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THE HNOSS HORIZONTAL CRYOSTAT AND THE HELIUM LIQUEFACTION PLANT AT FREIA

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Abstract

A horizontal cryostat to test superconducting cavities and magnets at liquid helium temperatures is installed at FREIA (Facility for REsearch Instrumentation and Accelerator development) at Uppsala University, Sweden. The cryostat allows full testing of superconducting spoke and elliptical accelerating cavities without the need of a specialized cryomodule per cavity. Because horizontal cryostats are custom-built, their number in the accelerator world is very limited. The FREIA horizontal cryostat is one of a kind as it has been designed to be versatile: it is able to house either two ESS double-spoke, or two ESS/TESLA type elliptical cavities, or superconducting magnets or a combination of these with all the ancillary equipment (power couplers, tuners, etc) and test them at the same time, reducing installation time but requiring extra design effort and cryogens supply. In order to achieve this, a helium liquefier with a capacity of 140 l/h delivers liquid helium to the horizontal cryostat while the return gases are directed towards a recovery system, connected in closed loop with the liquefier.

MOTIVATION

The European Spallation Source (ESS) will be a major user facility built in Lund, Sweden. ESS, which is an accelerator-driven neutron spallation source, will deliver the first protons to a rotating tungsten target by 2019 and will reach the full 5 MW average beam power in the following years. The block diagram of the ESS linac is shown in Fig. 1, where orange indicates the normal conducting sections and blue superconducting.

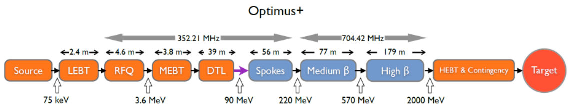

Figure 1: Block diagram of the ESS linac.

The superconducting spoke section, with RF specifications given in [1], will include a total of 26 double-spoke cavities arranged in pairs in 13 cryomodules. The testing of the double-spoke prototype cavity at high power has been conceded to Uppsala University, Sweden, where the Facility for REsearch Instrumetation and Accelerator development (FREIA) has been built to, among other projects, carry on these tests. This paper describes the different cryogenic subsystems that will be available at FREIA for such tests.

THE FREIA LABORATORY

A schematic of the 1000 m^2 FREIA laboratory is shown in Fig. 2. Currently, FREIA is procuring all the necessary equipment to test the spoke prototype cavity at high RF power. More general information regarding the FREIA laboratory and its equipment can be found in [2].

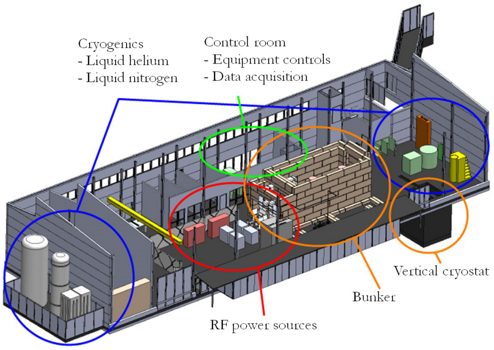

Figure 2: Schematic of the FREIA laboratory indicating the different components and their distribution.

HELIUM LIQUEFACTION PLANT

To ensure the superconducting state of the prototype spoke cavity during the high RF power tests, a helium liquefaction plant L140 from *Linde Kryotechnik AG* is in use. The system includes a standard coldbox with an extra 20 K adsorber, a custom made 2000 l liquid helium dewar and a recovery system with a 100 m^3 gasbag (Fig. 3).

Figure 3: The coldbox, helium dewar and filling station.

The helium dewar has four connections: one to fill dewars and three to connect to experiments, each with its own cryogenic valve. In case a higher throughput than the 140 l/h provided by the system is needed, the helium dewar also acts as a buffer.

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This system was commissioned mid March this year, yielding a liquefaction rate over 150 l/h at 4.5 K, at rising level and with liquid nitrogen pre-cooling.

