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# A new cryogenic test facility for large superconducting devices at CERN

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**Abstract.** To expand CERN testing capability to superconducting devices that cannot be installed in existing test facilities because of their size and/or mass, CERN is building a new cryogenic test facility for large and heavy devices. The first devices to be tested in the facility will be the S-FRS superconducting magnets for the FAIR project that is currently under construction at the GSI Research Center in Darmstadt, Germany. The facility will include a renovated cold box with 1.2 kW at 4.5 K equivalent power with its compression system, two independent 15 kW liquid nitrogen precooling and warm-up units, as well as a dedicated cryogenic distribution system providing cooling power to three independent test benches. The article presents the main input parameters and constraints used to define the cryogenic system and its infrastructure. The chosen layout and configuration of the facility is presented and the characteristics of the main components are described.

## 1. Introduction

Several test facilities exist at CERN to test large superconducting magnets in liquid and superfluid helium [1]. However, the space available and the lifting equipment in the existing facilities are not adequate for testing the 57 FAIR S-FRS magnets [2] that are planned to be tested at CERN starting in 2017 in the framework of a collaboration between CERN and the GSI Research Center of Darmstadt, Germany [2,3]. These magnets that will be cooled by a bath of saturated liquid helium (LHe) at 4.5 K will be delivered to CERN in their cryostat and will be tested as standalone units. Some of the magnets have a total height larger than 5 m and a mass up to 70 ton and cannot be installed in the existing facilities at CERN. To be compatible with the required testing schedule, a capacity to test 21 magnets per year will be required. To implement the test program for the S-FRS magnets and to extend the test capacity of CERN to future large magnets and other superconducting devices, CERN is therefore building a new test facility with larger maximum dimensions and more lifting capacity than the existing ones. The cryogenic system of the new facility, which will also include a full range of equipment to power and characterize the superconducting magnets, will use a pre-existing cold box, cool-down/warm-up unit and a valve box that were used to test the superconducting magnets of the ATLAS experiment [4].

## 2. Main input parameters

The first devices to be tested in the new facility will be the S-FRS magnets. The test program requirements are the main drivers for defining the cryogenic characteristics of the test facility. The 57 S-FRS magnets will be of three types: dipoles, multiplets 1 and multiplets 2 [2,3]. Their main



**Table 1.** Main characteristics and number of the Super-FRS magnets [5].

Type	Quantity	Mass [ton]	Cold mass [ton]	LHe volume [m <sup>3</sup> ]	Static 4.5 K heat load [W]	Static thermal shield heat load [W]
dipole	24	50	2	0.025	4	35
multiplet 1	24	70	45	1.350	30	160
multiplet 2	9	25	20	0.900	30	160

characteristics are shown in table 1 [5]. The cold mass of the multiplet 1 is the largest of the three types, and it therefore drives the definition of the required maximum cryogenic parameters.

A detailed study was performed to determine the mass flows and powers required in the various phases [5], and the results are used as an input to define the cryogenic system configuration. After preparation, the magnets will be cooled with a speed of 1 K/h to 90 K. During this phase, the maximum allowed temperature difference across a magnet is 50 K. The magnets are then cooled with no speed restriction down to 4.5 K. The cryostat is then filled with liquid helium. This phase will take approximately 10 days and will be followed by 12 days of powering and magnetic measurement tests. The magnets will then be warmed up with no speed restriction to 90 K and then with a speed of 1 K/h to 293 K. The total test cycle is about 42 days, or about 7 magnets per year (taking into account holidays and maintenance periods). To fulfil the requirement to test 21 magnets per year, the facility must thus have three test benches and must have the possibility to simultaneously have at least one test bench in the 293 K – 4.5 K cool-down phase, one test bench in the 4.5 K – 293 K warming-up phase and one test bench in the cold testing phase at 4.5 K. The main cryogenic dimensioning requirements are summarized in table 2.

