DESIGN OF A NEW HORIZONTAL TEST CRYOSTAT FOR SCRF CAVITIES AT THE UPPSALA UNIVERSITY

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Abstract

At Uppsala University, the FREIA facility for research and development of new accelerators and associated instrumentation, is presently in construction. Associated to a new Helium Liquefier, a Horizontal Test Cryostat will be used for high power RF tests of completely equipped SC cavities. This paper presents the main characteristics of the cryostat. Two types of cavities have been considered for test purpose: SC elliptical cavities for future free electron lasers and SC cavities for high intensity proton accelerators. A special valve box including a subcooling stage and power coupler cooling with supercritical Helium supply have been designed, for temperature operation ranging from 2 K to 4.2 K. This facility will play an essential role in the development and test of cavities, couplers and cryomodules for the ESS project. High power RF sources will be installed in order to allow unique and complete tests of spoke cavities and cryomodules at high nominal peak power..

THE FREIA FACILITY

The new FREIA laboratory at Uppsala University is constructed for research and development of new accelerators and instrumentation for accelerator based research. The FREIA laboratory is situated in a 1000 m2 hall as a stand-alone facility: all equipment required for high power testing of superconducting accelerator cavities is within the laboratory. It includes two radio-frequency (RF) power stations delivering up to 400 kW peak power at 352 MHz, 3.5 ms pulses at 14 Hz repetition rate. A horizontal test cryostat, installed inside a concrete bunker for radiation protection purposes, is the central part to cool down and test the accelerating cavities at temperatures down to 1.8 K. A helium liquefier with a capacity of 140 l/h liquid helium production, 2000 l liquid helium storage and 20 m3 liquid nitrogen storage will provide the required cooling power. To recycle the helium gas, a gas recovery system is part of the complex and consists of a 100 m3 gas balloon and 3 high pressure recovery compressors. For testing at temperatures below 4.5 K, sub-atmospheric pumps and a gas heater will be installed.

The present main goal for the FREIA laboratory is the high power testing of the prototype RF power station, double spoke cavity and spoke cryomodule for the European Spallation Source (ESS) linear proton accelerator. Horizontal test cryostat, liquefier and RF power stations are to be commissioned by June 2014 to immediately perform tests of the first prototype spoke cavity; testing of the first spoke cryomodule prototype, with two spoke cavities, is scheduled for July 2015. The experiments at FREIA will include one station with a horizontal test cryostat, and, at a later stage, a cryomodule; both connected to the helium liquefier.

SPECIFICATIONS OF THE CRYOSTAT

The horizontal cryostat's primary aim is the test of superconducting RF cavities equipped with their helium tank, cold tuning system, piezo tuners and power couplers. The layout of the horizontal test cryostat is based on previously built cryostats for superconducting cavity testing like HoBiCat (HZ Berlin, [1]), CryHoLab (CEA Saclay, [2]) or CHECHIA (DESY, [3]).

The versatile cryostat design makes it able to accommodate a whole range of different superconducting devices: cavities, solenoids or dipole magnets.

The cryostat is able to contain two different SC cavities simultaneously, which makes it possible to test either a 352 MHz or a 704 MHz power amplifier chain in combination with a superconducting cavity without the need to open the cryostat and replace the cavity. The cavities are contained in the same insulation vacuum, and share a common helium bath; cavity cool-down and coupler cooling loops have been doubled to provide independent control of each of the cavity's /coupler's temperature during cooldown/coupler operation.

CRYOSTAT CHARACTERISTICS

FREIA Bunker

86 K@2.5 bar LN2 and 4.5 K@1.25 bar LHe are transferred via a transfer line (TL) from the dewars to the inter-connexion box (ICB). A view of the cryostat and associated equipment is shown in Figure 1. Its main parameters are listed in Table 1. The valve box (VB) contains the necessary set of tanks, valves, and heat-exchangers (HX) to provide LN2@80 K, LHe@2 K, LHe@4.5 K and supercritical He@5 K to the cryostat. He bath temperature in the cryostat is adjustable between 1.8 K and 4.2 K. Supercritical helium (SHe) is used for power coupler outer conductor cooling. The atmospheric pressure GHe is directed towards the cold vapour heater and sent back to a gasbag or to the coldbox. The subatmospheric pressure He return vapors are also heated, then compressed back to near atmospheric pressure and routed back to the gasbag.

