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THE GERSEMI VERTICAL CRYOSTAT AT FREIA

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ABSTRACT

“Gersemi”, a vertical cryostat to test superconducting magnets and radio-frequency cavities at liquid helium temperatures, will be installed at FREIA Laboratory at Uppsala University, Sweden. With three independent inserts, the same cryostat can be used to test different superconducting equipment at low power: a “vacuum” insert for cavities equipped with a helium vessel, a “bath” insert for cavities (and other equipment) without a helium vessel and a “lambda-plate” insert for magnet testing. Each insert has been designed to be as versatile as possible, making the available space inside the cryostat the main constraint for equipment testing. The cryostat will have an internal diameter of 1.1 m and 4.7 m total height. For magnet testing, “Gersemi” will be able to handle superconducting magnets with a stored energy up to 340 kJ. A valve box to direct the cryogens, a reheater for warming up the output gases and a control system complete the setup.

"Gersemi" vertical cryostat is connected to a helium liquefier and recovery system, and in parallel to an existing horizontal cryostat for testing superconducting equipment already operational at FREIA Laboratory.

Keywords: FREIA, vertical cryostat, cryostat insert, superconducting, cavity, magnet, liquid helium.

1. FREIA LABORATORY

At Uppsala University, Sweden, a new laboratory named FREIA [1] (Facility for REsearch Instrumentation and Accelerator development) was built in 2013. The purpose of this laboratory is to add a new facility for developing accelerator equipment, especially superconducting. Since its start, most of the equipment needed for general tests has been already acquired (Figure 1): a helium liquefier plant to produce liquid helium at 4 K and a horizontal cryostat HNOSS [2,3] to test superconducting equipment.

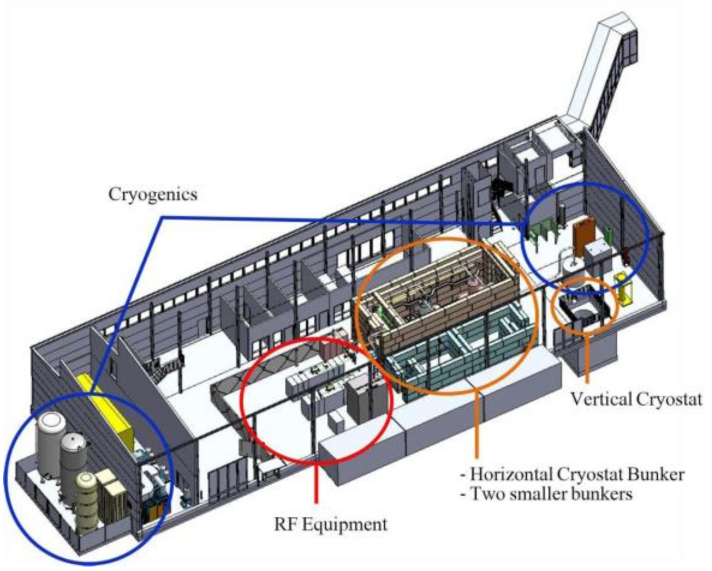

Figure 1: Schematic view of FREIA Laboratory.

For more specific tests of radio frequency (RF) equipment at high power, two RF stations to drive the superconducting equipment to up to 400 kW peak power at a frequency of 352 MHz are also available [4]. The latest equipment to be added to the laboratory is a vertical cryostat named Gersemi, complementing the tests that can be done in the horizontal cryostat.

2. DESIGN OF THE VERTICAL CRYOSTAT GERSEMI

The two main starting points for the design of the vertical cryostat were the size and the versatility. Since the underground pit was already excavated during the FREIA construction the possible dimensions were constrained. Also, because of FREIA being a university facility, the vertical cryostat had to be as versatile as possible to be able to accommodate a wide range of eligible equipment during its lifetime.

