MEASUREMENT OF HALO MITIGATION SCHEMES FOR THE SPALLATION NEUTRON SOURCE LINAC*

Dong-o Jeon#, ORNL, Oak Ridge, TN37830, USA

Abstract

A series of emittance measurements were performed at the end of Drift Tube Linac tank 1 of the Spallation Neutron Source to verify experimentally the previously proposed halo generation mechanism and its mitigation schemes [1]. The emittance measurements clearly showed a visible reduction in the halo as well as a significant reduction in the rms emittance when the proposed round beam optics is employed. This confirms experimentally the new halo generation mechanism.

INTRODUCTION

The Spallation Neutron Source (SNS) accelerator system is designed to accelerate intense proton beams to energy of 1-GeV, delivering more than 1.4 MW (upgradeable to 2 MW) of beam power to the neutron production target [2]. The peak current in the linac is 38mA and the macropulse average current is 26mA due to chopping. The SNS linac has the following structure; ion source, LEBT (Low-Energy Beam-Transport), RFQ (Radio-Frequency Quadrupole), MEBT (Medium-Energy Beam-Transport), DTL (Drift Tube Linac), CCL (Coupled Cavity Linac), and SCL (SuperConducting Linac). A primary concern is potential damage and radio activation of accelerator components resulting from uncontrolled beam losses. A major source of loss is beam halo that intercepts the bore of the linac.

The uncertainty in the initial matching condition is Beam dynamics simulations of the SNS linac showed that the beam halo develops at low energy, but some halo particles survive acceleration to higher energies before being lost primarily on the CCL bore. This particle loss at higher energies results in radio activation of the CCL. In order to find ways to mitigate this halo related beam loss, studies were conducted to identify the sources and mechanism of halo formation. It turns out that the MEBT is the largest contributor to Front End (FE) halo generation in the SNS linac.

A new halo generation mechanism was reported in the non-periodic lattices such as the SNS linac MEBT (Medium-Energy Beam-Transport between RFQ and DTL) [1]. It was found that the nonlinear space charge force resulting from large transverse beam eccentricity ~2:1 in the ~1.6-m-long MEBT chopper section shown in the upper plot of Fig. 1 is responsible for halo formation. This MEBT optics is called as "nominal optics". As a result, the beam distribution, based on the Front End emittance measurements and multiparticle simulation studies, develops halo that leads to beam loss and radio activation of the SNS linac. Designing lattices with transverse beam eccentricity close to 1:1 as shown in the bottom plot of Fig. 1 suppresses this kind of halo generation. This optics is called as "round beam optics". Multiparticle simulations show that the rms emittance in both planes and halo are reduced significantly when the round beam optics is employed. Modifying the MEBT optics and introducing adjustable collimators in the MEBT significantly reduced beam losses in the CCL, which is a preferred scheme for mitigating halo. For the details, please refer to the previous study [1].

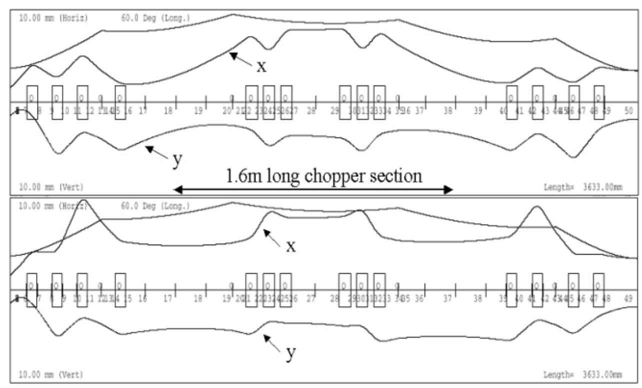

Figure 1: MEBT beam profiles obtained from Trace3D for the "nominal optics" at the top and for the "round beam optics" at the bottom employed for the emittance measurements. The beam is going from left to right.

A series of measurements were conducted to verify the effectiveness of the proposed halo mitigation scheme. One set of measurements was dedicated to see if the proposed round beam optics reduces halo and rms emittance. Round beam optics was adopted with transverse beam eccentricity close to 1:1 as shown in the bottom plot of Fig. 1. Matching was performed prior to measurements by minimizing the rms emittance in both planes. The other set was dedicated to see the effectiveness of the halo collimation in MEBT. For the DTL tank 1 commissioning, dedicated "Diagnostics-plate" [3] is attached at the end of DTL tank 1 (see Fig. 2). There are horizontal and vertical emittance slits and harps installed for the emittance measurements, enabling emittance measurements in both planes. The arrows indicate the horizontal slit and harp.

