THE NEW LEBT FOR THE SPALLATION NEUTRON SOURCE POWER UPGRADE PROJECT *

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Abstract

A magnetic 2-source LEBT is proposed for the Spallation Neutron Source Power Upgrade. It allows for switching between the two ion sources within less than an hour. The high-current H^- beam is transported and injected into the RFQ. A transverse electric chopper at the entrance of the RFQ chops ~300 ns beam every ~1 µs. Beam envelope calculations show that the new LEBT is robust because it is capable of perfectly matching the beam into the RFQ for broad ranges of the parameters describing the input beam. Physics design of the individual elements of this new LEBT is also presented.

INTRODUCTION

The Spallation Neutron Source (SNS) power upgrade will roughly double the neutron flux by increasing the LINAC beam energy from 1 to 1.3 GeV and by increasing the LINAC beam peak current from 38 to 59 mA at 6% duty-factor [1]. Because the beam losses in the RFQ increase with beam current and emittance, the RFQ input current needs to be increased from 41 to 67 mA if the normalized rms emittance can be maintained at 0.2 π·mm·mrad, or to 95 mA if the emittance increases to 0.35 π·mm·mrad, which is the largest acceptance desirable for the linac. This imposes challenging requirements on H^- ion sources with regard to current output, emittance and lifetime. Efforts to develop H^- sources that meet the requirements are discussed by R.F. Welton et al [2]. Equally important is a robust Low Energy Beam Transport (LEBT) system to transport and match the high current H^- beam into the RFQ without drastically increasing the beam emittance. Our existing electrostatic LEBT is vulnerable to losses from high power, high duty-factor beams and also to sparks induced by high voltages in the H^- source inherent high pressure vacuum environment. Magnetic LEBTs are spark free, durable to uncontrolled beam losses and can transport high current H^- beam with space-charge neutralization [3]. As most magnetic LEBTs, our LEBT features two solenoids, but has an intermediate dipole magnet, which allows for switching between two ion sources. This is needed to meet the 99.5% ion source availability requirement for the SNS ion source and LEBT.

LEBT LAYOUT DESIGN

Fig. 1 shows the conceptual design of the proposed new magnetic LEBT that connects the ion sources to the RFQ. Right in front of the RFQ is a four-quadrant circular aperture electrical beam chopper which chops the 1 ms macro pulse beam from the ion source and LEBT to ~700 ns mini pulses with ~300 ns gaps between them. The 1 MHz fast chopping fields and the RFQ entrance fields prevent the ion beam from accumulating neutralizing charges from collisions with the residual gas. To match the beam twiss parameters at the RFQ entrance ($\alpha = 1.79$, $\beta = 0.0725$ m/rad), the required values at the chopper entrance are approximated for different beam currents and different distances from the chopper entrance to the RFQ by Trace-3D calculations assuming a uniform space charge distribution. Table 1 shows the results for a beam with an normalized rms emittance of 0.35 π·mm·mrad.

Table 1: Required α and β at the entrance of the chopper

mA\mm		30	40	50	60	70	80	90
20	α	3.8	4.51	5.23	5.96	6.71	7.47	8.24
	β	0.24	0.32	0.42	0.53	0.66	0.80	0.96
40	α	4.07	4.91	5.78	6.68	7.61	8.55	9.52
	β	0.25	0.34	0.44	0.57	0.71	0.87	1.05
60	α	4.35	5.32	6.35	7.41	8.52	9.67	10.8
	β	0.25	0.35	0.47	0.60	0.76	0.95	1.15
80	α	4.63	5.74	6.92	8.17	9.47	10.8	12.2
	β	0.26	0.36	0.49	0.64	0.82	1.02	1.25
100	α	4.91	6.17	7.51	8.94	10.4	12.0	13.6
	β	0.27	0.38	0.52	0.68	0.87	1.10	1.35

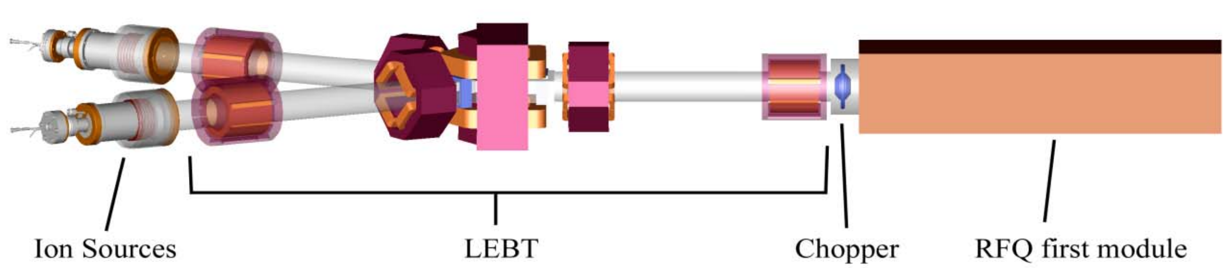

Fig. 1: Schematic Layout of the new magnetic LEBT for SNS power upgrade.