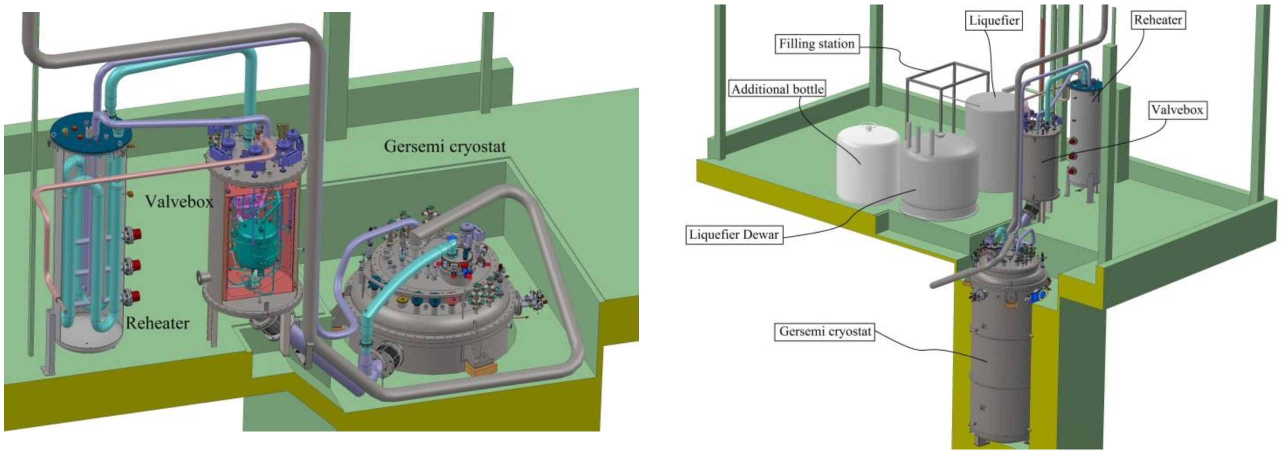

Figure 2: Sketch of the setup showing the vertical cryostat, valve box and reheater (left) and its integration with the helium liquefier plant (right).

This led to an effective 1.1 m in internal diameter and 4.7 m in height cryostat and the possibility to attach a different insert depending on the equipment to be tested and the test conditions: a vacuum insert for test of RF cavities or magnets surrounded by a helium tank, a bath insert for RF cavities or magnets that do not have a helium tank and a lambda-plate for tests of magnets of up to 340 kJ in stored energy under pressurized helium.

Table 1: Overall dimensions of the equipment for the vertical cryostat.

Dimension	Cryostat		Reheater	Valve box
	Vacuum vessel	Pressure Vessel		
Height [mm]	4330	4770	2970	2330
Diameter [mm]	1960	1450-1120	800	1016

Apart from the vertical cryostat itself, other equipment like a valve box to direct cryogens, a reheater to warm up the output cold helium gas and a control system are also part of the setup (Figure 2) with main dimensions given in Table 1. All this equipment is connected in series with a L140 helium liquefier and a set of sub-atmospheric pumps and in parallel with the horizontal cryostat HNOSS. Because Gersemi shares the sub-atmospheric pumps with HNOSS, Gersemi can also operate between 4.5 K and 1.8 K and the cooling capacity at 1.8 K is 90 W. The theoretical thermal losses for the relevant equipment are given in Table 2.

The mechanical and cryogenic design of the vertical cryostat Gersemi has been carried out by the company *Accelerator and Cryogenic Systems* and is currently under manufacturing.

Table 2: Thermal loads of the valve box and the vertical cryostat at different temperatures.

Equipment	Insert	at 80 K	at 4 K	at 2K
Valve box	n.a.	20 W	4 W	n.a.
Cryostat	Vacuum	50 W	2 W	2 W
	Bath	200 W	4 W	4W
	Magnet	150 W	20 W	17 W

2.1. Valve box

In order to supply the needed cryogens to cool the thermal shields, the cryostat and the superconducting equipment, a valve box (Figure 3, left) is placed in its proximity. This valve box, also used as a liquid helium buffer at 4 K for the cryostat, contains all necessary cryogenic valves and a 50 L tank. For the initial operation of the vertical cryostat below 4 K a Joule-Thomson valve, operating together with a counterflow heat exchanger, are included in the valve box. An independent circuit consisting of an extra heat exchanger is also housed in the valve box and is used for the cooling of the vertical cryostat's neck with supercritical helium.

The valve box has a copper thermal shield cooled with liquid nitrogen and all piping is thermally anchored to this shield. The flowing of the cryogens to the cryostat is via a four-pipe transfer line exiting below the valve box's lower flange.

