THE ESS LOW ENERGY BEAM TRANSPORT LINE DESIGN

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Abstract

The linear accelerator of the European Spallation Source (ESS) will deliver proton beams of 50 mA and 2.5 GeV onto the 5 MW neutron production target. The Proton Source for ESS (PS-ESS) [1] is based on the experience of TRIPS and VIS developed at LNS Catania [2,3]. A two solenoid Low Energy Beam Transport (LEBT) is foreseen to match the beam into the first acceleration stage, the Radio-Frequency Quadrupole (RFQ) [4]. Beam production means also detailed characterization of produced beam, with this scope the LEBT houses many instrumentation devices and use different techniques that will be described in this work. The LEBT will be also equipped with an electrostatic chopper in order to remove the unwanted part of the beam pulse during the natural rise and fall times of the ion source. Beam dynamics calculations of the LEBT have been carried out considering also the Space Charge Compensation (SCC) produced by the interaction of the beam with the residual gas, and its effect on beam transport and chopping. Particular emphasis has been put on the evaluation of the beam transient behavior, due to the chopping process, at the entrance of the RFQ, results of the study are presented in this paper.

INTRODUCTION

The ESS, to be built in Lund, Sweden, will use a high current proton linac required for generating high flux of pulsed neutrons by the spallation process. The linac layout [5] is made of a warm section and a superconducting section. The warm linac is composed of an ion source (75 keV), a LEBT, a RFQ (3 MeV), a Medium Energy Beam Transport (MEBT) line and a 4-tank Drift Tube Linac (DTL) to accelerate the beam up to 80 MeV. Double-spoke resonators and five cell-elliptical cavities will accelerate the beam in the superconducting linac up to 2.5 GeV. This paper will focus on the LEBT line of the ESS project. The purpose of the LEBT is to transport and adapt the 50 mA beam from the ion source into the RFQ. The beam pulse duration will be 2.86 ms for a repetition rate of 14 Hz; and rise and fall time must be of around 100ns, for that purpose two electrostatic chopper will be used, one located in the LEBT and the other in the MEBT. Beam dynamics investigations have been performed to design the pre-chopper (LEBT) and to evaluate the performances of the latter.

LEBT LAYOUT

The beam focusing in the LEBT is performed by dual solenoid system. The design of the solenoids is similar to the one of the IFMIF LEBT [6]. The deflecting plates of the chopper are inserted between the solenoids. The total length of the line from the plasma electrode to the RFQ entrance is 2.10 m. Two pumping system will be installed in the line, one before the first solenoid and one in between the magnetic elements. The position of the different optical and monitor components are still under discussion and they are subjected to modification. A preliminary layout is shown in Fig. 1.

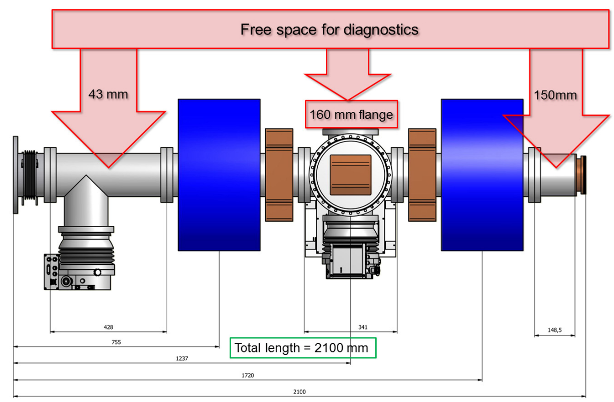

Figure 1: Diagram of the ESS LEBT with beam instrumentation

BEAM INSTRUMENTATION

Beam Profile Measurements

Beam profile measurement will be performed with SEM grids at two locations in the LEBT, between the two solenoids, and after the second solenoid. Each grids will be moved by a stepping motor in order to increase the resolution if it is needed. The profile measurements will be used for the beam steering strategy, and match the beam at the RFQ entrance. In LINAC4, using tungsten wire, the profile measurement was perturbed by thermoionic emission when the beam pulse is longer than 600 µs at a current of 30 mA, the measurable pulse length can be increased by using a carbon wire.

