

DESIGN PROGRESS OF THE MYRRHA LOW ENERGY BEAM LINE

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Abstract

The MYRRHA project, a flexible spectrum neutron irradiation facility, is designed according to the Accelerator Driven System (ADS) reactor concept. The MYRRHA driver consists of a high power superconducting proton linac. A prototype of the front end injector is being built up into a test platform conceived to experimentally address its design issues. Currently, the ECR proton source has been industrially procured. LPSC Grenoble designed the subsequent Low Energy Beam Transport (LEBT) section. Right before the RFQ, a short section hosts an electrostatic beam chopper producing carefully controlled beam interruptions. In this paper the status of the LEBT design with the associated beam instrumentation is reviewed. Future experimental plans including LEBT beam characterization and optimization of the beam transmission are presented.

INTRODUCTION

The MYRRHA project, proposed by SCK•CEN, aims to demonstrate the feasibility and operability of a safe and efficient transmuter reactor, comprising a subcritical core fed by an external spallation neutron source, in turn obtained by an high intensity proton beam delivered by a superconducting linac. The specifications set on the MYRRHA accelerator are typical for ADS [1, 2]: in particular, the issue of reliability is considered the main design challenge and concerns all the R&D activities [3]. In the framework of the RFQ@UCL R&D program [4], a test platform of the MYRRHA Linear Accelerator Front-End is being built-up to experimentally address the injector design through prototyping. The program is a collaborative effort of SCK•CEN, the Cyclotron Resources Center (UCL/CRC), the CNRS/IN2P3 laboratories IPN Orsay (IPNO) and LPSC Grenoble, the IAP Frankfurt laboratory. Currently, the 30 keV proton source industrial procurement has been achieved with the successful production of a stable beam. The subsequent Low Energy Beam Transport (LEBT) line has been engineered and designed by LPSC and entered the construction phase in late 2013. First beam tests are scheduled for late 2014 in Grenoble.

THE ION SOURCE

The proton source has been procured by Pantechnik (France). The design choice is an Electron Cyclotron Resonance (ECR) ion source at 2.45 GHz. A specific flat mag-

netic confinement configuration is provided by two Permanent Magnets (PMs), while tapered axial RF injection up to 1.2 kW is adopted. Beam is extracted from the plasma chamber by a multi-stage cascade of polarized electrodes. The source extraction box is equipped with a Einzel electrostatic focusing lens, which can be used to adjust the beam size in case of excessive beam divergence at this stage. During the acceptance tests, the source has been capable to deliver a 30 keV proton beam up to 16 mA (DC), with a vertical beam emittance of $\sim 0.1\pi\cdot\text{mm}\cdot\text{mrad}$ RMS norm. at 5 mA H^+ . The total beam production efficiency has been estimated around 84% (comprising HV losses), with particular ionization efficiency of $\sim 63\%$ for H^+ . Long test runs (24 hours) showed a good beam stability, with brief recovery time in case of electrical discharges. Preliminary investigations on the influence of the Einzel lens on the transverse beam emittances are currently performed. The goal is to optimize the extraction settings in view of the future LEBT line commissioning.

THE MYRRHA LEBT

The MYRRHA LEBT layout is based on a short magnetic solution and is designed to maximize the proton beam quality injected into the RFQ by considering the Space Charge Compensation (SCC) effects of the beam. At the same time, this solution helps to fulfill the ADS reliability requirements, minimizing beam trip risks due to HV breakdowns and beam losses [5].

The overall length of the line, from the plasma chamber extraction hole to the RFQ rods, is around 2.8 m. The beam transport and focusing is assured by a pair of solenoid magnets with integrated dipole steerers. The first set is placed as close as possible to the ion source so as to limit the beam size at this stage. The second is situated at the end of the line and allows a net beam species separation. A magnetic model of the magnet set has been created in OPERA 3D. A nominal axial magnetic field $B_0 = 0.25$ T at the center of the solenoid is obtained through a total of 48900 At generated by 496 hollow copper turns. Two separate inner windings produce an additional transverse component for dipole corrections (H&V) up to 12.5 mrad. The inner solenoid diameter (including steerers' coils) is 158 mm, a good compromise to minimize geometrical aberrations potentially leading to emittance growth. Particular care was taken in limiting stray magnetic fields to a maximum of 3.3 mT on the solenoid axis at 300 mm from its center. Solenoid magnets are currently under industrial procurement from

SigmaPhi (France). The magnetic solution leaves enough room for insertion of beam diagnostics allowing for interceptive beam current, profile and transverse emittance measurements. Right before the RFQ injection flange, a short RFQ interface section hosts a slow electrostatic beam chopper, adopted to create a precise and flexible time structure of the beam delivery towards the future MYRRHA reactor. A complete picture of the MYRRHA ion source, LEBT and RFQ interface is shown in Fig. 1.