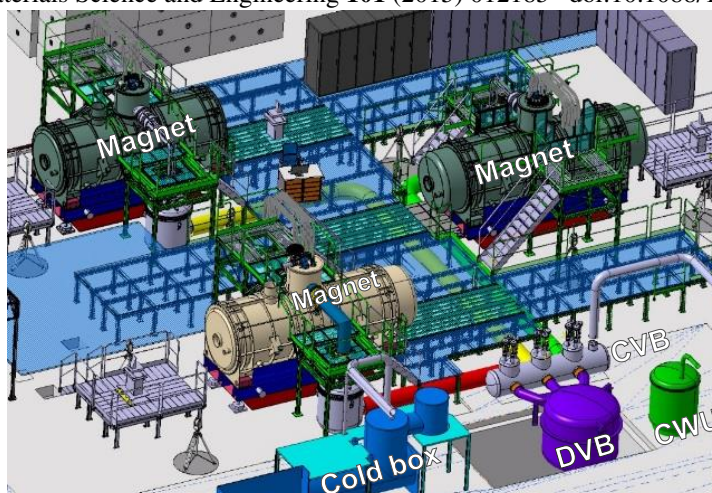
**Table 2.** Summary of the main dimensioning requirements for testing the largest of the S-FRS magnets [5].

Test Phase	Requirement
Cool-down 293 K – 90 K	5.6 kW cooling power, 21.4 g/s at 10 bar
Cool-down 90 K – 4.5 K	6.2 m <sup>3</sup> of saturated LHe at 4.5 K
Filling of magnet With LHe	1.4 m <sup>3</sup> of saturated LHe at 4.5 K
Cold tests heat loads	30 W static at 4.5 K, 35 W dynamic during 10 minutes, 160 W at 60 K – 90 K (screen) 1.6 g/s at 4.5 K – 300 K (liquefaction load)
Warm-up 90 K – 293 K	5.4 kW heating, 20 g/s at 10 bar

### 3. General infrastructure of the test facility

The new facility will be constructed in building 180 (B180) and building 279 (B279) at CERN. B279 will host the compressor stations while a dedicated area of 1400 m<sup>2</sup> in B180 will host the cold components of the cryogenic system, the cryogenic distribution system, the magnets, the powering and test systems and a control room as well as the necessary offices.

B180 is one of the largest buildings at CERN and was used to test the magnets of the ATLAS experiment [4]. The facility can accommodate devices with a height up to 7 m for masses up to 55 ton and, by coupling two cranes, devices with a mass up to 89 ton and a height of 5 m.



**Figure 1.** Planned layout of the test facility showing the magnets and some of the components of the cryogenic system.

For the compressor building, particular attention is paid to the safety and environmental aspects. The proximity of office buildings requires a noise level lower than 60 dB (A) outside of the building. To avoid pollution of the environment by an oil spill, the complete building will be sealed. Experience has shown that a simple collection vessel under the compressor station is not sufficient in case of a significant leak of high pressure oil.

#### 4. The cryogenic system of the test facility

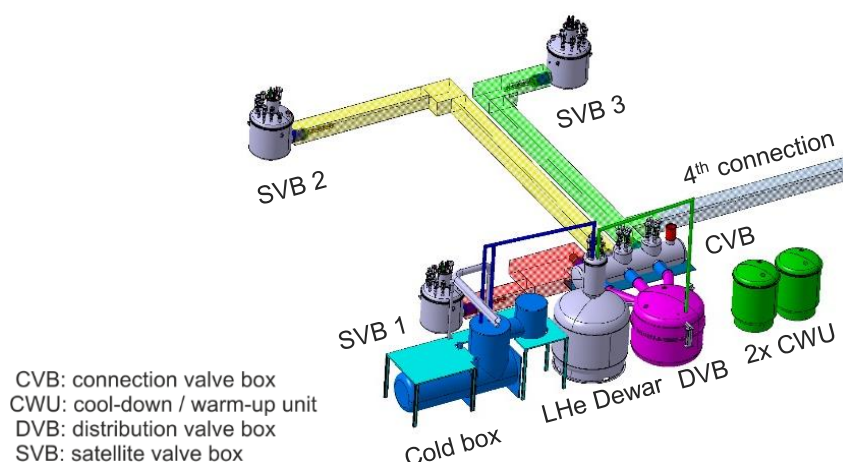
To provide the required mass flows and cooling/heating powers required for the tests of the S-FRS magnets, the cryogenic test facility will include the following main cryogenic systems:

