PHYSICS DESIGN OF A PROTOTYPE 2-SOLENOID LEBT FOR THE SNS INJECTOR*

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Abstract

To mitigate the operational risks associated with the SNS electrostatic LEBT, an R&D effort is underway to develop a 2-solenoid magnetic LEBT, which should improve the reliability while matching or exceeding the beam dynamic capabilities of the present electrostatic LEBT. This paper discusses the physics design of a prototype 2-solenoid magnetic LEBT.

INTRODUCTION

The Spallation Neutron Source (SNS) injector consists of a Cs-enhanced, RF-driven, multi-cusp H^- ion source and a low-energy beam transport (LEBT) section as shown in Fig. 1.

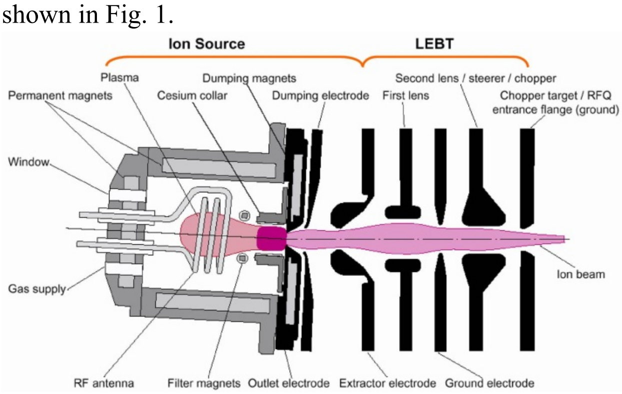

Figure 1: A schematic view of the present SNS injector.

Typically ~300 W from a 600-W, 13.56-MHz amplifier generates continuous low power plasma to facilitate the formation of high power plasma. The high current H^- beam pulses are generated by the plasma, driven with 40-70 kW from a pulsed 80-kW, 2-MHz amplifier.

The electrostatic, 2-lens LEBT is ~12 cm long and focuses the 65-keV, ~6% duty factor, high-current H^- ion beam into the radio frequency quadrupole (RFQ) accelerator with the required Twiss parameters $\alpha \approx 1.7$ and $\beta \approx 0.06$ mm/mrad. The second lens is split into 4 electrically-isolated segments, which allow small superimposed voltages to steer, and rapidly switched superimposed ±2.5 kV to chop the beam [1]. The LEBT's compactness prohibits any beam characterization before it is accelerated to 2.5 MeV by the RFQ. The first beam current monitor is located near the exit of the RFQ.

High voltage transients from lens-2 sparks occasionally break the chopper electronics [2]. Uncontrolled beam losses and beam- and corona-induced secondary ions heat the lenses and the extractor. Sometimes lens-1 reaches temperatures where thermionically-enhanced field emissions make the lens inoperable.

* Work supported by SNS which is managed by UT-Battelle, LLC, for the US Department of Energy.
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To reduce the operational risks associated with the electrostatic LEBT, and to improve functionality of the ion source and LEBT, we are developing a magnetic 2-solenoid LEBT that can match or exceed the requirements for the present electrostatic LEBT, including the fast beam chopping at ~1 MHz. This paper discusses the physics design of our prototype 2-solenoid magnetic LEBT. The design work used several computer codes, including PBGUNS, SIMION, Trace-3D, Opera, and MagNet.

THE PRESENT LEBT

The SNS injector delivers H^- beam to the RFQ to support neutron production with a linac peak current of ~38 mA. Linac peak currents of 50 mA have been demonstrated at the end of run 2010-2. Even higher currents have been demonstrated several times during extended maintenance periods. Figure 2 shows an illustration of the beam transport capability of the electrostatic LEBT using PBGUNS [3] simulation with an ion source extracted beam current of 60 mA. Shown in Fig. 3 are simulation outputs of the beam phase-space distribution and emittance at the RFQ reference plane.

