HIE-ISOLDE LINAC: STATUS OF THE R&D ACTIVITIES

M. Pasini, CERN, Geneva, CH and Instituut voor Kern- en Stralingsfysica, K.U.Leuven, Leuven, BE
S. Calatroni, J-C. Gayde, G. Lanza, C. Lasseur, M. Lindroos,
C. Maglioni, R. Maccaferri, D. Parchet, P. Trilhe, CERN, Geneva, CH
A. D'Elia, CERN, Geneva, CH and Cockcroft Institute, Warrington, UK
M. A. Fraser, CERN, Geneva, CH and Cockcroft Institute, Warrington and U. of Manchester, UK

Abstract

For the post-accelerator of radioactive ion beams at CERN a major upgrade is planned to take place in the next 4-5 years. The upgrade consists in boosting the energy of the machine from 3 MeV/u up to 10 MeV/u with beams of mass-to-charge ratio 2.5<A/q<4.5 and in replacing part of the existing normal conducting linac. The new accelerator is based on two gap independently phased 101.28 MHz Nb sputtered superconducting Quarter Wave Resonators (QWRs). Two cavity geometries, "low" and "high" β, have been selected for covering the whole energy range. A R&D program has started in 2008 looking at the different aspects of the machine, in particular beam dynamics studies, high β cavity development and cryomodule design. A status report of the different activities is given here.

INTRODUCTION

The ISOLDE facility at CERN (see Fig. 1) is object of a general upgrade in view of an extended demand of the physics program with accelerated radioactive ion beams (RIBs). In particular, nuclear physics experiments request for higher energy, up to 10 MeV/u, for higher intensity, and for better beam quality, in terms of purity and smaller emittances [1]. In order to match the higher energy requirement a modular superconducting linac based on quarter wave resonators (QWRs) is planned to be installed downstream the present normal conducting linac. In the short term the new accelerator modules will boost the energy up to 5.5, 8 and 10 MeV/u, while in the longer term, part of present normal conducting linac will be replaced by new superconducting cavities in order to allow the full energy variability between 1.2 and 10 MeV/u [2].

Concerning the higher beam intensity, ISOLDE will profit from the ongoing upgrade of the proton injectors chain at CERN [3] which will allow the beam power on target to be doubled and for which new target stations, targets and their associate handling system will need new development. Moreover, an upgrade of the REX trap and charge breeder is planned to cope with the increased intensity.

Finally in order to improve the quality of the beam a new mass separator with higher resolution is under study and new targets and ion sources are under development.

Because of the limited resources available the whole upgrade project has been split in two parts, namely HIE-ISOLDE 1, and HIE-ISOLDE 2. In the former it is aimed at the design and construction of the SC linac up to at least 8 MeV/u and also a design study of the intensity upgrade. In the latter it is envisaged a further extension of the energy up to 10 MeV/u and the construction of higher power targets with their adequate handling system and a high intensity charge breeder.

The highest priority of the project is the construction of the superconducting linac. In particular the R&D effort has focused so far on the the development of the high β cavity ($\beta = 10.3\%$), for which it has been decided to adopt the Nb sputtered on Cu substrate technology. Other R&D activities are related to the beam dynamics studies which seek to define a very compact accelerating lattice and consequently the shortest possible machine, a design of the SC solenoids with limited fringe fields, and the design of the cryomodule concept.

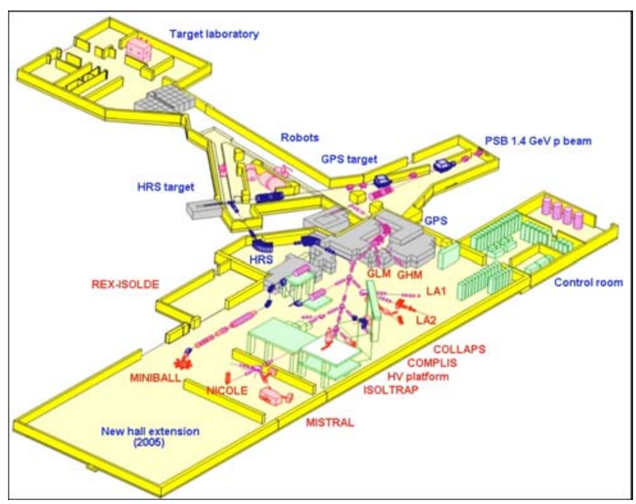

Figure 1: The ISOLDE facility.