- Three test benches for three independent magnets and related cryogenic distribution boxes.
- Two LN<sub>2</sub> cooled cool-down/warm-up units (CWU) and their compressor stations.
- A 4.5 K LHe refrigeration/liquefaction system with its compressor station, a storage dewar and related systems.

A 3D view of the planned test facility is shown in figure 1 for the whole facility and in figure 2 for the cryogenic system. As can be seen in figure 2, the possibility to connect a fourth test bench for future needs is integrated into the design although no valves box is associated to it in the current design. A schematic flow diagram of the cryogenic system is shown in figure 3.

##### 4.1. Cold box and compressor station

The function of the cold box is to provide all the necessary cooling power during the final cool-down phase to 4.5 K and during nominal operation of the magnets. The cold box is a pre-existing Sulzer TCF200 with an equivalent refrigeration power of 1.2 kW at 4.5 K or a liquefaction capacity of 5.6 g/s, last used for testing the ATLAS magnets [4]. The cold box produces supercritical helium at 4 bar and 4.5 K, and the return pressure of the GHe at 4.5 K is 1.3 bar. In addition, the cold box has a cooling capacity of about 1.0 kW at 60 K – 70 K and 16.7 bar for thermal shield cooling. It will be completely refurbished with an extensive maintenance and upgrade program of all its components. The cooling power provided by the cold box guarantees a large margin with respect to the required needs.