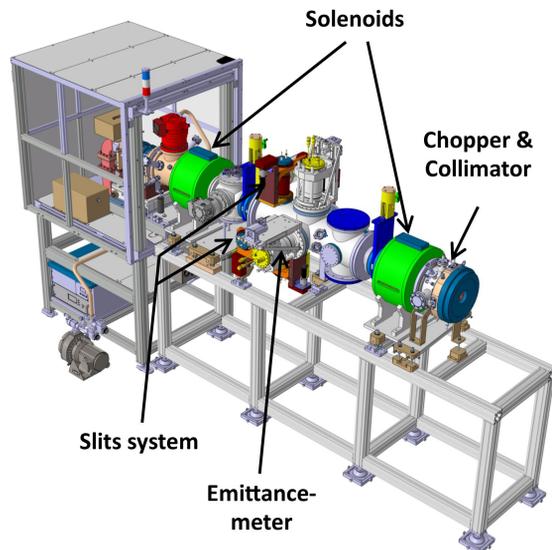


Figure 1: 3D model of the MYRRHA ion source, LEBT, RFQ interface.

Beam Transport

The LEBT design is based on beam dynamics simulations carried out at IPNO with the CEA TraceWin code [6], using a 3D space-charge PIC routine for multiparticle simulations. Solenoids fields are adjusted according to the engineering design. The design goal is to ensure the beam transport providing a centered matched beam at the RFQ entrance with an acceptable transverse emittance (below $0.2 \pi \cdot \text{mm} \cdot \text{mrad}$ RMS norm. [7]). Tracking simulation results are illustrated in Fig. 2. As an input hypothesis, a beam emittance of $0.1 \pi \cdot \text{mm} \cdot \text{mrad}$ RMS norm. ($\beta_{x,y} = 0.32 \text{ mm}/(\pi \cdot \text{mrad})$; $\alpha_{x,y} = -3.4$) is assumed 100 mm after the source extraction hole. These values are inspired from past experiences, especially from the SPIRAL-2 project [8].

Transport tuning was performed by adjusting the magnetic field of each solenoid and steerer. In nominal conditions, the required center magnetic fields are respectively 0.17 T and 0.19 T for the first and second solenoid. The transverse beam emittance is $< 0.18 \pi \cdot \text{mm} \cdot \text{mrad}$ RMS norm. at the RFQ entrance for a matched beam. Collimation slits, located in the middle of the LEBT, are used for beam cleaning to minimize losses in the RFQ. The slits also enable to intercept unwanted ions species, in particular H_2^+ .

In conditions of Fig. 2, 98% of the H_2^+ are lost in the slits and the collimation aperture at the LEBT end.

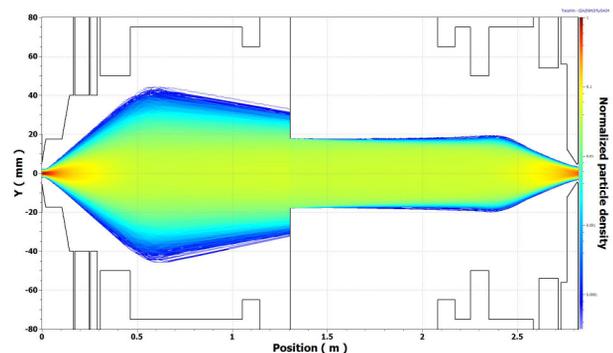


Figure 2: Multiparticle proton tracking and aperture model in the vertical plane.

Design simulations have been carried out with rough estimates of the Space Charge Compensation (SCC) effect. In steady-state simulations, the beam is assumed to be SC compensated at 90% in most of the LEBT, while less compensated at the source exit (80%) and fully uncompensated in the last centimeters before the RFQ (electron repeller). During chopper transients, the process is more difficult to be accurately modeled. In order to maximize the injector performances, it is highly necessary to have a better understanding of SCC effects [9]. The MYRRHA LEBT test stand is a valuable opportunity to develop and improve existing models (such as SOLMAXP [10] and WARP [11] codes) against experimental results. Such experiments will require chopper-synchronized beam instrumentation and control of the vacuum system, in order to evaluate the influence of different injected gas types (N_2 , Ar, Kr, etc.) and pressures on the SC compensation process.

Diagnostic Devices

Beam instrumentation comprises a Faraday Cup (FC), a 2-axis collimation slits system, two Allison scanner for emittance measurements. Additional instrumentation including a beam profiler and four-grid analyzer is under evaluation.

The FC is placed at the exit of the first solenoid and is used during the tuning of the ion source. The cup has a 100 mm diameter aperture, necessary to fully intercept the incoming beam, which nominally has large size after the first solenoid. The FC is made by monolithic OFHC copper and is designed to evacuate a deposited centered beam power up to 1.2 kW ($\sigma_x = 3 \text{ mm}$) by active water cooling. It is equipped by a biasable electron repeller and is inserted/extracted by a pneumatic actuator.

