HIGH POWER PROTON LINAC FRONT-END: BEAM DYNAMICS INVESTIGATION AND PLANS FOR THE ESS

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Abstract

Beam dynamics investigations and plans for the European Spallation Source (ESS) [1] concerning the Low Energy Beam Transport line (LEBT) and the Radio-Frequency Quadrupole (RFQ) are presented in this paper. The LEBT aiming at controlling and matching the 75 keV 50 mA proton beam coming out of the ion source into the RFQ has been chosen to be a dual solenoid section. Its preliminary design includes a chopper system either between the two solenoids or just after the second solenoid. Key points to study the Space Charge Compensation process (SCC) along the line and the efficiency of the chopping system on the beam time structure are given here. The 352.21 MHz 4-vane-type RFQ then accelerates up to 3 MeV, focalize and shape the beam in a train of bunches suitable for RF acceleration in the linac subsequent components. The paper reports the design strategy and the beam dynamics results.

LOW ENERGY BEAM TRANSPORT LINE

Considerations and Plans

Understanding the beam SCC process is mandatory when dealing with high intensity light ion beams [2]. Electron generation induced by the ionization of the residual gas by the proton beam may result in about 90 % decrease of the space charge potential.

Studies of the SCC shall include the following points:

- modeling of the pressure profile along the line including gas flow from the ion source, wall degassing and pumping systems;
- evaluating the characteristic time of the beam equilibrium state;
- finding the correct tuning of the solenoids to match the beam into the RFQ.

Furthermore injection of gaz in the LEBT to increase the compensation may be required to minimize emittance growth and to obtain the required RFQ injection parameters.

In addition to the static fields of the magnetic solenoids, the time dependant electric field of the chopping system to remove the head and the tail of the 2.86 ms beam pulse has to be taken into account. Analysis of the effects of the voltage rise time and fall time on the beam pulse time structure is required. Secondary electrons produced by the impact of the deflected beam onto the RFQ injection cone may also play an important role in the beam transient dynamics during the chopping process.

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Preliminary Designs

Two designs, resulting in a total LEBT length of 2.1 m, with two different locations of the chopping system – between the solenoids (see Fig. 1) and just after the second solenoid (see Fig. 2) –are being considered. The angle of the injection cone differs in the latter case in order to accommodate the chopping system. Two circular iris diaphragms protect the chopping system at the rear and front of the deflecting plates. The IFMIF-type solenoids of 30 cm physical length are separated by 90 cm and produce a magnetic induction field on axis of about 0.25 T in order to match the beam into the RFQ.

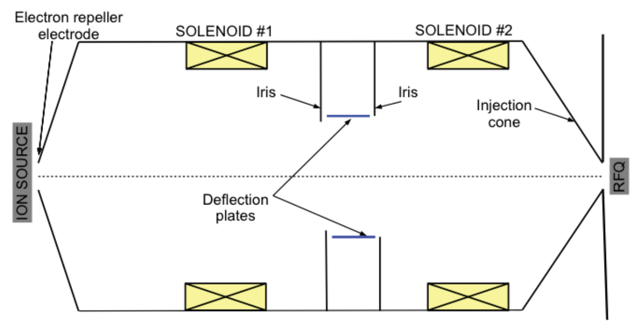

Figure 1: Schematic layout of the LEBT with the chopping system located between solenoids.

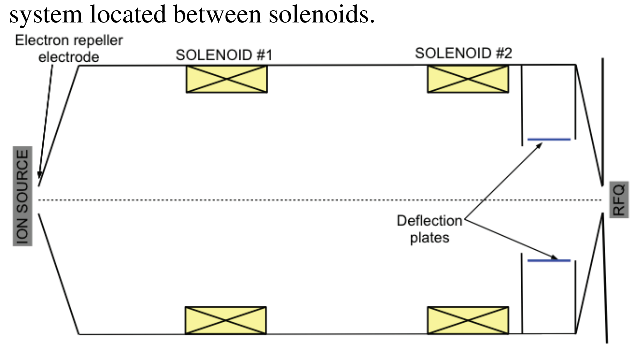

Figure 2: Schematic layout of the LEBT with the chopping system located after the second solenoid.