Emittance Measurement

An emittance measurement is foreseen to characterize the ion source and the beam optics in order to optimize the beam injection in the RFQ entrance and provide beam distribution for end to end simulations. The measurements will be performed during commissioning phase and during operation for dedicated beam studies. For operation, the system will be installed between the two solenoid, the slit will be positioned as close as possible to the first solenoid, the SEM grids used for profile measurement will be reused for this measurements. For the commissioning the emittance meter will be positioned

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[7] in different positions: after the source, after the first solenoid, and after the second solenoid. The slit shall be designed in order to stand the full beam power. In order to fit this requirement, the slit will be made in graphite, and its geometry will be made in order to spread the energy deposition in a larger surface [8].

Current measurement

A Faraday cup will be installed after the source; as for the slit, the Faraday cup shall be designed in order to stand the full beam power. This Faraday cup shall be integrated in the Machine Protection System (MPS) and shall be used as a slow mitigation device. In addition, a Beam Current Transformer (BCT) will be installed as close as possible to the RFQ entrance. This BCT shall be integrated in the MPS, the transformer will be used with a second one installed at the RFQ exit in order to measure the beam transmission. This device is relatively slow and for commissioning a Fast Faraday with a time response in the order of the ns or less shall be installed in order to measure the effect of the LEBT chopper on the current rise time.

Optical methods

The emitted light due to the interaction between the beam and the residual gas can be used for different type of measurements, specially the ions species fraction. With a digital camera installed in the focal plane of a monochromator with a few tens of degree angle with respect to the beam propagation axis, the Doppler shift observation of the H_{α} hydrogen Balmer series allows isolating the fluorescence of each ions species of the beam. The ratio of the different ions is proportional to the light intensity [9].

BEAM TRANSPORT AND CHOPPING

In low energy beam transport of high intensity beams the self-generated repulsion between charged particles can generate a large and irreversible emittance growth, while the optimum matching with the RFQ require high focussing and low emittance. To reduce this negative effect the space charge neutralization of the beam charge can be done by ionizing the residual gas. The generated electrons are captured by the beam potential, while the generated ions are repelled by the beam and lost on the surface of the vacuum chamber. Such SCC regime has many similarity to a plasma but the electric field produced for example by the pre-chopper introduces many significant variations especially in the transition regimes. In order to preserve the SCC from the high electric field located in the extraction system and inside RFQ, a repelling electrode was inserted in the extraction system and in the RFQ collimator, shown in Fig. 2. Then, to reduce the longitudinal dimension of the LEBT and to keep free space for the installation of diagnostics, we designed the chopper chamber coupled to the Turbomolecular Pump (TMP) as shown in Fig. 3. Care was used to locate the high voltage power source as close as possible to the chopper plate to obtain low impedance connection and maintaining high switching speed of the used electronics (15 ns). The measured performances of the chopper power system, already developed for the SPIRAL2 project, are presented in Fig. 4.

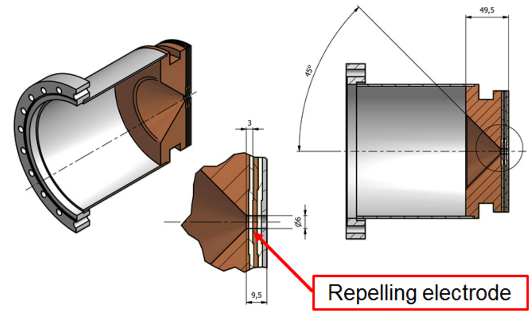

Figure 2: RFQ collimator with integrated repelling electrode.

