CRYOGENIC PERFORMANCE OF THE HNOSS TEST FACILITY AT UPPSALA UNIVERSITY

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Abstract

The FREIA Laboratory at Uppsala University, Sweden, is developing part of the RF system and testing the superconducting double spoke cavitites for ESS. During 2014 it was equipped with HNOSS, a versatile horizontal cryostat system for testing superconducting cavities. HNOSS is designed for high power RF testing of up to two superconducting accelerating cavities equipped with helium tank, fundamental power coupler and tuning system. In particular it will be used to characterise the performance of spoke cavities like used in the accelerator for the ESS project. HNOSS is connected to a cryogenic plant providing liquid helium and a sub-atmospheric pumping system enabling operation in the range 1.8 to 4.5 K. We present a brief description of the major components, installation and results from the recent operation and tests.

INTRODUCTION

The FREIA Laboratory at Uppsala University was created in 2011 to continue the expertise in accelerator science and technology initiated with the construction of a cyclotron in the late 1940's. FREIA was inaugurated in 2013 [1]. Its first major project is to be a test environment for the superconducting spoke cavities and develop their high power RF amplifiers to be used in the ESS accelerator. In addition the laboratory provides cryogenic fluids such as liquid nitrogen and helium to experimental groups at the university. The global layout of the FREIA Laboratory is shown in Figure 1. The main equipment consists of a horizontal test cryostat (HNOSS), a helium liquefier, high power RF transmitters and several concrete bunkers. The infrastructure of the FREIA Laboratory has been designed to accommodate modest future extensions for other test facilities and experiments.

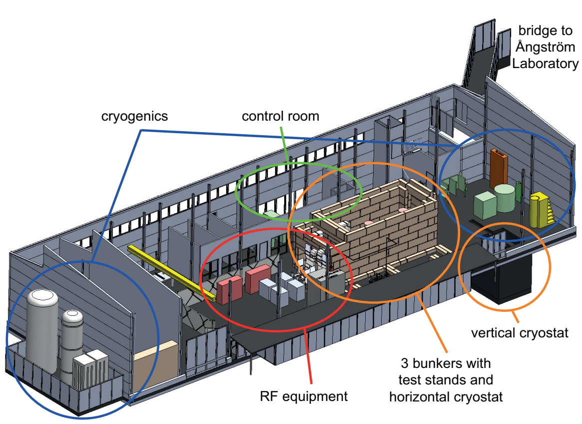

Figure 1: Layout of the FREIA Laboratory.

The main project for the FREIA Laboratory at present is the development of the ESS accelerator while a THz-FEL study has been started for the longer term future. Among the critical elements of the ESS proton accelerator are the superconducting accelerating cavities and their RF power stations. FREIA is concentrating on the spoke linac part of the accelerator and in specific on the development of the RF power station and high power test of the spoke resonators.

The ESS accelerator will contain 26 double spoke resonators which are being developed by IPN Orsay [2]. The prototype spoke resonators will be tested first at the SupraTech vertical test stand at IPN Orsay. One resonator has been brought to FREIA where it is being tested in HNOSS: first at low power with a high-Q antenna to verify vertical test stand results, then fully dressed with the high power coupler and tuning systems at nominal power. This testing programme will continue until mid-2016, after which the first prototype cryomodule, with a pair of spoke resonators, also will be tested at FREIA.

INSTALLATION

Last year the cryostat and its cryogenic system were installed at FREIA. First the liquefier with gas recovery system, then the cryostat and the sub-atmospheric pumping system.

The HNOSS Horizontal Cryostat

FREIA has constructed a versatile horizontal cryostat called HNOSS (Horizontal Nugget for operation of Superconducting Systems[1]) for test of superconducting accelerator cavities, magnets or other devices. With an internal length of 3.3 m, up to two accelerating cavities can be installed and tested simultaneously in order to investigate possible coupling between the two devices. The design of HNOSS has been described elsewhere [3–5]. HNOSS has an available internal diameter of 1.2 m and full size access doors on each side to facilitate installation work. Its total height is 4 m with the central horizontal axis line at 1.7 m. HNOSS is designed to accommodate TESLA type 1.3 GHz and ESS type 704 MHz elliptical cavities as well as ESS type 352 MHz double-spoke resonators. HNOSS has an integrated internal magnetic shield and a valve box located on top as shown in Figure 2. The 1 mm thick, room temperature, mu-metal magnetic shield is installed between the warm vacuum vessel and the thermal radiation shield.

