CONCEPT DESIGN STUDIES OF THE REX-ISOLDE CRYOMODULES AT CERN

V. Parma, S. Calatroni, N. Delruelle, C. Maglioni, M. Modena, M. Pasini, P. Trilhe, J.Hansen, CERN, Geneva, Switzerland
S. Pattalwar, STFC, Daresbury Laboratory, UK

Abstract

The High Intensity and Energy (HIE) proposal plans a major upgrade of the existing ISOLDE and REX-ISOLDE facilities at CERN [1], with the objective of substantially increasing the energy and the intensity of the delivered radioactive ion beams. In the frame of this upgrade activity, a superconducting linac, based on Nb sputtered Quarter Wave Resonators (QWRs) is proposed to be installed downstream the existing normal conducting machine. The present design of the accelerator lattice features housing of five high-beta cavities (β=10.3%) and a superconducting solenoid in a common cryomodule. In most of the existing low-energy heavy-ion installations worldwide, insulation and beam vacuum are in common, with the risk of cavity surface contamination in case of accidental leak of the cryostat vessel. Following a concept study, we report in this paper on three design options, namely cryo-modules with *single* vacuum, with *separate* or with *hybrid* vacuum systems (the latter having a low conductance between insulation and beam vacuum) and compare them in terms of technical complexity, performance, reliability and maintainability.

INTRODUCTION

QWRs are commonly used in linacs for the acceleration of heavy ion beams in the range of 5-10 MeV/u, due to their high velocity acceptance allowing the coverage of a wide variety of nuclei and beam energies. Examples of heavy ion accelerators based on similar superconducting resonators are the ISAC-II at TRIUMF (Vancouver, Canada) [2], in operation since 2007, the ALPI at LNL (Legnaro, Italy) [3], in operation since several years, ATLAS at Argonne national laboratory [4], in operation since 1992 (Argonne, Illinois, US), the QWR superconducting linac for the 15 UD Pelletron at IUAC (New Delhi, India) [5], and the SPIRAL II at Ganil (Caen, France) [6], now in the construction phase.

In most of the projects, a single vacuum system was chosen both for beam and thermal insulation of the cryo-modules, essentially because it leads to simpler mechanical design and assembly of the cryo-modules; despite the required cleanliness, the number of components is generally smaller and complex flanged connections in the usually compact inter-cavity spacing can be avoided. But, as a consequence, in order to preserve the superconducting surface from contamination, a high level of cleanliness of all internal surfaces is needed, and the use of Multilayer Insulation protection (MLI) and of volatiles like lubricants and brazing fluxes is precluded.

The choice of single vacuum carries a number of drawbacks, the main one being the risk of contamination in case of accidental break of the insulation vacuum leading to particulate contamination of the cavity surface at any stage of the preparation of the cryo-modules outside clean-room or during machine operation. Similar events have been reported and discussed on existing linacs [7], and in some cases the disassembly of the cavities for reconditioning was the only alternative to recover performance. A failure in one of the cryo-module would also propagate through the adjacent units affecting an entire SC linac, unless a sound protection system with fast-closing interlocked vacuum valves is capable of isolating the leak.

Single-vacuum cryo-module is also subject to higher radiation heat loads due to the absence of MLI protection, only in part compensated by low-emissivity surface plating of cold surfaces, and therefore lead to larger cryo-plants, capital and cryogenic operating costs.

Spiral II has made the choice of cryo-modules with separate vacuum, despite the higher complexity of the design, considering contamination of the cavities a major risk for reliability and the heaviness of repair interventions would hinder the machine availability.

THE REX-ISOLDE SC LINAC

In the present REX-ISOLDE facility the radioactive ion beams are accelerated to higher energies with a compact normal conducting linac where, with a complex scheme of several acceleration stages and re-bunching, the energy at extraction is of 3 MeV/u. For the increase in energy, a SC linac is proposed, designed to achieve a final energy of at least 10 MeV/u, delivering an effective accelerating voltage of at least 39.6 MV.

The linac requires a total of 20 high β and 12 low β cavities, and 8 SC solenoids, cooled by boiling helium at 4.5 K.

Cryoplant and Cryogenic Distribution

The possibility of making use of an existing refrigerator at CERN, formerly used for the ALEPH experiment during the LEP operation, would allow substantial cost saving in the HIE upgrade; keeping the heat load budgets well below the refrigeration capacity of 630 W at 4.5 K and 2700 W at 55-75 K (measured capacities during commissioning in 1998), is mandatory to leave overcapacity for cool-down in a reasonable time. A 35-m dedicated transfer line from the plant to the linac will provide independent feeding of the cryomodules and operational flexibility allowing warm-up and removal of individual cryomodules in case of need.