As mentioned above the first part of the SC linac that will be installed is the high energy section. The first high β cryomodule will be installed at his final position so that when the low β cryomodule will be installed no further modifications and/or displacements of the cryomodules needs to be done. This is of high importance since it allows to minimize the down time of the machine and the installation can be done during the usual maintenance period in the winter. Fig. 1 shows also the new extension hall that was built in 2005 in order to house the extension of the linac.

A study covering all the issues of the infrastructure and

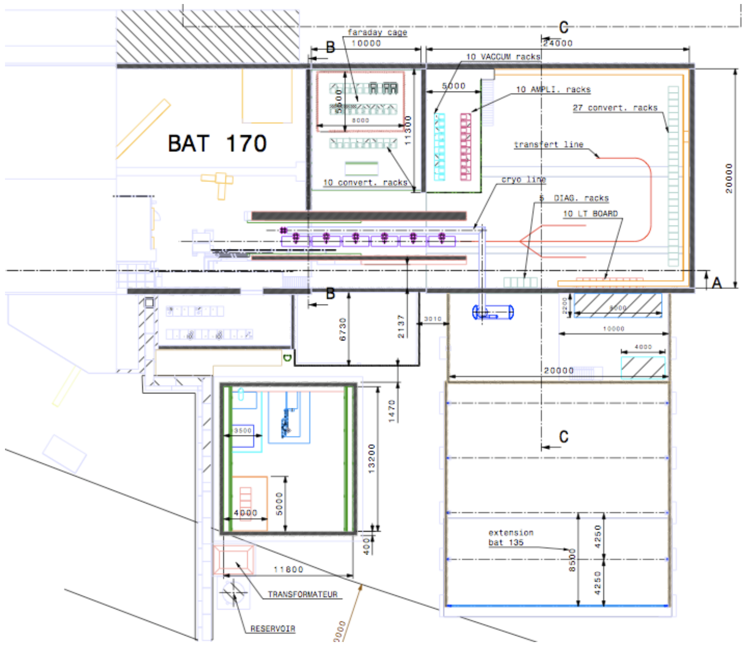

Figure 2: ISOLDE facility planimetric view. In the bottom left part one can identify the compressor building, while on the centre right there is the He liquefier. This configuration minimizes the length of the LHe distribution line, and set the condition for the optimum operation of the cryogenic system.

the integration of the machine inside the experimental hall is ongoing. This study has permitted to identify the suitable area for the construction of the building for the compressor for the liquid He system, the location of the He liquefier with the associated control room and also the other subsystem like the new ventilation unit, the new electricity distribution panels and the position of the different racks. This aspect of the project cannot be left behind as the location of such infrastructures determines the free space left for the accelerator, for the high energy beam transfer line and for the physics instrumentation. Fig. 2 shows the result of the study. Around the linac a semi-permanent tunnel-like shielding made of concrete blocks will be installed all along the machine length. This is strictly required from the radioprotection point of view as the whole area will remain accessible during the physics runs. The LHe liquefier will be installed at the end of the machine in a separate light construction building. In this way it is possible to minimize the length of the LHe distribution system and to maintain the geometry of the line as simple as possible which is a condition for a easier and stable operation of the cryogenic system.

BEAM DYNAMICS

The aim of the beam dynamics study is to define an optics and acceleration scheme that minimises the machine length and at the same time maintains the emittance of the beam. The resulting lattice has been discussed in [4] and latest results are reported in [5]. Fig. 3 shows a layout of the high energy sector of the SC linac attached to the present NC machine. In the high β section the lattice consists in

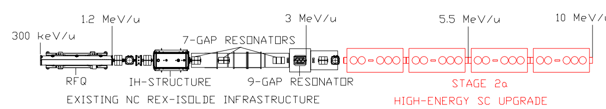

Figure 3: High energy section of the of the HIE-LINAC.

a short drift length outside the cryomodule where all the beam instrumentation and small corrector magnets will be installed, followed by two superconducting cavities, a single SC solenoid and finally three more SC cavities.

A full three dimensional integration of the motion equation routine has been written in order to study the motion of the single particle inside the high β cavity. The electromagnetic cavity fields used in the tracking code were calculated using the MSW code [6]. The multi-particle beam dynamics simulations are performed by implementing the fields map in the TRACK code [7].

An intrinsic characteristic of the QWR is the asymmetry of the electromagnetic field in the beam region. There is in fact a net magnetic component which steers the beam depending on the accelerating phase. The radial electric field is also not symmetric and the compensation scheme proposed by Ostroumov [8] would lead to a loss of aperture of roughly 30% in case of a circular aperture. It was then decided to modify the shape on the beam port from circular to a race-track one, and the loss of aperture due to the compensation scheme is now only 1%. Fig. 4 shows the effect of the compensation scheme. The net diverging kick given to the beam is reduced to less than 0.1 mrad only for the first cavity and as soon as the beam picks more velocity the kick becomes rapidly negligible.

