Commissioning and performance of the cryogenic system of the new test facility for large superconducting devices at CERN

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Abstract. CERN has built a new test facility for large and heavy superconducting devices that will be first used for testing the Super-FRS magnets of the FAIR project being built at GSI in Germany. This paper reports on the commissioning results and performance of the cryogenic system. The cryogenic system includes a new compression station coupled to a refurbished 1.2 kW equivalent power at 4.5 K TCF200 helium refrigerator. The cryogenic system contains further a 5 m³ liquid helium dewar, two liquid nitrogen cool-down / warm-up units for precooling to 80 K and warming-up the devices after the tests, and a dedicated cryogenic distribution system consisting of multiple valve boxes and transfer lines to distribute helium to the three test benches.

1. Introduction
CERN has built a new test facility for large and heavy superconducting devices that cannot be tested in existing test facilities because of their size and/or mass. The facility can accommodate devices with a maximum height of 7 m and a mass up to 55 ton and, by coupling two cranes, devices with a maximum height of 5 m and a mass up to 89 ton. The facility occupies a surface area of 1400 m² and contains three test benches, the cryogenic system, the powering and testing systems, a magnet preparation area and a control room with offices. The compression stations for the helium refrigerator and for the cool-down / warm-up units (CWUs) are installed in a separate dedicated building. A photo of the test facility with its main components is shown in figure 1.

The Super-FRS superconducting magnets for the FAIR project [1] are the first devices that will be tested in this new facility in the framework of a collaboration between CERN and the GSI Research Center in Darmstadt, Germany. These magnets are iron dominated superconducting magnets cooled by a liquid helium (LHe) bath at 4.5 K [1]. In total 57 magnet assemblies of three different types will be tested at CERN in their cryostat as stand-alone units. The magnet assemblies will have a total mass up to 70 ton, a cold mass up to 45 ton and a height up to 5 m. The design of the test facility was mainly driven by the test program requirements of the Super-FRS magnets and is discussed in [2,3].

Pre-series testing will start in autumn 2018, and the series testing in autumn 2019. The test program will take about 3 years with a testing speed of 21 magnets per year.
2. Compression station building
The two compression stations are installed in a separate building that was built in 1971. This building was fully renovated to fulfill the current standards with respect to safety and environmental aspects.

The noise level outside the building shall be lower than 60 dB(A) due to the proximity of office buildings. A study was performed to measure the noise damping coefficients of the building. Instead of isolating the building, which required complex and costly civil engineering work, it was decided to install a noise hood around the screw compressors and electrical motor of the helium refrigerator compression station that reduces the noise to 90 dB (A) at 1 m from the compression station. The maximum noise level of the CWU compression station is 88 dB (A). The noise hood ensures the required noise level of 60 dB (A) outside of the building.

The compression stations contain in total about 2 m$^3$ of oil. To avoid pollution of the environment in case of oil spillage an oil retention system was installed that prevents oil leakages outside the building or through the drainage system. To obtain this, the floor is sealed with a resin, and profiles and steps are installed at doors, corners and openings. Via gutters and a drain pipe, the oil is finally collected in two retention tanks, each with a volume of 1.9 m$^3$, installed in the basement.

3. The cryogenic system of the test facility
The cryogenic system is designed to fulfill all requirements for the cool down, cold testing and warm up of the Super-FRS magnets. The configuration of the cryogenic system is shown in figure 2. The main components are:

- a helium refrigeration system with its compression station, gaseous helium storage (GHe) and distribution system at room temperature, a 5 m$^3$ LHe dewar and dedicated distribution system consisting of several cryogenic valve boxes and cryogenic transfer lines;
- two CWUs driven by one compression station, a 50 m$^3$ liquid nitrogen (LN$_2$) storage tank and dedicated nitrogen distribution system.

