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THE FIRST TESTS ON VERTICAL CRYOSTAT GERSEMI AT FREIA FACILITY

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Abstract

"GERSEMI", a vertical cryostat to test superconducting magnets and radio-frequency cavities at liquid helium temperatures, is installed at FREIA Laboratory at Uppsala University, Sweden. This cryostat can be used to test different superconducting equipment: a "Liquid insert" for cavities without a helium vessel and a "Magnet insert" with Lambda plate for magnet testing. The vertical cryostat is connected at a valve box which manages the cryogenic fluids and the gas led towards the helium recovery system. For the first step cryostat commissioning, a simulator (small vertical cryostat) has been used to make the valve box cryogenic tests. This article describes the GERSEMI cryo-system and summarizes the results obtained with the simulator.

INTRODUCTION

The GERSEMI cryo-system, the new equipment of FREIA Laboratory [1], is composed of a vertical cryostat, a valve box used to manage the cryogens and a reheater to warm up the output cold helium gas [2]. The valve box itself is filled of liquid helium by a L140 helium liquefier Dewar. After reheating, the helium gas is returned to the recovery system. The external dimensions of the vertical cryostat are 1.8 m in diameter and 4.7 m in height while its internal diameter is 1.1 m and the height is 4.3 m. The cryostat is installed in a pit of a 5 m deep and 2 m diameter and can be surrounded on the sides and the top by a radiation protection shield made of concrete beams. The dimensions of GERSEMI allow the tests of superconducting cavities and small magnets (see Fig. 1). Two types of insert will be used depending on operation, "Liquid insert" with saturated liquid helium bath for the cavity tests or "Magnet insert" with pressurized liquid helium bath for the magnet tests. All actuators and sensors are monitored by a Programmable Logic Controller (PLC), a software manages the control sequences of the valve box and the vertical cryostat.

In order to go with cryostat to temperatures lower than 4.2 K, sub-atmospheric pumps operating at room temperature are used. The minimum pressure that can be reached depends on the mass flow through the pumps: the flow capacity is 10 g/s at 70 mbar and gets down to 3.2 g/s at 10 mbar. To supply liquid nitrogen to GERSEMI, a large LN2 tank is installed outside of the building.

Prior to deliver by manufacturer, all the components of the cryostat underwent a complete series of tests to check the tightness of the enclosures, the absence of leaks in the cryogenic circuits and the valves. The validation of the electronic components and their wiring to the control system was also done. Several control program sequences were tested as well with a liquid nitrogen filled simulator.

The different components of the cryo-system were shipped at Uppsala in Mars 2018. After assembly and installation of GERSEMI, the cryogenic tests started in September 2018. To enable the validation of each equipment of the cryo-system without having to test all the components together, it was decided to build a simulator that would reproduce the cryostat behavior but using low mass to cool and requiring small amounts of liquid helium. The first step of the validation work is the evaluation of the valve box performances. When the simulator is connected at the valve box, it is possible to check the valve box operations monitored by the PLC software which controls all components of the cryo-system. During the operations with GERSEMI, all data and I/O procedures are operated under EPICS system and it can be analyzed in line or at any time later.

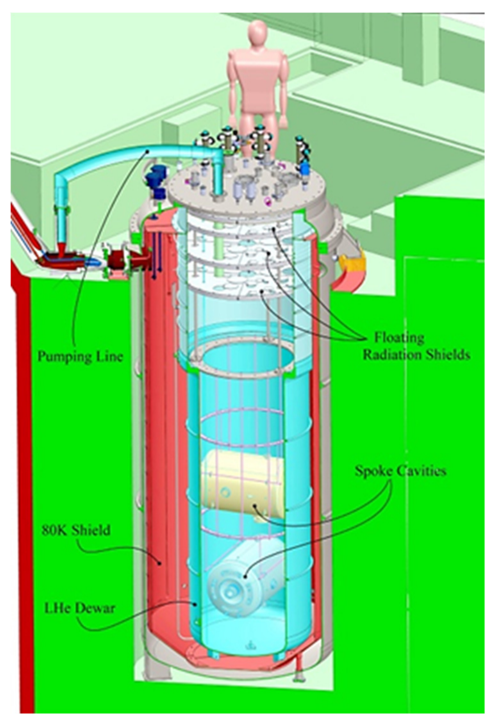

Figure 1: Liquid insert installed inside the GERSEMI vertical cryostat.

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GERSEMI CRYO-SYSTEM

To complete the FREIA installations at Uppsala University, the vertical cryostat has been installed in the second half of 2018.