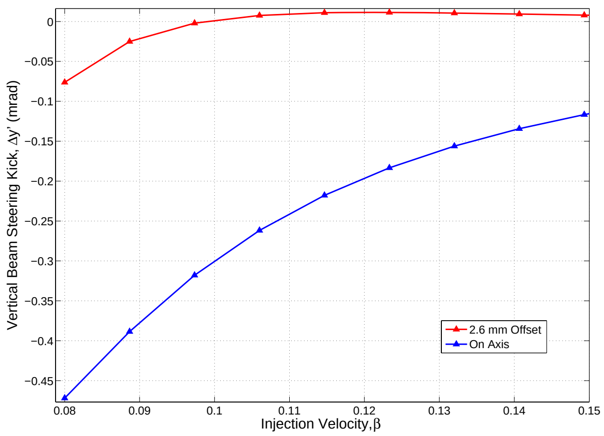

Figure 4: Divergence of the beam in case of a compensated (red) and not compensated (blue) case for a synchronous phase of -20 as a function of the incoming beam velocity.

Figure 5 shows the result of the beam dynamics study of the high energy section in case of a beam with A/q=4.5 and with a transversed matched beam coming from the present NC machine.

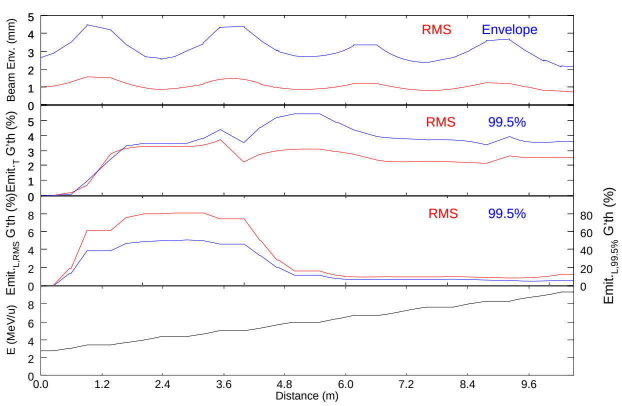

Figure 5: Beam dynamic of A/q=4.5 in the case of the high energy section only.

The beam dynamics study is now focused on the error study, considering longitudinal fast error (RF jitter) and static error as well as static transverse misalignment. It is found that the longitudinal emittance in the high energy section of the machine increases by a factor 1.9 if the RF jitter is limited at 0.5% in amplitude and at 0.5 in phase for a beam with A/q=4.5.

SC Solenoid

The employment of the SC solenoids as unique focusing elements allows to increase the transverse acceptance of the beam with respect to the un-matched beam condition and allows a great reduction of the tuning knobs, hence making the tuning and operation of the machine easier. The magnetic and mechanical specifications of the solenoid are summarized in Table 1.

Table 1: Solenoid Specifications

Magnetic Integral $\int B^2 dz$	16.2 T^2 m
Mechanical Length	0.4 m
Fringe field at 23 cm from center	$<$ 0.2 G
Inner Diameter	30 mm

A 2D electromagnetic study of the solenoid has been performed: the specifications are met with 570A Nb_3Sn coils which produces a peak field in the center of the solenoid of 120kG. The return yoke is made by high quality iron. The fringe field is cut by two additional coils in reversed sign. These coils, at this moment of the design, are powered independently from the coils that build the main field, but a solution to have a unique power supply is under study. Fig. 1 show a schematic of the mechanical assembly of the solenoid.

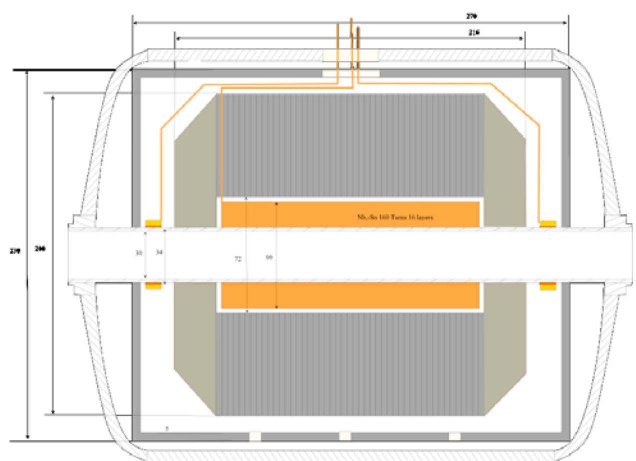

Figure 6: Solenoid schematics.