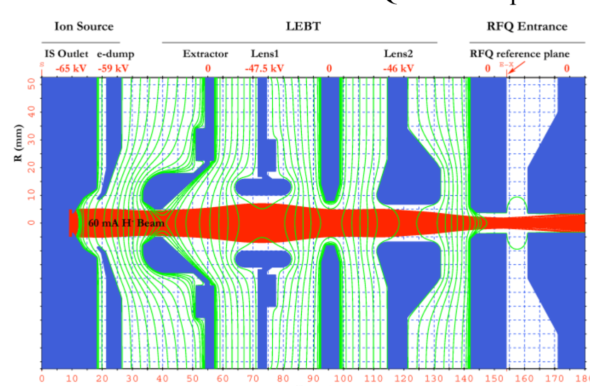

Figure 2: PBGUNS simulation of beam transport using the electrostatic LEBT.

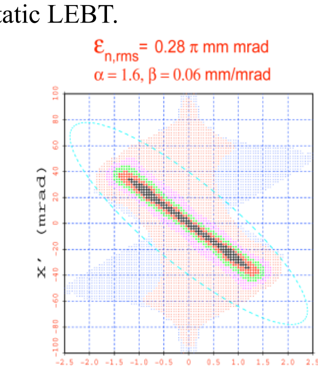

Figure 3: Beam phase-space distribution and emittance at the RFQ reference plane indicated in Fig. 2.

By applying ±2.5 kV on the opposite pairs of lens-2 segments with a ~1 MHz frequency, the H^- beam is chopped in the LEBT to create the clean gaps in the beam required for a low-loss beam extraction from the accumulator ring. Figure 4 is a diagram of the SNS chopper system. In operation, the timing system is set to deflect the beam sequentially in four different transverse directions.

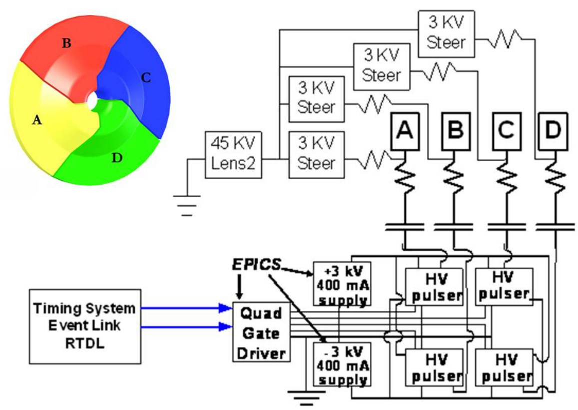

Figure 4: SNS chopper system diagram.

Figure 5 is a simulation of the reference particle (center ray) using SIMION code [4] to evaluate the deflection power of the chopping voltages. With ±2.5 kV chopping voltages and the same settings on the ion source and LEBT electrodes as in Fig. 2, at the RFQ entrance the reference particle is 4.5 mm away from the axis with a trajectory angle of 7.33°.

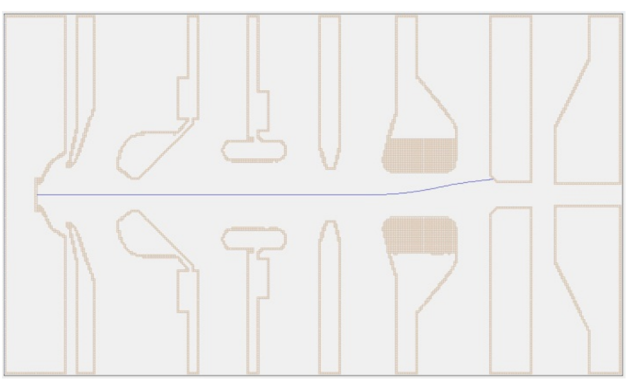

Figure 5: Deflection of the reference particle at the chopper target location with the electrostatic LEBT.

