EVOLUTION OF THE LEBT LAYOUT FOR SNS*

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Abstract

As the startup Low-Energy Beam Transport (LEBT) for the Spallation Neutron Source (SNS) project is undergoing commissioning aimed at transporting a 35-mA H- beam, a new LEBT layout has been developed that is designed to transport a beam current of 65 mA, consistent with the revised nominal SNS beam-power goal of 2 MW. The SNS LEBT employs two electrostatic einzel lenses and provides static beam steering as well as fast chopping, implemented by splitting the second lens into four quadrants. The development was carried out using the code IGUN in a novel way that allows working with finite ion temperatures without encountering any problems. The changes with respect to the Startup LEBT layout affect electrode shapes in the upstream part only; the downstream part is kept as previously designed, to preserve the chopping action. In addition, the overall length was kept constant, and only minor changes had to be made to the design of some of the support structures; the vacuum tank design is identical to the previous one. The expected performance of this new LEBT, based on the simulations, is described for a large range of output Twiss-parameters and compared to simulation results for the startup configuration.

1 INTRODUCTION

The SNS Low-Energy Beam-Transport line (LEBT) utilizes two electrostatic einzel lenses to achieve two-parameter transverse beam matching at its exit plane. It also provides static beam steering as well as fast chopping, implemented by splitting the second lens into four quadrants and applying dc or pulsed voltages. Only the main matching function of the LEBT is being addressed in this paper, discussing the evolution of the electrode shapes after the Conceptual Design layout [1]

With the adoption of a 2-MW average beam-power scenario for the SNS Accelerator Systems, the Front-End Systems (FES) are required to deliver a 52-mA H^- beam to the Drift-Tube Linac. Under the conservative assumption of 20% beam loss in the RFQ, the first two FES subsystems, i.e. Ion Source and LEBT, have to produce a 65-mA beam of 65-keV energy at 6% duty factor with a transverse normalized rms emittance of 0.2 π mm mrad.

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The path of development at LBNL towards the stated performance goals goes through a series of demonstration experiments with a so-called R&D Ion Source in various configurations, a Startup Ion-Source/ LEBT system aiming at 35-mA beam current, and lastly the 65-mA Production System [2].

The 2D code IGUN [3] was used (substituting protons for H^- ions) to simulate the ion beam for various electrode shapes. IGUN assumes cylindrical symmetry, is rather easy to set up and run on a personal computer, and has proven to generate reliable results [4]. The code appears to exhibit a functional error, however, in cases such as the SNS ion-source extraction system, when a finite ion temperature is chosen among the input conditions. Then unrealistic splits of the output emittance and overly chaotic arrangement of the beam trajectories near the axis result from the calculations. Our detailed studies showed that these effects are associated with an anomalous curvature of the equipotential surface (meniscus) that separates ion-source plasma and beam.

Another complication is due to the presence of electrons in the extracted H^- ion beam, subject to the action of the 'electron-dumping' magnetic dipole field. The method of dealing with both of these effects is discussed in the following paragraph.

2 FINITE ION TEMPERATURE AND TREATMENT OF ELECTRONS

To overcome the meniscus problems in IGUN simulations associated with finite ion temperature, as well as to deal with the electron share in the upstream part of the beam, the calculation is split into three segments. In the first segment, from the upstream plasma boundary to the equipotential surface at 200 eV below meniscus potential (for protons), zero ion temperature is assumed. The trajectories crossing that equipotential surface are read out, and transverse angles are added to each of them, corresponding to the assumed ion temperature and alternating between radially outward, unchanged, and inward directions, see Figure 1. These modified trajectory data are used as input parameters for the subsequent calculation.

The relation between added or subtracted angles, $\Delta\alpha$, and the assumed ion temperature in this method is:

$$\Delta\alpha = 1000\ (3kT_i/4E_L)^{1/2} \quad [\text{ mrad }]$$

with T_i, transverse ion temperature and E_L (eV), longitudinal ion energy at the boundary equipotential.