Further in the LEBT, four independent beam collimators or slits are present. Their function is to reshape the beam profile at the exit of the first solenoid magnet and cut any unwanted beam tails. This process prevents particles from impinging on undesired locations downstream the line and helps isolating the proton beam core from molecular

pollutants. Besides, slits may: reduce transverse (H&V) beam emittances or reshape distorted emittances; reduce the beam intensity delivered by the ion source to a percentage of the generated intensity. The (four) slits are transversally arranged onto two axis and are independently adjusted by stepper motors. Each slit is grounded via a dedicated current measurement path, allowing an estimation of the quantity of impinging beam.

Two independent, respectively H&V Allison scanner type emittance meters are adopted to measure beam transverse emittances. The emittance meter is equipped by two narrow (0.1 mm) tungsten slits which scan the incoming beam, determining the particles displacement (x). The slits are shielded by an actively water cooled thermal screen and are designed to sustain a 1.6 kW, gaussian ($\sigma_x=1.5$ mm) DC beam. Between the slits, the beamlet crosses a pair of electric deflection plates driven by a linear ramp voltage power supply (up to ± 1.4 kV), which sorts the particles angle and determines the beam divergence (x'). A maximum of 80 mm beam size, ± 100 mrad divergence can be measured. The beam distribution is plotted in the phase space xx' and its emittance and Twiss parameters are calculated.

Interface to the RFQ

The LEBT line ends with a ~ 280 mm RFQ interface that hosts a slow beam chopper. Two 100 mm long, transversally curved copper plates are designed to be individually polarized/grounded up to ± 10 kV, resulting in a nominal beam deflection of ~ 140 mrad @ 7 kV. The chopper's goal is to produce a 250 Hz macrocycled, 5 to 190 μs @ 5.128 kHz repetition time pulsed beam structure required for average intensity regulation of the beam on target and for subcritical monitoring of the MYRRHA reactor. It is compatible with the insertion of an ISOL@MYRRHA facility. Initially, it will be used for establishing a pulsed regime for SCC studies onto the DC LEBT beam. Deflected beam is taken out the RFQ injection acceptance and dumped onto an actively water cooled, OFHC copper made RFQ collimator. The collimator has a conical adaptation that follows the nominal H^+ converging angle toward the RFQ rods and offers a limit aperture of 9 mm at its very end. Its front face has been designed to sustain high power density (up to ~ 100 W/mm²) beam deposition and is easily replaceable in case of excessive sputtering erosion. The collimator is grounded via a dedicated current measurement path and can be polarized as well. The design of the RFQ interface vacuum chamber is conceived to sustain high deposition of sputtered atoms, with particular attention to shield electric insulations. The collimator is further equipped with an electron repeller lens which helps keeping neutralizing particles (e^-) in this SCC uncompensated region (due to the presence of high electric fields), as well as preventing injection of electrons into the RFQ.

A non-interceptive beam current monitor is provided by Bergoz Instrumentation, France. It is a 100 mm diameter, up to 1 MHz, magnetic shielded ACCT, which has been

integrated in the RFQ flank. The ACCT will allow to measure the produced pulsed beam structure, and ultimately the RFQ transmission efficiency.

Control System

The MYRRHA LEBT line's control system is being developed by Cosylab (Slovenia), and LPSC. The 3-tier architecture of EPICS is chosen. EPICS is currently widely used as control system infrastructure for large scientific installations and is considered a potential candidate for the final MYRRHA implementation in view of its provisions for high availability [12]. The LEBT integration in EPICS represents a good exercise, at reduced scale, of the final superconducting linac implementation. For the LEBT integration, the adoption of cPCI Input/Output Controllers (IOCs) along with Scientific Linux has been retained. Micro Research Finland (MRF) timing transport layer based on FPGA is chosen as reference for the timing system. Industry based field bus (Profibus) and automation (PLC) solutions are adopted whenever applicable as standard for devices integration.

CONCLUSIONS

The current status sees the ECR source ready to be installed at LPSC Grenoble for further characterization and the LEBT in advanced construction phase. After the commissioning, an extensive experimental program is planned. Such an initial injector will be an efficient test platform for many beam related and/or technologically critical issues. Currently, interest is focused on: (i) a systematic study of the SCC phenomenon through global efficiency assessment in the LEBT, both during steady-state and transients, and including gas injection techniques and pressure controls; (ii) development of a robust and comprehensive control system in EPICS; (iii) developments of interceptive and non-interceptive diagnostic devices for high intensity CW beams.

ACKNOWLEDGMENTS

The authors wish to acknowledge M. Loiselet, F. Davin (UCL/CRC) and D. Mäder (IAP) for their contribution in the design of the RFQ interface.

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