HIGH β CAVITY MANUFACTURING

The construction of a high β cavity prototype started in the middle of 2008 and the copper body which makes the substrate for the Nb sputtering was completed in April 2009. During the same period a new sputtering chamber was constructed and is now under commissioning. The cavity manufacturing process has been reported in [9] and now the critical fabrication steps have been identified. In details the long longitudinal full penetration electron beam weldings have shown the creation of some porousness that could harm the Nb deposit. This defect could be removed by passing the electron beam in smoothing mode from the inside of the cavity - this operation would require the use of a special electron beam welding machine with a miniaturized head - but at this time it was not felt as a immediate action to take. Moreover it is possible that the chemical etching needed for the surface preparation for coating could solve the problem by enlarging the pocket enough so that no acid is trapped and released afterwards, for example, during the sputtering. The most critical and also time-consuming step was the direct extrusion of the beam port. This step requires high precision in mounting and remounting the different tools and particular care in handling the cavity since for the production of the beam ports, the cavity needs to undergo to eight heat treatments which locally soften the copper. Finally the construction of the prototype suffered a couple of accidents which are related to human errors. For this reason a strong QA procedure needs to be in place for the series production. The cavity has been checked also with a series of RF measurement, especially the variation of the resonance frequency during the several manufacturing steps and all the measurements are in line with the prediction. Fig. 7 shows an advanced status during manufacturing of the copper substrate.

Figure 7: Cavity copper substrate towards final machining steps.

In parallel to the copper cavity a dummy cavity made in stainless steel was built. The purpose of this dummy cavity is to use it as samples holder for the characterization of the plasma inside the chamber, to test the assembly procedure of the sputtering chamber itself and to serve also as a training tool for the handling operation during the chemical treatment.

The sputtering chamber is now operational and the first plasma has been produced. The vacuum level of the chamber after baking reached the low 10^{-8} mbar level and minor adjustments should push the vacuum level another order of magnitude lower. This is of course of great importance as the vacuum level is directly linked to the quality of the Nb films produced. All subsystems have been checked and a characterization of the plasma and hence of the Nb deposit quality is ongoing as a function of the different gas pressure level, cathode voltage and bias voltage. First Nb deposit on the copper cavity is expected towards the end of July. Fig. 8 shows on the left a moment during the installation of the dummy cavity inside the sputtering chamber and on the right the sputtering chamber closed.

Figure 8: On the left the dummy cavity during mounting for the first sputtering. On the right the sputtering chamber closed.

Coupler

An adjustable power coupler has been designed with an extreme dynamic range. In fact the $Q_{\rm ext}$ can be adjusted between 10^4 up to 10^9 so that it is possible to reach critical coupling at room temperature and a moderate undercoupling when the cavity is superconducting. This feature allows to perform some preliminary room temperature conditioning that should help in cleaning the multipacting barrier at low field level and allow to fine tune the coupling needed for the field and phase stabilisation loops. From the mechanical point of view the sliding mechanism concept is dust free as the contact points are reduced to the minimum (see Fig. 9). This should avoid any seizure of the moving parts and guarantees the functionality of the system. A first prototype is under construction and expected to be delivered by the end of July.

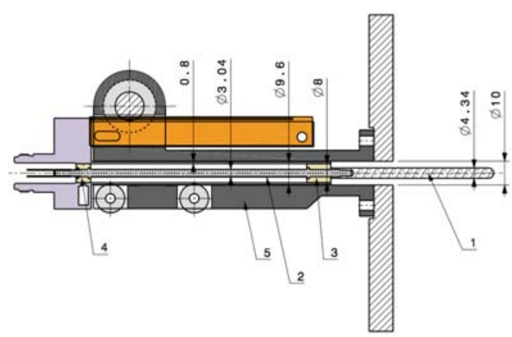

Figure 9: Coupler schematics.

Tuner

The tuning system chosen for the HIE-ISOLDE cavities take advantage from the experience developed at TRIUMF [10]. An *oil-can* shaped diaphragm of CuBe has been hydroformed with a pressure up to 120 bar. All radial slot necessary for the elongation and contraction of the diaphragm are performed with a laser beam. The same plate can be mounted directly on the low β cavity or welded to a flange in the case of the high β cavity. The actuator is designed to have no backlash. A coarse frequency tuning range of 220 kHz is expected. The first prototype of the tuner is available and the internal surface should be sputtered by the end of June.