[1] In Norse mythology, Hnoss is one of Freia's daughters.

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The valve box is the most complicated component. It contains the necessary piping, cryogenic valves, heat exchangers and liquid helium pots to store incoming helium from the cryogenic plant at 4 K and distribute it to the cavities. The initial cool down of a cavity is done from the bottom until the liquid helium level is filled up into the 2K pot inside the valve box. After that a heat exchanger and Joule-Thomson valve in the valve box are used to refill the cavity with liquid helium from the top when working below 4 K. The temperature operation range is down to 1.8 K with up to 90 W heat load.

Through the valve box there is also a supply of liquid nitrogen and 5 K supercritical helium. They are used for cooling of the thermal radiation shield and ancillary equipment of the cavity like the fundamental power coupler. The supercritical helium is produced in a secondary circuit cooled by a heat exchanger on the exhaust of the 2K pot and is fully separated from the liquifier's helium circuit as shown in Figure 3.

Cryogenics

The cryogenic system is built around a 140 l/h helium liquefier cold box with an internal freeze-out purifier for cleaning recovered helium gas. Furthermore, it includes a 2000 l storage dewar with three integrated cold valves to connect transfer lines to experiments plus a connection to fill mobile dewars for external users. The gas recovery system has a 100 m^3 gas balloon and three 27 m^3/h compressors with 200 bar discharge pressure connected to a high pressure gas storage and the cold box internal purifier. A 20,000 l liquid nitrogen storage dewar provides the liquid nitrogen for the liquefier pre-cooling [3].

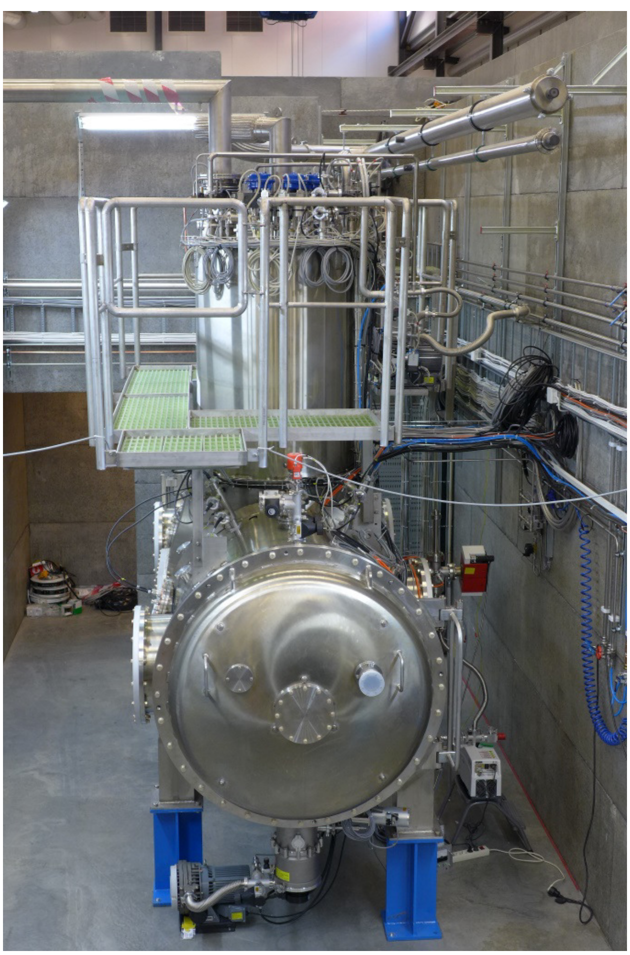

Figure 2: The HNOSS horizontal cryostat and valve box.