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A ~4 cm long chopper with its end face 2 cm apart from the RFQ entrance is presently considered. The LEBT has two identical ion source beam lines located symmetrically to the RFQ injection beam line with an angle determined by the dipole bending angle. The beam path consists of a solenoid, a quadrupole singlet, a sector dipole (normal entrance and normal exit), a quadrupole singlet and a solenoid in this sequence. The quadrupole singlets are placed close to the entrance and exit of the sector dipole to focus the beam normal to the bending plane while defocusing in the bending plane. This defocusing is desired to compensate the focusing by the sector magnet. Four tunable elements provide convenience and flexibility for matching the beam Twiss parameters in both horizontal and vertical planes.

Designing a compact LEBT is desirable for H^- beams to minimize the losses from collisions with the residual gas. Accordingly, we selected short solenoids (12 cm) and quadrupoles (10 cm), and kept the drift distances to the minimum required for pumps and necessary diagnostics devices. We focused on the design of the dipole magnet. Trace-3D was used to find the best combination of the dipole bending angle and radius. The calculations were performed for 0 mA current, reflecting fully neutralized beams. Besides matching the Twiss parameters at the chopper entrance and avoiding beam crossover within the LEBT, the third goal was to reduce the vertical beam size inside the dipole magnet. Table 2 summarizes the maximum radius within the dipole calculated from the 5σ vertical ellipse of a neutralized 80 mA beam with a normalized rms emittance of 0.35 π·mm·mrad for different combinations of bending angles and radii. The table shows the smaller bending angles and larger bending radii to yield smaller vertical beam radii inside the dipole magnet. Considering spatial interference between the two ion source beam lines, we chose 30° angles with a 30 cm radius requiring a ~60 mm gap.

Table 2: Vertical beam radii (mm) vs. dipole bending angle (degree) and radius (cm)

Radius (cm) / Angle (deg)	15.0	20.0	30.0	40.0	45.0	50.0	55.0
25.0	19.0	20.6	23.6	28.6	38.2	-	-
30.0	19.0	20.6	22.7	26.4	28.6	33.3	38.1
35.0	19.0	20.2	22.5	24.6	26.6	29.4	33.3
40.0	19.0	20.2	22.2	23.8	25.4	27.8	29.8

Trace-3D was used to study the robustness of this lattice: For a broad range of input beam parameters, i.e. currents 20–100 mA, emittances 0.2–0.35 π·mm·mrad with different beam sizes and divergences, the 2 solenoids and the 2 quadrupoles can be tuned to achieve a perfect matching of the beam to the chopper entrance. Solenoid fields are in the range of 0.4 – 0.6 T and the field gradients in the quadrupoles are between 0.2 – 0.3 T/m. Fig. 2 shows the 5σ beam envelope of an 80 mA beam with a normalized rms emittance of 0.35 π·mm·mrad being transported through the LEBT and matched into the chopper. The total length of the beam path is about 185 cm. Along the entire beam path, the beam diameter does not exceed ~50% of the 100 mm apertures of the solenoids and quadrupoles, nor exceeds ~60% of the 90 mm wide horizontal opening of the dipole magnet at the entrance.

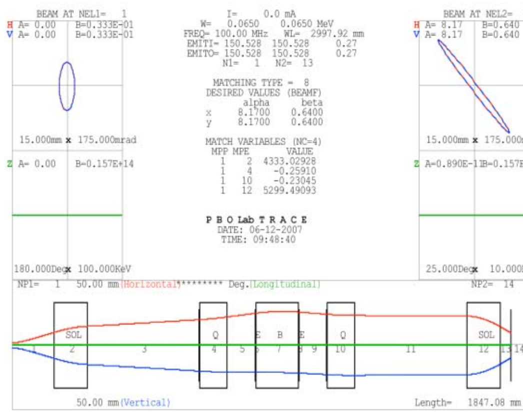

Fig. 2 Envelope of a 80 mA, 0.35 π·mm·mrad beam through the LEBT (elements are not drawn to scale).

INDIVIDUAL ELEMENTS DESIGN

The physics design of individual elements of the LEBT is being detailed using Infolytica's MagNet program [4].

Dipole Magnet

The 30° angle lines simply coincide with the pole shoe edges. In order to confine the fringe fields, a field clamp is placed at each entrance and the exit of the magnet. Shown in Fig. 3.1 is the model of the dipole magnet built for field calculation and in Fig. 3.2 is a shaded plot of the calculated field on the midplane. Fig. 3.3 and Fig 3.4 are field distributions along the line (a) and (b) on Fig. 3.2, respectively.