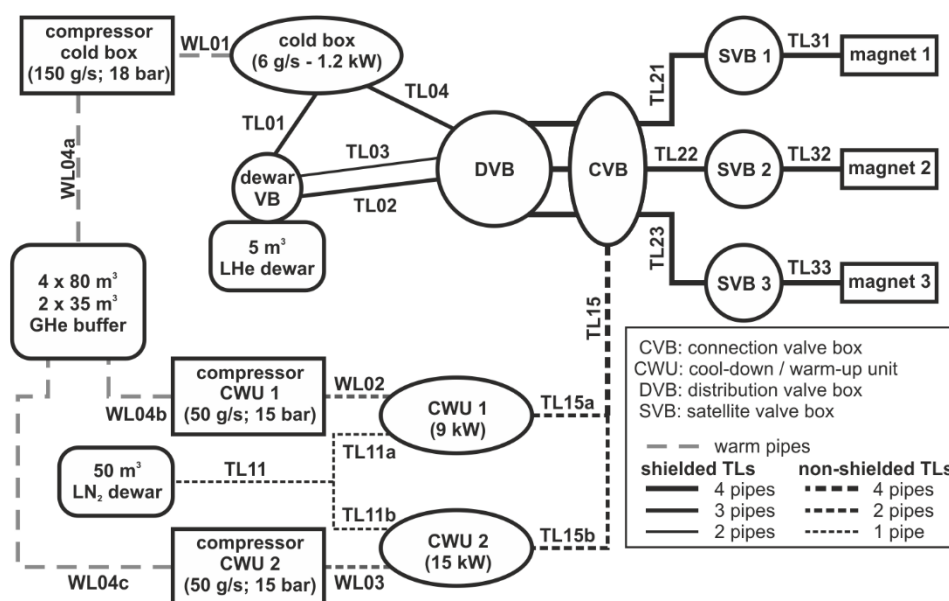


**Figure 2.** Planned layout of the cryogenic system in B180.

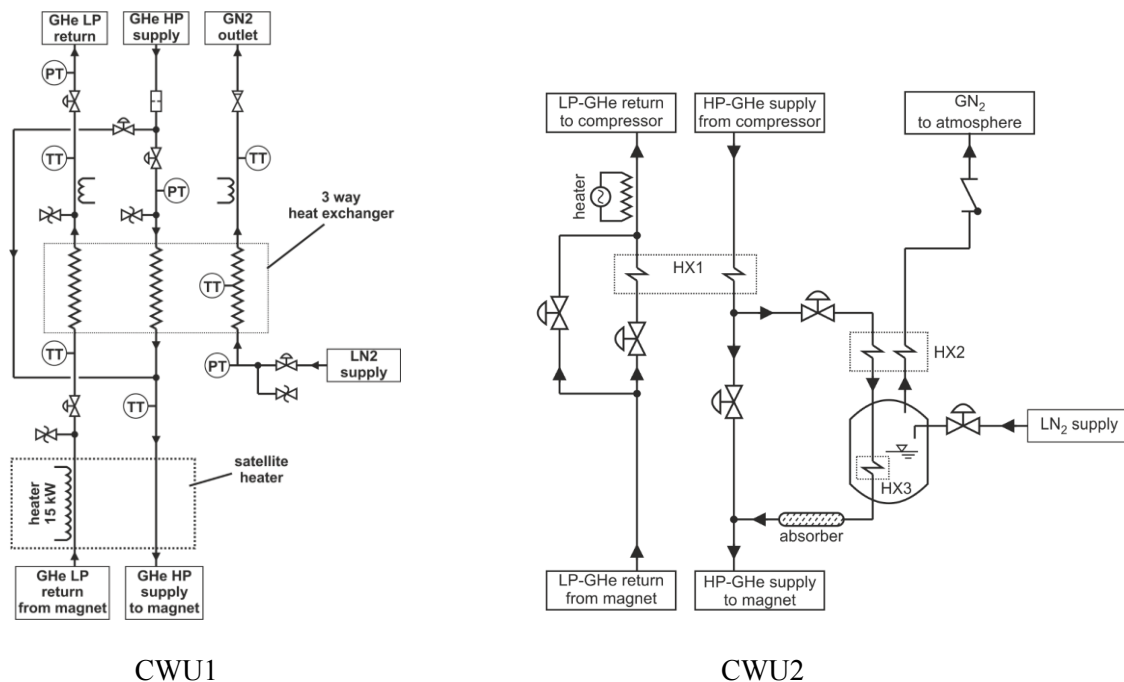
The cold box will be fed by a new compressor station providing a helium flow of 150 g/s at 18 bar and maximum 300 K with a suction pressure of about 1 bar. The compressors will be of the oil flooded type with an electrical power requirement of about 700 kW. The compressor station will be equipped with a primary oil separation system followed by 3 coalescing filters and a charcoal adsorber to supply high purity helium to the cold box.

#### 4.2. LHe storage dewar and associated valve box

A LHe dewar with a capacity of 5 m<sup>3</sup> will be used as a buffer volume that will also provide a booster capacity for the final cool-down and filling of the magnets. The dewar will be operated at 1.4 bar and



**Figure 3.** Cryogenic system layout of the test facility.



**Figure 4.** Flow diagram of CWU1 (left) and CWU2 (right).

supplies LHe to the test benches. The dewar is equipped with a heater of 1.5 kW that allows the commissioning of the cold box at full refrigeration capacity.

A valve box installed on top of the dewar connects it to the cold box and to the cryogenic distribution system. The valve box makes it possible to distribute the supercritical helium from the cold box to the LHe dewar or directly to the test benches. The pressure of the dewar is controlled by regulating the GHe return flow by a control valve located in this valve box.

