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A new cryogenic test facility for superconducting magnets at IMP

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Abstract. To test the superconducting magnets for HIAF, CiADS and other scientific research projects, a new cryogenic test facility is under construction at IMP. The cooling power of the refrigerator in this test facility is 500 W @ 4.5 K and the liquefaction capacity is 150 L/h. Three vertical test cryostats and three horizontal test benches are planned. A 700 mm inner diameter vertical test bench and one general horizontal test bench is under installation. A standalone cool-down/warm-up unit which can supply 30 g/s helium gas at 80 K is designed. The commissioning of the cryogenic plant includes the refrigerator, the helium recovery system, the purifier, the gas tanks and the vacuum system have been finished, and the installation of two test benches are almost done. The general design and some features are described in this paper.

1. Introduction

The High Intensity Heavy-ion Accelerator Facility (HIAF) is under construction in Huizhou city in China. The current test facility at Institute of Modern Physics Chinese Academy of Sciences (IMP) in Lanzhou city is no longer satisfying the raising testing needs for the Superconducting magnets [1]. So, a new one was planned and is under construction in the Testing & Assembly Hall of the HIAF park. The new test facility is aiming to test the magnets mainly from the HIAF and the China Initiative Accelerator Driven System (CiADS) and also the magnets from upcoming scientific research projects, such as Isotope Pharmaceutical Production Platform based on Superconducting Accelerator Facility for Effective Therapy (IP-SAFE).

The scale of the test facility is designed by considering the developing plan of the accelerators at IMP in the next few years. The refrigeration capacity of the refrigerator is about 500W. Three vertical test dewars and three horizontal test benches are planning for both prototype and series testing. Also, large capacity helium recovery & purification system and a cool-down/warm-up unit (CWU) are built.

Considering the functions and the relations between the devices, the test facility could be divided into two parts, the cryo-stand and the test benches. The sub-systems of the cryo-stand include the gas storage tanks, the refrigerator, the helium recovery system, the purifier, the cool-down/warm-up unit and the vacuum pumps. The sub-systems of the test benches include the distribution box, the cryogenic transfer lines, the valve boxes associated with the corresponding test benches. All the utilities include the building, the cooling water, the instrument air, the air conditioner and the electrical utility are prepared by other departments of IMP.

