EXPERIMENTAL CHARACTERIZATION OF THE SPALLATION NEUTRON SOURCE ACCUMULATOR RING COLLIMATION SYSTEM

S. Cousineau , S. Assadi , J. Holmes, M. A. Plum, SNS, ORNL, Oak Ridge, TN 37830, USA

Abstract

The SNS ring and associated transport lines, commissioned in January 2006, are designed to accumulate and deliver up to 1.5e14, 1 GeV protons at 60 Hz to a liquid mercury target for neutron production. In order to control activation and to allow for routine hands-on maintenance of accelerator components, beam loss in most of the ring must remain below 1 W/m. For the full 1.4 MW beam, this translates to a fractional beam loss limit of 0.02%. Accomplishing this loss limit at full beam power will require successful utilization of the ring's two-stage betatron collimation system. In this paper we present the results of initial collimation experiments. We characterize the collimation-induced beam-loss pattern and compare our results with simulations.

INTRODUCTION

The Spallation Neutron Source accumulator ring is a 248 meter storage ring designed to accumulate up to 1.5×10^{14} protons per pulse (ppp) for use in neutron production. In order to minimize activation and allow for hands-on maintenance of accelerator hardware, uncontrolled beam loss must remain below the 1 Watt/meter level [1]. For the nominal ring beam intensity, this translates to an uncontrolled beam loss limit of 0.02% of the beam intensity. To aid in achieving this limit, a betatron collimation system has been installed in one of the four straight sections of the accumulator ring. The purpose of the collimation system is to pre-emptively intercept and remove beam halo particles before they impact the machine aperture.

The SNS ring collimation system is a two stage system. The first stage consists of four, 4.5 mm tantalum scrapers. The scrapers are aligned at angles of 0 degrees, 90 degrees, 45 degrees, and -45 degrees, and thus cover half of the beam aperture. Additionally, their radial distance from the beam pipe center is adjustable in the range of a few mm from the center of the beam pipe, to a completely retracted position near the edge of the beam pipe. The purpose of the scrapers is to project the intercepted particles to high emittances, which leads to better absorption efficiency during the second stage of collimation. The presence of these adjustable scrapers distinguishes this system from a single-stage system, where particles are initially intercepted by the secondary absorbers.

The second stage of the SNS ring collimation system consists of three fixed aperture secondary absorbers. These collimators have apertures of approximately 300 πmm-mrad, which is roughly half-way between the anticipated full intensity beam emittance, and the machine aperture; therefore the collimators are the limiting aperture in the ring. The three collimators vary in length between 1.2 m to 1.8 m. The core of the collimators is composed of a steel sphere particle bed mixed with recycling borated water, and surrounded by solid steel shielding; additional shielding flanks both ends of the collimators. The collimators a situated downstream of the scrapers, in locations optimized for efficient absorption and minimum contamination of local area machine hardware [2]. A schematic layout of the collimation system is shown in Figure 1.

Since commissioning of the accumulator ring in January of 2006 [3], the collimation system has been exercised several times for dedicated collimation experiments. In this paper we present the analysis of on of these experiments, as well as a benchmark simulation of the experiment.

ANALYSIS OF EXPERIMENTAL DATA

One method for studying collimation system behavior is through the use of single-minipulse beam experiments, whereby a single, 690 ns beam pulse is injected into the ring and sent to the collimation system in various fashions. With the use of a single minipulse of beam, we deposit of a known amount of beam power into the collimation system without violating any loss limits. The goals of this experiment were threefold: 1) To compare loss distributions for single-stage versus two-stage collimation, 2) To measure the loss distribution for different scraper positions, 3) To benchmark with simulation.

In the experiment described here, a single minipulse of beam was lost to the collimation system for a number of vertical (90 degree) scraper positions, from a fully retracted position to an almost fully inserted position. The injection amplitude of the minipulse was adjusted until the minipulse intercepted the collimation system. Beam loss monitors (BLMs) spaced in strategic locations through the collimation straight and the remainder of the ring indicated the loss pattern for each setting. The BLMs report in units of rads/pulse. The conversion of BLM signals to more meaningful units of joules of energy deposition will be addressed in the benchmarking section.

1-4244-0917-9/07/$25.00

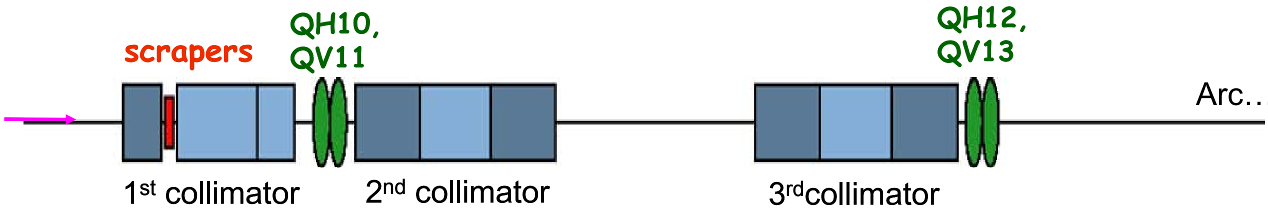

Figure 1. Layout of the ring collimation system. The beam direction is indicated with the pink arrow at left. The variation in blue in the collimators indicates shielding (dark blue) versus particle bed (light blue). This figure is not to scale.

