

STATUS OF THE SUPERCONDUCTING PROTON LINAC (SPL) CRYO-MODULE

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Abstract

The Superconducting Proton Linac (SPL) is an R&D effort conducted by CERN in partnership with other international laboratories, aimed at developing key technologies for the construction of a multi-megawatt proton linac based on state-of-the-art SRF technology. Such an accelerator could serve as a driver in new physics facilities for neutrinos and/or radioactive ion beams [1].

Amongst the main objectives of this effort, are the development of 704 MHz bulk niobium beta=1 elliptical cavities (operating at 2 K and providing an accelerating gradient of 25 MV/m) and the test of a string of cavities integrated in a machine-type cryo-module. In an initial phase, only four out of the eight cavities of the SPL cryo-module will be tested in a half-length cryo-module developed for this purpose, which nonetheless preserves the main features of the full size module.

This paper presents the final design of the cryo-module and the status of the construction of the main cryostat parts. Preliminary plans for the assembly and testing of the cryo-module at CERN are also presented.

INTRODUCTION

The SPL cryo-module (CM) development work at CERN is motivated by the need of understanding how high-gradient SRF cavities can be efficiently put into operation in an accelerator’s environment. It is well known that cavity performance can be degraded by surface contamination occurring between vertical testing and final operation in a cryo-module due to the high number of intermediate preparation steps (dressing in their helium vessels, clean-room assembly to form a string, etc); mastering the complete preparation cycle of a CM is therefore mandatory and requires learning from prototyping. Furthermore, alignment issues of the cavities inside the CM are essential for the performance of a linac and design considerations must be validated on a prototype. Last but not least important, the thermal performance of cavities operating at 2 K, including measuring static heat loads of the cryostat, as well as RF and cryogenic operation experience, need an experimental validation on a full-scale CM.

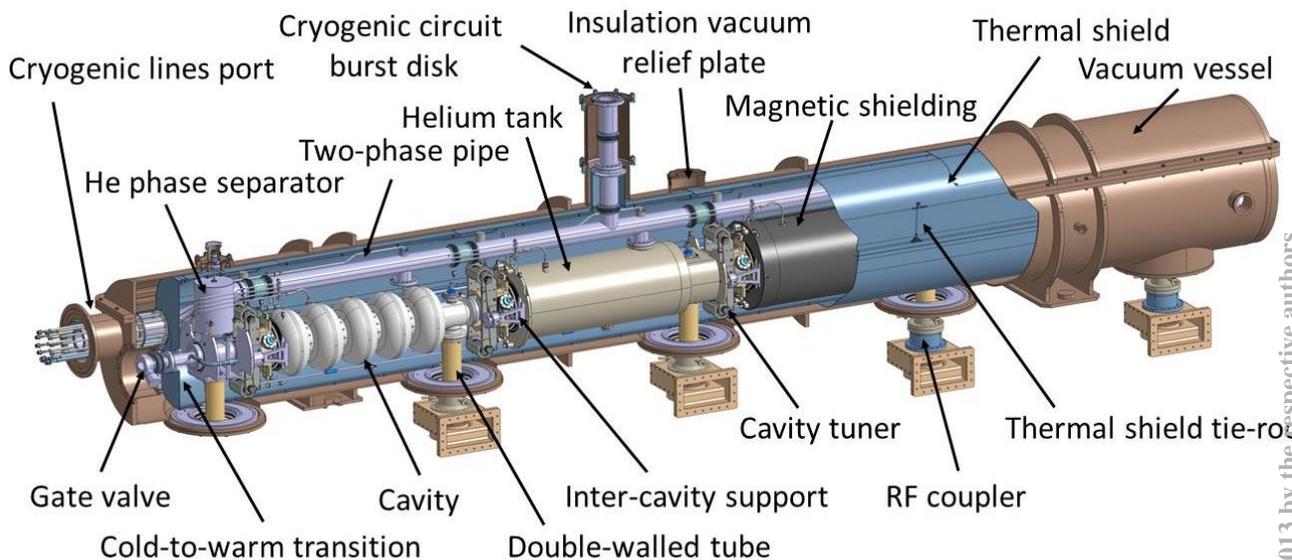


Figure 1: General Assembly View of the SPL Short Cryo-module.

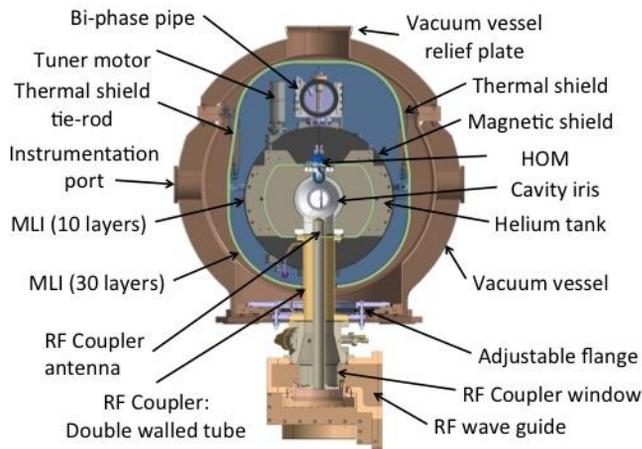


Figure 2: Cross-sectional view of the SPL cryo-module.