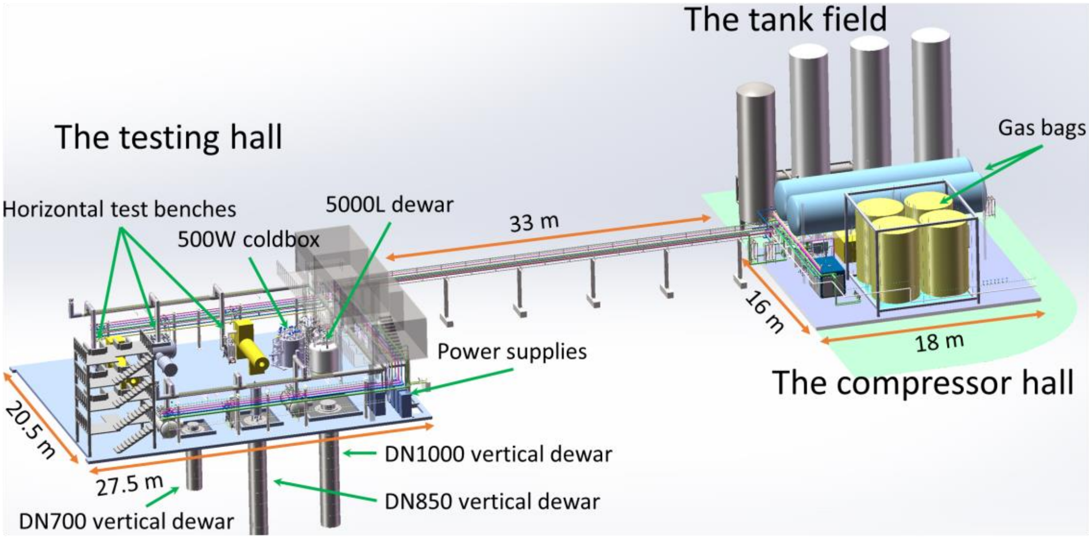

Figure 1. The 3D layout of the test facility. The compressors, the gas bags and the purifier are installed in the compressor hall. The buffers, the LN_2 tank and the high pressure impure GHe tank is installed next to the compressor hall. The cold box of the refrigerator, the 5000 L dewar, the cold box of the CWU and all the devices belongs to the test benches are installed in the testing hall.

Table 1. Main parameters of the cryo-stand.

Parameter	Value	Note
Capacity of the refrigerator	500 W @ 4.5 K, 150 L/h	With LN_2 precooling
Volume of the dewar	5000 L	Max working pressure 1.9 bar
Buffer tanks	100 m^3 × 3 @ 13 bar	-
Flow rate of the CWU	30 g/s @ 80 K	40 g/s screw compressor
Recovery compressor	100 m^3/h × 2	20 MPa max
Impure gas storage	26 m^3 @ 20 MPa	-
Total volume of gas bags	> 600 m^3	-
Purifier	≥200 m^3/h	98% inlet and 99.999% outlet
LN_2 tank	50 m^3	For one week use

To minimize the effects from the noise and the vibration to the testing, different types of devices are placed in different buildings. The devices which are quiet and directly associated with the testing are installed in the testing hall, while other devices are installed in the compressor hall which is about 33 meters away from the testing hall.

2. The main sub-systems of the Cryo-stand

2.1 The refrigerator and associated devices

The refrigerator is supplied by Institute of Plasma Physics Chinese Academy of Sciences. The cooling capacity of the refrigerator is about 500 W, and the liquefaction rate is about 150 L/h. The refrigerator could produce SHe, LHe and also a stream of 80 K GHe, but it cannot supply 50 K GHe for cooling HTS current leads. To remedy that a heat exchanger is installed in the distribution box to produce 50 K GHe up to 3 g/s by cooling the 80 K @ 13 bar helium Gas with LHe.

The estimated maximum LHe consuming is at least 3000 L/day during vertical testing, so a 5000 L capacity was chose for the dewar. Three 100 m³ buffer tanks with 13 bar maximum working pressure are installed, which can supply GHe for liquefacation until the pressure reaches about 2.5 bar. In the summer (47 ℃), the total useful capacity of the buffer tanks equals to about 3500 L LHe, which is enough for the refrigerator to liquify for one day.

2.2 The cool-down/warm-up unit

To control the temperature difference of the magnet during cooling down and warming up, a CWU is built referring to CERN's design [2] [3] [4]. The cooling power of the CWU is provided by LN_2, and the warming up power is generated by electrical heaters. When the CWU serves only one test bench, the CWU will supply GHe with continuously changing temperature according to the cooling status of the test bench. When the CWU serves more than one test benches and the different test benches need GHe with different temperature, the CWU cold box will only supply 80 K GHe, the