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#jeond@ornl.gov

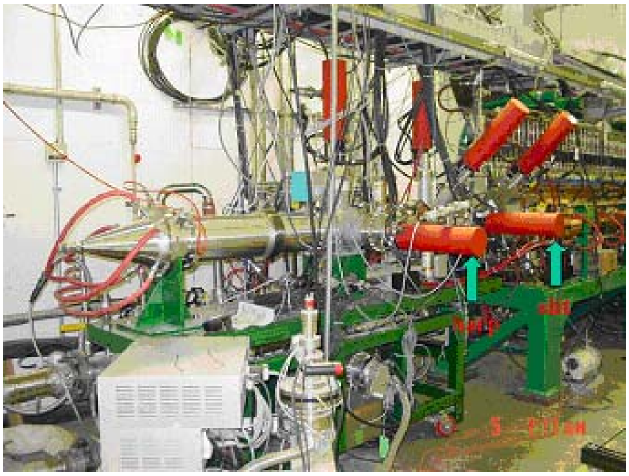

Figure 2: Photo of the Diagnostics plate attached at the end of DTL tank 1. The beam direction is right to left.

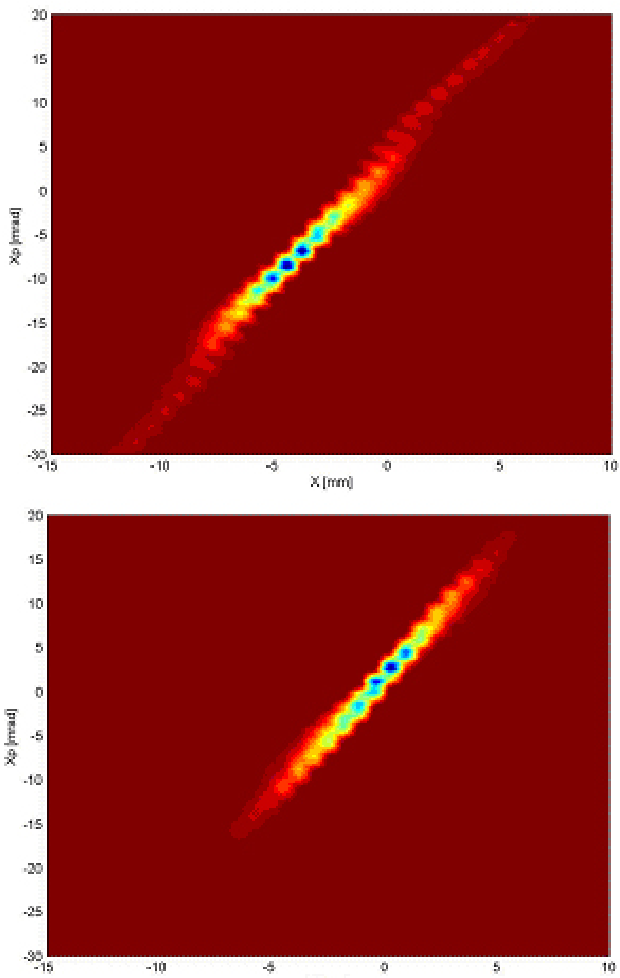

Figure 3: Horizontal emittance plots of the nominal MEBT optics (the top plot) and the round beam optics (the bottom plot). The halo is visibly reduced. The rms emittance is reduced from 0.593 mm-mrad to 0.376 mm-mrad.

Figure 3 shows the results of horizontal emittance measurements for two different MEBT optics; one is the nominal optics and the other the round beam optics. Compared with the nominal MEBT optics, the halo is visibly reduced and the rms emittance is significantly reduced from 0.593 mm-mrad to 0.376 mm-mrad when the proposed round beam optics is employed. Because there is one electromaget quadrupole between the downstream end of DTL tank 1 and the emittance slits, the beam is rather stretched out in horizontal plane. Figure 4 shows the results of the vertical emittance measurements. Again visible reduction in the halo should be noted. The rms emittance is reduced from 0.353 mm-mrad to 0.264 mm-mrad.