Sub-atmospheric Pumps

The sub-atmospheric pump system is used to lower the pressure of the liquid helium bath in the 2K pot of the valve box and thereby its temperature and that of the cavity. The minimum pressure (and temperature) that can be reached is dependent upon the mass flow through the pumps: three roots and four dry screw-pumps with an ultimate pressure of 19 mbar and a flow capacity from 10 g/s at 70 mbar down to 3.2 g/s at 10 mbar (helium gas at room temperature). The pumps are connected to the 2K pot in the HNOSS valve box via a water filled cold gas heater.

Vacuum

The horizontal cryostat and valve box parts of HNOSS share a common insulation vacuum. The internal vacuum (beam vacuum) of the superconducting cavities is connected by a feedthrough in HNOSS. HNOSS has multiple feedthroughs to accommodate diverse instrumentation and installation options. Feedthroughs are also available on the axis of the access doors (like a beam tube for a cryostat in an accelerator). A laminar flow cabin is installed next to HNOSS when making the vacuum connections for the cavity.

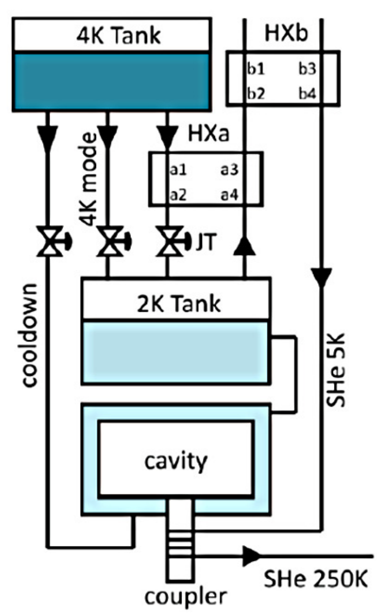

Figure 3: The HNOSS cryogenic circuit.

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CONTROLS

EPICS [6] is used as a main control system at the FREIA Laboratory. The HNOSS cryostat itself is controlled by a dedicated Programmable Logic Controller (PLC, Siemens S7-300 series) that collects all necessary data and supervises the operation of the cryostat. The PLC and field equipment are installed in a cabinet outside the concrete bunker shielding of HNOSS (Figure 4). Some of the field equipment are connected directly to the PLC's I/O modules, other (like Cernox temperature sensors, vacuum meters and valve controllers) are connected via fieldbus Profibus DP and serial lines RS-232. The communication between EPICS and the PLC is based on the s7plc driver module from PSI [7]. The program running on the PLC can autonomously control more than ten different operation modes, like purging the transfer lines, cooling down, 4 K and 2 K operation, warming up, etc.

An operator controls the cryostat either via local WinCC based Graphical User Interface (GUI) or from EPICS using Control System Studio (CSS) [8] framework. EPICS is used for general services like archiving, alarms, operator's GUI and for connecting all subsystems involved in the operation of the cryostat including helium liquefier, sub-atmospheric pumps (also locally controlled by a separate PLC) and a vacuum system.

The temperature of the liquid helium in 2K operation mode is maintained by controlling the pressure of the 2K bath with the help of a butterfly valve between the cryostat and the sub atmospheric pumps. Thus a temperature down to 1.8 K can be reached. In this scenario the pumps are running at constant speed. It is also possible to put the pumps in an automatic mode during which the pressure at the inlet to the pumps is kept constant by regulation of their rotation speed. Combination of these two modes seems to be possible but requires further tests.

Figure 4: Electric cabinet with controls hardware.

COMMISSIONING

The commissioning of HNOSS plus all the ancillary components, such as transfer lines and cold gas heater, took from its arrival in August to December 2014 to be completed. Since then, the system is being checked and debugged with a cavity (Figure 5) until a close-to automatic operation of the complete setup can be achieved.

First Cryogenic Tests

The commissioning of HNOSS and the rest of the system were done in several steps according to the available equipment. In the first step, there was no cavity inside HNOSS, only the cryogenic piping connecting the inlets of the cryogens directly to the outlets. This helped check the overall system in terms of hardware, thermal cycles and vacuum and cryogenic leaks.

