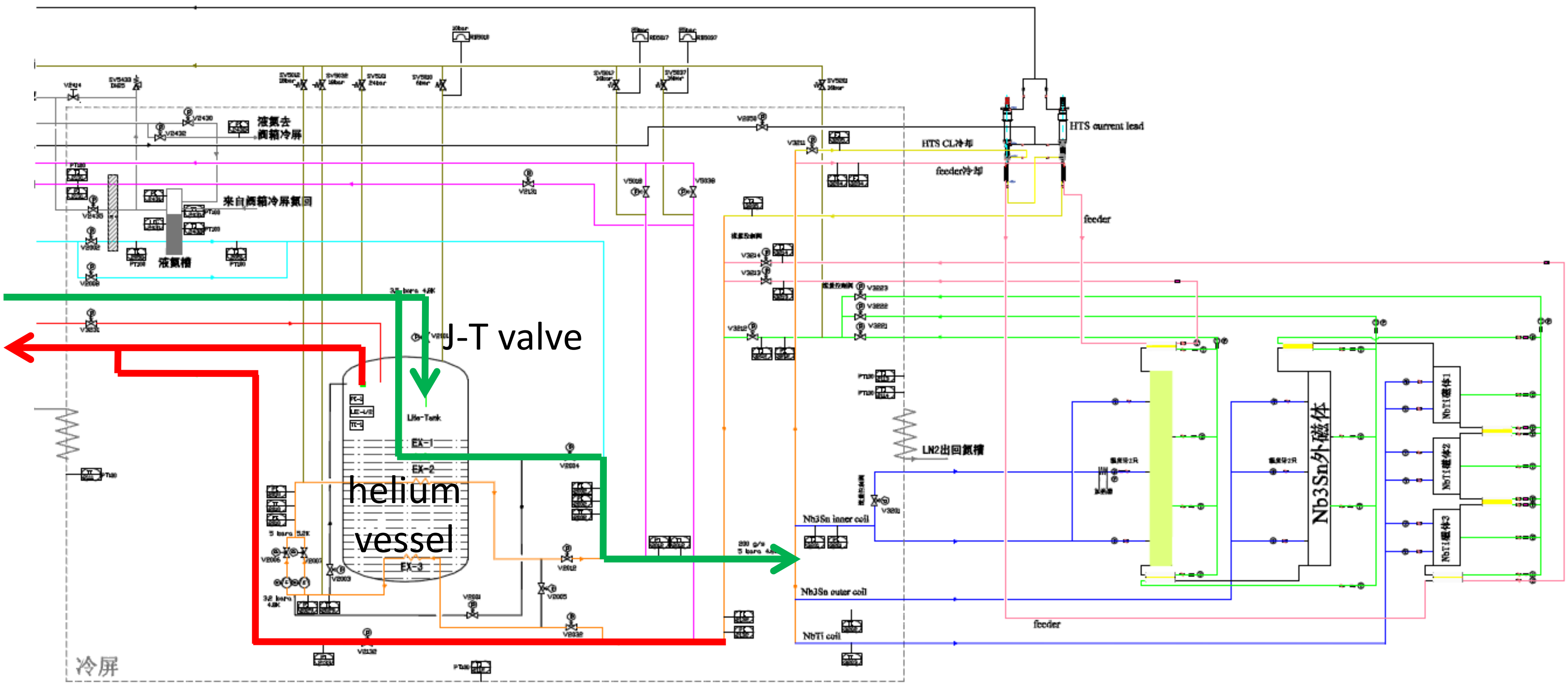
- Precooling the model coil from 300 K to 80 K
- Precooling the model coil from 80 K to 4.5 K
- Forced-flow cooling by using circulation pump
- Quench protection processing flow in the distribution system