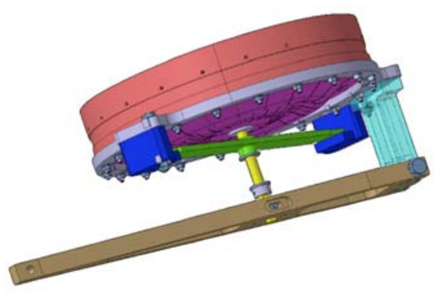

Figure 10: 3D view of the tuner with the lever actuator.

CRYOMODULES

An initial study of the cryomodule concept was reported in [11]. Specifically, in that report the choice for a single vacuum system with an active thermal shield was shown to best fit the requirements of the new machine. In the last months, work has continued at a level of a concept study and a series of major choices have been taken concerning the dimensions, accessibility, assembly procedure and maintenance of the cryomodule, the holding system for the cavities and for the solenoid, and the alignment system.

One of the general considerations that set the pathway to the concept of the HIE-ISOLDE cryomodule was the maintenance service. In order to minimize cost and downtime of repairs it is clear that the maintenance should take place at CERN and that at this point one needs to consider the available infrastructure such as clean rooms. All the clean rooms at CERN are quite limited in height but they are quite large and long. As a consequence the dismounting of the cryomodule can occur only if the access is from the lateral side (see Fig. 11). Starting from this consideration a study concerning the stability of a mechanical structure with two openings on the side has been performed and found that this structure is feasible. The mounting and prealignemt of the cavities will be externally in the support girder which, with the help of a special forklift, can be positioned inside the cryomodule and hooked to the support stems. Given the recent result in the error study it has been decided to have a separate frame for the support of the solenoid which can be adjusted from outside even when the system is cold.

Concerning the alignment system, it is under study the possibility to use a BCAM system [12]. Such a system consists of a calibrated laser source that can track changes in the position with an accuracy in the order of few tens of μm with a rather large span in distances. The advantage of such system is that the active part of the alignement system is kept outside the vacuum envelope and that it is possible to perform a continuous survey so that in case of accident one can retrace the position of the different elements just before the accident.

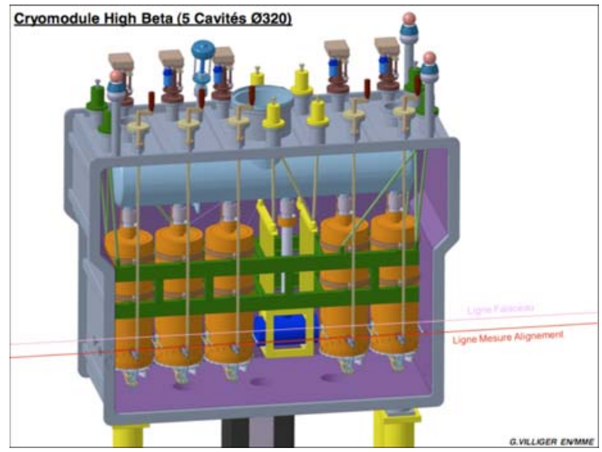

Figure 11: Cryomodule schematics.

ACKNOWLEDGMENTS

The authors wish to thank all the designers and technicians that have worked and continue to work in this project. Their commitment and dedication has been greatly appreciated.

REFERENCES

[1] HIE-ISOLDE: the scientific opportunities, CERN Report 2007-08.

[2] M. Pasini et al., “A SC upgrade for the REX-ISOLDE accelerator at CERN”, Linac’08, Victoria, Canada, Sept. 2008.

[3] http://linac4.web.cern.ch/linac4/.

[4] M. Pasini et al., “Beam Dynamics Studies for the SCREX-ISOLDE linac at CERN”, Linac’08, Victoria, Canada, Sept. 2008.

[5] M. A. Fraser et al., “Beam Dynamics Studies fr the HIE-ISOLDE Linac at CERN”, Pac’08, Vancouver, Canada, May 2009.

[6] http://www.cst.com.

[7] P. Ostroumov at al., http://www.phy.anl.gov/atlas/TRACK/

[8] P. Ostroumov and K. Shepard, Phys. Rev. ST. Accel. Beams 11, 030101(2001).

[9] M. Pasini et al., “SC Nb sputtered QWRs for the REX-ISOLDE accelerator at CERN: prototype design and manufacturing”, Linac’08, Victoria, Canada, Sept 2008.

[10] T. Ries et al., “A mechanical Tuner for the ISAC-II Quarter Wave Superconducting Cavities”, PAC’03, Portland, USA, May 2003.

[11] V. Parma et al., “Concept Design Studies of the REX-ISOLDE cryomodules at CERN”, Linac’08, Victoria, Canada, Sept. 2008.

[12] http://alignment.hep.brandeis.edu/Devices/BCAM/.