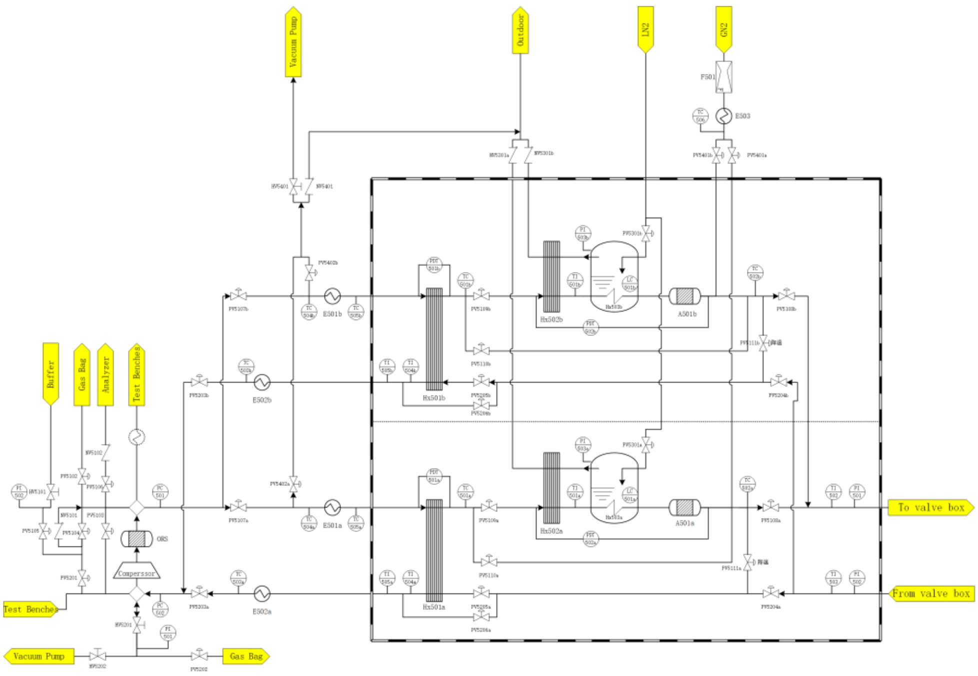

Figure 2. Flow scheme of the cool-down/warm-up unit

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CWU compressor will supply room temperature GHe to the test benches, and the mixing of the two streams of gas will be controlled by the valve box of the test benches.

The CWU has dedicated compressor, oil removal system and gas management panel. The input parameter to design the CWU unit is to cool down or warm up three 3 t cold mass between 80K and 300 K in 48 h at the same time, and the temperature difference of the magnet should be kept under 30 K. So, a 40 g/s maximum flow rate for the compressor is choosing, and the cold box of the CWU can produce up to 30 g/s 80 K cold GHe. It can provide a maximum cooling capacity of 15 kW (30 g/s) to one test bench. The power of the heaters used to warm up the magnet is 15 kW. The maximum temperature of the gas supplied to the magnet can reach 350 K, which can ensure that the magnet could be warmed beyond the dew point of the atmosphere. This is important to avoid condensation of moisture on the magnet. 80 K adsorber filled with charcoal is used to remove impurities coming from the surface of the magnet and the cryostat to keep purity of the gas during the cooling down. Considering the continuity of the series test, two sets of heat exchangers are placed in the cold box, they can operate alternatively to keep the effect of the adsorber.

2.3 The helium recovery system and the purifier

The circulation of the LHe during the vertical testing and some of the horizontal testing is in an open loop. In this condition, the vapor is gathered by the gas bags and then recovered by the compressors instead of returning back to the cold box. So when the magnet quenchs, the risks of helium pollution and impacting to the refrigerator are minimized. Two 100 m^3/h recovery compessors operated at 20 MPa are installed in the facility. The recovered gas is stored in the high pressure storage tank which could store up about 5000 m^3 gas.

The impure gas will be purified by a purifier which consists of two alternately operating cryo-adsorption units. Each cryo-adsorption unit can process 98% purity GHe about 2400 m^3. As the regeneration time of each cryo-adsorption is less than 8 hours, the whole purifier can process about 4800 m^3 gas every day.