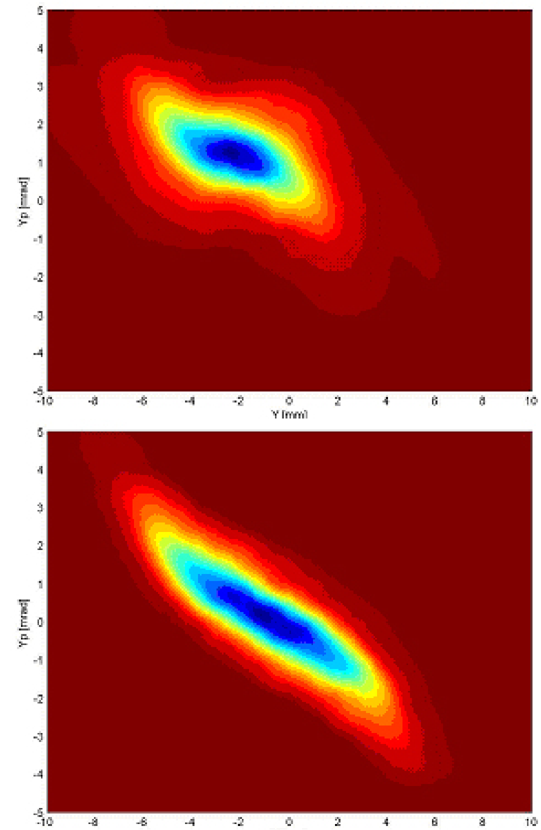

Figure 4: Vertical emittance plots of the nominal MEBT optics (the top plot) and the round beam optics (the bottom plot). The halo is substantially reduced. The rms emittance also is reduced from 0.353 mm-mrad to 0.264 mm-mrad.

The ratio ε(round beam optics)/ ε(nominal optics) of measurement results are consistent with the multiparticle simulations using the Parmila code [4]. One thing to note was that the horizontal rms emittance was about 1.5 bigger than the simulated rms emittance, whereas the measured vertical rms emittance was consistent with the simulated rms emittance. The cause of this consistent discrepancy in horizontal rms emittance is still under investigation. For instance, a factor 1.5 difference was noticed between the X beam profile obtained from the wire-scanner measurement and emittance measurement. However, the Y beam profile from wire-scanner measurement was consistent with that from the emittance measurement.

Plots of beam distributions obtained from the simulation are shown in Fig. 5. The upper plots are beam distributions when the nominal MEBT optics is used and the lower plots when the round beam optics is used. The model predicts that the extended halo in the horizontal plane for the nominal optics disappears when the round beam optics is used, just like the measurement results in Fig. 3. The model also predicts that the rms emittance in both planes is reduced significantly when the round beam optics is employed instead. The ratio of ε_x(round beam optics)/ε_x(nominal optics) = 63% for the measurement and 60% for the simulation. Likewise ε_y(round beam optics)/ε_y(nominal optics) = 75% for the measurement and 88% for the simulation.

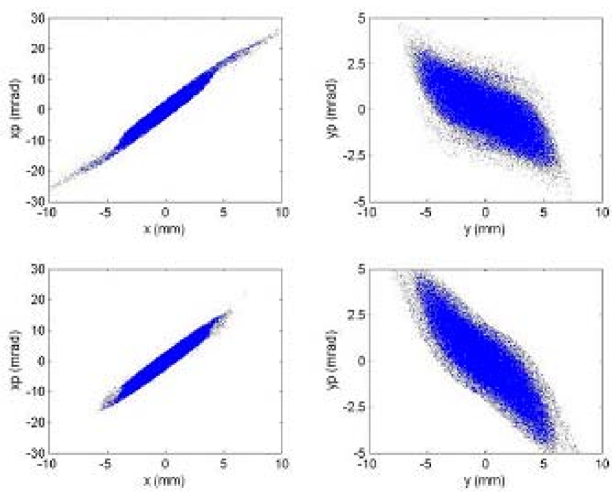

Figure 5: Plots of simulated beam distributions. Upper plots are obtained using the nominal MEBT optics and lower plots using the round beam MEBT optics. Reduction in halo is visible in both planes.

There exist some uncertainty in comparing the model with measurements. It seems that the read-back signals from the quadrupoles are not so accurate judging from our experience during the commissioning. So it's unclear how accurately the model reflects the real machine. Nonetheless simulation results are consistent with the measurement results.

CONCLUSION

A series of emittance measurements demonstrated the validity of the halo mitigation schemes the previous study proposed [1]. Emittance measurements confirmed significant reduction both in the rms emittance and in the halo when the round beam MEBT optics is employed. This also serves as a valuable benchmarking of space charge codes demonstrating that measurements results are quite consistent with the simulation. Collimation experiment was also consistent with the model predictions.

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