THE 2-SOLENOID LEBT DESIGN

The design goals for the 2-solenoid magnetic LEBT are to improve operational reliability without compromising the beam dynamic capabilities of the present electrostatic LEBT; specifically the Twiss parameters, the speed of the chopping, and the beam in the gap. Figure 6 shows a schematic view of the designed 2-solenoid magnetic LEBT. The chopper will operate at the potentials needed for the beam chopping and steering, because no high voltage is required for electrostatic focussing. This eliminates the high voltage sparks and their harmful transients. Uncontrolled beam losses will spread over the beam pipes, which are cooled by ambient air, which eliminates the thermal runaways of insufficiently-cooled high voltage electrodes in vacuum. In addition, the beam can be characterized before being injected the RFQ improving and simplifying the beam diagnostics.

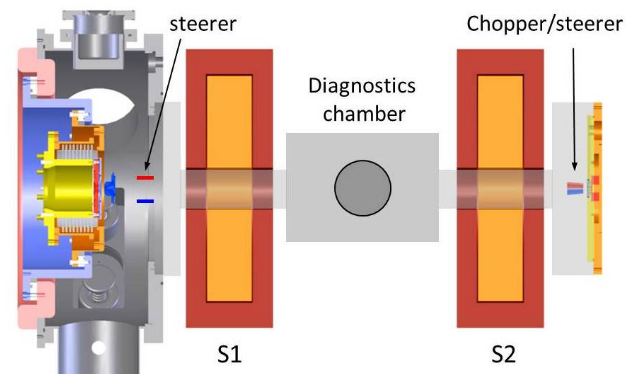

Figure 6: A schematic view of the 2-solenoid LEBT.

The design effort focused on the dimensions and the system layout to achieve the beam dynamic requirements within the constraints of the existing laboratory infrastructure. The initial layout and dimensions for the beam transport were estimated using PBO Lab Trace-3D code [5], and the detailed treatments were carried out using PBGUNS. The dimensions for the two solenoids were decided to be the same with an effective length of 135 mm. Figure 7 shows a PBGUNS simulation of the beam transport in the prototype design 2-solenoid LEBT. A 60 mA beam was extracted from the source and transported in the 2-solenoid LEBT with neutralized space-charge because negative ion beams rapidly accumulate the secondary ions produced in collisions with the residual gas. However, the rapidly changing electric fields in the chopper prohibit a substantial accumulation of neutralizing ions, and therefore the beam inside the chopper is simulated with full space-change, as shown in Fig. 8. Figure 9 shows the beam phase-space distribution and emittance at the RFQ reference plane simulated with solenoidal fields of -0.291 T and 0.456 T. The calculated beam size and emittance at the RFQ entrance exceed the

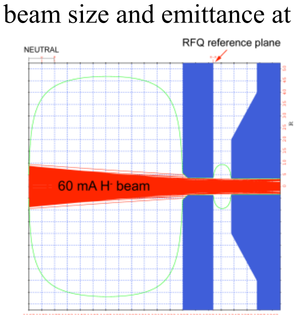

Figure 8: Beam with full space-charge in the chopper.

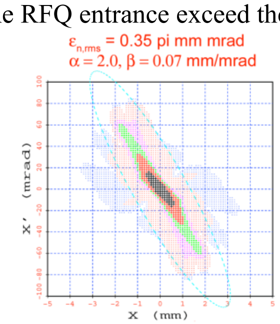

Figure 9: Beam phase-space distribution and emittance at the RFQ reference plane.