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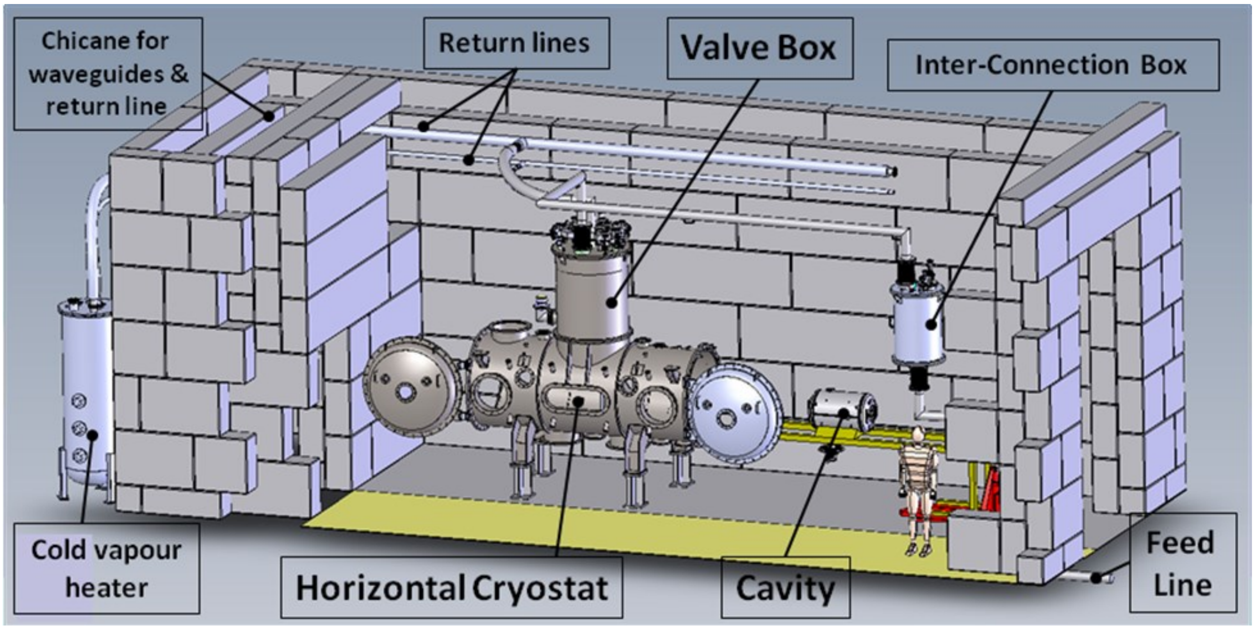

Figure 1: Layout of the FREIA bunker.

Heat Loads

Estimated static heat losses of the cryogenic components in the bunker are shown in Table 1.

Radiation static heat losses are minimized by isolating the 4 K components with a LN2 cooled radiation shield. Insulation is ensured by 30 layers of single-aluminized mylar sheets between 300K and 80 K and 10 layers between 80 K and 4 K; corresponding radiation flux values are 2W/m² to 80K and 0.05 W/m² to 4K.

Conduction losses are minimized by using low conductivity material for all supports and thermalizing to the 80 K shield where possible; the LHe 4 K tank is held in place by three 80K-thermalized epoxy glass tie-beams hanging from the valve box top; the 2 K tank is supported by the 4 K tank; all cryogenic valves which are in permanent contact with liquid helium are thermalized to the 80 K shield.

Cool-down and Warm-up

Cool-down of each cavity is ensured by a separate loop for each cavity. This loop reaches the cavity tank from below, so that the cavity is cooled down by the cold vapors. During cool-down, if the cavity hasn't been heat-treated, the transition from 150 K to 70 K can be made in <1 hour to minimize the effects of Q-disease [4]. Thin film Kapton insulated heaters are uniformly distributed on the cold mass to ensure warm-up of the installation within 8h.

HORIZONTAL CRYOSTAT

Main Vessel

The cryostat main vessel is 4 m long, 1.3 m in diameter, made out of 8 mm thick 304L stainless steel, closed at either end by convex doors on hinges. The vessel with its flanges and doors weights about 2 tons; fully equipped with SC cavities and together with the valve box, up to 4 tons can weight on the four feet of the cryostat.