Process flow diagram-300 K to 80 K cooling loop



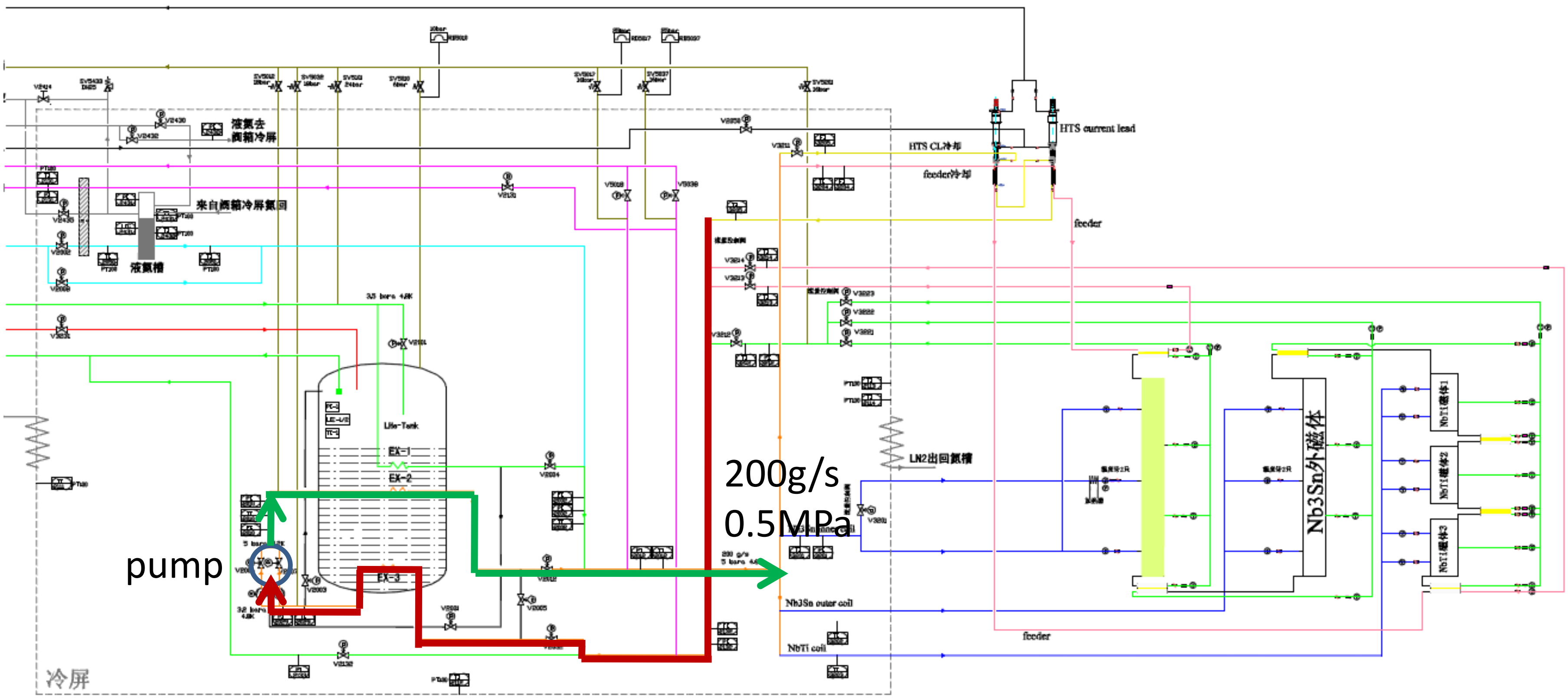
Liquid nitrogen is employed to precool helium to 80 K. The helium (300 K) mass flow from the outlet of the compressor system is transferred to the distribution valve box, which is divided into two routes. One is to obtain refrigeration power at a 80 K temperature level through heat exchanger 4 (EX4) and liquid nitrogen vessel, and then to mix the other room temperature helium route. The mixed helium will cool down the model coil from 300 K to 80K.