First simulations assuming 90 % current compensation and 0.2 π.mm.mrad RMS KV transverse distribution have been performed with the TraceWin/Partran code [3]. Voltage difference between plates is 5.2 kV in both case. The deflectors are two rectangular plates of 15×16 cm (transverse and longitudinal dimensions) located a distance of 5.5 cm from the beam axis. Results are shown on Figs. 3, 4 and 5 for the chopper respectively off, located between the solenoids and after the second solenoid.

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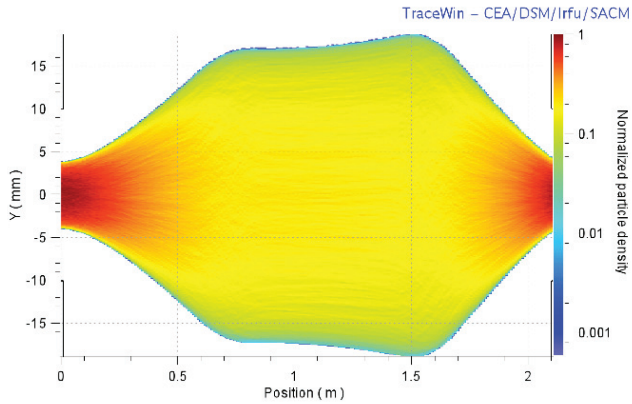

Figure 3: Beam distribution with chopper turned off.

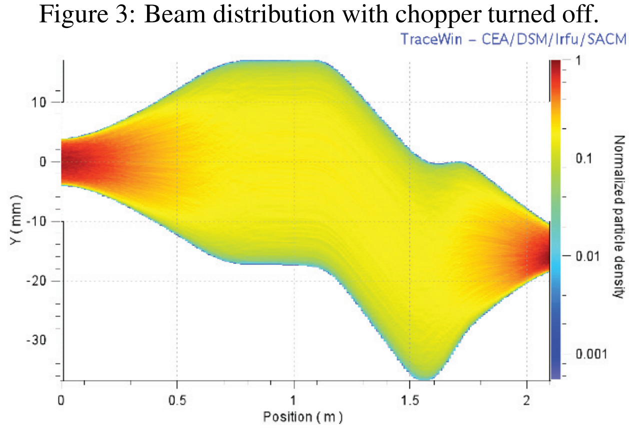

Figure 4: Beam distribution with chopper between solenoids.

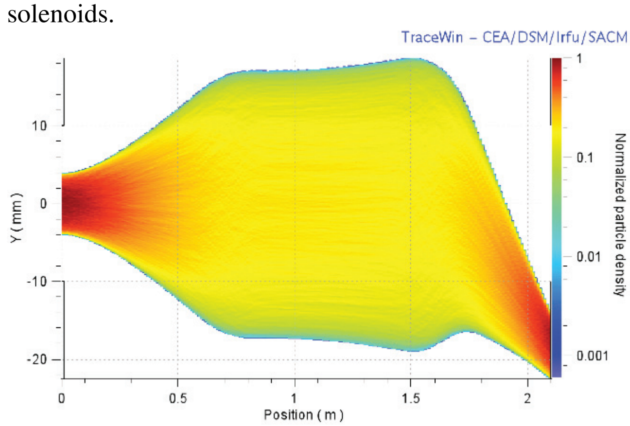

Figure 5: Beam distribution with chopper after the second solenoid.

