APPLICATIONS OF A BPM-BASED TECHNIQUE FOR MEASURING REAL SPACE DISTRIBUTIONS IN THE SPALLATION NEUTRON SOURCE RING AND TRANSPORT LINES

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Abstract

The SNS accumulator ring and associated transport lines are designed to accumulate and transport up to 1.5e14 ppp to a liquid mercury target for neutron spallation. Since commissioning, a dedicated effort has been put forth to characterize the lattice and beam dynamics at low intensity. Toward this goal, a BPM-based technique for measuring real space beam distributions at low beam intensities was developed [1]. Recently, this technique has been used to diagnose and localize a strong source of coupling in the lattice, to verify and troubleshoot complementary diagnostics devices, and to provide data for code benchmarking. In this paper we present the results of these studies, including the first ORBIT beam dynamics benchmarks of the SNS ring and RTBT.*

INTRODUCTION

The SNS ring and associated transport lines are designed to accumulate and deliver up to 1.5e14 protons per pulse to a liquid mercury target for neutron Spallation. To accomplish this, a 1 GeV, 1 millisecond long train of minipulses from the linac is accumulated in the ring and then sent to the target via the Ring to Target Beam Transport (RTBT) line. Eight programmable injection kickers allow transverse painting in both planes in order to optimize the transverse beam distribution.

The ring diagnostics suite consists of 44 BPMs for monitoring horizontal and vertical transverse beam positions, and a large number of beam loss monitors; no transverse profile diagnostics equipment are currently available in the ring. In addition to several BPMs and BLMs, the RTBT line is outfitted with five wirescanners and a harp to aid in characterizing the extracted ring beam.

Recently, a novel technique was developed which utilizes the BPMs to measure the full transverse beam distribution in the ring and RTBT at low beam intensity [1]. The technique relies on the fact that a single minipulse of beam can be injected and stored in the ring without decoherence for over 100 turns when the four families of sextupoles are set to provide zero beam chromaticity. By injecting and storing a single minipulse in the ring and then measuring the BPM signal in the ring or RTBT line at the appropriate time in the storage cycle, one can identify the location of that single minipulse within an accumulated beam distribution. Aggregating the results of all minipulse measurements gives the full beam distribution.

In this paper we discuss three independent studies that were performed using this technique. Valuable information about the SNS Ring and RTBT optics has resulted from these studies.

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DIAGNOSIS OF A TILTED BEAM

Following the commissioning of the ring in 2006 [2], an effort was undertaken to understand the low intensity beam in the ring through a set of ORBIT [3] benchmarks. The simplest case of a low intensity beam with no transverse injection painting was chosen for this study, and the main benchmark goal was to match the simulated profiles to the measured wirescanner beam profiles in the RTBT. During this process, two interesting features were noted about the wirescanner profiles: First, most of the profiles did not display the hollow shape indicative of an un-painted beam. Instead, they varied in shape from hollow to sharply centrally peaked (almost triangular in some cases). Second, a change in beam size in one transverse plane was reflected in both the size and shape of the profiles in the alternate plane. An example of this is shown in Figure 1, where three vertical beam profiles measured on a single wirescanner are plotted. The three different vertical profiles correspond to three settings of the horizontal injection kicker amplitudes. As seen in the plot, the vertical profiles change dramatically with horizontal beam size change.

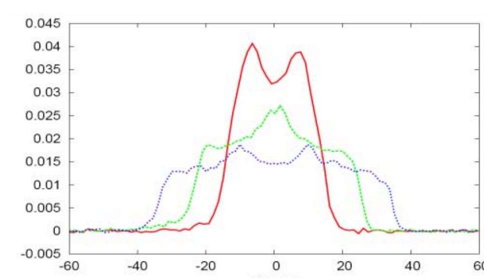

Figure 1: RTBT vertical wirescanner profiles. The three profiles correspond to three different settings of the horizontal beam size (varied by changing the amplitude of the horizontal ring injection kickers).

This evidence pointed towards a strongly tilted beam in the RTBT, which “wobbled” as it went down the line, thus creating a different density projection at each wirescanner for each different aspect ratio beam. Since it seemed unlikely that such a strong source of coupling existed in the Ring or RTBT, an independent test was needed to confirm the prediction. The BPM technique described above for measuring real distributions in the ring and RTBT was proposed.

