CONCEPTUAL DESIGN OF THE SUPERCONDUCTING PROTON LINAC SHORT 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 Superconducting Radio Frequency technology, which would serve as a driver for new physics facilities such as neutrinos and radioactive ion beams.

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 field of 25 MV/m, and testing of a string of cavities integrated in a machine-type cryo-module. In an initial phase only four out of the eight cavities of an SPL cryo-module will be tested in a ½ length cryo-module developed for this purpose, and therefore called the Short Cryo-module.

This paper presents the conceptual design of the SC, highlighting its innovative principles in terms of cavity supporting and alignment, and describes the integration of cavities and their main equipment (RF couplers, helium vessels, tuners) inside the cryo-module and possible assembly methods.

INTRODUCTION

A first proposal for building a superconducting proton linac (SPL) at CERN to replace some of the existing accelerators was reported about 14 years ago [1], with the potential for evolving towards very high beam power, which would support new physics facilities for neutrinos and/or radioactive ion beams [2]. Later, the design of the SPL evolved towards a low-power 4 GeV version (LP-SPL), with potential use in a new injector chain for the LHC, together with Linac4, presently under construction, and having the potential to be up graded to a multi-MW proton injector [3]. Following recent changes in the mid-term plan strategy at CERN, the construction of the LP-SPL has been stopped, but the continuation of the R&D effort towards a high-power version of the SPL has been endorsed. As one of the priorities of this program, 704 MHz bulk niobium $\beta=1$ elliptical cavities are to be developed and tested in collaboration with the European Spallation Source (ESS). The main cavity and cryogenic design parameters are summarised in Table 1, for a 50 Hz pulsed operation, 20 mA current and 0.8 ms beam pulse length.

Machine architecture and integration studies made for the SPL at CERN, featuring 60 $\beta=0.65$ cavities, and 184 $\beta=1$ cavities in an SRF linac of about 500 m length, led to the choice of housing 8 $\beta=1$ cavities in standalone cryo-modules, individually connected to a cryogenic distribution line cryostat running parallel to the linac (Figure 1).

Table 1: $\beta=1$ cavity, main parameters

Property	Units	Value
Cavity material	-	bulk niobium
Gradient	MV/m	25
Quality factor Q_0	-	$5 \cdot 10^9$
R/Q	-	570
Operating Temp.	K	2
Cryo duty cycle	%	8.22
Dynamic heat load	W	20.4

This cryo-module will therefore feature two cryostat end closures, equipped with Cold-To-Warm transitions (CWT) for the beam tube, as well as a connection to the cryogenic distribution line for the feeding of helium at cryogenic temperatures.
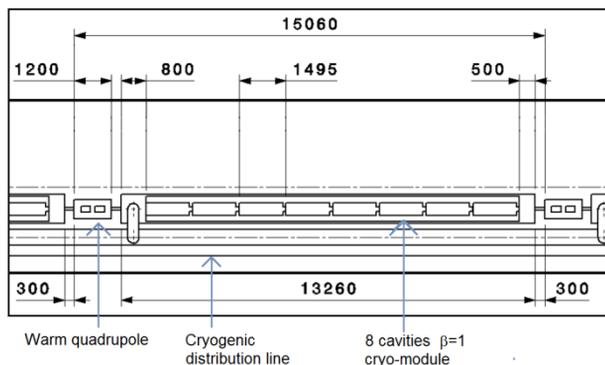
Figure 1: Layout (top view) of the SPL cryo-module.

Considering that in an initial phase only four out of the eight cavities will be made, and will need to be tested together as they would operate in a machine-type cryo-module, a ½ length cryo-module, the so-called Short Cryo-module (SC), has to be designed and constructed. This cryo-module will serve primarily as a test-bench for RF testing of the cavities, powered by specifically developed RF couplers, but will also provide the opportunity of developing a first prototype of a machine-

type cryo-module for the SPL or for similar high-power proton drivers. For this reason, the SC is being designed under the constraint of being compatible with a full size unit housing eight cavities.

