EXPERIMENTAL VERIFICATION OF HALO FORMATION MECHANISM OF THE SNS FRONT END*

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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].

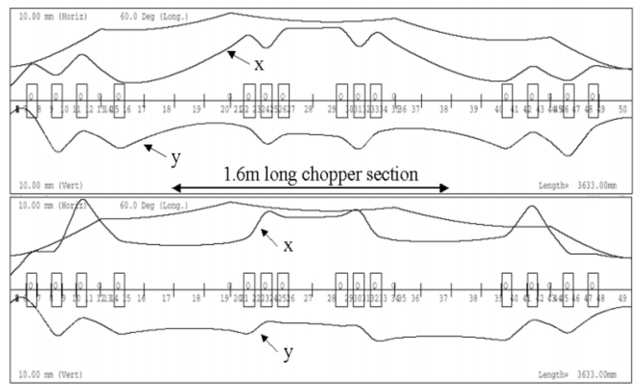

Figure 1: MEBT beam profiles obtained from Trace3D for the “nominal optics” at the top and for the “round beam optics” at the bottom employed for the emittance measurements. The beam is going from left to right.

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. 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.

* SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.
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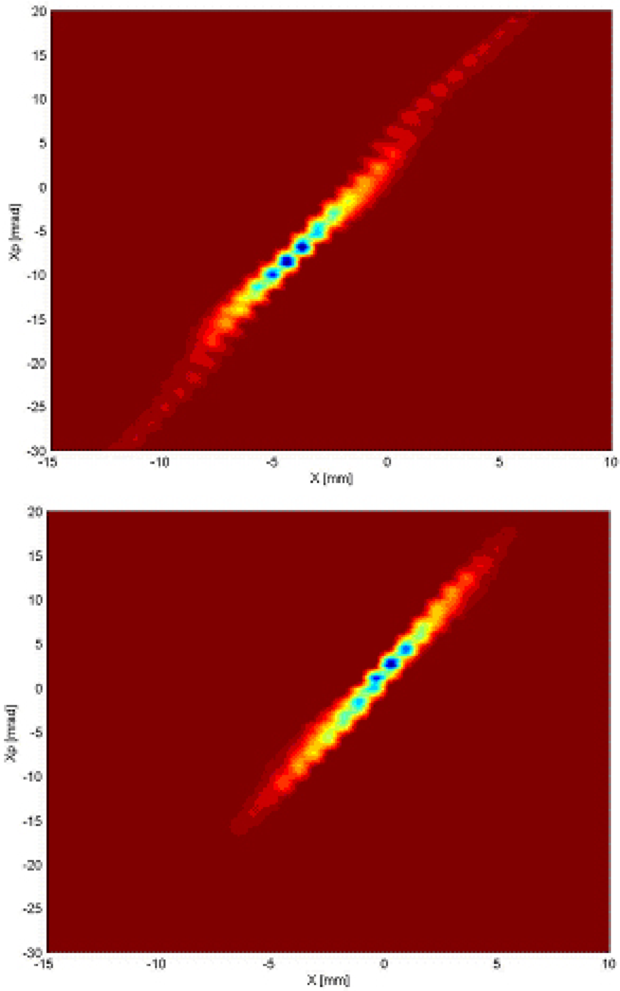

Figure 2: Horizontal emittance plots of the nominal MEBT optics (the top plot) and the round beam optics (the bottom plot). The halo is visibly reduced. The rms emittance is reduced from 0.454 mm-mrad to 0.289 mm-mrad with 0% threshold.

Figure 2 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 0.454 mm-mrad to 0.289 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. The results of the vertical emittance measurements are shown in Fig. 3. Again visible reduction in the halo should be noted. The rms emittance is reduced from 0.472 mm-mrad to 0.306 mm-mrad.

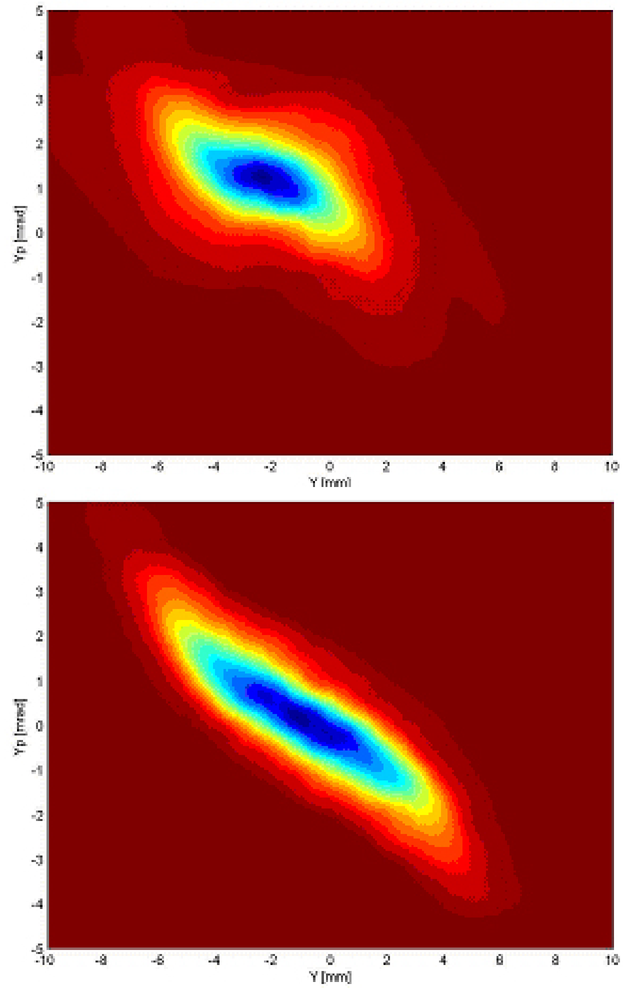

Figure 3: Vertical emittance plots of the nominal MEBT optics (the top plot) and the round beam optics (the bottom plot). The halo is substantially reduced. The rms emittance also is reduced from 0.472 mm-mrad to 0.306 mm-mrad with 0% threshold.