Table 1: Main Parameters

Characteristic	**value**
Internal available length	3.2 m
Internal available diameter	1.2 m
Number of cavities	2 Spoke cavities
Helium bath temperature & pressure	1.8K ,16 mbar 4.5K, 1.25 bar
Thermal capacity (design)	120 W @ 4.5 K 90W @ 1.8K 400 W @ 86K
Static losses (design)	9W @ 4.5K 90 W@ 86K
Table cooling	4.5K loop
Coupler cooling	Supercritical He 5K-200 K LN2 86 K
Radiation shield	LN2 86 K
He bath pump suction pressure	10 mbar
He bath pump capacity	75W @ 1.8K

The cryostat presents numerous flanges to make it as versatile as possible. A table made out of cast aluminium profile, cooled by a 4 K helium loop, can be mounted at the bottom of the cryostat. It is supported by 3 epoxy fiberglass Ø=150mm posts, thermalized on the 80 K shield, that rest on 3 distinct flanges. Alternatively, support of the cavities can be ensured by

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tie-beams. Power couplers can be connected either to the side for TESLA couplers or to the bottom for ESS couplers. The bottom flanges have deliberately been positioned close to the center of the cryostat so the user can have better access to the cold tuner once the cavity with its coupler is installed. A 500 mm flange on the top of the cryostat has been foreseen for connection of current leads for SC magnet tests. Access to the center of the cryostat is eased by a 800 mm long oval flange in the center of the cryostat. Various other smaller flanges are included for insulation & cavity vacuum, instrumentation, safety valves etc.

A room-temperature magnetic shield is fixed to the inner cryostat wall, doors, and valve box sides to prevent penetration of the vertical (50 µT) Earth magnetic field component. To take some safety margin, we have chosen for the magnetic shield design a thickness of 2 mm. The magnetic field can further be lowered to ~1 µT by installing a cavity-specific magnetic shield [5] as foreseen in ESS.

Thermal Shield

The cryostat thermal shield consists of a 3 mm thick 5454-T6 aluminium alloy sheet cylinder, weighting 130 kg. It is cooled by 4 x 3.3m longitudinal strips of Ø=10 mm LN2 pipes soldered to the shield. The doors will be bolted to the main cylinder after installation of the cavities, and are cooled by thermal contact. The cryostat shield is separated from the room-temperature vessel by 16 cylindrical PTFE spacers lying on their side (on one edge). Finally, for SC magnet tests, the thermal shield is cut along its length to prohibit the flow of Eddy currents in the shield around the cryostat axis in case of a magnet quench. Mechanical integrity of the shield is preserved by four electrically insulating EpoxyGlass straps.

VALVE BOX

One of the main innovations of this cryostat is the use of a double heat-exchanger (see ture 2). The first module is used during 2 K operation of the cryostat. The cold vapors (2-3 K) from the cavity bath subcool the incoming LHe from the 4 K tank to enhance Joules-Thomson (JT) liquid yield. The second module uses again the enthalpy of the cold return vapours (~4-5 K) to produce a stream of supercritical helium at 3 bar and 5 K, for coupler cooling. The refrigeration capacity of this module naturally increases with coupler power, as a greater power in the coupler induces increased cavity dissipation and return cold vapour flow. Since the low-pressure return cold vapour loop is common to both modules, the two modules can be fused in one compact component.

We have opted for an annular 4.5 K, LHe tank (capacity: 90 L) design to provide room for other components within the valve box (VB). A smaller, 35 L 2 K tank is situated below the 4 K tank.

SHe is circulated in closed loop through the cryostat by a diaphragm pump. To prevent any contamination of this loop, we installed an 80K cooled activated charcoal trap in the valve box. The SHe loop outlet is also equipped with a 1 kW heater for a maximum flow of 1g/sec (for both cavities).

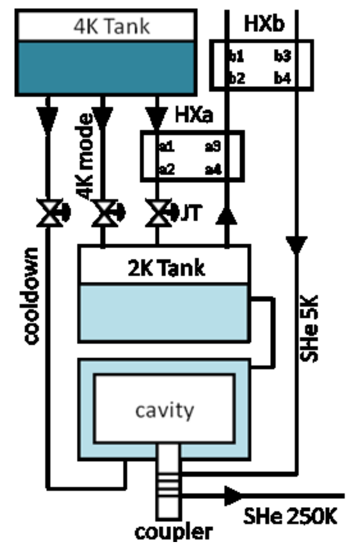

Figure 2: Valve Box Flow diagram.

Two pairs of superconducting wire gauges are installed on the 4 K and on the 2 K tank to monitor liquid helium level. Pressure gauges measure the important pressures within the installation: cavity & insulation vacuum, 4 K and 2 K tank. Warm flow meters and gas counters monitor the main mass flows to adapt them to the heat load during operation.

Six helium safety valves are installed on the cryostat and its associated equipment, with an opening pressure of 1.5 barA. The biggest one, Ø=63 mm is installed on the 2 K tank. It has been sized to allow exhaust of cold He vapors with little overpressure in case one of the cavity's vacuum ruptures [6].

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