Process flow diagram-80 K to 4.5 K cooling loop



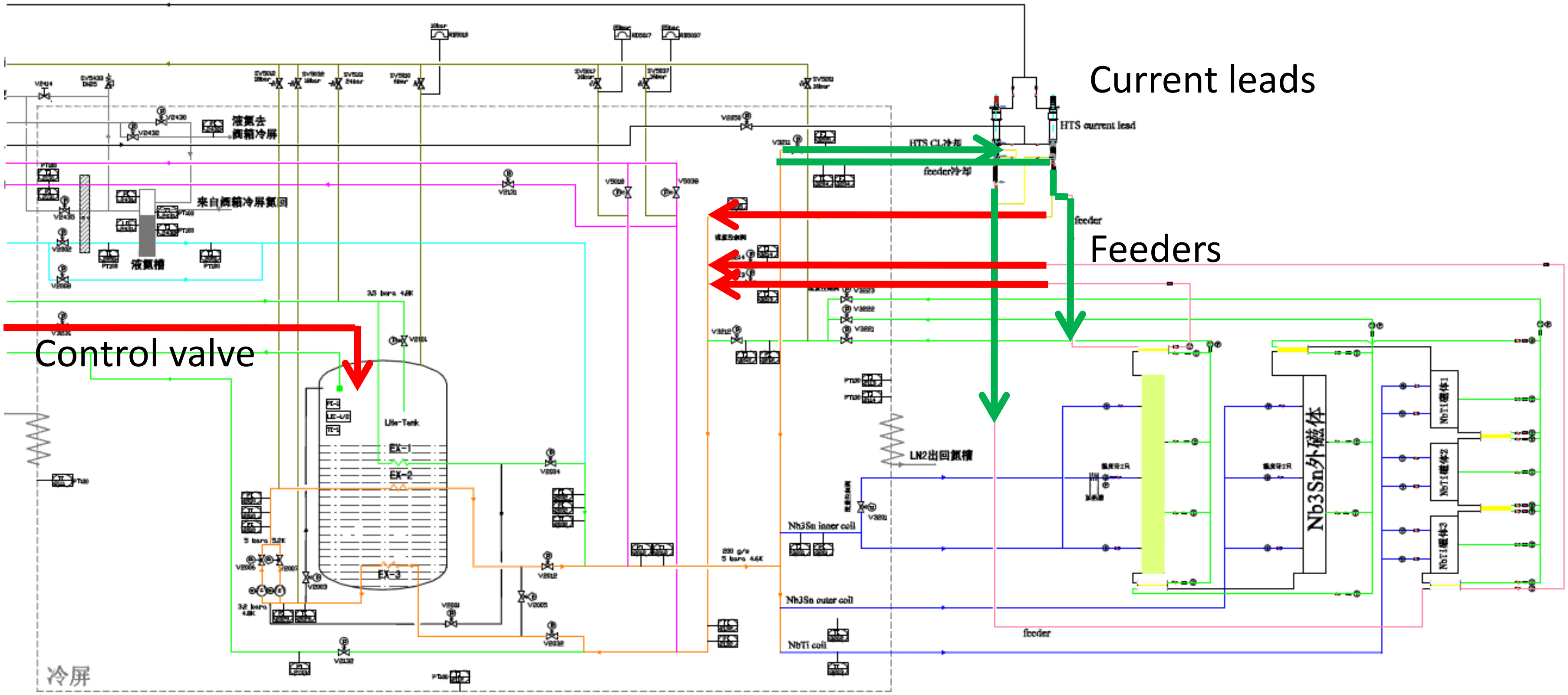
When all of the cold components of model coil are cooled down to a temperature of 80 K. The helium mass flow from the refrigerator is transferred to the valve box, which is divided into two loops. One is used for cooling the helium vessel through the Joule Thomson line, and the helium is then liquefied by the Joule-Thomson effect in liquefaction. The other is used to cool down the magnet coils and cold components to a temperature of 4.5 K. The helium cooled the model coil returns to the refrigerator.

Process flow diagram-Forced flow cooling loop



There are two pairs of SHe circulation pump in the valve box, one of which is used as an alternate. When the liquid level in the helium vessel rises to 15%, it is time to precool the SHe pump. When the liquid level rises to 60%, we can start the SHe pump to supply the forced flow of SHe to cool down the magnet coils and other cold components. When the mass flow rate and temperature reaches to their required operational parameters, they can perform all the operational modes of model coil.