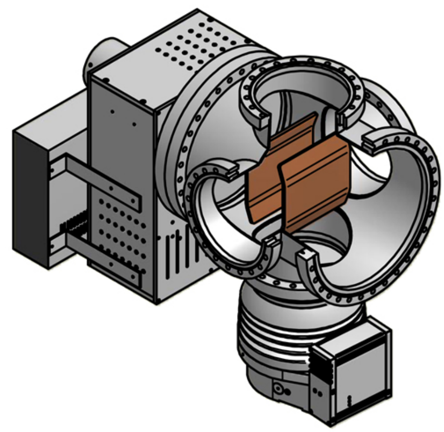

Figure 3: Chopper, TMP, high and low voltage electronics boxes.

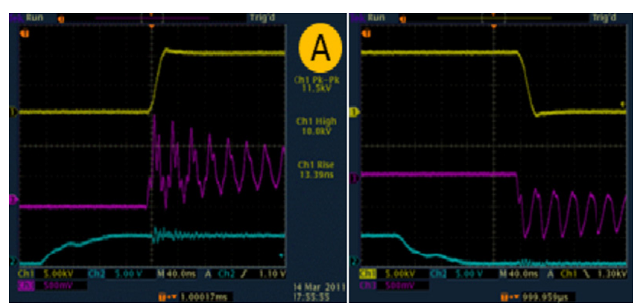

Figure 4: Chopper electronics measured performances.

The extraction system has been simulated with AXCEL and the emittance parameters at the position z = 0.14 m [4] have been used as input for the simulation of the LEBT by using the TraceWin code. This software has been chosen because is able to take into account a SCC map along the LEBT and it is able to perform the optimization of the optical element parameter so that we may achieve the RFQ Twiss parameters ($\alpha x = 1.4464$; $\beta x = 0.0579$; $\alpha y = 1.4847$; $\beta y = 0.0591$). Fig. 5 shows the beam trajectory and the emittance shape obtained at the RFQ entrance by using a SCC value of 98%. At the center of the LEBT, between the two solenoids, the shape of the chopper electrodes can be seen.

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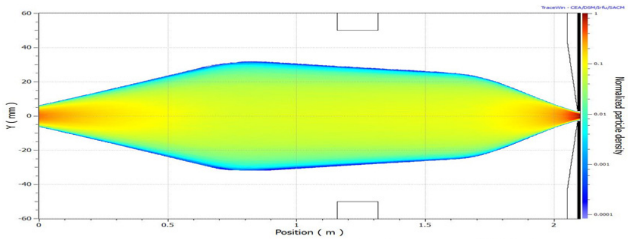

Figure 5: Simulated beam trajectory inside the LEBT.

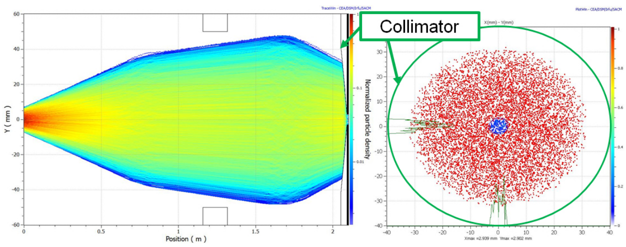

Figure 6: Secondary beam trajectory and its shape inside RFQ collimator.

AXCEL and TraceWin are also able to include in the simulation the secondary beam, that in our case is H_2^+. In sources like VIS and SILHI the proton fraction can reach 90%. As shown in Fig. 6 the RFQ collimator was designed to accept the 10 mA secondary beam shape. The RFQ collimator was also designed to dump the high power transported by the chopped beam (90 mA at 75 keV). Due to the position of the chopper the trajectory of the chopped beam is not trivial because the beam is also deflected by the second solenoid. Fig. 7 shows the radial distribution of the chopped beam and its impact shape over the RFQ collimator. As we can see the chopper deflects the beam out of the center of the collimator while the solenoids rotate of 45° the not centered beam.

