Cryogenic infrastructure supplied by Linde Kryotechnik AG for the Series Magnet Test Facility for FAIR

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Abstract. In order to test the fast-ramped superconducting magnets for FAIR (Facility for Anti-proton and Ion Research), a cryogenic test facility with an equivalent overall capacity of 1.5 kW at 4.4 Kelvin was designed and commissioned at GSI Helmholtzzentrum für Schwerionenforschung GmbH.

For efficient testing of the 108 dipole magnets the cryogenic infrastructure consists of a refrigeration system and four main test benches. Due to the different operating modes and load fluctuations a dedicated process and control concept was developed which allows an independent operation of each test bench and ensures highest efficiency over the whole operating range. The system is designed in a way that one magnet can be cooled down to its operating temperature while simultaneously another magnet is kept at cold state for the
measurements. The third and fourth test benches serve for warming up and exchanging the magnets respectively.

The high flexibility of the set-up moreover allows the testing of other FAIR magnets like the SIS100 quadrupole modules or the operation of a string configuration.

The project was executed in a close collaboration between GSI and Linde Kryotechnik AG. The paper will show the key solutions of the refrigeration system and the test benches and highlight some commissioning results.

1. Introduction
An in-depth understanding of the evolution of the universe from the Big Bang to the present has occupied the scientific community over the last centuries. To obtain better knowledge about the structure of matter a new international accelerator facility FAIR will be built at GSI in Darmstadt, Germany. Linde Kryotechnik AG designed, supplied and commissioned a test facility for the fast-ramped superconducting magnets manufactured for the new accelerator. The use of standardized components for the coldbox setup ensures hereby a compact and cost efficient design, while a customized modulated approach for the test-bench setup guarantees high flexibility in response to the transient load requirements due to the frequent exchange of the dipoles.

2. Refrigerator coldbox and cryogenic test facility
The warm recycle compressor station of the process consists of two parallel screw compressors, one gas management panel for pressure control as well as a pure helium storage buffer. For high efficiency over a wide operating range, the compressor system is equipped with a variable speed drive which reduces in combination with an automatic high pressure adaption the electrical power consumption of the refrigerator system. Three coalescers in series and one fine one oil adsorber guarantee an oil concentration of less than 0.1 ppm in the high pressure helium stream which is entering the refrigerator coldbox. Thereafter liquid nitrogen is used to precool the helium supply to approximately 80 K in a first step before traces of nitrogen and oxygen are removed in two fully automatic operated, parallel arranged cryogenic adsorbers. Two turbines located at a temperature level between 10 and 60 K as well as one Joule-Thomson turbine provide the refrigeration power demanded by the cryogenic load. The use of dynamic gas bearing turbines ensures hereby highest efficiency while demanding only a minimum amount of maintenance. Subsequent the last heat exchanger, the high pressure stream is subcooled to approximately 4.5 K by evaporating liquid helium at a pressure of 1.20 bar before it is supplied to the test-facility. The connection between the coldbox and the test facility consists of a transfer line system containing supply and return lines for the 4.5 K loop and for the shield cooling as well as one separate cold gas return line.

Figure 1. Refrigerator coldbox and warm compressor station.
The test setup itself consists of a series of two valveboxes with two feedboxes each. The feedboxes are used to cool-down, test, warm-up or exchange a magnet independently of the operation of the other feedboxes, whereby the valve boxes form the core of the test bench which is permanently kept at its cold operating conditions. This flexible operation ensures a time efficient testing of the dipoles. In addition to the four feedboxes which test the magnets individually, a supplementary box offers the possibility to test a string of dipoles at a later stage of the campaign. The modular set-up of the test bench is shown in the process flow diagram, depicted in Figure 2.

**Figure 2.** Modular set-up of the cryogenic test facility.

Prior to a magnet exchange, the feedbox and the corresponding transferline are warmed up to prevent condensation on the surface of the equipment. Furthermore each feedbox is pumped and purged separately before coupling to the valvebox to minimize the impurity intake into the cryogenic system.

During the transient modes (cool-down and warm-up of the dipole magnets) the overall plant efficiency is optimized by including multiple bypasses at distinct temperature levels from the cold gas return to the low pressure return line or to the warm compressor station via an ambient heater. The warm helium return line is equipped with a dual line dryer as shown in Figure 1 to cope with humidity intake due to the magnet exchange. A separate impure buffer volume upstream the line dryers is used to handle the increased mass flow in case of a magnet quench.

Beside the frequency drive in one of the screw compressors mentioned above, further key design measures to support the automatic load adaption of the plant include a variable high pressure, the Joule-Thomson turbine equipped with a bypass as well as the possibility to liquefy into the LHe dewar. Both bypasses between the supply and return lines in the string test box are equipped with heaters for fast responding load adaption in case the capacity demand of the feedboxes is falling below the supplied refrigeration power.
3. Commissioning Results

The refrigerator coldbox has been successfully commissioned by Linde Kryotechnik AG in the first half of this year. The liquefaction performance at 4.5 K met the expected performance features, while both the refrigeration power at 4.4 K and 50 K exceeded the guaranteed values. In total the measured refrigeration performance had a surplus of 5.3 % compared to the specified values by GSI. The test values are summarized in Table 2.

| Temperature Level | Guarantee | Measurement |
|-------------------|-----------|-------------|
| Refrigeration capacity | 4.4 K | 700 W | 778 W |
| Liquefaction capacity | 4.5 K | 6.0 g/s | 6.0 g/s |
| Refrigeration capacity (shield) | 50 – 80 K | 2000 W | 2030 W |
| Equivalent overall capacity | 4.5 K | 1500 W | 1580 W |

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