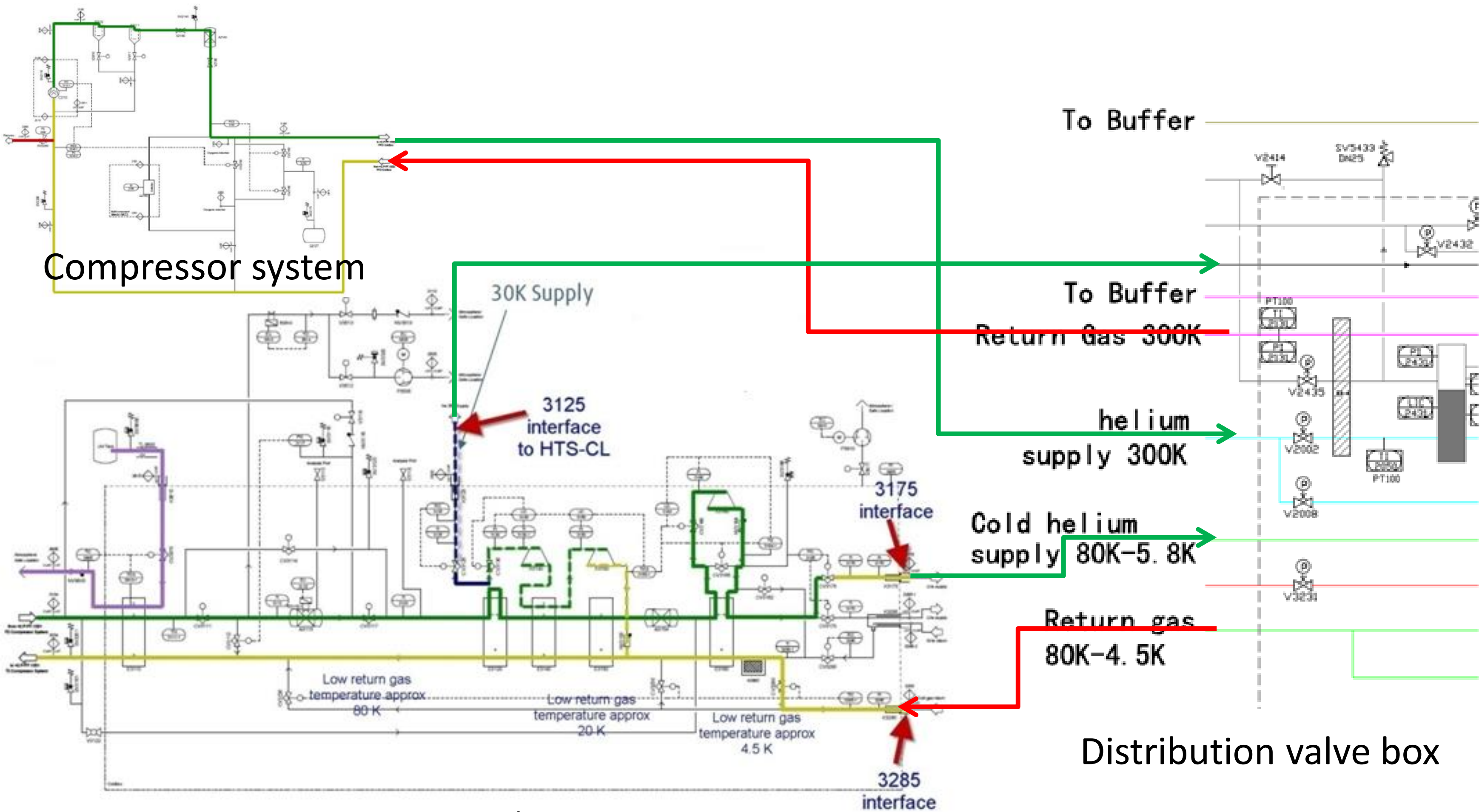
Process flow diagram



There are very few independent cooling loops. The cold end of the current leads and feeders are also cooled by a forced SHe flow. A control valve is used for importing liquid helium to helium vessel when the head load increases.

The interfaces between distribution box and refrigerator system

3175 interface: cold helium supply to experiment (for cooling the model coil)
3285 interface: cold helium gas return form experiment
3125 interface: 35 K helium supply to experiment (for cooling the hot end of the current leads)

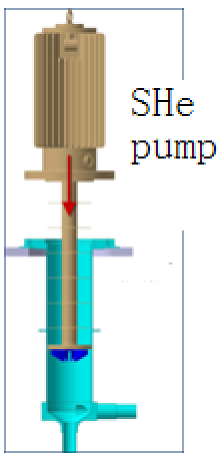


Process Flow Diagram of 900 W/4.5 K Refrigerator

The heat loads to the refrigerator system

A SHe circulation pump is used to achieve forced-flow cooling for the model coil magnet. The parameters of pump is:

mass flow rate	0.2 kg/s	pump head	0.18 MPa
pump efficiency	53%	Inlet pressure	0.32 MPa
Inlet temperature	4.8 K		