On the second step a hollow cylinder, called dummy cavity, was received and inserted in HNOSS. This dummy cavity has approximately the same volume as a double spoke helium vessel tank while its shape and dimensions are also alike. Since this cavity has no antenna or power coupler, a couple of heaters were glued to its frame to provide heating power. Several temperature sensors were also glued to check for cryogenic performance. This setup helped checking the hardware for different modes of operation (at 4 K or 2 K) as well as the overall performance with and without load.

The end of the official commissioning of HNOSS took place at the same time as the commissioning of the sub-atmospheric pumps in December 2014. A total of 110 W of power at 2 K can be removed by this pump set while still keeping a stable inlet pressure.

Tests with Hélène

The first real cavity inserted in HNOSS has been a single spoke cavity (Hélène) equipped with an RF antenna and a beam vacuum port, courtesy of IPN Orsay (Figure 6(a)), and several temperature sensors and heaters. Tests on this cavity revealed two main issues: Taconis effect on the outlet of the

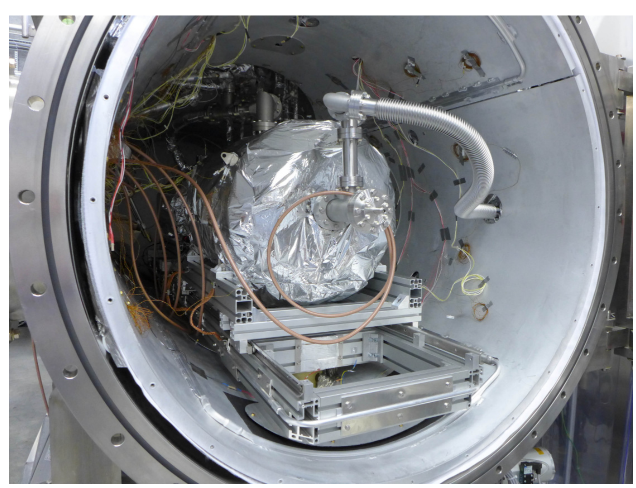
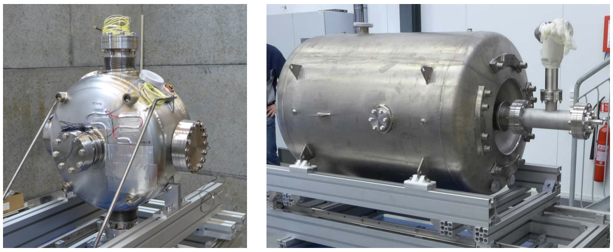


Figure 5: Double-spoke cavity installed in HNOSS.



(a) (b)

Figure 6: a) The single spoke cavity Hélène and b) the double spoke Germaine from IPN Orsay.

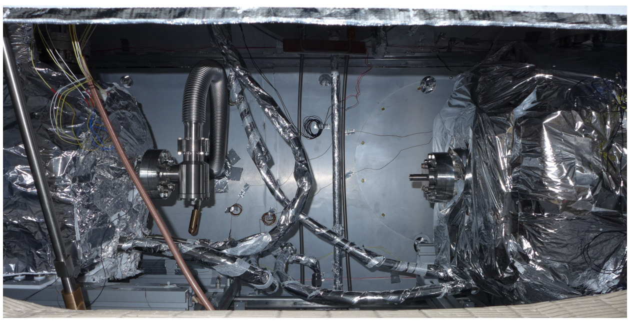


Figure 7: Hélène (left) and Germaine (right) in HNOSS.

2K pot when working at 2 K and a restrain on the maximum power that could be sent to the cavity.

The first issue is thought to generate in the second heat exchanger of incoming line (supercritical helium circuit), but it vanishes when the supercritical helium circuit is started. The second issue gave more problems since the maximum power that could be sent to the cavity was 35 W. This was due to the cryogenic pipe connecting the cavity to the 2K pot being undersized, so that the inner diameter of the pipe could not provide enough cooling.