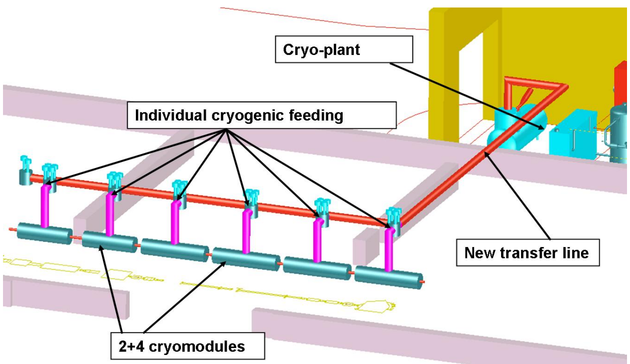

Figure 1: Cryoplant and cryogenic distribution line. Each SC cavity module is independent from the others.

CRYO-MODULE CONCEPTS

The high β cavities are grouped into 4 cryomodules of 5 cavities and 1 solenoid each, while the low β cavities are grouped into 2 cryomodules with 6 cavities and 2 solenoids each. This arrangement yields comparable overall dimensions of the low β and high β cryomodules, offering the advantage that a standardised solution for the main cryostat parts, in particular the vessel, can be envisaged. For the sake of clarity, only the high β cryomodules (for which the main parameters are described in Table 1.), will be discussed hereafter, but similar considerations can be extended to the low β cryomodules.

Table 1: Main parameters of high β cryomodule

Parameter	Value
No. cavities	5
Mechanical length of cavity	320 mm
Beam aperture diameter	20 mm
No. of SC solenoids	1
Solenoid max field, current	9 T, 900 A
Vacuum vessel (approximate dimensions)	Length: 2.5 m; width: 1 m; height: 2 m
Cavity/solenoid operating temperature	4.5 K
Helium vessel volume (preliminary)	150 l
Thermal shield temperature	50 K (gaseous helium)

Figure 2 illustrates the two concepts of cryomodules with single or separate vacuum. In the former, the cavities and solenoid beam tubes are open to the cryostat envelope which would contain only clean equipment, all assembled in a clean room of class 100.

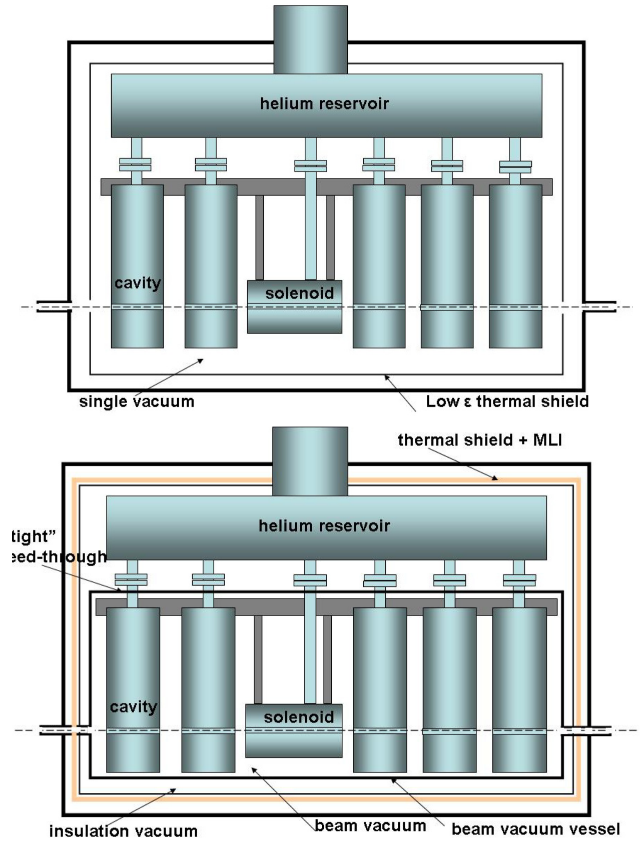

Figure 2: Single vacuum (top) and separate vacuum (bottom) concepts.

The thermal shield would require a low emissivity surface (lower than 0.06), resulting for example from nickel plating.