CONCEPTUAL DESIGN OF THE SHORT CRYOMODULE

Each of the four cavities of the SC is independently housed in a stainless steel helium tank. A 100 mm diameter low pressure bi-phase helium pipe, running above the cavities, provides cooling to a common helium bath at 2 K and the collection of the boil-off vapours which are pumped back to the cryogenic plant; the excess of liquid in the bi-phase tube is collected in a phase-separator volume, housed in a so-called Technical Service Module (TSM), where all cryogenic control instrumentation and valves are placed. The SC cryostat mounts end closures and CWTs for an 80 mm diameter beam tube, as it would be in a machine-type cryo-module. CEA-Saclay lever-arm type tuners, mounted at the extremity of the cavities, have been chosen due to their proven performance on similar cavities (Figure 2).
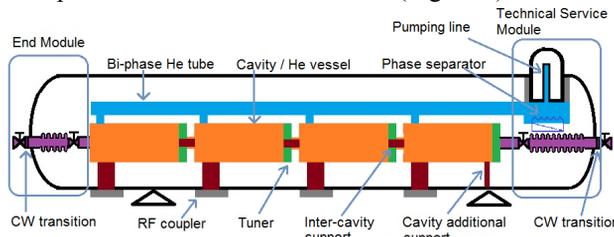
Figure 2: Schematic view of the Short Cryo-module.

Each cavity is powered by a fixed RF coaxial coupler, with a single ceramic window, providing a 100 kW average (1 MW peak) power. Due to its single window, the entire RF coupler has to be mounted onto the cavity in the clean-room, so all subsequent assembly activities of the SC, outside the clean-room, in particular the insertion in the vacuum vessel, are constrained by its large radial size. The outer conductor of the RF coupler is a 100 mm copper plated stainless steel tube. In order to keep static heat loads to 2 K as low as possible, a double-walled tube with active cooling by helium between 4.5 K at the cavity end and Room Temperature (RT) at the vacuum vessel end is used. A flow regulation valve and an electrical

heater at the warm side of the double-walled tube are needed for control reasons, depending on the RF coupler operation (Figure 3).

Table 2 illustrates the mass flow and heater power settings when the RF coupler is powered or not, and the residual heat load to 2 K.

Table 2: Operation of He-cooled double-walled tube

Property	Units	Value	
Mass flow	mg/s	42	
RF Power	-	ON	OFF
Temp gas out	K	232	180
Q thermal load to 2 K	W	0.1	0.1
Q heater	W	46	44

Cavity Supporting System

An innovative cavity supporting principle is being proposed, where the RF coupler double-walled tube serves as the main support of the cavity/helium vessel/tuner assembly to the vacuum vessel. This solution simplifies the design of the cryostat and enhances thermal performance to 2 K by limiting the number of heat conduction paths from RT and due to the particular efficiency of vapour cooling of the RF couplers.

The double-walled tube can withstand the mechanical loads of the cavity/helium vessel/tuner, but in order to compensate the self-weight vertical sag of the cantilevered assembly and to keep the straightness within acceptable limits (in the order of 0.1-0.2 mm) an additional vertical support is needed at the extremity of the cavity opposite to the RF coupler. This is achieved by a support attached to the adjacent cavity, providing a vertical reaction and allowing unhindered longitudinal thermal contraction movements (Figure 4).
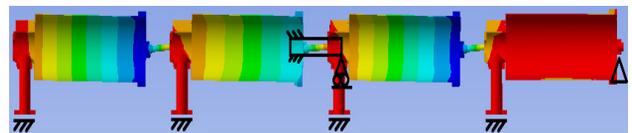
Figure 4: Self-weigh vertical sag with inter-cavity supports (sketched on 1 cavity). Displacements amplified 200x. Maximum value, in blue: 0.09 mm.

Figure 3: Cavity/helium vessel assembly, supported by an actively cooled RF coupler.

Since this inter-cavity support connects bodies at the same temperature, no additional conduction paths are created.

Vacuum Vessel and Assembly Considerations

The design of the vacuum vessel must be intimately linked to the cryostat assembly procedures and tooling, and although this study is still in progress, two distinct conceptual approaches are now being compared. A first one making use of a tubular type vessel denoted as "LHC type" similar to the LHC magnet cryostats, where the string of cavities is firstly pre-aligned on a girder, then inserted longitudinally and fixed to the vessel. A second approach features firstly the alignment and mounting of the cavity string on a base-plate, followed by closure with a top cover to form the vacuum vessel. This is called a "two-part vessel". The two approaches are schematically illustrated in Figure 5.
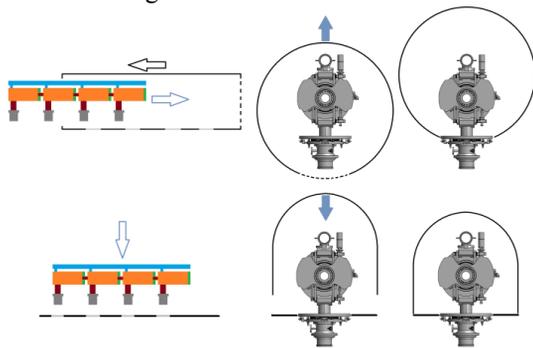
Figure 5: Vacuum vessel and assembly approaches: "LHC type", (top view), vs. "two-part vessel" (bottom view).