Tests with Germaine and Hélène

A double spoke prototype (Germaine, Figure 6(b)), intended for the ESS accelerator, was inserted in HNOSS in June 2015. This cavity, equipped with an RF antenna, temperature sensors and heaters shares the inner space of HNOSS with Hélène. Both cavities have independent beam vacuum pumping groups but share the connection to the liquid helium level probe and the 2K pot (Figure 7).

In this configuration, a first initial run has been made to check and debug all automated sequences, from purging of the system to 2 K operation. A main issue that appeared in this case was again Taconis effect in the 4K line. The main consequence was the evaporation of more liquid helium than needed, leading to longer times to fill the 4K pot. A non return valve has been inserted at the outlet of the heater and the outcome seems favorable.

PERFORMANCE

The first step to be able to work at low temperatures is to evacuate HNOSS before any cryogens flow into HNOSS.

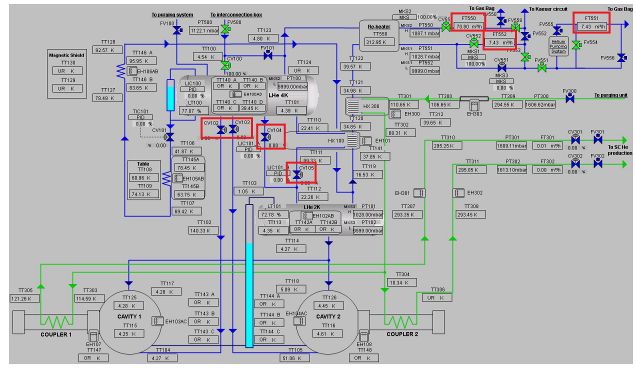


Figure 8: GUI screenshot showing the layout of the complete system.

Once there is a reasonable vacuum level (typically 10^{-4} mbar) liquid nitrogen is used to cool the thermal shields. When the temperature of the shields is acceptable, liquid helium can then be directed to start the cooling of the pipes, tanks, table and cavities.

A screenshot of the graphical user interface (GUI) showing an schematic view of the complete system for the liquid helium path is given in Figure 8, where marked in red are the valves and flowmeters mentioned next. The initial cooldown of the cavities is done from below via the cryogenic valves CV102 and CV103 until the level reaches the 2K pot. When the cooldown is finished, the 2K pot is filled either via CV104 or CV105, depending on the working pressure of the 2K pot. The heat loads are measured through FT550 for the 4K pot and, depending on the mode of operation of the cavities (4 K or 2 K), FT551 or FT552 are used.

For working temperatures other than 4.5 K, the pressure can be regulated by either a butterfly valve connected after the heater (CV551) or by the sub-atmospheric pump system. Normal operation of the system sets CV551 as the valve regulating the pressure in the 2K pot.

Insulating Vacuum

The total internal volume of HNOSS is ca. 7 m^3. In this volume multilayer insulation, Aluminium thermal shield, mumetal magnetic shield, Stainless Steel piping and cabling in general contribute to outgassing. By means of a 1500 l/s turbomolecular pump backed by a 30 m^3/h scroll pump, the time it takes to evacuate HNOSS from atmospheric to 10^{-4} mbar is approximately 9.5 h.

Beam Vacuum

Each cavity has its own pumping group connected to the beam pipe. A dry turbomolecular and scroll pumps evacuate the cavities to low 10^{-6} mbar pressures. Afterwards, an ion pump keep their pressure around 10^{-9} mbar while the turbopump and forevacuum pump are isolated from the beam vacuum by a gate valve.

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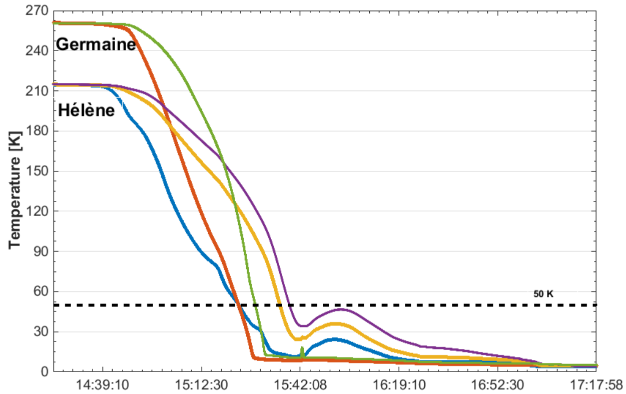

Figure 9: Cool down graph for Germaine (upper) and Hélène (lower).