RADIO-FREQUENCY QUADRUPOLE

Strategy

The ESS overall reliability is foreseen to be better than 95 %. The RFQ beam dynamics design strategy, defining the geometry of the pole tips, has been achieved in order to meet the tight requirements of the ESS guidelines. Following rules have been considered:

1. relying on the knowledge and know-how of collaborating labs within the Accelerator Design Update (ADU);
2. proposing a conventional design;
3. taking margins/over-designing;
4. integrating the RF and mechanical design in the early stage of the beam dynamics design.

The transmission has been maximized to overcome thermo-mechanical and sparking issues. Since it will impact the beam behavior throughout the rest of the linac, minor transverse emittance growth and good longitudinal emittance production are mandatory: the RFQ must deliver high quality beams to reduce the probability of hazardous losses at high energy. Furthermore for more flexibility and in order to reduce sparking problems the Kilpatrick limit [4] does not exceed 1.8.

A complete study of the ESS RFQ pole tip geometry optimization is developed in [5].

Results

The ESS 4-vane-type 352.21 MHz RFQ beam dynamics results performed with the Toutatis code [6] for 50 mA and 75 mA (respectively the nominal and the possible upgraded intensity) are shown in Tab. 1. Uniform and gaussian (truncated at $4\,\sigma$) distributions have been considered with $0.20\,\pi$.mm.mrad input RMS transverse emittance.

Negligible transverse emittance growth is experienced and the total transmission is better than 99 % for the nominal current.

Table 1: Output Emittances and Transmission

Current (mA)	Distri-bution	Output tanvs.em. RMS (π.mm.mrad)	Output long.em. RMS (π.mm.mrad)	Trans-mission (%)
50	Uniform	0.21	0.26	99.40
	Gaussian	0.21	0.28	99.56
75	Uniform	0.21	0.30	98.98
	Gaussian	0.20	0.32	98.66

The main parameters of the final design proposed for the ESS RFQ are summarized in Tab. 2 and their evolution are shown on Fig. 6.

Table 2: Main Parameters of the Reference RFQ

Inter-vane voltage	V	80 to 120 kV
Synchronous phase	ϕ_S	-90 to $-31°$
Minimum aperture	a	3 to 3.9 mm
Modulation factor	m	1 to 2.06
Pole radius of curvature	ρ	3 mm (Constant)
Vane length	L	4.93 m

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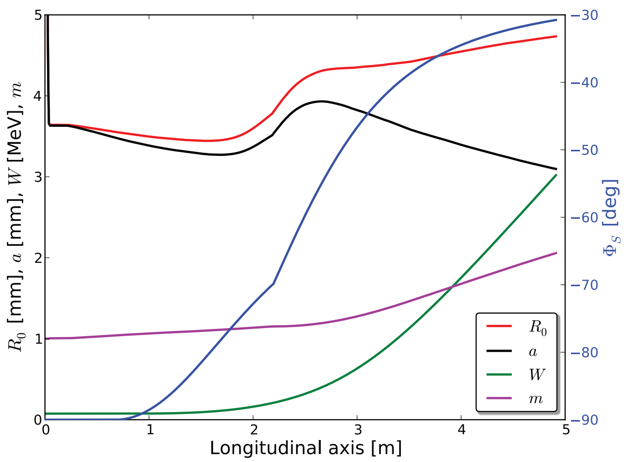

Figure 6: Evolution of some relevant parameters for the reference design.

CONCLUSION AND PERSPECTIVES

First designs of the ESS dual solenoid LEBT have been presented. Two options are being considered for the chopping system: chopper between the solenoids or located just after the second solenoid. A study of the beam transient behavior is mandatory. We want to have a precise description of the time structure of the proton beam before it enters into the RFQ.

The ESS overall reliability goal to be better than 95 % has then been emphasized. The latter has driven the RFQ design strategy. Beam dynamics study has resulted in a $\sim$ 5 m long structure. The ESS RFQ is foreseen to deliver high quality beams in addition to very low losses ($>$ 99 % total transmission for 50 mA beam current) and minor transverse emittance growth.

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