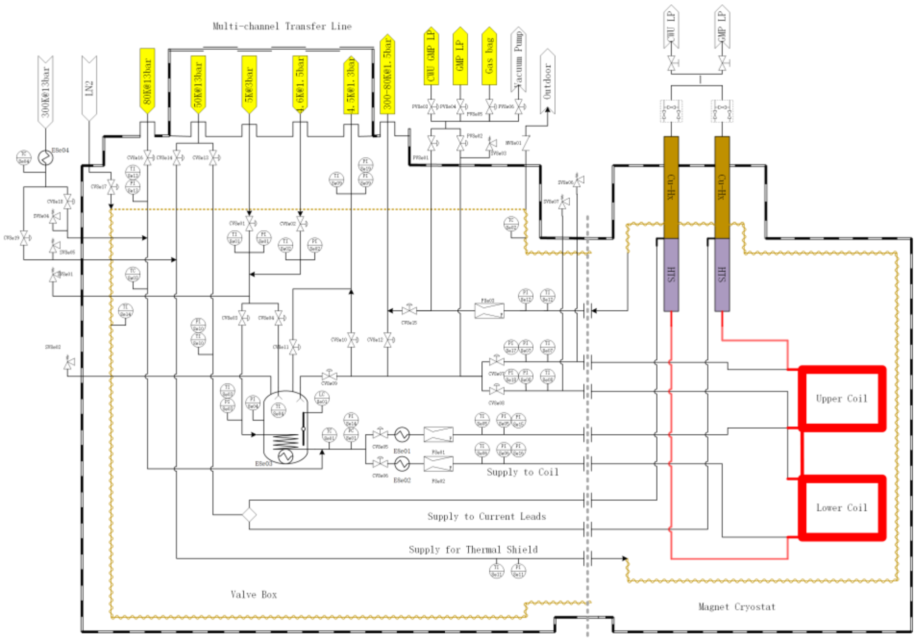

Figure 3. Flow scheme of the general horizontal test bench in forced flow cooling method.

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3. The test benches

3.1 The horizontal test benches

There are three horizontal test benches are planned in the new test facility, and one of them is designed as a general test bench which is now under construction. The rest two horizontal test benches are used to test the HIAF Fragmentation Separator (HFRS) magnet for HIAF project with the dedicated connection valve box which will be disassembly and installed into the HFRS tunnel after the testing [5].

The general horizontal test bench is designed both for forced-flow cooling and bath cooling. The cooling mode is chose by the design of the magnet. The flow sheme for forced flow cooling is shown in figure 3. Two 4.5K cooling channels are designed in the valve box in case that the magnet have a pair of coils. Each cooling channel has pressure sensors and temperature sensers at the inlet and the out let of the coil, and also a Coriolis flowmeter at the inlet, so the loss of the magnet could be measured by calorimetric method. When the forced flow magnet is tested, the SHe from the cold box or pressured LHe from the dewar is transferred into the valve box, then the pressure, the temperature and the flow rate is adjusted by the sub-cooler, the electrical heater and the valves. When the bath cooling magnet is tested, only one cooling loop will be used to supply LHe to the helium vessel of the magnet. The loss of the magnet will be estimated by the evaporation rate of the LHe.

