HIGH ENERGY BEAM LINE DESIGN OF THE 600 MeV, 4 mA PROTON LINAC FOR THE MYRRHA FACILITY

H. Saugnac, J.L. Biarrotte, L. Perrot CNRS/IN2P3/IPNO, Orsay, France
D. Vandeplassche, SCK/CEN, Mol, Belgium
A. Ferrari, HZDR, Dresden, Germany

Abstract

The general goal of the CDT project is to design a FAst Spectrum Transmutation Experimental Facility (FASTEF) able to demonstrate efficient transmutation and associated technology through a system working in subcritical and/or critical mode. A superconducting LINAC, part of the MYRRHA facility, will produce a 600 MeV, 4 mA proton beam and transport it to the spallation target located inside the reactor core. On this paper we focus on the final beam line design and briefly describe optic simulations, beam instrumentation, integration inside the reactor building, mechanical and vacuum aspects.

INTRODUCTION

The high energy beam line of the MYRRHA/FASTEF facility has the functions to connect the LINAC to the spallation target, situated inside the reactor core, by guaranteeing the shape, the position the intensity and the energy of the beam spot on the target. It has also to connect the LINAC to a full power beam dump necessary for the beam adjustments. The proton beam general specifications are summarized in Table 1. A preliminary conceptual design was produced within the EUROTRANS project [1]. It was based on the use of two up and down achromatic beam lines using two 45° double-deviations dipoles. Due to costs considerations and building fabrication constraints, a new layout was studied were the final double-deviation is replaced by a single 90° magnet.

BEAMLINE REFERENCE LAYOUT

The MYRRHA high-energy beam line has been designed to ensure achromaticity at first order, and to bring telescopic properties between a convenient “object point” and the “image” target. On the following text, numbers into brackets refer to Figure 1 which describes the line reference layout. A set of quadrupoles (❶) is located at the entrance of the line. These 3 focusing magnets will be used to tune the beam on the “object point” (point **O**) and therefore on the spallation target window (see next section). The main line to the reactor is composed of 3 bending magnets in the vertical direction, with bending angles of - 45° (❷), 45° (❸) and 90°(❹), 3.2 meters curvature radius, and edges of respectively 22.5°, 22.5° (45° dipoles w/ parallel edges) and 26.565° (doubly focusing 90° dipole). The last 90° bending magnet is located 26.5 m from the target window. Three quadrupoles triplets are inserted in between (❺) for focusing purposes. A couple of scanning AC magnets (❻) is located in the upper part of the line, close to the last magnet, in order to paint the window target with the desired beam footprint. An additional 20° bending magnet (❽) is used to bend the beam towards the beam dump. Two associated quadrupoles (❼) are used to strongly defocus the beam and match its size to the dump entrance. The beam tube aperture has been set to 100mm diameter, except for the dipole vacuum chambers (95mm). Several beam diagnostics boxes are present along the beam line (illustrated in green on Figure 1) in order to insert instrumentation devices to tune and monitor the beam behavior: BPM, wire profilers, halo monitors, current monitors, ToF. Several small DC dipole steering magnets (illustrated in blue on Figure 1) are also available along the path for beam orbit corrections purpose.

Table 1: Proton Beam General Specifications

Beam energy	600 MeV
Beam pulse current	4 mA Maximum
Average beam Power	2.4 MW Maximum
Beam energy stability	Better than +/- 1%
Beam Current stability	Better than +/- 2%
Beam footprint on the target	Φ 85 mm Donut-Shape
Beam footprint Stability	Better than +/-10%
Beam reliability	< 10 beam trips longer than 3 s during a 3 months operation period

BEAM DYNAMICS STUDIES

Nominal beam envelopes in the horizontal and vertical planes at a given time (i.e. at given AC magnets fields) are illustrated on Figure 2, from multi-particle simulations, using the TraceWin code developed by CEA. No beam loss is observed all along the line, except in the last 3 meters where about 15kW (over 2.4MW) is lost on the vacuum chambers located inside the reactor core.

Along the final drift length located inside the reactor hall and vessel, about 25 meters long, neither focusing element nor classical instrumentation device can be placed (highly irradiated zone). It is therefore mandatory to ensure that the line is fully achromatic at first order to minimize any beam spot movement due to beam energy jitter, which will be in the order of ±1 MeV (i.e. far below the ±1% specification). Preliminary statistical error studies show more generally that this very long ‘naked’ final drift makes the line quite sensitive to any kind of errors, and will induce tight specifications for the magnets stability (quadrupole vibrations and dipole field stability) and the input beam jitters (both divergence & position).

The beam line tuning has to provide a beam spot radius on target of about 9 mm rms. To be able to provide this beam spot size by design (tuning process, robustness of the optics), a telescopic properties have been included in the line design. These properties ensure by construction that the size at the target is always nine times the beam size at point O (see Figure 1). With such a solution, once the commissioning achieved, the tuning of the beam spot on target is therefore simply achieved by tuning the first quadrupoles of the line to obtain a 9 times smaller beam size at point O, i.e. ±1mm RMS in the nominal case.

