PRELIMINARY STUDIES OF THE CRYOGENIC REFRIGERATOR AND DISTRIBUTION SYSTEMS FOR THE MYRRHA PROTON LINAC*

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Abstract

In the framework of recent European programs (FP6-Eurotrans, FP7-MAX), the SC proton Linac for the MYRRHA project (associating an accelerator to a subcritical nuclear reactor, to be installed in the SCK-CEN at Mol-Belgium), has been extensively studied and optimized to reach strict requirements in beam power and reliability as needed for this ADS demonstrator. The linac, composed of 150 SC cavities (CH, spoke and elliptical) installed in 60 cryomodules, operates at 2K, delivering a beam power of 2.5 MW (600 MeV, 4 mA) in CW mode, will be installed in a tunnel of 240 m length. In this paper we present the evaluation of the cryogenic power requirements, a preliminary architecture of the cryogenic refrigerator system including all its major components, and preliminary proposals for the cryofluids distribution along the SC linac.

THE MYRRHA SC LINAC

The MYRRHA project, an ADS (Accelerator Driven System) proposed by the SCK-CEN (Belgium) and the international collaboration, is based on a linear accelerator, which delivers a high intensity proton beam impinging on a metal spallation target and producing a high yield of neutrons to feed the subcritical core of the fast spectrum reactor [1].

The main parameters of the accelerator are:

- **Beam: protons, 2.5 mA (max 4 mA) in CW mode**
- **Energy: 600 MeV**

The reliability performances needed by the MYRRHA system are very high:

- **Less than 10 beam trips, of duration > 3 sec, for 3 months of operation period**

leading to an equivalent MTBF (Mean time Between Failures) greater than 250 hours. This goal must be compared to presently running high power accelerators which operates with MTBF of only a few hours.

The Linear Accelerator (Linac) is one of the critical components in this project, and it represents a major technological challenge: to deliver a high energy proton beam at high intensity in a continuous wave mode (CW). Only a solution based on Superconducting (SC) Cavities can offer the required feasibility and performances. The SC Linac is composed of 3 sections: an injector composed of SC–Crossbar H mode (CH) cavities operating at 176 MHz, a medium energy section using spoke SC cavities operating at 352 MHz, and a high energy section using SC elliptical cavities operating at 704 MHz.

Recently, within the present EU project (FP7-MAX), one important goal was to analyze, with much higher level of details, the cryogenic technology that could guarantee the performances and a reliable operation of the MYRRHA accelerator. One important result was the choice of the optimal operating temperature for the SC Linac: 2K (superfluid helium) was adopted for all the linac sections.

Table 1 presents the heat loads associated to the 3 SC linac sections. These loads include both the static and dynamic loads. Static load is mostly related to the cryomodules mechanical configuration and the values in this table (5 W/m) are extrapolated from similar cryomodules in other project and prototypes measurements. The dynamic loads depends on surface RF losses (Qo) and accelerating field in each cavity. In the MYRRHA project the typical foreseen operating values are: $10^9 < Qo < 10^{10}$, and, 4 MV/m < Eacc < 12 MV/m. The dynamic load includes also the losses at low temperature (2K) induced by the RF power couplers connected to each cavity.

Table 1: MYRRHA SC Linac Heat Loads

Sections	Injector SC-CH	Spoke SC	Elliptical SC
Energy	3 – 17 MeV	17 – 100 MeV	100 – 600 MeV
nb. of Cavities	6 (each injector)	48 (beta 0.35)	34 (beta 0.47) + 60 (beta 0.65)
nb. of Cryo-modules	3 (each injector)	24	17 (beta 0.47) + 15 (beta 0.65)
Heat Load (W)	**200 @ 2K**	**680 @ 2K**	**635 @ 2K + 1360 @ 2K**
	Total Heat Load: 2875 W @ 2K		

Cryogenic Refrigerator Capacity

In addition to the heat loads at 2K presented in Table 1, cryogenic refrigeration must be also supplied at intermediate temperature levels for thermal shields cooling at 40 K (total heat load of 15.2 KW), and the RF

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couplers outer conductor cooling (equivalent load of 500 W at 5 K). Table 2 present the final cryogenic budget at the different temperature levels.