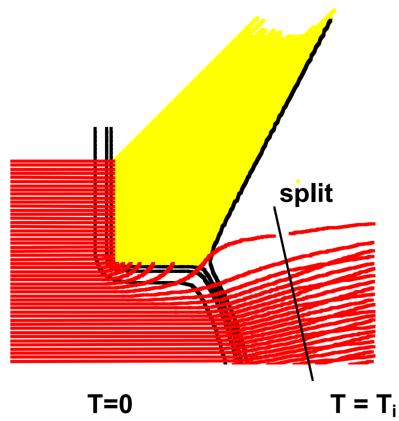

Figure 1. Detail showing the tip of the outlet electrode, plasma meniscus, and modified angles applied to the trajectories at the equipotential marked by 'split.'

In the real LEBT, the electrons that are extracted together with the negative ions are removed from the beam by a transverse magnetic dipole field generated by magnets inside the ion-source outlet electrode [5]. We are simulating this 3-dimensional problem by adding an equivalent amount of ion current to the actual beam current that is under investigation. The increased current value is applied over a longer section of the extraction gap than the zero-temperature region mentioned before, to the equipotential surface at 2 keV below meniscus potential, as shown in Fig. 2. This method was developed in an earlier work [6].

In the third section of the calculation, the ion current is reduced to the actual value. To find the correct shapes for
the equipotentials between these three sections the problem has first to be run twice with zero ion temperature, over a length of approximately two adjacent sections in each case, before individual sections can be treated one after the other.

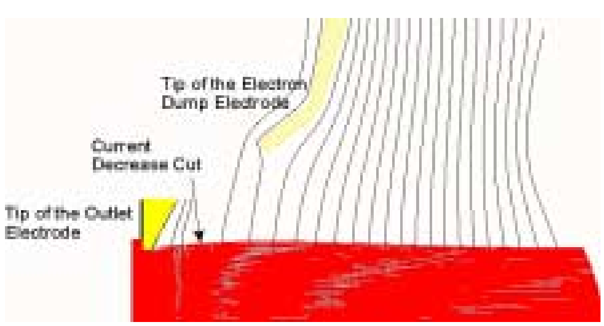

Figure 2. Formation of a 90 mA H^- beam with 2-eV ion temperature. Downstream of the 'Current Decrease Cut' mark, the ion current amounts to 65 mA.

The choice of the added current amount as well as the location where the current is reduced to nominal is rather arbitrary, especially so because the axial electron velocity will gradually decrease from very high values to zero over the region of interest. To resolve this issue, we empirically calibrated the process by comparing a measured emittance with simulation results for a 40-kV, 8-mA ion-beam current in the Startup LEBT. It turned out that an 'electron' current higher by a factor of 6 than the ion current led to good agreement with the measured emittance size and Twiss parameters in this case, where no cesium was used in the ion source. For source operation with cesium, no measured emittance values were available, but a 1:2 ratio between 'electron' and ion currents appeared appropriate, consistent with the scaling of actually measured electron currents for both modes of operation.

By varying this ratio in test simulations, we established that the assumed value is rather uncritical and that in any case residual effects can easily be corrected in the real system by adjusting the potential of the extractor electrode. Such a change would modify the voltage in the main extraction gap without affecting the beam energy in the LEBT exit plane.

3 LEBT ELECTRODE SHAPES

The first version of the Startup LEBT was characterized by a pointed extractor shape and short lens electrodes of equal inner aperture [7]. A simulated emittance diagram for this LEBT is shown in Fig. 3, and Fig. 4 shows the shapes of its electrodes, together with the outlines derived for later versions of the Startup as well as the Production design. The ion-optical qualities of the Startup LEBT suffer from the action of the electron-dumping magnet field in the extraction gap that extends beyond the front face of the extractor electrode.