The measurement of beam distributions using BPMs was performed on all 44 ring BPMs and 17 RTBT BPMs. The result was indeed a strongly tilted beam in the RTBT which wobbles as it is transported down the line. In addition, comparisons of BPM-based beam distributions in the ring and RTBT indicated that the source of coupling was located somewhere in the extraction channel between the ring and RTBT, i.e., very little beam tilt was observed in any of the ring distributions, and large beam tilt was observed at the first BPM in the RTBT line. Magnet multipole simulations eventually identified the extraction septum as the source of the coupling, and possible correction schemes for the coupled beam are underway [4]. An example of a measured beam distributions in the ring and in the RTBT are shown in Figure 2 below.

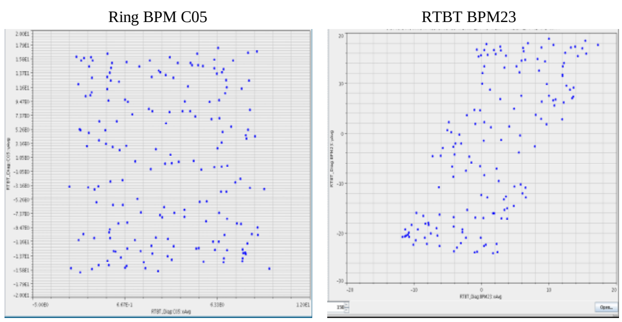

Figure 2: Transverse beam distributions in the ring and the RTBT measured using BPMs.

ORBIT BENCHMARKS

The measurement of real beam distributions using the BPMs has given us a unique opportunity for benchmark simulations. Whereas most simulation code benchmarks are aimed at reproducing beam density projections derived from wirescanner data, the BPM technique allowed us to benchmark the full transverse real space distribution at low beam intensities where collective effects are negligible. In addition, the abundance of BPMs available in both the ring and the RTBT gives us many more benchmark points than we would normally have using the usual wirescanner profile benchmark.

Ring Benchmarks

The ORBIT particle tracking code [3] was used to perform the benchmark. The ring was modeled using the injection and lattice parameters of the experiment. Nonlinear tracking was incorporated in the simulation, but since the beam intensity was very low, space charge effects were ignored. Because the BPMs measure only the centroid of the minipulse distribution, in order to best simulate the experiment we injected only 1 on-energy particle per turn. Figure 3 shows the simulated and measured beam distributions at four different locations in the accumulator ring.

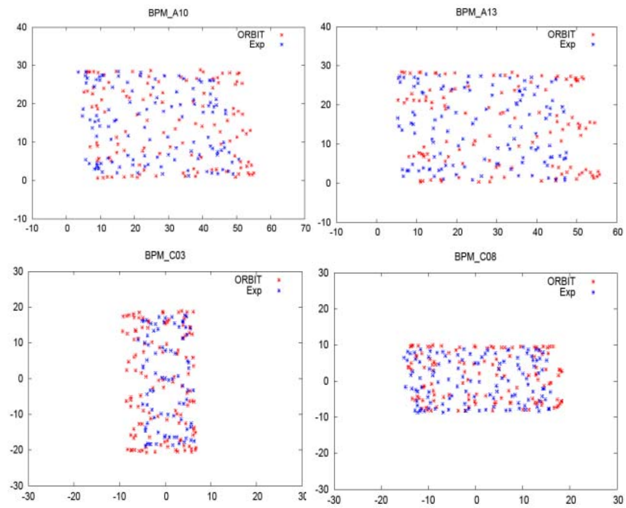

Figure 3: Experimental measurements (blue dots) versus ORBIT simulation at two ring straight section BPMs (top plots) and two arc BPMs (bottom plots).

For most locations in the ring, the agreement is quite good. Observed differences between measured and simulated beam distributions are repeated at symmetric locations in the ring, and thus are attributed to differences in the optics between the real machine and the model. In fact, this benchmark helps us identify which regions of the ring have the largest lattice discrepancies. The unique pattern displayed at some BPM locations is likely due to a rational ratio of horizontal and vertical betatron tunes. This is closely but not perfectly simulated in the benchmark. In general the benchmark was successful enough to declare a good understanding of the injection and transport of low intensity beam in the ring. Orbit response matrix measurements are currently underway to understand the few lattice deviations observed.

RTBT Benchmarks

In order to obtain a successful RTBT benchmark, it was necessary to model the source of the coupling. The extraction septum multipoles responsible for the coupling were calculated using the TOSCA code [4] and incorporated into the ORBIT simulation. Figure 4 shows the results of the benchmark. The agreement between the measured and simulated beam in the RTBT is very good, although some deviation is apparent towards the end of the 150 meter RTBT line. This benchmark confirms an understanding of the basic optical properties of the RTBT line, and of the skew multipole component responsible for the beam tilt.