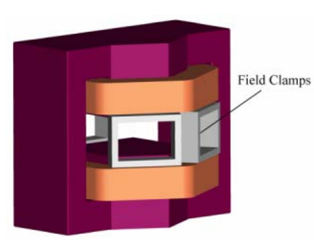

Fig. 3.1 Model of the dipole magnet.

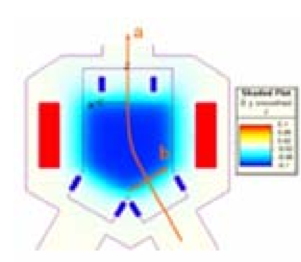

Fig. 3.2 Field distribution of the dipole on the midplane.

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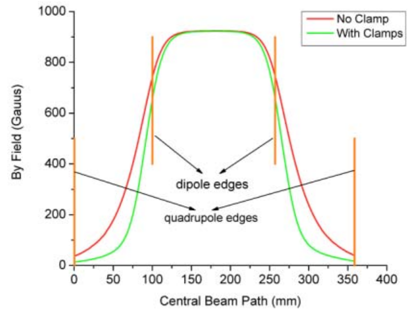

Fig. 3.3 Field distribution of the dipole along the central beam path on the midplane.

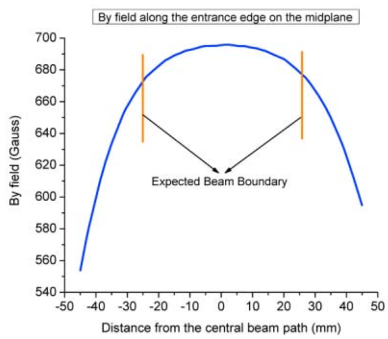

Fig. 3.4 Field distribution of the dipole along the entrance edges on the midplane.

The field clamps effectively shorten the fringe field extension and reduce its disturbance for the adjacent quadrupoles. For the expected beam filling regions, a field uniformity of better than 97%, which is at the smallest horizontal opening at the entrance, is anticipated.

Quadrupole Magnet

Poles are designed as circular shape with radius of 1.15 r_0 and width of 1.6 r_0 (r_0 is the quadrupole aperture radius). Fig. 4.1 is the model of the quadrupole magnet and Fig. 4.2 is a shaded arrow plot of the calculated field of the quadrupole on a slice cut normal to the axis at the mid length.

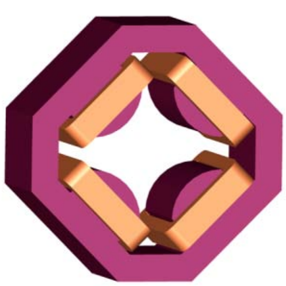

Fig. 4.1 Model of the quadrupole magnet.

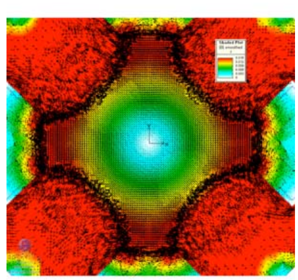

Fig. 4.2 Field distribution of the quadrupole on the mid length normal slice.

Fig. 4.3 shows a comparison of the calculated field of this quadrupole versus the analytical solution of an ideal hyperbolic shape quadrupole. Except the small random differences, no systematic field distortion is seen in the figure.

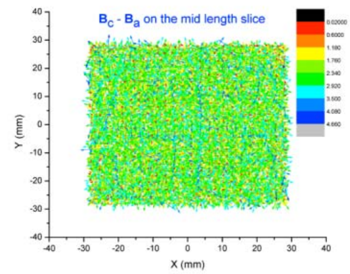

Fig. 4.3 Comparison of the quadrupole field to an ideal hyperbolic field.

Solenoid Magnet

Fig. 5.1 and 5.2 shows the conceptual design model of the solenoid magnet and its axial field distribution. We are also considering some other design from commercial vendors.

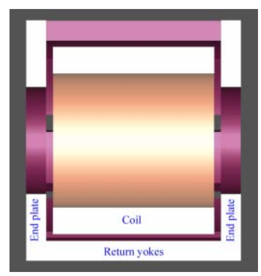

Fig. 5.1 Model of the solenoid magnet.

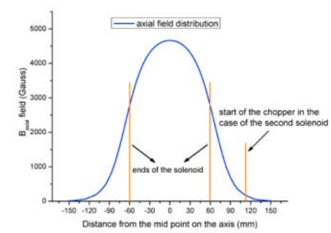

Fig. 5.2 Axial field distribution of the solenoid magnet.

CONCLUSIONS

The proposed magnetic, two-ion source LEBT for the SNS power upgrade will be capable of injecting high current, high duty factor H^- beams into the RFQ with perfect matching. This will allow maintaining a 99.5% availability even with limited ion source lifetimes. Ongoing design work is focused on individual element design and integration.

REFERENCES

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