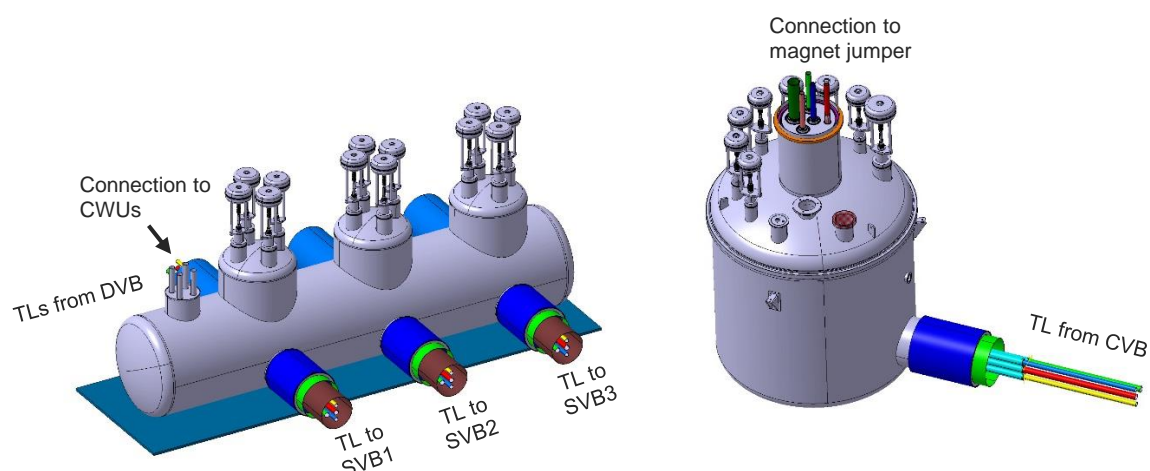
#### 4.3. Cool-down / warm-up units

To allow the simultaneous cool-down of one test bench and the warm-up of another test bench, the test facility will include two CWUs, both using LN<sub>2</sub> as a cooling source and an electrical heater with a power of 15 kW. The LN<sub>2</sub> will be supplied from a 50 m<sup>3</sup> LN<sub>2</sub> storage tank that will be installed outside the building. The circulation of the helium in the CWU loops is driven by two compression stations located in B279 that can each provide a flow of 50 g/s at a pressure of 12 bar. The interconnecting piping is designed in such a way that any compressor station can be used to feed any of the two CWUs. CWU1 is an existing unit that will be refurbished while CWU2 is an entirely new unit. The flow diagrams of both CWU are shown in figure 4. It is planned to install a helium dryer in the cooling loop to absorb any water that would be extracted from the magnets during cool-down (not shown in the diagram).

CWU1 contains a three channel heat exchanger; the incoming high-pressure GHe flow (HP-GHe) is separated into two parts. The first part passes through the heat exchanger and is cooled to about 80 K by the returning low-pressure GHe flow and the LN<sub>2</sub> flow flowing into the opposite direction. The second part is flowing around the heat exchanger and stays at room temperature. Both flows are mixed to obtain the required temperature for pre-cooling the magnets. CWU1 is designed to make a temperature difference of 40 K at a GHe flow rate of 50 g/s and thus has an equivalent cooling power of about 9 kW. For the warm-up phase an external electrical heater of 15 kW will be added to CWU1.

CWU2 is a newly designed unit. It will have an equivalent cooling and heating capacity of 15 kW and can produce a temperature difference of 50 K at a GHe flow rate of 50 g/s. Figure 3 shows the flow diagram of the CWU2. It contains within the same vacuum insulated tank a helium – helium heat exchanger (HX1), a helium – nitrogen heat exchanger (HX2), a phase separator for LN<sub>2</sub> with a





**Figure 5.** Proposed design of the connection valve box (CVB) (left) and of the satellite valve box (SVB) (right).

helium – LN<sub>2</sub> heat exchanger (HX3), an adsorber, a helium gas heater, several cryogenic valves, cold pipework and instrumentation. GHe (HP-GHe) supplied by the compressor station at 12 bar and room temperature enters the CWU2. While flowing through HX2, it is cooled by the returning GHe flow (LP-GHe) flowing in opposite direction. The HP-GHe flow leaves the HX1 at the temperature of the returning LP-GHe flow coming from the magnet and thus is approximately at magnet temperature. After HX1, the HP-GHe flow is divided into two parts. The first part flows subsequently through HX2 and HX3 in the phase separator and is cooled down by the LN<sub>2</sub> inside the phase separator to 80 K. It then passes through an active adsorber at 80 K to remove impurities in the GHe. The second part stays at the magnet temperature. By mixing both streams, the required temperature for pre-cooling the magnet is obtained which is maximum 50 K lower than the magnet temperature.