The GERSEMI Vertical Cryostat

The vertical cryostat is composed of a stainless-steel vacuum vessel of external diameter of 1.8 m and a height of 4.7 m. The stainless-steel cold vessel consists of two cylindrical parts of different diameter, 1.25 m on the upper part, and 1.1 m on the lower part. The seat links the upper and the lower part, this seat is used to install a lambda plate to create a double bath for the tests of the magnet in pressurized superfluid helium. The "Magnet insert" (see Fig. 2) is designed with a lambda plate and the equipment for hanging and cooling magnets. For the tests of cavities, the lambda plate is removed and the "Liquid insert" should be installed. This insert allows operation in saturated liquid helium. In order to limit the LHe volume, it is planned to use one or several filling parts made of wood or rohacell foam. A last mode of operation is possible to test cavity with its helium vessel: the cold vessel is used as vacuum vessel. This third mode with "vacuum insert" is expected in the design of the cryo-system but the insert has not been built yet.

To reduce the radiation thermal losses of the cold vessel, an aluminum thermal shield is installed around the cold vessel and is cooled by liquid nitrogen circulation. As well, a supercritical helium circulation around the cold vessel neck limits the conductive heat loads coming of the top flange.

Figure 2: The GERSEMI Vertical cryostat and the magnet insert.

The Valve Box

The valve box controls the cryogenic fluids used by the vertical cryostat for the different operation modes. The valve box contains a buffer of liquid helium (the 4 K tank), a heat exchanger for sub-cooling of the liquid helium at atmospheric pressure before expansion through the Joule-Thomson valve. It also includes a heat exchanger to produce the 5 K supercritical helium and the cryogenic valves which manage the fluids. All components are surrounded by a copper thermal shield installed inside a stainless-steel vacuum vessel. The thermal shield is also cooled by liquid nitrogen. Liquid nitrogen is used as well to solid conduction heat intercept at 80 K of the tie rods or the cryogenic valves. The valve box is designed to operate the vertical cryostat from 1.8 K at 4.5 K with up to 100 W heat loads.

The Simulator

The simulator is a small vertical cryostat designed to operate with saturated liquid helium from 1.8 K to 4.5 K. It is connected to the valve box instead of the vertical cryostat and it can simulate the main functions performed by the cryostat.

It can simulate all operation modes expected with the "Liquid Insert". Its main advantages are low mass to cool and the small volume of liquid helium needed to operate. The simulator is composed of a cold vessel to store liquid helium and a thermal loop to simulate a thermal load on the supercritical circuit. To simulate the thermal loads, electrical heaters are glued on the cold vessel and the helium loop. A copper thermal shield is installed around the cold vessel. The thermal shield is brazed on the cold vessel neck to intercept the conductive heat loads coming from the top flange. A foam plug is glued to the top flange. Floating radiative shields are installed on the top of the cold vessel to reduce the radiation thermal losses and to avoid the top flange freezing. To operate, the simulator must be connected directly to the valve box without using the cryogenic line of the vertical cryostat (see Fig. 3). The simulator and the valve box share a common insulation vacuum. The vacuum pump connected to the valve box vessel maintains the vacuum condition for the cryogenic operation for the valve box and the simulator.

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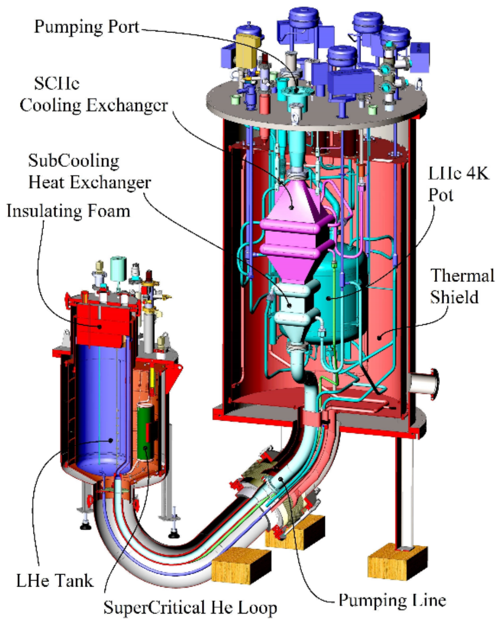

Figure 3: Simulator connected at the valve box.

Controls and Instrumentation

An Experimental Physics and Industrial Control System (EPICS) is used as a main control system at FREIA laboratory. The GERSEMI control system is similar to the HNOSS horizontal cryostat [3] in operation for many years. Driven by an analog current, the control valves of the cryogenic system are managed through the sensors and actuators connected to Programmable Logic Controller (PLC) S7-300 by Siemens. The connection is established via Profibus or Ethernet cables. For the commissioning, the EPICS system is associated to a Supervisory Control and Data Acquisition (SCADA) system using WINCC interface. The last one allows to display and proceed with all I/O data to obtain the dynamic real-time information essential for the cryostat supervision. The control hardware including the PLC, circuit breakers and power supplies is installed in electrical cabinets located nearby the vertical cryostat pit. To facilitate the commissioning and the insert changes, all cables relate to sets of plugs and connectors to general electrical distribution boxes. All electrical connections of the inserts are cabled at their distribution box.