HORIZONTAL TEST CRYOSTAT

The isolation of the cavity from the surroundings and the distribution, storage and recollection of the cryogens needed to reach low temperatures is achieved through the horizontal cryostat. The horizontal test cryostat includes the following components:

- Interconnection box: to distribute the liquid nitrogen and liquid helium towards the horizontal cryostat and to a second device inside the bunker, i.e. a ESS spoke cryomodule.
- Valve box: produces and stores liquid helium with temperatures between 4.5 K and 1.8 K.
- Horizontal cryostat: houses the device under test (DUT), the spoke cavity in this case, isolating it from room temperature.
- Heater: warms the vaporized liquid helium to room temperature. Depending on the gas pressure, it will be directed either towards sub-atmospheric pumps or the gasbag.

Figure 4 shows the block diagram of this subsystem showing the connections and the expected temperatures and pressures.

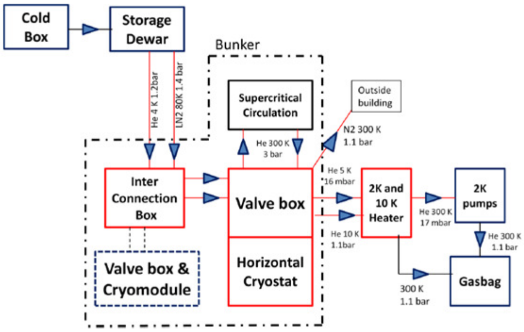

Figure 4: Block diagram of the horizontal test cryostat components, marked in red, and their respective connections.

The most complex component of such subsytem is the valve box together with the horizontal cryostat, namely Horizontal Nugget for Operation of Superconducting Systems (HNOSS). The complete design [3], made by *Accelerator and Cryogenic Systems* (ACS), France, is based on the HOrizontal BI-CAvity Test-facility (HobiCaT) in BESSY [4] and is currently being manufactured in industry.

HNOSS DESIGN

HNOSS can house up to either two ESS double-spoke, or two ESS/TESLA type elliptical cavities, or superconducting magnets or a combination of these with all the ancillary equipment (power couplers, tuners, etc). HNOSS is indeed unique due to the fact that it can house up to two DUTs, having independent paths for the cryogens. They can be cooled or warmed independently, including ancilliaries like tuners and power couplers, while in operation. Figure 5 shows a picture of HNOSS while Table 1 gives its main design characteristics.

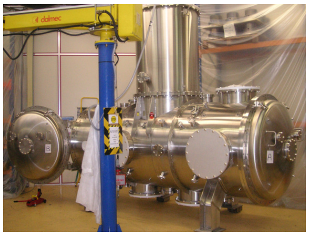

Figure 5: Picture of HNOSS.

Table 1: Main Design Characteristics of HNOSS

Parameter	Value
Helium bath temperature	4.5 K - 1.8 K
Helium bath pressure	16 mbar - 1.25 bar
Cooling power at 1.8 K	90 W
Pressure stability at 16 mbar	±0.1 mbar
Inner length	3.24 m
Inner diameter	1.3 m
Total height	4 m
Axis	1.7 m

Main Vessel

The purpose of the main vessel is to house the DUT under vacuum, isolating from room temperature and the Earth's magnetic field. It allows the installation of thermal and magnetic shields as well as supporting elements. Thus HNOSS has three main components (see Fig. 6):

- Vacuum shield: made of stainless steel, is evacuated to high vacuum, of the order of 10^{-6} mbar.
- Magnetic shield: at room temperature, made of mumetal and directly connected to the main vessel, reduces the Earth's magnetic field within the vessel by a factor of 5.
- Thermal shield: made of aluminium and cooled to ca. 80 K, intercepts heat radiating from the main vessel (at room temperature) and serves as a thermalization point for cabling and other components that go from room to liquid helium temperature regions.