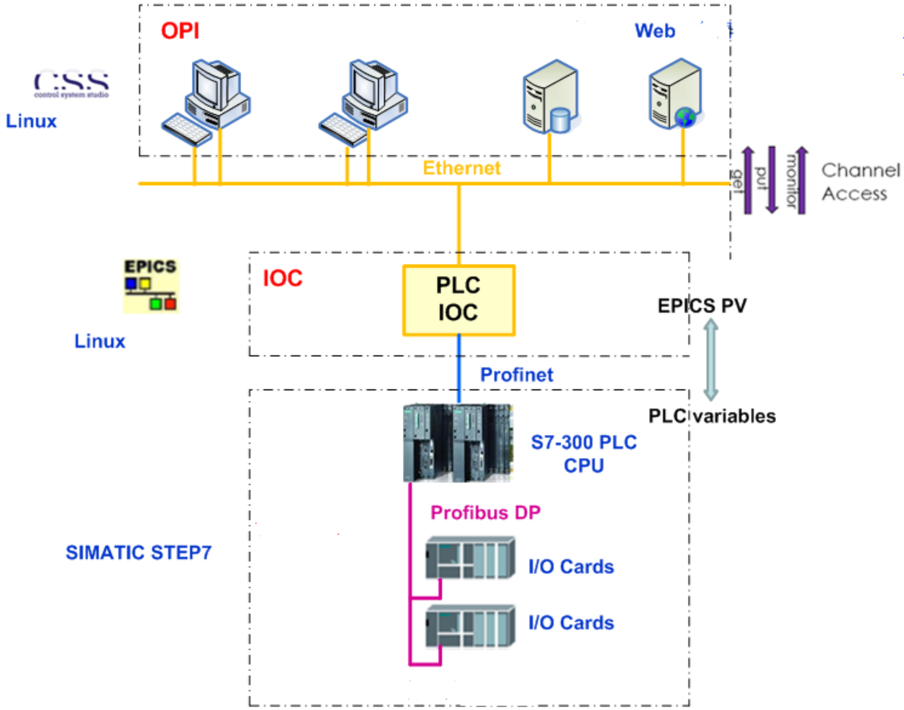
The heat load of the cryogenic circulation pump to the cryogenic system is:

$$Q_P = \frac{m_P \cdot \Delta P}{\eta_p \cdot \rho} \approx 546W$$

Where, m_p is the model coil mass flow, $\triangle p$ is pump head, η_p is adiabatic efficiency of pump, ρ is inlet density of the circulating SHe.

➢ Control architecture of cryogenic distribution system

Control system is based on EPICS（Experimental Physics and Industrial Control System）



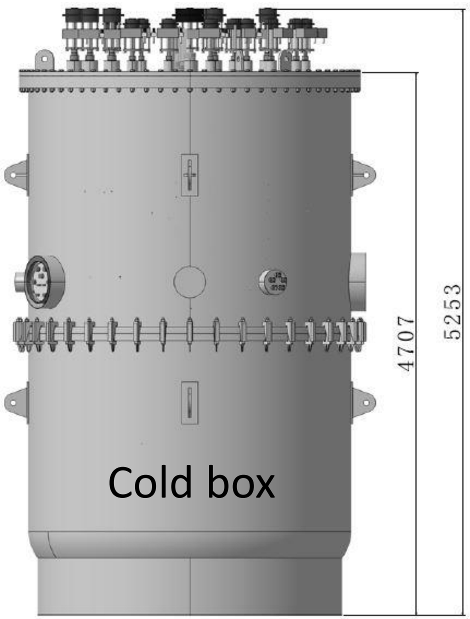
➢ Main Sensors and Executors -Summary

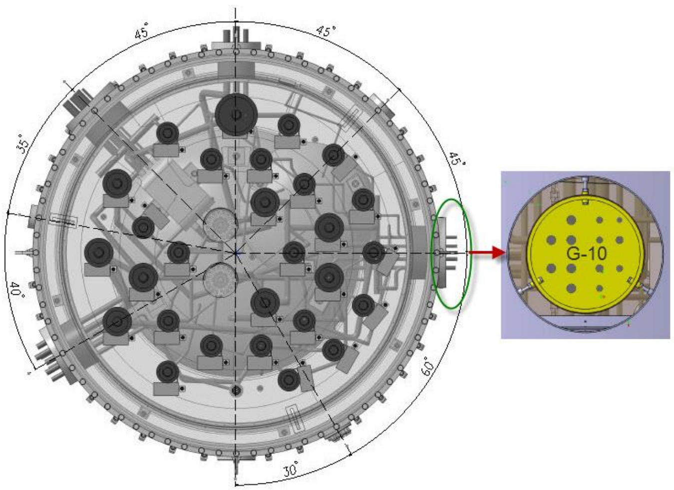
Type	Total	Area
Pressure	11	Cryogenic system
Temperature	32	
Flow	4	
Level	2	
Valve	28	
Frequency	2	