The cryogenic control system consists of more than 20 dedicated electronic racks that are constructed in-house used to read-out and control more than 3000 signals. The control interface is based on the standard CERN software Unicos.
3.1. Helium refrigeration system and compression station

An existing TCF200 helium refrigerator manufactured in 1978 is used for the LHe production. The original refrigerator was equipped with two turbines in series. In 1989, the refrigerator was upgraded by the addition of a third turbine to boost its performance. Between 2000 and 2004, the refrigerator was used for the ATLAS test facility [4]. The operation of the refrigerator was stopped in 2004.

The refrigerator was designed for delivering an equivalent refrigeration power of 1.2 kW @ 4.5 K or a liquefaction rate of 5.6 g/s, both combined with a shield cooling capacity of 1.0 kW at 58 K. The helium refrigerator was shipped back to the supplier for an extensive maintenance and upgrade program and afterwards re-installed at CERN. The main refurbishment work included:

- installing an additional GHe return line to 300 K and associated cryogenic valve and electrical heating elements with a total capacity of 24 kW;
- manufacturing a new purge and instrumentation rack;
- manufacturing a new cooling water distribution panel and turbine bearing gas panel;
- installing new turbine coolers and their associated brake valves;
- maintenance of all cryogenic valves, replacing the O-rings and checking all thermometers.

The cold box is fed by a new helium compression station designed to compress a GHe flow of 160 g/s from 0.9 bar to 18.7 bar with a power consumption of 706 kW. The compression station contains a two-stage compound screw compressor driven by a 3.3 kV AC motor. It is equipped with a primary oil separation system followed by three coalescing filters and a charcoal adsorber to supply high purity GHe to the helium refrigerator.

Due to the installation of an additional by-pass line connecting the high pressure side to the low pressure side, it was possible to commission the compression station fully by running on itself. Figure 3a gives the GHe flow rate and consumed electrical power versus the 1<sup>st</sup> stage compressor slide valve position for a compression from 1.0 bar to 17.2 bar. As shown, at maximum capacity the compression station produces a GHe flow rate of 185 g/s, which fits well with the design parameters. The consumed electrical power is 637 kW.

The helium refrigerator was restarted and commissioned successfully. In liquefaction mode, a LHe production rate of 6.9 g/s was measured supplying a GHe flow rate of 125 g/s. In refrigeration mode, the measured power was 1300 W supplying a GHe flow rate of 160 g/s. In both cases, the supply
pressure was 17.4 bar and the return pressure was 1.0 bar. Figure 3b gives the measured liquefaction rate versus the refrigeration power including the theoretical curve and the points measured in 1997. It is shown, that the current performance is about 10% higher than the measured performance in 1997. This is expected to be caused by the new compression station and the improved turbine coolers.

3.2. LHe storage dewar
The cryogenic system is equipped with a LHe dewar with a capacity of 5 m$^3$ and a design pressure of 6 bar. The dewar is used to boost the final cool down from 80 K to 4.5 K and for the filling phase of the superconducting devices. The dewar is equipped with a superconducting level gauge, Cernox™ temperature sensors and two heaters with a heating capacity of 650 W each. A cryogenic valve box installed directly on top of the dewar connects it to the cold box and to the cryogenic distribution system via several cryogenic transfer lines. In addition, the valve box allows to supply directly supercritical helium at 4 bar to the three test benches.

The dewar was cooled down and filled to about half of its total capacity. Preliminary measurements shown an evaporation rate of approximately 2.6% per day of its total capacity operating at 1.1 bar, which corresponds to a heat load of about 3.7 W. This heat load is estimated to originate from radiation, conduction through the neck, the LHe filling drawing tube and the supporting tubes for the electrical heaters and superconducting level gauges.

3.3. Cryogenic distribution system
The cryogenic distribution system consists of a distribution valve box (DVB), a connection valve box (CVB), three satellite valve boxes (SVB) and several multi-line cryogenic transfer lines.