THE CRYOMODULE AND ITS MAIN CRYOSTAT COMPONENTS

The innovative concept of the SPL cryo-module, featuring the main RF coupler acting also as the main mechanical support of the cavities [2], has now evolved, through the work done in collaboration with IPN d'Orsay, to a mature design which is presented hereafter and which is illustrated in Figures 1 and 2.

The CM contains four 704 MHz cavities [3], made in bulk-niobium, each housed independently in a stainless steel helium tank designed to match the tuning requirements when making use of the CEA-Saclay lever-arm type tuners.

The fixed RF coaxial coupler, with a single ceramic window, providing 100 kW average power (1 MW peak) is mounted onto the cavity via a ConFlat™ flange assembly equipped with a specific vacuum/RF seal designed at CERN and widely used in CM for other machines (including LHC). The single-window of the RF coupler imposes that it is mounted as a whole onto the cavity in the clean-room, constraining by its large radial size the subsequent assembly activities of the CM. For this reason the vacuum vessel has been designed in two parts, to allow a vertical assembly of the string inside the vessel.

Cavity Supporting System

With the aim of minimizing static heat loads from room temperature to 2 K by solid thermal conduction, the number of mechanical elements between the two extreme temperatures is reduced to the strict minimum: the cavities are supported directly via the external conductor of the RF coupler, the double-walled tube (DWT). The latter is made out of a stainless steel tube with an internal diameter of 100 mm, which is actively cooled by gaseous helium circulating inside a double-walled envelope in order to improve its thermal efficiency [4]. An additional supporting point to keep cavity straightness and alignment stability within requirements is obtained by supporting each cavity on the adjacent one via the inter-cavity support, which is composed of a stem sliding

inside a spherical bearing. As a result, a pure vertical supporting force is exchanged by adjacent cavities whereas all other degrees of freedom remain unrestrained allowing thermal contraction movements to occur unhindered.

The thermo-mechanical behaviour of this supporting system is presently being studied on a dedicated test bench at CERN.

Thermal Shielding and MLI System

The thermal shield is made of rolled aluminum sheets, and is composed of four main parts assembled before the vertical insertion of the string of cavities: two half-shells mounted around the string of cavities and two closure parts at its two extremities.

The shield is suspended to the vacuum vessel via adjustable tie rods in titanium alloy which also cope, by angular movements, with its thermal contractions. The absence of mechanical contact between the shield and the string of cavities eliminates the risk of interference with the alignment of the cavities induced by differential contractions and cooling transients.

The thermal shield is actively cooled at about 50 K via an aluminum cryogenic cooling line of 15 mm internal diameter. The same line ensures an intermediate cooling of the two Cold-to-Warm Transitions (CWT) of the beam tube at the cryostat's extremities.

A 30 layers MLI prefabricated blanket, of the same technology developed for the LHC superconducting magnet cryostats, protects the thermal shield whereas 10-layer blankets are mounted around each helium vessel.

Magnetic Shielding

The cavities are protected by individual magnetic shields made of 2-mm thick Cryoperm™ sheets. The shields are made of 2 half-shells mounted around the helium tank and fixed to it on the tuner side. Simulations confirm the effectiveness of the shielding, keeping Earth's magnetic field penetration in the cavity region to within $\sim 1 \mu\text{T}$.

Cryogenic Piping

The cavities are housed in individual stainless steel helium tanks connected by a 100-mm-diameter two-phase pipe placed above the cavities. This pipe ensures liquid feeding to the cavities by gravity, and is also used as a pumping line for gaseous helium. A saturated helium bath at 31 mbar maintains the cavities operating temperature of 2 K. Helium vapours are pumped along the two-phase pipe and through a phase separator reservoir of 5 l, which collects the liquid helium in excess and which houses a superconducting liquid level gauge for cryogenics operation and control purposes. Sub-cooled liquid helium, previously expanded through JT valves, is supplied to the two-phase tube through 10-mm capillaries (one per each cavity), and routed along the two-phase pipe. Redundancy in the number of filling lines and level measurements (each cavity has a helium level measurement) has been foreseen for testing purposes, though one single line,

filling from the extremity opposite to the phase separator, is deemed sufficient for normal operation. The cavities are also equipped with one additional 6-mm capillary each (also routed along the two-phase pipe), for their effective cool-down and warm-up.