The comparison is being made keeping in mind that the approach retained should be extendable to the full-size 8-cavity cryo-module, which will be roughly twice the length of the short cryo-module.

The major advantages of the "LHC type" approach are construction simplicity and cost effectiveness of the vessel. Drawbacks are the large vessel diameter (~1.2 m) to provide the required radial space during assembly of the cavity/RF coupler, and a more complex alignment girder for the longitudinal insertion of the string. On the other hand, the "two-part vessel" offers simplicity during the assembly of the cavities, but the construction of the vessel is more complex and its dimensional stability, upon which the alignment of cavities relies, may be difficult to guarantee when closing the vessel (by welding or organic sealing) and when pumping the insulation vacuum.

Cryogenics

The cryogenic scheme adopted for the short cryo-module (Figure 6), offers operational flexibility and redundancy for cavity filling and level control, as shown by the individual cavity filling valve and level sensors, making it an ideal test-bench for exploring various operational scenarios including the simplest machine-type scheme, where it is proposed to fill from one single point

at one extremity of the bi-phase tube, and control the He level in the phase separator only. The entire cryo-module can be inclined longitudinally up to about 2%, which will allow investigating cryogenic operation for machines in a sloped tunnel, as it is foreseen for the SPL at CERN.

Cool-down/warm-up of the cavities is ensured by individual circuits. The double-walled tubes of the RF couplers are cooled by a parallel circuit feeding 4.5 K helium vapours, with an individual mass flow regulation through RT valves outside the cryostat.

The cryo-module will have a single thermal shield cooled by a dedicated circuit at around 50 K.
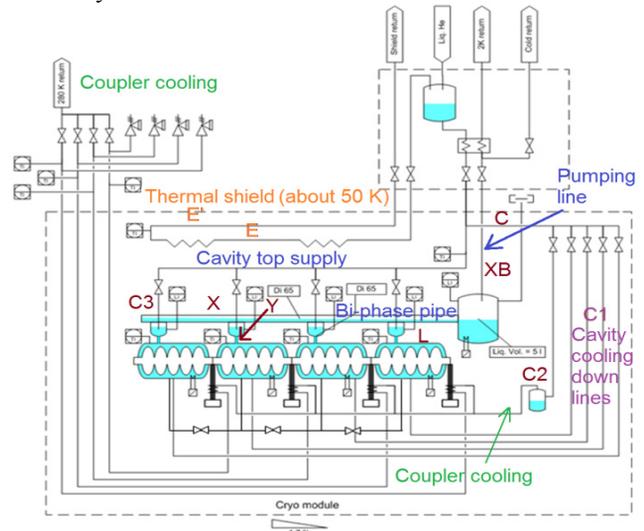
Figure 6: Cryogenic scheme of the short cryo-module.

SUMMARY AND OUTLOOK

The SPL Short Cryo-module is the first step towards the design of a machine type 8-cavity beta=1 cryo-module, and it will provide the bench for testing a string of 4 cavities in a machine-type configuration, powered by high-power RF couplers. The SC will also enable testing of an innovative supporting and aligning principle for the cavities via the RF coupler, which promises simplicity in the design and construction of cryo-modules. The cryogenic scheme adopted will provide flexibility for exploring operational aspects of the 2 K cooling of the cavities towards a simplified scheme for a machine-type solution.

The next design milestone is the choice of the vacuum vessel type and the associated cryostat assembly method. This choice will set the boundaries for the detailed design and integration study of the SC, which is expected to end mid 2012, in order to start the procurement of the SC components, for its assembly planned by end 2013.

REFERENCES

[1] R. Garoby and M. Vretenar, PS/RF/Note 96–27.
[2] M. Vretenar, CERN Report No. CERN-2000-012, http://doc.cern.ch/yellowrep/2000/2000-012/p1.pdf.
[3] O.Brunner et al. "Assessment of the basic parameters of the CERN Superconducting Proton Linac", Physical Review Special Topics-Accelerators and Beams, 12, 070402 (2009).