The DVB is an existing valve box that was used for the ATLAS test facility [4]. The purpose of the DVB is to distribute LHe to each of the three test benches. To be able to fulfill the requirements for the test facility, CERN has made some modification to the internal pipework and performed a thorough maintenance on all cryogenic valves.

The CVB, SVB and cryogenic transfer lines is new equipment. The purpose of the CVB is to connect the CWUs to each of the three test benches. To be able to fulfill the requirements for the test facility, CERN has made some modification to the internal pipework and performed a thorough maintenance on all cryogenic valves.

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The cryogenic system was successfully cooled down for the first time to check for mechanical integrity, leaks and vacuum jacket temperature. The heat loads of the components could not be measured precisely, but a qualitative assessment showed no major non-conformities. Cool-down / warm-up units and compression station

Figure 3. a) GHe flow rate and electrical power versus the 1$^{st}$ stage slide valve position for the compression station and b) liquefaction rate versus refrigeration power of the helium refrigerator.
The test facility is equipped with two CWUs to allow to precool a magnet from room temperature to 80 K and to warm-up another magnet from 4.5 K to room temperature simultaneously [2,3]. In both CWUs, LN$_2$ is used as cooling source and an electrical heater with a power of 15 kW as heating source. To remove gaseous impurities originating from the magnet during the cool-down phase, each CWU is equipped with an 80 K adsorber. This avoids contamination of the LHe cryogenic system with impurities when switching to LHe for the magnet tests.

CWU1 is an existing unit that was used for the ATLAS test facility [4] and has an equivalent cooling power of 9 kW. An extensive refurbishment was performed by CERN on this unit including adding an 80 K adsorber and a 15 kW heater unit, replacing the purge and instrumentation rack and all warm control valves, safety relief valves and instrumentation, and performing a maintenance on the cryogenic valves.

CWU2 is a new unit and has an equivalent cooling and heating capacity of 15 kW. It contains multiple cryogenic heat exchangers, a LN$_2$ phase separator, an 80 K adsorber, a 15 kW electrical heater and several cryogenic valves.

The LN$_2$ is supplied from a 50 m$^3$ LN$_2$ storage tank installed outside the building. The tank is vacuum-insulated with perlite powder and 10 layers of MLI and has a design pressure of 10 bar. The tank was cooled down and filled to its maximum capacity. The measured evaporation rate is 0.24% per day of its total capacity measured over 19 days, which is slightly below the specified rate.

Partly flexible cryogenic transfer lines are used to distribute the LN$_2$ to the CWUs and the resulting cold GN$_2$ to outside B180, where it is vented to the atmosphere. At the vent outlet, a de-icing unit is installed to prevent ice formation together with a silencer to keep the noise below the required level of 65 dB at 1 m of the exhaust due to the proximity of offices.

The CWUs are fed by an existing helium compression station with a Stal S26 screw compressor that is designed to compress a GHe flow rate of 43 g/s from 1.8 bar to 17.4 bar. The compression station is based on a vertical oil-flooded screw compressor driven by a 160 kW electrical motor. An oil separation system followed by three coalescing filters and a charcoal adsorber ensure the supply of high purity GHe to the CWUs. The compressor and electric motor were fully revised. A major overhauling of all other components was performed by the maintenance team of CERN.

4. Conclusions
CERN has built a cryogenic test facility for large and heavy superconducting devices suitable for testing the Super-FRS magnets of the FAIR project. Currently, most of its components including the helium refrigerator, its compression station, a LHe storage dewar, a LN$_2$ storage tank and the cryogenic distribution system consisting of several valve boxes and cryogenic transfer lines were installed and successfully commissioned. The measured performance corresponds well to the design parameters. The CWUs and associated compression station are installed and the commissioning of these components is planned for autumn 2018. The test facility is currently in final assembly and commissioning and will be ready to test the first magnet prototype that will arrive in autumn 2018. Series testing is planned to start in autumn 2019.

References
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