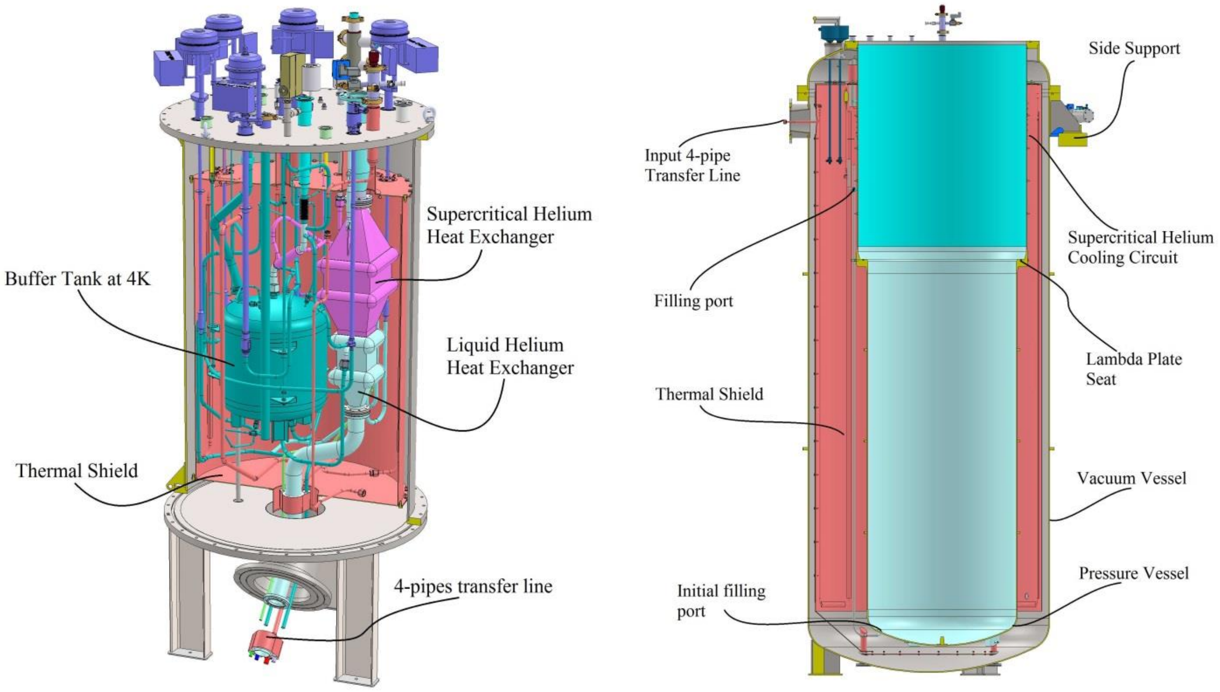

Figure 3: Schematic view of the valve box (left) and the vacuum and pressure vessels (right).

2.2. Vacuum and pressure vessels

The main container of the vertical cryostat is a 316L stainless steel vacuum vessel where the incoming cryogens from the valve box enter from the side (Figure 3, right). The liquid helium is rerouted depending on the mode of operation via extra cryogenic valves housed inside the vacuum vessel and the liquid nitrogen is used to cool the independent aluminium thermal shields of the vacuum vessel and, if in use, the vacuum insert.

Since the design of the cryostat is such that different modes of operation are possible, an extra vessel housed inside the vacuum vessel, referred to as pressure vessel, is necessary to be used as a liquid helium storage tank for the bath and lambda-plate inserts. It is because of the placement of all these valves inside the vertical cryostat, which minimizes heat leaks and facilitates connecting the insert's equipment, that this pressure vessel is off-center. The pressure vessel is fastened to the top flange of the vertical cryostat while the vacuum vessel is hanging in the pit by three side supports.

To reduce the heat leak coming into the pressure vessel from the top flange, a cooling circuit around the top part cools this neck with supercritical helium produced in the valve box.

Due to the pressurized bath used to test magnets, this vessel is a category III pressure vessel. This vessel has a larger diameter a third way up its length to accommodate the lambda plate needed for the pressurized bath when testing superconducting magnets.

2.3. Inserts

Depending on the superconducting equipment to be tested three different inserts are possible. Each insert has its own equipment attached to the top flange and to direct and collect the cryogens several transfer lines may be used depending on the insert.

There is a main transfer line between the valve box and vacuum vessel that provides the cryogens; a fixed transfer line between the valve box and the insert to collect cold gas helium and several smaller lines between the vacuum vessel and the insert plus one connecting directly the insert to the reheater if required by the mode of operation.