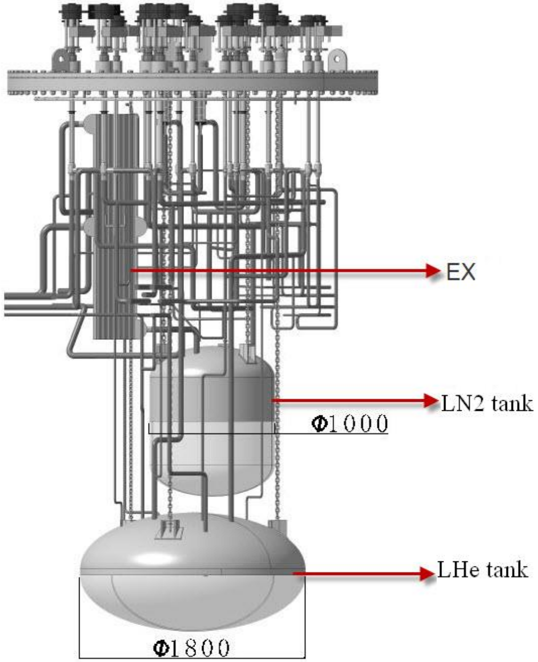
Note: the element s in magnet system is not included

Engineering design of cold box

There are one plate-fin and four coiled-tube heat exchangers in the distribution box. The coiled-tube exchanges (EX1-EX3) are installed in the liquid helium vessel, 28 cryogenic control valves are used in the box, approximate dimension as shown below.

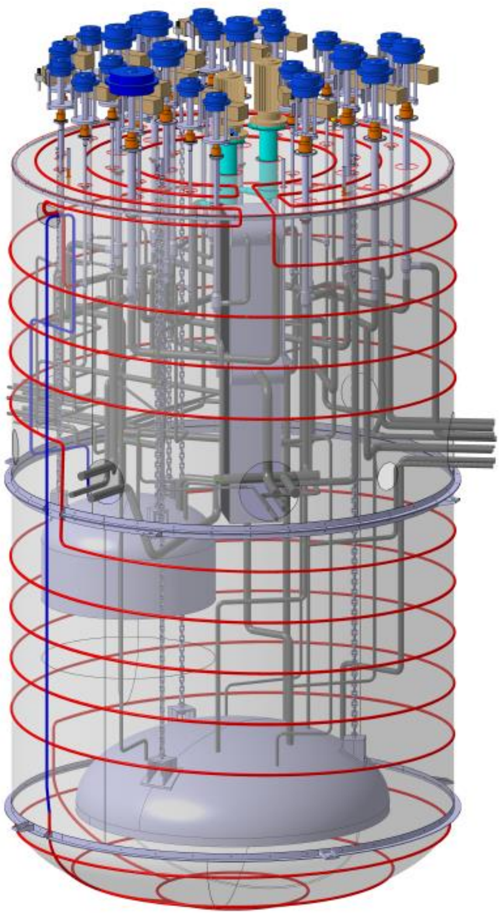


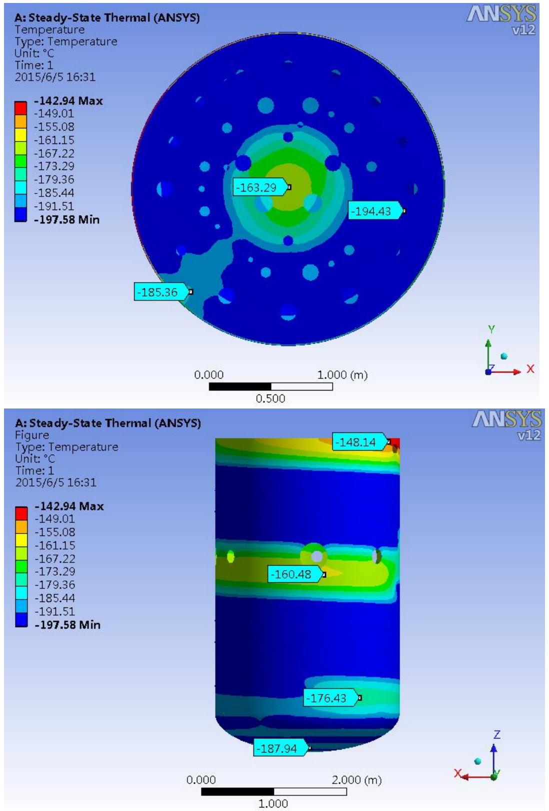




Engineering design of cold box

A thermal shield of approximate 80 K is used to reduce the heat radiation from the vacuum vessel to the equipment at 4.5 K, which is also cooled by liquid nitrogen.





Thermal shield

Conclusion

The design of the distribution system is progressing, all the fabrication work will expected to be completed within a period of two years.

Thank you!