The LN<sub>2</sub> level inside of the phase separator is regulated by a control valve. The LN<sub>2</sub> is supplied by a 50 m<sup>3</sup> LN<sub>2</sub> storage tank. The evaporated GN<sub>2</sub> flow passes through HX2 and pre-cools the HP GHe flow before it is vented to air. The GN<sub>2</sub> flow leaves HX2 at the magnet temperature. The cooling capacity of GN<sub>2</sub> from this temperature to room temperature is lost.

#### 4.4. Cryogenic distribution system

The cryogenic distribution system, shown in figure 2 and figure 3, consists of a distribution valve box (DVB), a connection valve box (CVB), three satellite valve boxes (SVBs) and various cryogenic transfer lines (TLs). The DVB is an existing valve box that is used to distribute liquid helium and supercritical helium via the CVB to the three test benches. The CVB connects the CWUs to each test bench and is connected to each SVB via a vacuum insulated transfer line containing four process pipes surrounded by a thermal shield. The satellite valve boxes are located next to the magnet test benches. A tentative design of these valve boxes is shown in Figure 5. They are connected to the magnets via a jumper with five shielded process lines used respectively for LHe filling to top and bottom of the LHe volume, GHe return, thermal shield supply and return.

#### 4.5. Performance of the cryogenic system with respect to the requirements of the S-FRS magnet tests

Table 3 summarizes the main performance of the cryogenic system of the new test facility. By comparing the performance with the requirements of table 2 and with the detailed study performed in the design phase [5], it is apparent that the cryogenic system will provide all the necessary functionalities

**Table 3.** Summary of the main performance of the test facility cryogenic system.

Functionality / device	Performance
Cooldown 293 K – 90 K / CWU1	9 kW cooling power, 50 g/s at 10 bar
Cooldown 293 K – 90 K / CWU2	15 kW cooling power, 50 g/s at 10 bar
LHe dewar capacity	5 m <sup>3</sup>
Refrigeration/liquefaction	1.2 kW at 4.5 K, 5.6 g/s liquefaction
Thermal screen cooling	1 kW, 60 K – 70 K
Warm-up 90 K – 293 K / CWU1 & 2	15 kW heating, 50 g/s at 10 bar

to test the S-FRS magnets. The performance margin might be used for parallel operation of test benches or for faster cool-down/warm-up phases if the 1 K/h speed is relaxed after testing the prototype magnets.

## 5. Conclusions

A cryogenic test facility for testing large and heavy superconducting devices is currently being built at CERN. The configuration and performance of its cryogenic system has been defined to fulfill the requirements of the first devices that will be tested in the facility: the S-FRS magnets of the FAIR project. The cryogenic system will feed three test benches. The system will include two LN<sub>2</sub> cooled – electrically heated cool-down/warm-up units with a capacity up to 15 kW and a helium flow up to 50 g/s. The 4.5 K LHe cooling will be provided by a 1.2 kW at 4.5 K refrigerator, and the system is equipped with a storage dewar of 5 m<sup>3</sup> for LHe. The facility fulfills all the requirements of the test program planned for the S-FRS magnets at CERN, and the performance margin can be used to provide some operational flexibility.

The project is currently in an advanced design and procurement phase with most procurement contracts planned to be placed in the third quarter of 2015. The cryogenic system is planned to be commissioned in the third quarter of 2016, with prototype S-FRS magnet tests starting at the beginning of 2017 and the series tests planned until 2020.

## Acknowledgements

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