For the 55 mm, scraper-retracted setting, the limiting aperture in the machine was the secondary collimators. Thus in this case the single minipulse went directly to the secondary collimators and underwent single-stage collimation. For the remainder of the scraper settings, the minipulse intercepted the scraper first, undergoing two-stage collimation. Figure 2 compares the difference in the loss distribution between single-stage and to two-stage collimation, e.g., between the retracted scraper setting (55 mm) and the first inserted scraper setting (35 mm). A significant difference is observable between the two loss patterns, with the single-stage system having a higher proportion of losses towards the end of the collimation straight, and in the downstream arc. Although the distribution of particles among the collimators in the single-stage system could be sensitive to the injected beam transverse phase space coordinates, the high readings in BLM_C01 and BLM_C02, which detect losses in a downstream arc quadrupole and dipole, respectively, clearly indicate collimation inefficiency.

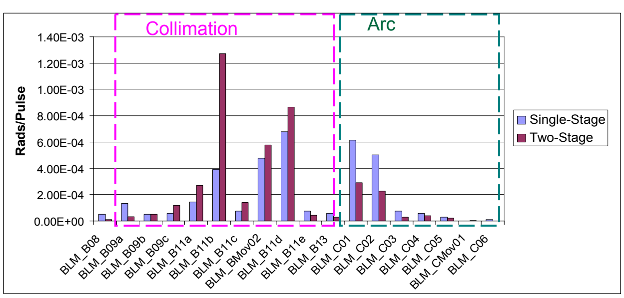

Figure 2. Comparison of the beam loss pattern in the collimation straight and downstream arc for a minipulse of beam collimated in a single-stage (blue) versus a two-stage (red) fashion.

Conversely, the two-stage loss pattern is dominated by losses in the upstream end of the collimation region. A much higher fraction of the particles in this scenario land in the collimators, and therefore, the efficiency of the system is much higher. However, some beam loss is still seen on the downstream arc BLMs.

In order to correctly assess the behavior of the collimation system, it is important to understand the source of the beam loss in the downstream arc. These losses are always present in the ring, regardless of whether the scrapers are in or out. A large amount of evidence, not shown here, supports the theory that these losses are due to single-stage collimation of foil scattered particles. Foil scattered particles have emittances greater than the collimator aperture, and are either lost immediately in the injection region, or downstream on the first pass through the collimation system. Since the scrapers enclose only one-half of the beam aperture, and because particle phasing will dictate that only a portion of the scattered particles will intercept the scrapers on the first turn, most of the foil scattered particles undergo single-stage collimation with low absorption efficiency. Particles which enter the collimation system and out-scatter before being absorbed are typically off-energy and outside of the dynamic aperture of the machine. These particles will land in the first appropriately phased limiting aperture, in this case the downstream quadrupole and dipole. Some reduction of loss has been observed by inserting one of the scrapers to appropriately collimate the foil-scattered tail, but this lead to only a modest (30%) reduction in the arc losses. A set of scrapers spanning the entire aperture of the beam would be necessary in order to realize a large reduction

With this in mind, to obtain the loss pattern for a two-stage system, one has to subtract out the contribution of single-stage collimation of foil losses. This has been done in another set of data, not shown here due to space limitations. The results indicate that that two-stage collimation leads to very little loss in the downstream arc, and therefore is efficient.

The next goal of the experiment was to test the loss distribution pattern versus scraper setting. This mimics scraping the edge of different emittance beams. Figure 3 shows the result, for seven different scrapers settings. The plot shows that the beam loss pattern is fairly independent of scraper setting, at least to within our ability to inject and collimate identical beam pulses.

Finally, we chose the loss distribution from the 35mm scraper setting shown in Figure 3 as a benchmark data set. The benchmark was performed with the ORBIT simulation code [4], a PIC-style code designed specifically for simulating high intensity beams. The code has a Monte-Carlo style collimation module, and the ability to place an arbitrary number of machine apertures at any locations in the ring for simulating beam loss.

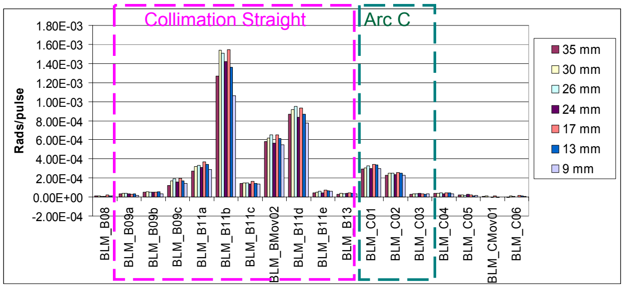

Figure 3. Comparison of the beam loss pattern in the collimation straight and downstream arc for a minipulse of beam collimated at different scraper positions.