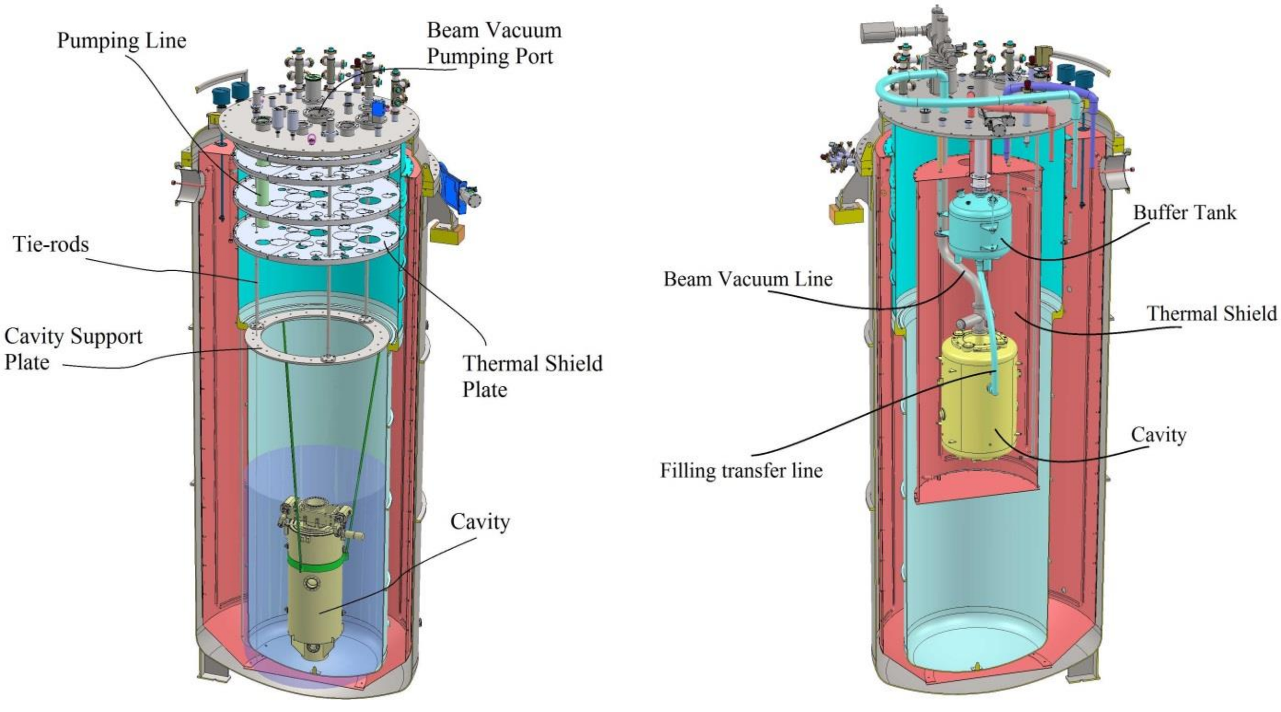

Figure 4: Schematic of the bath (left) and vacuum (right) inserts.

1.1.1. Bath insert

This insert is the simplest one and it is used for cavities or magnets without a helium tank (Figure 4, left). Depending on their size one or two cavities can be accommodated in Gersemi. The cavities are hung from a cavity support plate connected to tie-rods that are fastened to the top flange of the insert. To further reduce heat leaks into the bath several flat thermal screens made of aluminium, not actively cooled, and placed below each other hang from the top flange. All pipes connecting the top flange to the cavities are thermally anchored to these screens.

During operation, the initial filling of the bath is from below the pressure vessel and the following fillings through a side port above the lambda plate's seat. All instrumentation needed for monitoring and controlling the cavities and helium flow such as heaters, temperature sensors, level probes, pressure gauges, beam vacuum, etc. have dedicated feedthroughs on the top flange.

1.1.2. Vacuum insert

This insert, required for cavities with a helium tank, differs from the bath insert in that since the pressure vessel is under vacuum and only a small amount of liquid helium is used, it contains an extra buffer tank and the flat screens here are a complete liquid nitrogen cooled thermal shield (Figure 4, right). Apart from the general pumping line connecting the buffer tank to the sub-atmospheric pumps, two extra external transfer lines are needed to operate this insert: one for the initial cool down of the cavity/cavities from below and another one for the filling of the buffer tank. As with the bath insert, the top flange has dedicated feedthroughs for all necessary instrumentation as well as a for the liquid nitrogen regulation of the thermal shield.

1.1.3. Lambda-plate insert

This insert is the most complex one in terms of mechanical and cryogenic design. It involves a lambda plate to separate liquid helium at 4 K from the 1.8 K bath below and the safety system has to be such that it can handle the energy stored in the magnet if dissipated in the surrounding liquid helium. The mechanical design of the magnet insert follows the general design of a magnet insert recently developed at CERN [5].