A dedicated 6-mm circuit supplies 4.5 K vapour helium for cooling of the RF coupler double-walled tubes. The vapours are warmed up to room temperature before being recovered in a circuit outside the vacuum vessel.

Vacuum Vessel

For reasons of compactness and ease of assembly of the string of cavities inside the CM, the vacuum vessel (shown in Figure 3) has been designed in two parts, a main 10-mm-thick bottom part and a 6-mm-thick top cover. The bottom part of the vessel supports the cavities via adjustable flanged interfaces to the double-walled tube of the RF coupler, and the top cover is closed at the very end of the CM assembly. This leaves the possibility of checking the alignment of the cavities with optical devices (laser trackers for example) while making fine adjustments through the adjustable flanges. The top cover is closed onto the bottom part via a flanged assembly; a 10-mm diameter O-ring sealing keeps leak-tightness to better than 10^{-8} mbar/l/s in an insulation vacuum of 10^{-6} mbar.

The vacuum vessel mounts a number of ports which serve for routing instrumentation, and for interfacing vacuum or cryogenic equipment (pumps, level He gauges) as well as overpressure safety devices (burst disks for the cryogenic circuit and safety relief plate for the insulation vacuum).

Apart from the main flanges and ports, which are made in stainless steel AISI 304L, the vessel is made in low-carbon steel in order to provide a first level of magnetic shielding of the cavities with respect to external fields.

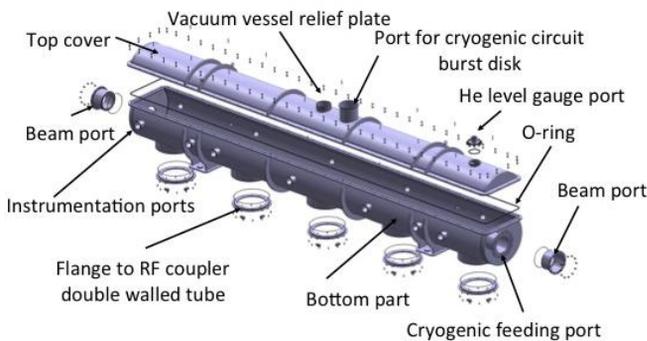


Figure 3: View of the two-parts vacuum vessel.

CRYOMODULE HEAT LOADS

Estimates of the static and dynamic heat loads for the CM, are given in Table 1. The residual resistance on the cavities surface yields the dominant contribution to 2 K heating, with 20 W/cavity (based on $E=25$ MV/m, a Q_0 of $5 \cdot 10^9$ and a cryo duty cycle of 8.22%). The remaining contributions, mostly static heat loads, account for less

than 10% of the total at 2 K. The total heat load of about 86 W at 2 K is equivalent to a mass flow of about 4.1 g/s of helium vapours in the two-phase line. The 50 K level circuit collects about 90 W, out of which half is attributed to the two cold-to-warm transitions of the beam tubes, and the rest is thermal shield radiation heating.

Finally, the active cooling of the RF couplers double-walled tubes, with nominal RF powering, requires a 4.5 K helium mass-flow of 40 mg/s per coupler, i.e. 160 mg/s total, to which 40 mg/s of a similar active cooled support of the phase separator has to be added.

Table 1: CM Static[#] and Dynamic Heat Loads

Temperature level	2 K	4.5-300 K	50 K
4 Cavities RF power	80 W	-	-
2 Cold-to-Warm transitions	~ 2 W	-	~ 15 W
4 RF couplers DWT	< 2 W	160 mg/s	-
1 Phase separator support	< 0.5 W	40 mg/s	-
Thermal radiation to thermal shield	-	-	~ 35 W
Thermal radiation to 2 K	~ 1.5 W	-	-
Total	~ 86 W	200 mg/s	~ 50 W

(# No contingency and excluding instrumentation induced heat loads)

CRYOMODULE ASSEMBLY AND TESTING

The CM is now entering the manufacture phase. The first cavities are being supplied to CERN by Industry and will be prepared at CERN in a new electro-polishing facility, while the cryostat components are now starting to be procured. Assembly of the string of cavities is planned in 2014 in a CERN class-10 clean-room, presently being upgraded. The CM assembly will follow with the goal of starting cryogenic and RF testing before the end of 2015.

CONCLUSIONS

The motivation for the design and construction of the SPL cryo-module has been presented and justified. The original design concept has evolved in the last two years towards a mature and detailed design. The procurement of cavities and cryostat components is now underway in European industry.

CERN is upgrading its facilities (cavity electro-polishing, clean-rooms and RF testing facility) in order to be ready for the challenging task of preparing 25 MV/m cavities,

assembling them first in a string, then in the cryo-module and be ready to start RF testing before the end of 2015.

REFERENCES

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