The ratio ε (round beam optics) / ε (nominal optics) of measurement results are consistent with the multiparticle simulations using the Parmila code [4].

Plots of beam distributions obtained from the simulation are shown in Fig. 4. 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) = 64% for the measurement and 74% for the simulation. Likewise ε_y (round beam optics) / ε_y (nominal optics) = 65% for the measurement and 91% for the simulation.

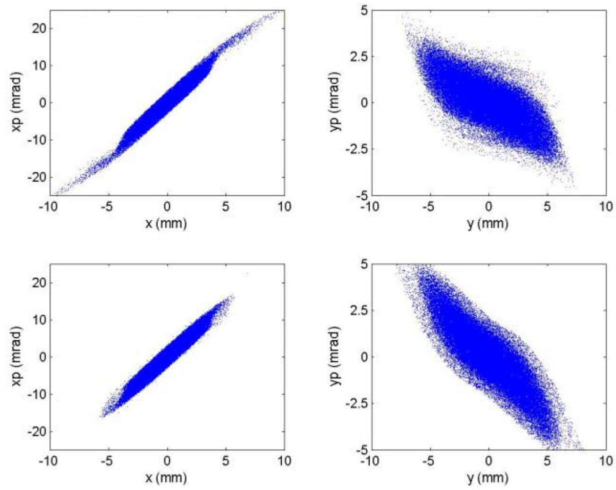

Figure 4: Plots of simulated beam distributions. Upper plots are obtained using the nominal MEBT optics and lower plots using the round beam MEBT optics. Reduction in halo is visible in both planes.

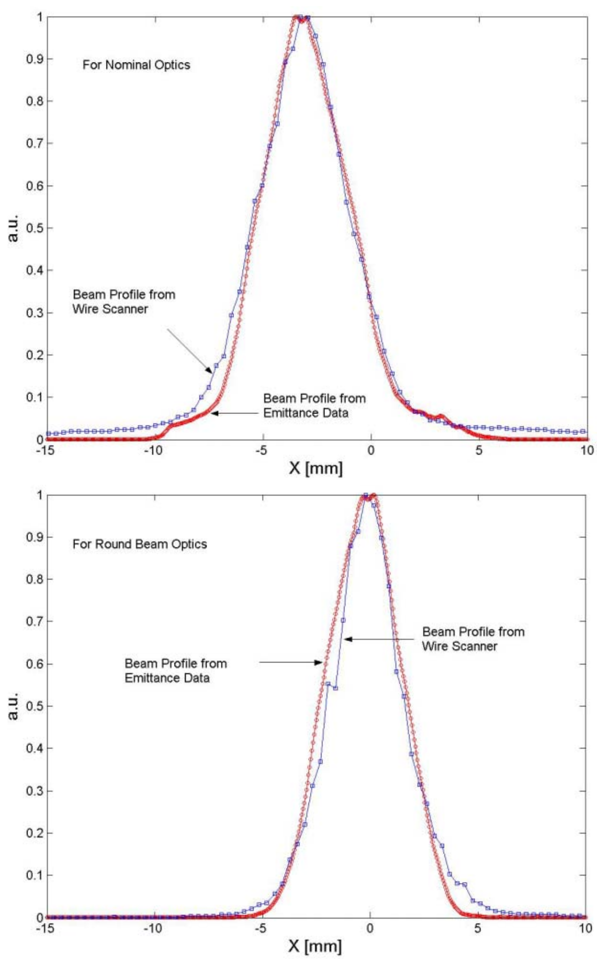

Figure 5: Plots of horizontal beam profile for two different optics sets. The top plot is for the nominal optics and the bottom for the round beam optics. Beam profile plots were obtained from the emittance data and wire scanner data. Wire-scanner seems to overestimate the tail at low intensity.

A comparison was made between the emittance data and raw wire scanner profile data. The beam profiles from the emittance data were consistent with the wire scanner beam profiles, as expected. The core of beam profiles obtained from the emittance data agrees well with the core wire scanner beam profiles for the two different sets of optics, as shown in Fig. 5. However, it is interesting to note that wire scanner seems to overestimate the beam tail compared with the profile obtained from the emittance data.

CONCLUSION

A series of emittance measurements verified the halo formation mechanism in MEBT of the SNS linac previously predicted through simulation studies [1]. Emittance measurements confirmed significant reduction both in the rms emittance and in the halo when the round beam MEBT optics is employed as predicted. This also serves as a valuable benchmarking of space charge codes demonstrating that measurements results are quite consistent with the simulation.

REFERENCES

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