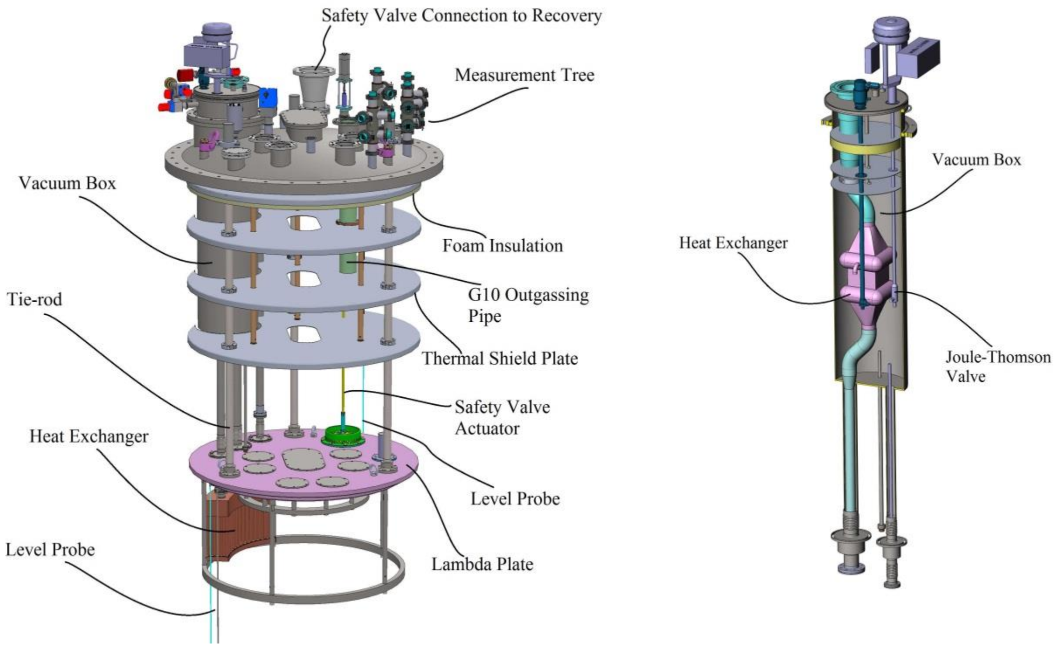

Figure 5: Schematic of the magnet insert (left) and detailed view of the vacuum box (right).

Since the operating pressure of this insert is between 1 bar and 5 bar, the top flange has a bulged design (Figure 5, left). As for the bath insert, several flat aluminium plates, stacked one below the other, screen the top part of the flange from the bath below. The lambda plate is made of 316L stainless steel of 64 mm thickness and seats on the rim where the pressure vessel changes diameter (Figure 3, right). The sealing of the lambda plate relies on weight since the magnet hangs from it, but both the seat and the lambda plate are manufactured with a flatness of at least 0.1 mm to secure the sealing between baths.

For the operation of this insert, the pressure vessel is first filled from below with liquid helium at 4 K. To cool the lower bath, a heat exchanger made of copper, with an inner pipe surface of 1 m^2 and a cooling power of 120 W at 1.8 K is located below the lambda plate. This heat exchanger works together with an extra counterflow heat exchanger and a Joule-Thomson valve located above the lambda plate and housed in a separated vacuum box or anticryostat (Figure 5, right). It is the exhaust of this heat exchanger that is connected to the sub-atmopsheric pumps. The subsequent filling of the lower bath is via a valve connecting both baths.

The powering of the magnets is done via up to four vapour-cooled current leads of max. 2 kA each. These leads, the input and output of the heat exchanger plus all the necessary instrumentation during operation go through the lambda plate via feedthroughs sealed with Stycast.

Following the other inserts, the top flange counts with dedicated ports for all pertaining instrumentation plus an extra transfer line that takes care of the outgassed helium from the upper bath.

Regarding safety, in case of pressure build up in the lower bath a safety valve connecting both baths through the lambda plate releases the pressure to the upper bath. This pressure increase can then be taken care of by the volume above the lambda plate plus an extra safety valve on the top flange.

1.1.4. Control system

The operation of the cryostat is supervised and controlled by a local Programmable Logic Controller (PLC) from Siemens S7-300 family. It collects the data from all temperature sensors, vacuum gauges, helium level monitors, flow meters, etc. and controls all valves and heaters. There are a few hundred channels that are connected to the PLC. All of them can be accessed both from the local interface (WinCC) as well from Epics based control system covering all FREIA laboratory’s subsystems.

The PLC program can execute over twenty automatic sequences such as conditioning the different systems, cooling down, operation in 2 or 4 K, restarting after a magnet quench and warming up. The PLC program is also responsible for all interlocks for the cryogenic components. Both WinCC and Epics support such general services as alarm handling, archiving and graphical user interface.

3. CONCLUSIONS

A new vertical cryostat for FREIA Laboratory is under manufacturing and will be commissioned after summer 2017. The first tests with Gersemi will be for orbit corrector magnets used for the High Luminosity LHC project at CERN, with a maximum stored energy of 340 kJ.

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