Table 2: MYRRHA Refrigerator capacity

Function	T (K)	Heat Load (kW)	Overcapacity	Cryo capacity (kW) @ 4.5 K
Cavities	2.1	2.875	(x 1.875) = 5.3	11.5
Couplers	5	0.5	(x 1.5) = 0.75	0.75
Thermal Shields	40	15.2	(x 1.5) = 22.8	3.5
	Total equivalent @ 4.5 K			15.75 KW

Table 2 includes two important specifications:

1) Equivalent overall refrigeration capacity at 4.5 K. To allow sizing and comparison with similar high power refrigerators.

2) Overcapacity, taking into account uncertainties in the heat loads estimations, and margin for enhancing cool-down speed and eventual additional equipments.

Two big Cryogenic Refrigerators for SC accelerators, presently in operation, have sizes and performances that can be considered as references for the MYRRHA design: the LHC(one unit) [2] with an equivalent cryogenic power of 18 KW at 4.5 K, and the SNS [3]**,** with an equivalent cryogenic power of 10 KW at 4.5 K. Both refrigerators operates at superfluid He temperatures (1.8 – 2 K) and are composed of several major components as represented in the Fig.1.

MYRRHA Cryogenic Refrigerator Proposal

The proposed scheme for the MYRRHA Cryogenic Refrigeration system, presented in Fig. 1, is based in two main principles: 1) **Distributed subcooling heat exchanger scheme:** The main cold box produces supercritical He (i.e. 4.5 – 5K, 3 bars) for cavities and couplers. Each cryomodule has a cryogenic interface (valve box) incorporating the subcooling heat exchanger to reduce the temperature and the Joule-Thomson valve to expand and obtain the nominal He bath at 2.1 K and 30 mbar. 2) **A "mixed compression cycle" as adopted by LHC** [2]: the 2K Cold Box**,** with the cold compressors and heat exchangers, recovers the low pressure cold gases from cryomodules. Room temperature compressors can be added in the same box, in order to optimize the efficiency and dynamic range of the system. In this case the pressurized He gas reaches the main cold box at an intermediate temperature level (~20 K).

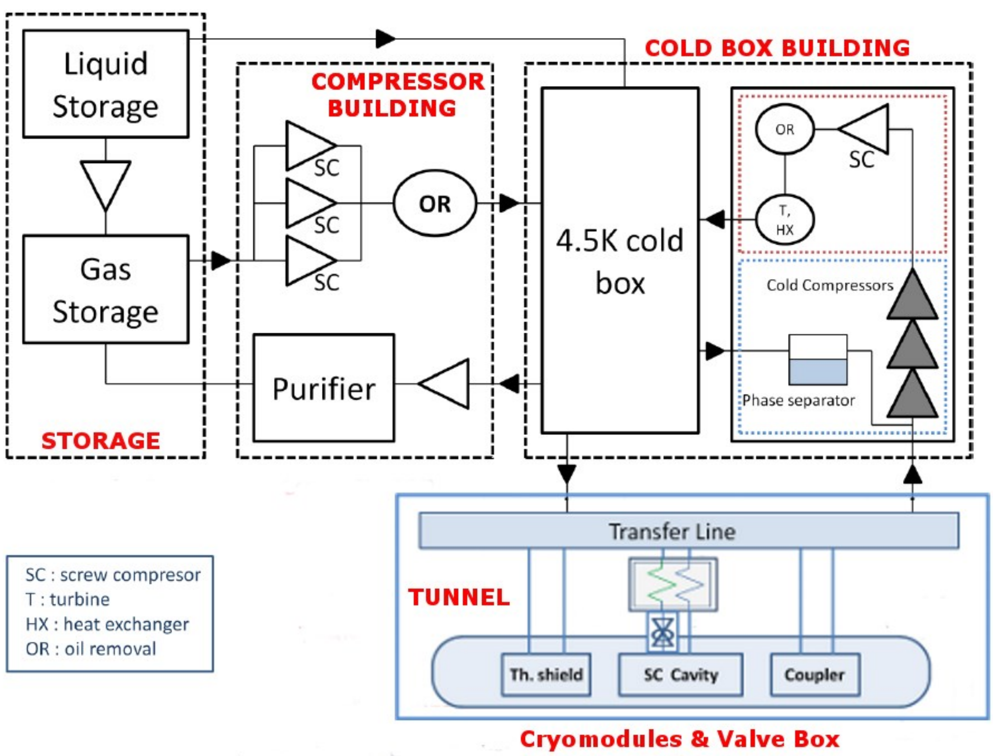

Figure 1: Components of the MYRRHA Cryogenic Refrigeration System.