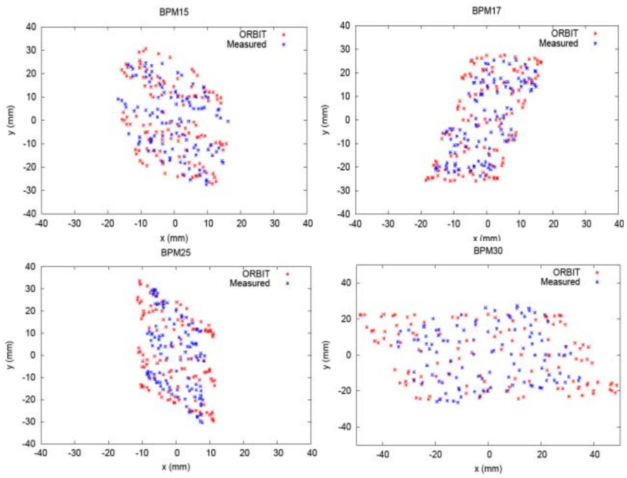

Figure 4: Experimental measurements (blue dots) versus ORBIT simulation at four different locations in the RTBT.

TROUBLESHOOTING DIAGNOSTICS

Outside of the realm of beam dynamics, another study conducted with the use of BPM measured beam distributions was aimed at independent verification of the accuracy of other complimentary diagnostics devices. In the RTBT, four of the five wire scanners, along with a Harp device, are routinely used to characterize the beam on the SNS target. Using the XAL physics software framework [5], a model for the beam envelope in the RTBT is fit to the transverse beam rms values measured by the wirescanners and harp. Once a good fit is obtained, the model is used to extrapolate the beam envelope to the target and obtain predictions for the beam size and density on the target, both of which are tightly constrained parameters.

Up until the spring of 2007, we routinely obtained excellent agreement between the model and all of the wirescanner and the harp measurements. However, at one point it became suddenly impossible to obtain a good fit to the data in the vertical plane. A good fit was possible if only the wires were included, but not if the harp was included. Since the harp is located several meters downstream of the four wirescanners, the question arose as to whether the problem was with the harp itself, or with the optics in the region between the wirescanners and the harp. An independent diagnostic was necessary.

Since the BPMs give the full distribution of beam, it is possible to derive rms beam sizes from each of the BPMs at the end of the RTBT. In this sense, we can treat them like wirescanners or harps. Use of the BPMs in this fashion was particularly valuable in this instance since there are BPMs in the region between the last wirescanner and the Harp, and thus the source of the disagreement between model and measurement could be localized.

It was found that the measured rms values from the BPM data were smaller than the wire rms values by a constant scale factor, likely due to a small amount of decoherence in the BPM minipulse measurements, and the fact that a minipulse has finite size. Also, in the BPM measurement method the minipulse does not undergo emittance growth due to Twiss mismatch between the linac and ring, as it does with the real accumulated distribution. Nonetheless, after deriving this scaling factor from a BPM adjacent to a wirescanner and applying it to all BPM rms values, it became clear that the BPMs and wirescanners agreed, and the Harp was in disagreement. Figure 5 shows the results, where the model fit to the wirescanner data is shown as lines, and the Harp and BPM rms's are overlaid on the model fit. Note that there is a BPM at nearly the same location as the Harp in the RTBT, and in the vertical plane it agrees with the model (and thus wirescanners), but not with the Harp.

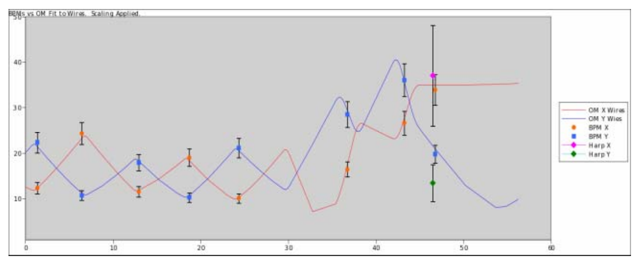

Figure 5: Beam envelope in the RTBT. The blue and red lines are the model fit to the measured wirescanner data, the orange and points are the measured beam rms in the horizontal and vertical plane, respectively, and finally the pink and green dots are the measured horizontal and vertical beam rms using the Harp.

With evidence more decisively pointing to a harp problem, it was discovered that the vertical and diagonal harp wire signals had been accidentally swapped. After swapping back the signals, we recovered good fits to the model data again in the vertical plane, and confidence in the predictions of the beam on the target.

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