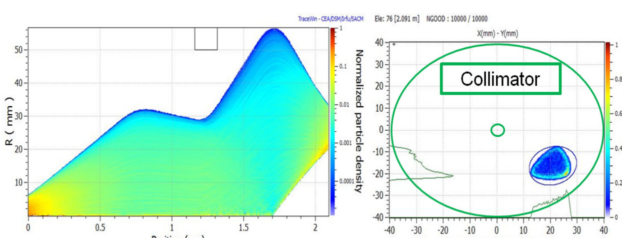

Figure 7: Chopped beam trajectory inside the LEBT; Dump of the beam inside the RFQ collimator.

TIME DEPENDENT BEAM TRANSPORT SIMULATION

The beam longitudinal front at the end of the LEBT is extremely important for the design of the following accelerator cavities of ESS linac. The required rise and fall time is 100 ns while the source modulation is able to perform 2 μs rise time. The chopper was inserted to cut slow edge and fast power electronics with 15 ns transition time was selected. But the chopper electric field and the difference in the two beam trajectories produce a low SCC value during the transport of the first part of the beam. Using the literature result about the SCC creation time [10] and some plasma consideration about the electron gas that neutralizes the beam, we have been able to evaluate the time dependent SCC map along the LEBT, so we have been able to obtain the time shape of the beam at the RFQ entrance.

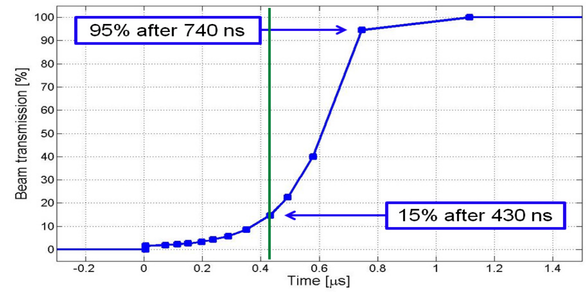

Figure 8: Simulated beam pulse rise time.

The time dependent simulations show that the pulse beam fall time is below 20 ns, while Fig. 8 shows, that 300 ns actually is the limit on the faster possible beam rise time. The time dependent simulations give also the shape, the emittance and the Twiss parameters time dependency. These results are extremely important for the design of the following accelerator cavity and the fast-chopper that must be placed in the MEBT to reach 100 ns pulse rise time. More investigations and a series of measurements are planned within the fall of the year at INFN-LNS and CEA-IRFU to verify this results.

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REFERENCES

[1] L. Neri et al., "The Proton Source for European Spallation Source", these proceedings.
[2] L. Celona et al., "TRIPS: The high intensity proton source for the TRASCO project", Rev. Sci. Instrum. 71, 771
[3] S. Gammino et al., "Tests of the Versatile Ion Source (VIS) for high power proton beam production", ECRIS'10, Grenoble, France, MOPOT012.
[4] A. Ponton, "The ESS RFQ beam dynamics design", these proceedings
[5] M. Eshraqi et al., "End-to-end Beam Dynamics of the ESS Linac", IPAC'12, New Orleans, LA, USA
[6] N. Chauvin et al., "Final Design of the IFMIF-EVEDA Low Energy Beam Transport Line", PAC'09, Vancouver, BC, Canada.
[7] B. Cheymol et al., "First Results From Beam Measurements at the 3 MeV Test Stand For CERN LINAC4", DIPAC'11, Hambourg, Germany.
[8] B. Cheymol et al., "Design of the Emittance Meter for the 3 and 12 MeV LINAC4 H- Beam", IPAC'10, Kyoto, Japan.
[9] F. Senee et al., "Diagnostics for High Power Ions Beams with Coherent Optic Fiber for IFMIF-EVEDA Injector", DIPAC' 09, Basel, Switzerland.
[10] A. BenIsmaïl et al., "Space charge compensation in low energy proton beams", CARE Conf-04-025-HIPPI.