Natural defocusing is therefore used in the last straight line to get the desired beam spot size of 9 mm radius RMS, and from this, the required "donut-shape" footprint is then obtained by raster scanning, using a (possibly redundant) set of fast steering magnets operated at frequencies of several tens of Hz (frequency still to be defined), and acting in the two transverse directions, as shown on Figure 3. The obtained beam power density at the window surface is therefore uniform in the rotation direction, and keeps the natural beam profile, supposed to be Gaussian, in the radial direction. Such a solution used in different projects [2] is very simple and reliable. The on-line monitoring of the target will be performed using an optical near-target beam diagnostic inspired from the VIMOS apparatus [3] developed at PSI.

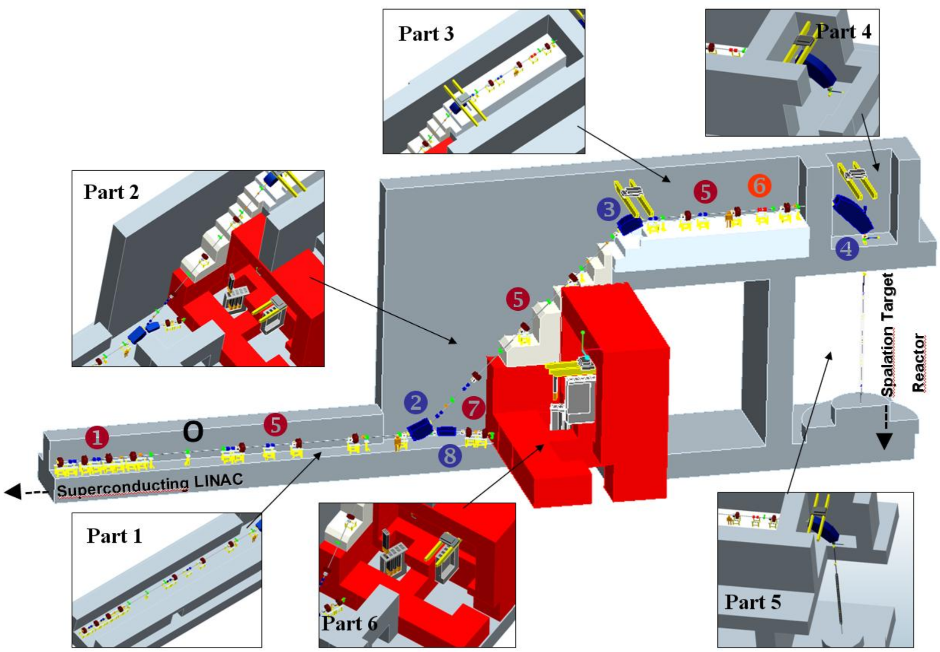

Figure 1: Beam Line Reference Design

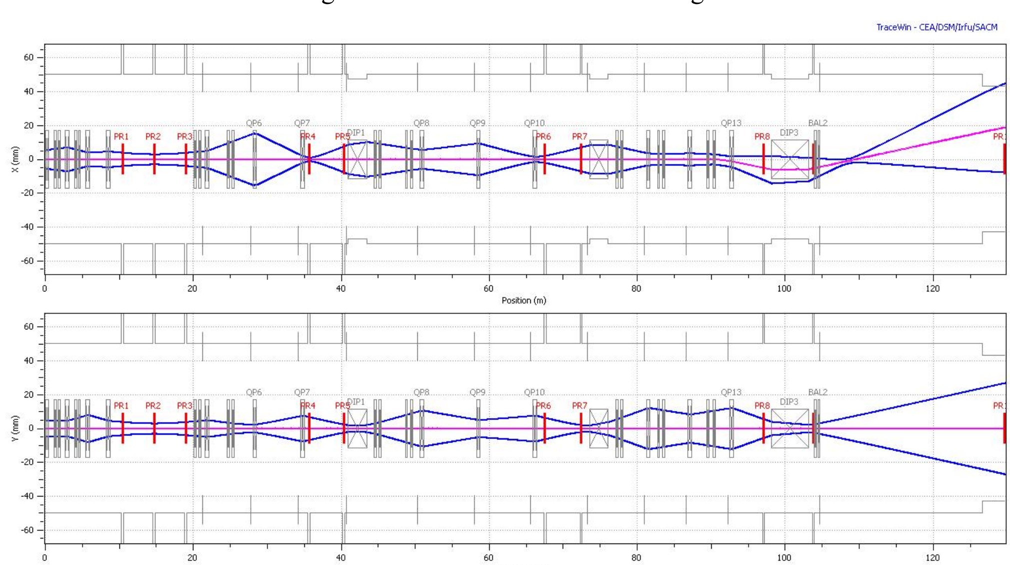

Figure 2: Nominal beam envelopes through the beam line (99%, 3sigma envelopes)