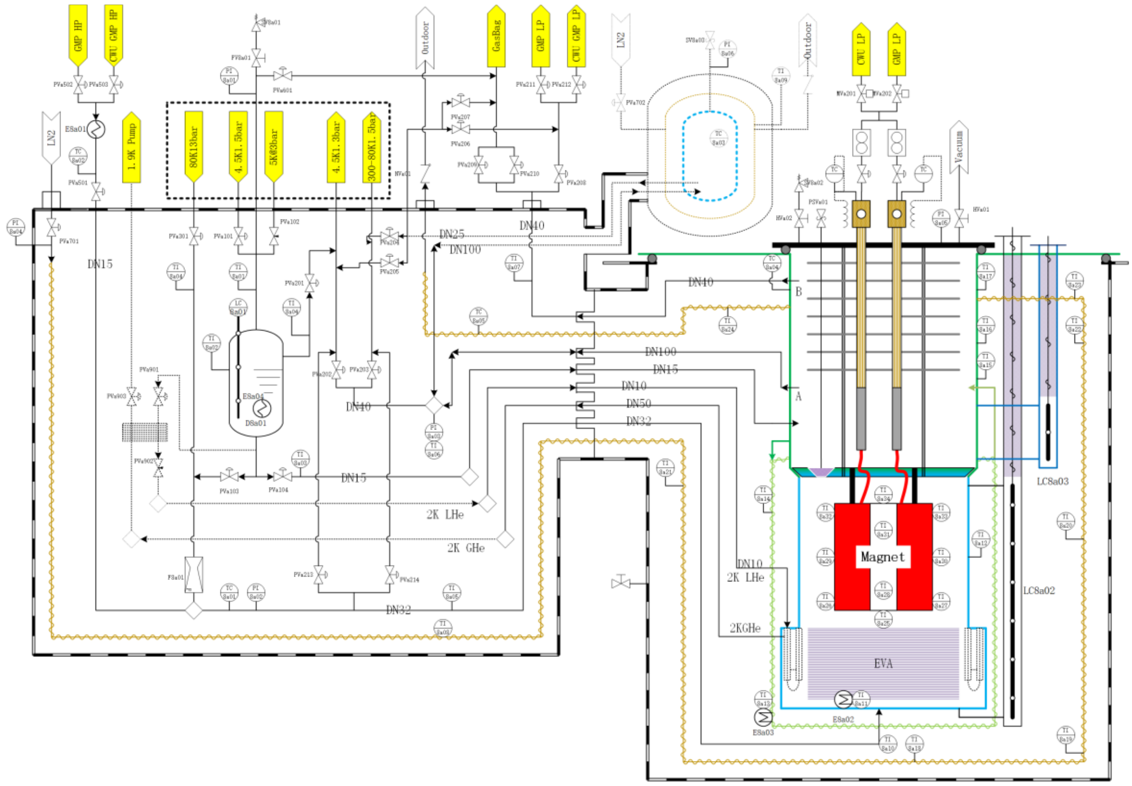

Figure 4. Flow scheme of the vertical test bench

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3.2 The vertical test benches

Three vertical test benches were planned, the inner diameter of the dewars are 700 mm (DN700), 850 mm (DN850), and 1000 mm (DN1000). The depth of the DN700 one is 5000 mm, and the other two are both 8000 mm. Currently, only the DN700 one is under construction. The design of the test bench mainly referred to the CERN's High Field Superconducting Magnet Test Station (HFM) Cryostat and a BNL's dewar [6] [7]. The DN700 test bench is designed to carry out both 4.5 K saturated bath cooling and pressurized 1.9 K bath cooling. But considering the present testing needs, only 4.5 K part is built. The 1.9 K gas/liquid heat exchanger and the pump system has not been manufactured, only the interface is built. The maximum working pressure of the dewar is 6 bar. This high-pressure design could delay the venting of the relief valve when a magnet with relatively large storage energy quenches, which can enhance the quality of the GHe gathered by the gas bags. A quench buffer is also considered and will be integrated when it is needed.

4. Status and Conclusion

The installation of the test facility has been started in September 2023, and the commissioning of the sub-systems include the helium recovery system, the purifier, the vacuum pumps and the gas storage tanks have been started in December 2023. The most difficult work during this phase is the leakage fixing and the purifying of the buffer tanks. A leakage on the pipe between the buffer jar and the pistons of a recovery compressor in the compressor case cause most of the loss of the helium gas. And it appears that the most efficient method to purify the buffer tanks is filling less helium in the tanks and then circulating the gas with the screw compressor of the refrigerator between the buffer and the purifier. It takes less than 48 h to purify a 100 m^3 tank to better than 99.999%.

The commissioning of the refrigerator was finished in early March 2024. The refrigeration capacity with LN_2 precooling reached 513 W, and the liquefaction rate reached 160 L/h. Five super-Ferric dipole magnets of the HFRS have been tested with the cryo-stand. The installation of the test benches is almost done, and the commissioning will be started in August 2024.

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