Thermal Shield

The thermal shield of HNOSS is made of two parts: one for the shield on the valve box and another one for the horizontal part of the cryostat. The liquid nitrogen inlet is split into two to cool each shield separately. With a working pressure of 2.4 bar both shields reach a temperature lower than 120 K in about 25 h.

Cool Down and Warm-up Rates

With this system, the cooling graph for both cavities is shown in Figure 9, Germaine having the highest starting temperature at ca. 260 K while Hélène starts at 215 K. The cooling rates for Hélène and Germaine from close to room temperature down to 50 K are 3 K/min and 3.5 K/min, respectively. The reason for the cooling rate of Hélène to be close to that of Germaine is because, in the current setup, it is preferable to have both cavities following the same temperature gradients since this means that the liquid helium will flow almost equally through both pipes (CV102 and CV103). This cooling rate is more than enough to avoid the so-called Q-disease through the 100 K zone.

The warm-up rates have not yet been checked since the system has been left to warm-up on its own, coinciding with the vacation periods.

Static Heat Loads

Preliminary static heat loads have been measured and for the 4 K pot is 2.2 W at 4.5 K. For the combination of table, 2K tank and both cavities it rises to 4.7 W when operating at 4.2 K and the table is set to regulate between 70 K and 80 K while table evaporates ca. 2.7 W when operated between 50 K and 60 K.

Measurements to confirm the static losses of the different equipment in HNOSS and at different temperatures are ongoing.

Constant Level

Since the 2K pot acts as a phase separator, it is important to be able to keep a constant level. The current setup allows for two different possibilities: intermittent or continuous transfer. Intermittent transfer of liquid helium sets the filling between a minimum and a maximum level while a continuous transfer is done by regulating the level close to a certain value.

Pressure Stability

As mentioned before, the pressure regulation can be done either via the sub-atmospheric pumps through their rotation speed or via a butterfly valve (CV551). For the latter, the standard deviation at 20 mbar is ca. 0.15 mbar.

The pressure stability of the system when regulating via the sub-atmospheric pumps has a maximum standard deviation of 0.2 mbar between 840 mbar and 250 mbar. Outside this range, the pumps that come into operation cannot be kept running below their minimum frequency, and so there is a stronger suction that limits the possibility to regulate the pressure. The possibility to increase the operating range is being discussed.

CONCLUSIONS

The SRF test facility with the unique HNOSS horizontal cryostat has been successfully commissioned at the FREIA Laboratory. Two (spoke) cavities have been installed, cooled down to temperatures between 1.8 and 4 K and are being tested. It provides an excellent prototyping environment for ESS and for other future projects.

ACKNOWLEDGEMENTS

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REFERENCES

[1] R. Ruber et al., "The New FREIA Laboratory for Accelerator Development", IPAC 2014, THPRO077.

[2] P. Duchesne et al., "Design of the 352 MHz, Beta 0.50, double-spoke cavity for ESS", SRF 2013, FRIOC01.

[3] R. Santiago Kern et al., "The HNOSS horizontal cryostat and helium liquefaction plant at FREIA", IPAC 2014, WEPRI110.

[4] N.R. Chevalier et al., "Design of a horizontal test cryostat for superconducting RF cavities for the FREIA facility at Uppsala University", AIP Conf. Proc. 1574 (2014) 1277.

[5] T. Junquera et al., "Design of a new horizontal test cryostat for SCRF cavities at the Uppsala University", SRF 2013, MOP080.

[6] `http://www.aps.anl.gov/epics/`

[7] `http://epics.web.psi.ch/style/software/s7plc/s7plc.html`

[8] `http://controlsystemstudio.org/`