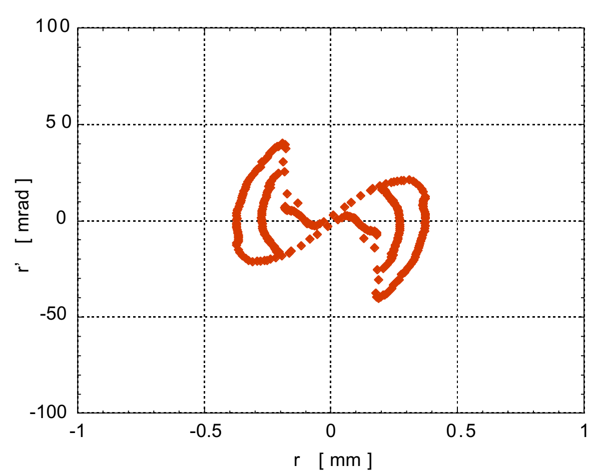

Figure 3. Simulated emittance for the 35-mA Startup LEBT with a normalized size of 0.076 π mm mrad.

Even though the ion source can be tilted with respect to the LEBT axis there remains a bending effect on the ion trajectories that cannot be compensated mechanically. By changing the material from copper to ferromagnetic stainless steel a field clamp was generated that effectively annihilates the harmful fringe field [8].

The first simulation attempts to pass a 65-mA ion beam through the startup LEBT showed that the beam blows up too much in the extraction gap. Therefore the extractor aperture was widened, and in consequence the first lens aperture had to be widened as well and made longer to stay within a voltage range around 45 kV. With this design as shown in Fig. 4, the simulations show that a 65-mA beam can well be transported, and the calculated emittance of 0.09 π mm mrad leaves a comfortable margin for effects that are not accounted for in our simplified 2-dimensional treatment.

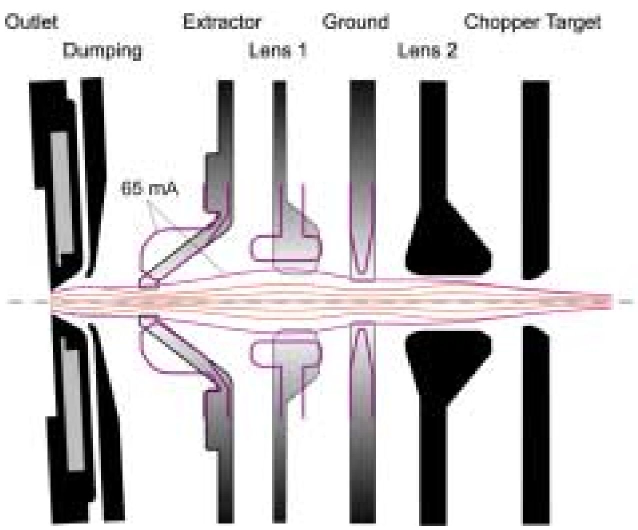

Figure 4. LEBT electrode shapes. Full black, outlines of electrodes that were not modified. Faded solid shapes depict the early 35-mA Startup LEBT. Open contours depict the 65-mA Production LEBT. All beam trajectories are artist's conceptions emphasizing the optical characteristics of the two basic structures.

The simulated emittance for the Production LEBT is shown in Fig. 5. The extractor with the new shape was already tested experimentally at the LBNL Integrated Testing Facility [8], together with the other Startup LEBT electrodes, and the other modified electrodes that characterize the Production LEBT have just been mounted and are ready for testing.

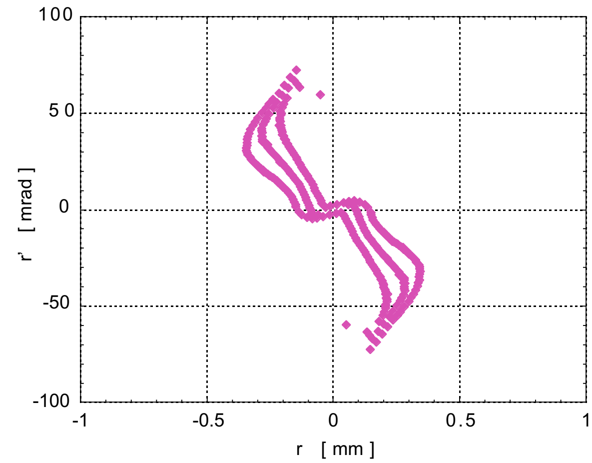

Figure 5. Simulated emittance of the 65-mA production LEBT with a normalized size of 0.09 π mm mrad.

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