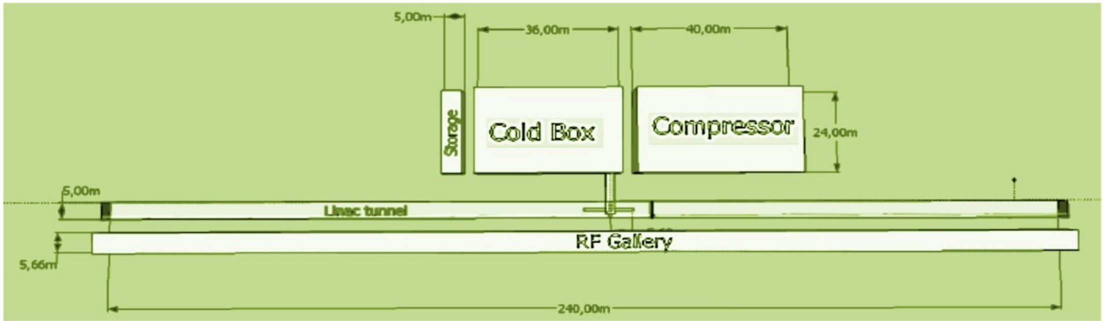

Figure 2: Preliminary design of MYRRHA Cryogenic buildings and Linac tunnel.

In the LHC, the 1.8 K boxes are installed underground at -100 meters, close to the accelerator tunnel. The proposed installation of MYRRHA with a Linac tunnel installed at the ground level and closer to the cryogenic buildings, could lead to an integration of both cold boxes (4.5 K and 2K). This is one major aspect of the cryogenic system of MYRRHA that would need further development.

Figure 2 shows the proposed cryogenic building installation. Two main buildings and some outdoor surfaces for storage reservoirs, are necessary for the installation of the Refrigeration Systems:

1. **Compressor building: 40 x 24 m²**
2. **Cold Boxes building: 36 x 24 m² including 4.5 K and 2K cold boxes**
3. **Helium Liquid and Gas Storage: 5 x 20 m²**

Cryogenic Distribution

A proposal for cryogenic fluids distribution is presented in Fig.3. Cavities and couplers need a supply of 4.5 K at 3 bar with a mass flow of 160 g/s and pipe diameter of 40 mm, thermal shields need a supply of 40 K at 4 bars with a mass flow of 40 g/s and pipe diameter of 45 mm. Low pressure He gas at 30 mbar, requires a large pipe diameter of 240 mm.

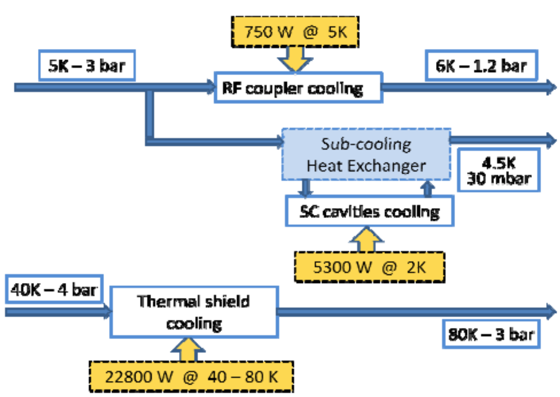

Figure 3: Cryogenic fluids distribution and heat loads.

All the 5 pipes (supply and return) can be grouped in a unique composed transfer line, vacuum insulated with a total maximum diameter of 400 mm.

A preliminary cross view of the SC linac tunnel is presented in Fig. 4. It includes the cryomodule, the associated valve box, and the cryogenic transfer line [4].

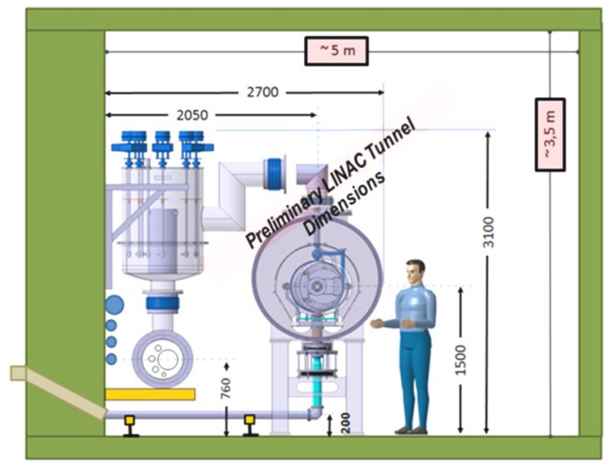

Figure 4: Preliminary design of the SC Linac Tunnel.

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