To further reduce heat in-leaks, 30 layers of multi layer insulation (MLI) are placed between the magnetic and the thermal shield.

Valve Box

The tower on top of HNOSS, or valve box, contains all the necessary piping, valves and tanks to produce, store and distribute liquid helium at 4 K and 1.8 K. Available at the valve box is also liquid nitrogen and supercritical helium used for the cooling of the ancillary equipment from HNOSS and the DUT. The purpose of the different cryogens is:

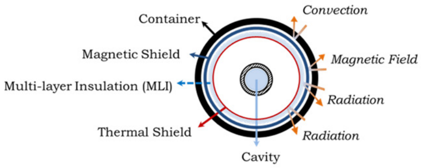

Figure 6: Distribution of HNOSS' shields with respect to the cavity, placed in the axis.

- Liquid helium: cool the cryogenic lines and the DUT, if needed.
- Liquid nitrogen: cool the thermal shield and the table where the DUT is placed inside HNOSS, if used.
- Supercritical helium: cool the power coupler of the cavities, if suited and needed.

Figure 7 shows a part of the cryogenic diagram of HNOSS. The liquid helium at 4.5 K from the 2000 l dewar enters the top of the valve box to the so-called 4 K tank and from there it goes through a heat exchanger and a Joule-Thomson valve to the 2 K tank. At this point, the liquid helium has a temperature as low as 1.8 K. The DUT is cooled from below using the cooldown circuit and the supercritical helium circuit is used for the power coupler. In reality, both heat exchangers, labeled HXa and HXb, are merged as the low pressure return line is common.

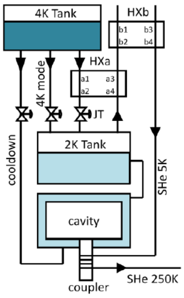

Figure 7: Cavity and power coupler cooling schematic.

To change the temperature of the DUT from 4.5 K to a minimum of 1.8 K, a butterfly valve and a sub-atmospheric pump set are used. The dominant constraint for this pump set is the return helium gas mass flow at the lowest pressure. The pump set is designed for an average of 3.2 g/s gas helium at 10 mbar and 300 K at the inlet, which in turn determines the total size of the system. Following new tendencies to avoid the presence of oil in the processed helium gas, FREIA has opted for oil free pumps. FREIA will count with a dry pump set consisting of three roots pumps with a pumping speed of 4400 m^3/h backed by four screw 650 m^3/h pumps.

Ports

To be able to insert the cavities with their ancillary components and to monitor both these and the cryogens during operation, different port sizes have been foreseen. These ports include access, instrumentation, power couplers (from below for ESS spoke cavity and from the side for TESLA cavity, for example), pumping (both the main vessel and the DUTs), viewports, safety valves, magnet leads and device's support, see Fig. 8. The big amount of ports in HNOSS, together with their size, made it necessary to reinforce the main vessel by adding stiffeners around the valve box port and the central oval port, which can be used when connecting cavities to the cooling circuits.

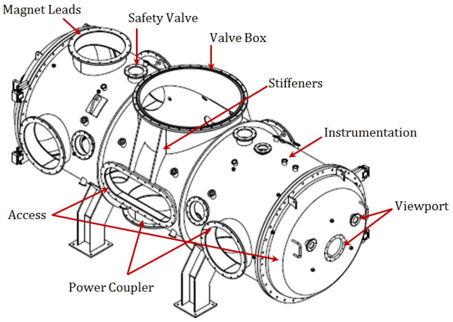

Figure 8: Sketch of the lower part of HNOSS showing the distribution and relative sizes of the ports.

CONCLUSIONS

The horizontal test cryostat will be commisioned at the beginning of September this year. The FREIA laboratory will be fully operational by the beginning of October and the prototype spoke cavity is expected to be delivered to FREIA by the beginning of December. The testing of the spoke cavity at full RF power will continue until June 2015.

ACKNOWLEDGEMENTS

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