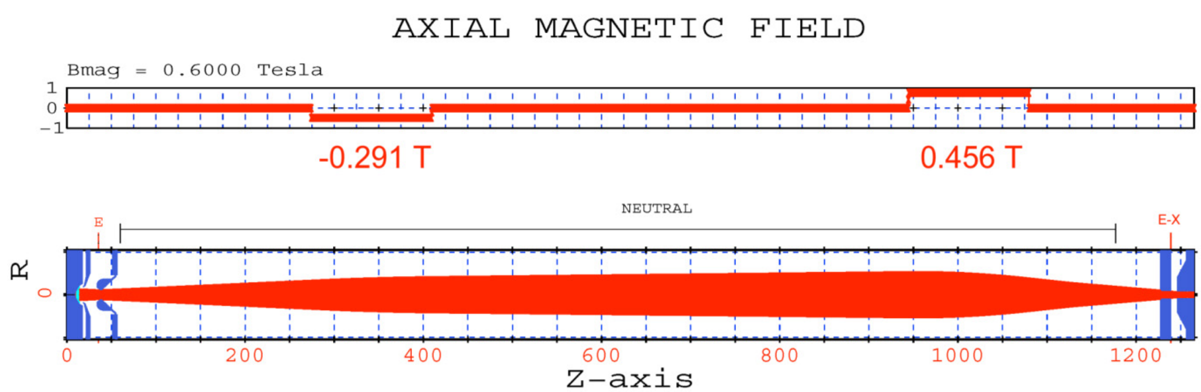

Figure 7: PBGUNS simulation of beam transport using the prototype 2-solenoid LEBT.

values in Fig. 3, but are still within the 0.35 π·mm·mrad acceptance limit of the SNS RFQ and linac.

The 40 mm long (compare with 22 mm in the present electrostatic LEBT) tapered chopper, shown in Fig. 10, is designed to accomplish the beam chopping with the existing chopper electronics system. Shown in Fig. 11 is a SIMION simulation of the reference particle with full energy of 65 keV. At the RFQ entrance ±2.5 kV chopping voltages displace the reference particle 5 mm from the axis with a trajectory angle 8.09°, which exceeds the chopping capability of the present electrostatic LEBT.

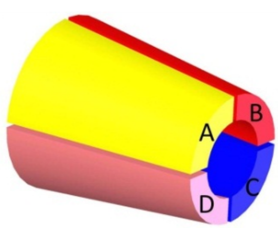

Figure 10: The long chopper for the 2-solenoid LEBT.

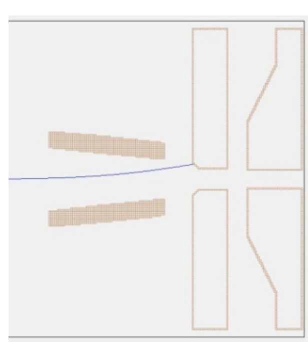

Figure 11: Deflection of the reference particle at the chopper target location with the 2-solenoid LEBT.

The solenoid magnet physical geometry was designed using Opera 2d [6] and MagNet [7] by cross checking the calculated fields. Figure 12 shows the magnet cross sectional view and calculated field distribution.

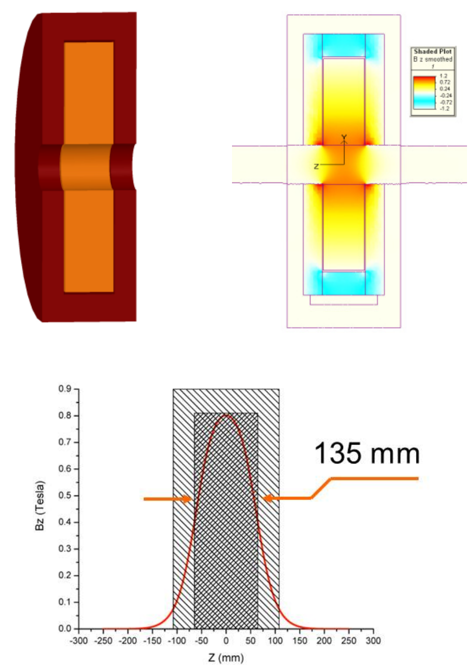

Figure 12: The solenoid magnet geometry and field.

REFERENCES

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[3] PBGUNS, http://www.far-tech.com

[4] SIMION, http://www.simion.com

[5] PBO Lab Trace-3D, http://www.ghga.com/accelsoft/

[6] Opera 2d, http://www.cobham.com/

[7] MagNet, http://www.infolytica.com/