The separate vacuum concept features an additional vessel, so-called *beam vacuum vessel*, creating a second vacuum envelope around the cavities and the solenoid, thus limiting the extent of the clean equipment to a strict minimum. The insulation vacuum vessel and the thermal shield can be made of more conventional materials and levels of cleanliness. MLI could be used on the thermal shield thus improving thermal performance. Adopting a beam vacuum vessel presents the major advantage that it allows making use of cavities developed for a single vacuum application (as those developed by INFN-LNL for example) with only minor modifications; a more conventional solution with a beam tube interconnecting cavities and solenoid would require a considerable redesign of the cavities. The separate vacuum concept is nevertheless technically more complex. A number of leak-tight feed-through passages to the cavities are needed for the tuners (externally operated), the coaxial cables of the couplers, and the electrical feeding of the solenoid. Also, the beam vacuum vessel needs a dedicated pumping system and an appropriate overpressure protection (burst disk or valve). Cold-to-warm transitions between the beam vessel and the room temperature insulation vacuum vessel are also needed.

An intermediate concept, the *hybrid* one, has been taken into consideration. By hybrid we intend essentially a separated vacuum concept with no leak tight separation between the beam and insulation vacuum. It was decided to investigate this option since, in our case, the basic design choices for the cavity were already assessed and integration at the cavity level of the separate vacuum would have been very difficult at this moment. A not perfect separation (typically in the order of 10^{-1}mbar.l/s at RT) would anyhow allow a better preservation of the cleanliness of the cavity surface in case of vacuum leak from the outside world into the insulation vacuum. Assuring this, the advantage is a shorter down-time, as it would not require a reprocessing (rinsing, conditioning) of the cavities. In addition MLI could be used and reduce as well the heat load at 50-75 K.

A preliminary comparison of heat loads between the single and separate solutions, is presented in Table 2, shows identical heat loads at 4.5 K in both cases, these being dominated by RF loads. The single vacuum solution presents a heat load at 55-75K which is about 6 times the one of separate vacuum, which would reduce the cooling overcapacity of the existing cryoplant.

Table 2: Linac heat load (HL) estimates

Source	**Type**	**HL at 4.5 K** [W]	**HL at 55-75 K** [W]	
			Single vacuum	Separate vacuum
Cavities	dynamic	420	-	-
Solenoids	dynamic	8	-	-
Cryostats	Static	42	1620	210
Transfer line	Static	35	140	140
Valves	Static	72	-	-
Totals		**580**	**1760**	**350**

For the evaluation of the three concepts we look at different aspects of the design issues of the cryomodules. These issues are not of the same importance; some of them are linked to the running cost of the cryomodules, others have an impact on the schedule, resources and capital cost, others concerns the availability of the machine and others bring along technical risks. We have given the maximum importance to the availability of the machine, and a weighted factor has been considered when comparing the different cryomodules concepts. In Table 3 are listed all the items considered for the comparison and our rating ("+" is an advantage, "-" is a drawback). A common vacuum system can be seen as the one that better covers all the aspects taken into consideration.

SUMMARY

A first analysis among the three concepts has been made, highlighting their relative advantages and drawbacks. For the purposes of the REX-ISOLDE cryomodules the common vacuum solution seems to provide the best compromise. Further analysis will follow together with a more detailed design of the cryomodule.

Table 3: Comparison between the three concepts

Issue	**Com. Vacuum**	**Sep. vacuum**	**Hyb. vacuum**
Heat loads	-	+	+
Risk of cavity pollution	---	+++	++
On-site cryomod. intervention	+	+++	++
Size of clean room infrastructure	-	++	++
Disassembly cav. for maintenance	+++	+	+
Design/construction/ assembly complexity	++	-	+
Cryostat cleanliness requirements	-	++	+
Alignment at assembly	++	-	-
Longitudinal space requirements	++	-	-
Capital cost	++	-	+
Development	++	-	+
Learning curve and construction time	++	-	+

REFERENCES

[1] M. Pasini *et al* "A SC upgrade for the REX-ISOLDE accelerator at CERN," these proceedings.
[2] G. Stanford, R.E. Laxdal, C.Marshall, T.Ries and I.Sekashev. Proceedings CEC-ICMC 2003, p.552, Vol 49, 2004.
[3] A. M. Porcellato *et al.* "Production, installation and test of Nb-sputtered QWRs for ALPI", Pramana journal of physics, Vol.59, No.5 November 2002, pp.871-880.
[4] http://www.phy.anl.gov/atlas/facility/index.html
[5] P. E. Bernaudin *et al.* "Design of the low-beta, QWRs and its components for SPIRAL 2". Proceedings EPAC'04, Lucerne, p.1276, (2004)
[6] S. Gosh *et al.* "Commisioning of SC linac at IUAC-Initial challenges and solutions". Proceedings of EPAC'08, Genoa, Italy, p.856. (2008)
[7] R.E. Laxdal, "Commisioning and early experiments with ISAC-II", Proceedings of PAC07, Albuquerque, USA.