In order to compare the simulation with experiment, its is necessary to convert the BLM readings from rads/pulse to Joules/pulse. To do this, we carefully classified each of the BLM behaviors, and then made two approximations. First, that the BLMs could generally be sorted into two categories: 1) Normal BLMs, and 2) Highly shielded BLMs which detect collimator losses. The second approximation was that the sum of the BLM losses, converted to Joules, should equal the total beam energy lost in the ring. From here, we did localized beam spills to determine the "normal BLM" conversion factor from rads/pulse to Joules. Then, by depositing a known amount of beam charge in collimation system, we tallied the amount of beam energy lost to the normal BLMs, and assigned the remainder to the shielded BLMs, giving us our "shielded BLM" conversion factor. The approximations should hold in a first-order sense, at least for beam losses primarily in the collimation region.

The resulting benchmark is shown in Figure 4, where the bluepoints are the ORBIT simulation, and the pink points are the BLM readings, converted to Joules. The dashed blue lines are present only to guide the eye, not as data points. The benchmark produces a loss pattern very similar to that seen in measurement. The losses on the scraper and first two collimators are in reasonable agreement with measurement; however, the simulated loss on the third collimator is high compared to measurement. Full injection modeling and foil scattering was not included in the simulation because of computational expense, and thus it is not surprising that the measured losses are higher in the arc than in simulation. Finally, one area where the simulation clearly underestimates the amount of beam loss is in the quadrupole doublet between the first and second collimator. This is not yet understood. The BLM reporting this loss is located on the front face of the second collimator, but we believe it primarily detects losses from the upstream quadrupole doublet, and not from the collimator. However, if it did detect losses from both areas, then our treatment of the BLM would be incorrect. Further investigation is needed to resolve this issue.

ACKNOWLEDGMENTS

Research on the Spallation Neutron Source is sponsored by the Division of Materials Science, U.S. Department of Energy, under contract number DE-AC05-96OR22464 with UT-Battelle Corporation for Oak Ridge National Laboratory.

REFERENCES

1. J. Wei, et al, "Low-loss design for the high intensity accumulator ring of the Spallation Neutron Source", Phys. Rev. ST Accel. Beams 3, 080101 (2000)
2. S. Cousineau, "Understanding Space Charge and Controlling Beam Loss in High Intensity Synchrotrons," PhD Thesis, Indiana University, 2003.
3. M. Plum, "Commissioning of the Spallation Neutron Source Accelerator Systems," These proceedings.
4. J. A. Holmes et al, "ORBIT: beam dynamics calculations for high intensity rings", Proc. EPAC'02, Paris, June 2002, p. 1022.

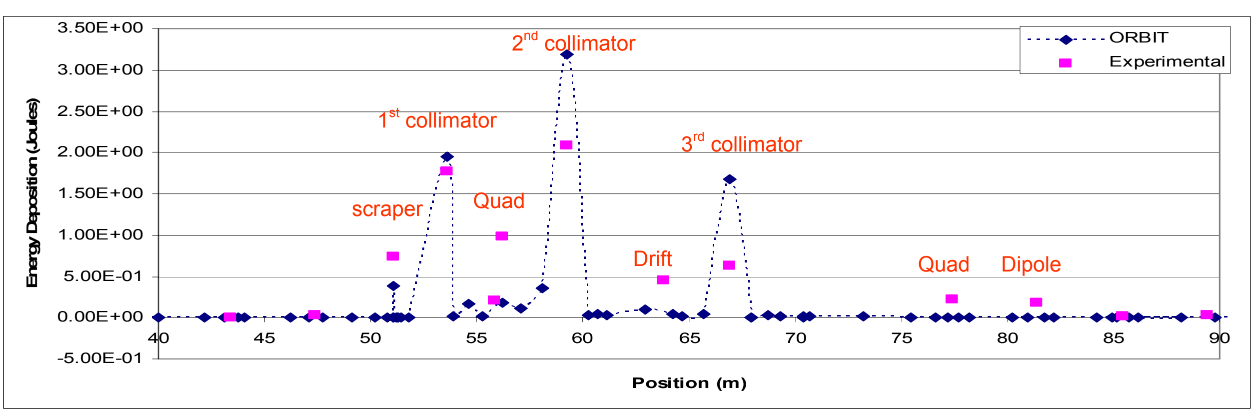

Figure 4. Benchmark of the beam loss pattern for a single minipulse of beam collimated in a two-stage system. The pink boxes are the measured BLM readings, converted to energy deposition, and the blue diamonds are the ORBIT simulation results.