All equipment cooled by liquid nitrogen are controlled by means of platinum thermometers (Pt100), thin film or wound. They deliver direct measurements to analog input cards of the Siemens PLCs.

The temperature of the circuit cooled by liquid helium or supercritical helium is measured with Cernox thermometers (CX1050SD). The sensors are connected to a CABTF controller which contains 16 inlets and could manage the input from 48 Cernox thermometers.

Liquid helium levels of the valve box tank and the inserts are measured with superconducting level probes located at different places:

- one probe in the valve box
- one probe in 4 K tank
- two probes used in series in the “Liquid Insert”
- four probes to measure the three helium baths of the “Magnet Insert” (two of them used to simulate a very long one)

The flow of nitrogen and the helium gas mass is measured by mass flowmeters. Measurements from them are used to evaluate the thermal losses of the cryogenic circuits.

The pressure in the 4 K and 2 K tanks are regulated by VAT butterfly valves operating at room temperature. Each valve is controlled by PLC proportional–integral–derivative (PID) routines. The helium bath pressures are measured by capacitive pressure sensors.

COMMISSIONING

During the factory commissioning, a leak test was carried out on each component. A cool down of the valve box was made with LN2 to check the instrumentation and to verify the absence of cold leaks appearing during the cooling. The commissioning at Uppsala is planned in several steps:

- the first one is a new leak control at room temperature
- the second step is the cryogenic test with LN2 and LHe necessarily made with a simulator. The cryogenic commissioning of the valve box with the simulator was conducted during the period from September 2018 to March 2019.

Before the end of 2018, the valve box operation remained unvalidated by the tests with the simulator as there were detected cold leaks preventing normal operation of the valve box. However, during this period, the SCADA program controlling the cryostat was checked and debugged. Moreover, the parameters of control sequences were optimized. The program running on the PLC can control more than twenty different modes of operation. During the tests with the simulator about fifteen sequences have been checked and debugged.

After repairing the localized leak on the body of one of cryogenic valves, the tests restarted again early 2019. During these tests, the thermal losses of the valve box thermal shield and the cryogenic line were obtained though the measurement of LN2 mass flow rate during the steady state. This is possible as the thermal shield temperature is regulated by the vaporization of liquid nitrogen circulating in a pipe exchanger, thus removing heat at constant temperature. The thermal losses deducted of the LN2 flow rate was 42 W which is higher than the design value of 35 W. Nevertheless, the measured value stays close to the expected one. The time needed to cool down the valve box thermal shield is about 2 hours; however, the thermal steady state is reached only after 1 day.

The last period of cryogenic tests (March 2019) validated the 4 K circuit of the valve box and the helium pumping system. The helium circuits and simulator were cooled down and the 4 K tank and the simulator cold vessel were fully filled. The thermal losses were evaluated from the valve box helium mass flow rate, outgassing of the 4 K tank after one day of steady state. This flow corresponded to a power of 1.3 W at 4.2 K. The design values of the thermal losses were estimated in the range from 0.8 W to 1.6 W

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which validates the concept of the system. The main contributions of these thermal losses were in the cryogenic valves of 0.3 W and due to the thermal conduction through the bayonet of the cryogenic line of 0.5 W.

The simulator was used to check the program which supervises the operation at 2 K. The main goal was to validate the control of the VAT butterfly valve which regulates the pressure of the helium bath and limits the mass flow rate during the cool down period. At 2 K@31 mbar, the power dissipated in the simulator was in the range from 7 W to 25 W. During these tests, the maximum helium pumping speed expected during the cool down stayed unreached, but the helium low pressure regulation mode with the VAT valve was validated.

The supercritical helium circuit was also tested in parallel of the 2 K operation benefiting the important evaporation mass flow rate at 2 K. The last one allows cooling the supercritical helium at 5 K thanks to the heat exchanger loop. The supercritical helium production was tested with several different loads in the pressure range from 3 bara to 4.5 bara. We also used an electrical heater installed on the thermal loop and simulating the thermal loads as it was explained above.

CONCLUSION

The GERSEMI cryo-system installed in FREIA Laboratory aims to provide a test stand for superconducting cavities and magnets. It is possible thanks to availability of two types of inserts: “Liquid Insert” and “Magnet Insert”. All equipment was delivered but not yet completely validated.

The first sequences of GERSEMI tests allowed correcting and updating the experimental program as well as validation of its operation with the simulator. The last one operated in a saturated helium bath which corresponds to the “Liquid Insert” configuration for the superconducting cavity tests. This commissioning also provided the validation of the valve box and the tests of fifteen sequences of the control program. Therefore, the tests with simulator are successfully finished. The next phase of the vertical cryostat commissioning is ongoing and will continue in the second part of 2019. It is planned to validate the “Liquid Insert” followed by “Magnet Insert” tests.

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