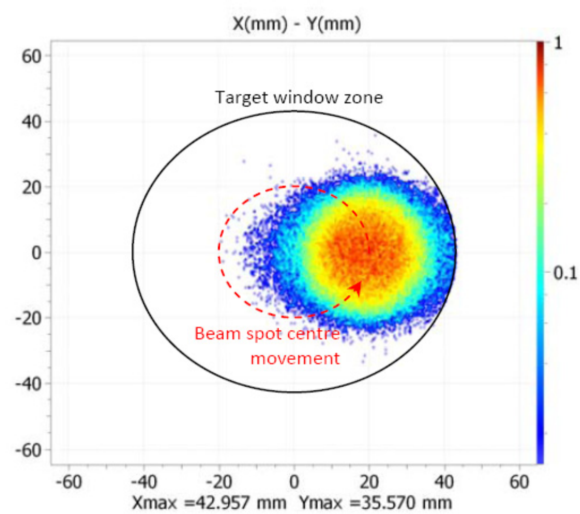

Figure 3: Beam spot movement on target

BEAM LINE MECHANICAL DESIGN

The mechanical design and the corresponding beam line layout is strongly subjected to the building design for which the security constraints imposed by the nuclear environment are a major concern. The line is described in Figure 1. The line axis situated at 1.5 meter from the tunnel ground (2 meters from the soil) is offset, to allow the circulation (3 meters space) of the different components on the side of the LINAC. So far no crane is foreseen for handling purpose in this area. The 45° slope of the line is situated in 30 meters high, 9.5 m large and 28 meters long hall. The supporting frames of the 45° line part will be supported by a stage made from concrete at roughly 1.5 meters from the beam axis. In parts 1,2 &3 shown on figure 1 the components alignment will be performed using 'laser tracker' technology. All the vacuum components and fittings will be ConFlat® type and a turbo-molecular pumping group with 200l/s capacity will be placed every 3 meters to ensure the 10^{-7} mbar vacuum specification in this part of the line.

The last 90° dipole will be irradiated by the neutrons backscattering coming form the spallation target. It will, therefore, be placed inside a hot cell where only remote handling will be possible. The last part of the line will be intensively irradiated and for reliability and maintenance purposes will not be equipped with active components (diagnostics, magnets, vacuum valves & vacuum pumps…) which will be located inside the 90° magnet hot cell (part 4 on fig. 1). A 15 meters long part of the line situated inside the reactor hall (part 5 on fig. 1) has to be removed to give access to the reactor plate during each experiment preparations. This part, maintained by moving arms will be disconnected and reconnected in the good position by remote handling. In parts 4&5 on fig. 1 the components will be surveyed using photography methods which will give the possibility to check continuously the alignment without human intervention. Vacuum in the last 25 meters part of the line will be ensure by a turbo-molecular pumping group of 200l/s capacity situated just after the 90° magnet outside the reactor hall. A pressure of 10^{-4} mbar will be achieved in this part of the line, since beam losses due to proton interactions with the residual gas are very low at this energy, estimated to be in the order of 0.05 nA/m at 10^{-4} mbar. Two fast valves with a closing time below 20 ms are situated after the 90° deviation magnet, one inside the magnet hot cell and one inside the reactor hall. These valves have to prevent from contamination inside the line in case of failure of the spallation target window.

A 2.4 MW, full power beam dump, based on the 1.2 MW PSI proton beam dump, is foreseen to allow the commissioning of the MYRRHA accelerator independently from the reactor. Parts of the dump made from copper will be highly irradiated and considered as nuclear waste. Therefore the beam dump will be placed inside a hot cell whom dimensions, set from preliminary irradiation simulations, are 23 meters long, 18 meters high, 15 meters deep (part 6 on figure 1) with a concrete wall thickness of about 5 meters. The cell will be equipped with a 20 tons crane and remote handling capabilities.

CONCLUSIONS

During the CDT programme a reference layout of the high-energy beam line section for the MYRRHA accelerator has been done in term of beam dynamics and mechanical integration. The three years long European programme MAX, started at the beginning of 2011, will review this design through the consolidation of the whole MYRRHA accelerator.

ACKNOWLEDGMENTS

This paper has been written on behalf of the CDT team. The research leading to these results has received funding from the European Atomic Energy Community's (EURATOM) Fifth and Sixth Framework Programmes, and is being supported from the Seventh Framework Programme FP7/2007-2011 under grant agreement n°232527 (CDT Project).

REFERENCES

[1] J.L. Biarrotte and al., "Accelerator reference design for the MYRRHA European ADS demonstrator", Proc. XXV Int. Linear Accelerator Conf.,Tsukuba, Japan, September 2010

[2] Th. Haberer, W. Becher, D. Schardt & G. Kraft, "Magnetic scanning system for heavy ion therapy", Nucl. Inst. & Meth., A330, 1993.

[3] K. Thomsen, "VIMOS, beam monitoring for SINQ", Proc. of the DIPAC'09 workshop, Basel, Switzerland, May 2009.