EXPERIMENTAL STUDY OF BEAM COLLIMATION IN LOW ENERGY PROTON RINGS *

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Abstract

With a maximum level of uncontrolled loss of 10^{-4} of the total beam, the design of the Spallation Neutron Source (SNS) accumulator ring is severely constrained by loss budget considerations. It is then mandatory to have an accurate prediction of the collimation systems efficiency and uncontrolled loss distribution at low energy (1 GeV). Significant effort is being invested in benchmarking of the codes for collimation simulation at SNS. In particular, we are performing experiments in the U-70 ring at Protvino, Russia. This proton machine can operate at 1.3 GeV, close to the SNS baseline of 1 GeV. In these experiments, we plan to measure the dependence of the collimation efficiency on the impact parameter. We also study the behavior of different materials when used as primary scrapers. This paper describes the experimental setup and procedures for the experiment and presents the first experimental results.

1 INTRODUCTION

In order to reach a tolerable radiation level for hands-on maintenance around the Spallation Neutron Source (SNS) accumulator ring, uncontrolled beam loss has to be reduced to 10^{-4} of the beam. Accurate simulations of halo growth and collimation efficiency are needed to predict losses at this level [1].

For the collimation simulations of the SNS cleaning system we use K2 [2], a code developed at CERN for the LHC collimation system. We have updated the scattering subroutines to work at the SNS energy range (1.0-1.3 GeV). Experimental beam studies have been performed at CERN SPS using a 120 GeV energy proton beam [3]. Measurements of collimation efficiency and loss distribution agreed with computer simulations done with the K2 code within a 20% accuracy. However there is no, to the best of our knowledge, experimental verification of collimation efficiency at a lower beam energy.

A series of experiments aimed to benchmark the simulation codes at energy closer to 1 GeV have been launched by the SNS project in collaboration with the Institute for High Energy Physics (IHEP) at Protvino, Russia. The experiments are carried out in the U-70 synchrotron. The accelerator and experimental setup are described in section 2. The first results were obtained during the spring run of the machine last April. They are presented and discussed in section 3. The plan and objectives for future experimental sessions are detailed in section 4.

2 THE U-70 SYNCHROTRON

The U-70 ring at Protvino is a twelve-superperiod proton synchrotron with an injection energy of 1.3 GeV and a final energy of 70 GeV. Each superperiod contains ten combined function magnets more than nine meters long with straight sections in between (1.19 to 4.79m long). The total circumference is 1495.7 meters.

During the low energy flat-top period lasting approximately two seconds, up to 29 bunches with an intensity of $3{\cdot}10^{11}$ protons per bunch are injected from the Booster. After ramping to 70 GeV, three extraction lines provide beam for fixed target experiments. At the end of the cycle, the excess beam not used for physics experiments is dumped in a collimator using a local bump.

Immediately after injection, half a second is available for measurements at low energy. The collimation experiments are performed in parasitic mode taking only a fraction of the injected beam for a small number of cycles from physics operation.

2.1 Experimental layout

A two meters collimator block called Beam Emittance Shape (BES), made of stainless steel, located between magnetic units #85 and #86. The collimator, of rectangular aperture is surrounded by heavy shielding blocks. It can be horizontally skewed in steps of 0.05-0.1 mrad within a $\pm$3 mrad range.

A schematic view of the Beam Emittance Shaper is shown in Fig. 1. A secondary emission profile monitor with 24 horizontal and 32 vertical wires is bound to the upstream face of the collimator .It allows direct measurements of the impact parameter in the block for each loss scenario. The resolution is limited by the 1.25mm wire spacing. Supports for movable thin targets or bending crystals are available at the beginning and at the end of the collimator straight section. Presently, a Carbon and a Silicon target 2mm thick are installed immediately downstream from the collimator and can be moved horizontally to intercept the beam.

We drive the beam into the collimator by exciting a backleg winding in magnets 76-88 and 79-91 which produces an injection energy local bump at the collimator location. The distance between the center of the vacuum chamber and the edge of the collimator is 65 mm. To completely place the

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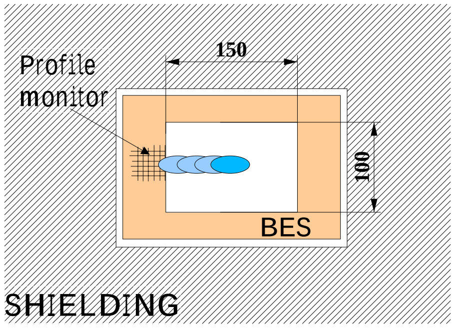

Figure 1: Front view of the Beam Emittance Shaper (BES). The beam is steered into the inside face of the collimator where the profile monitors measure the impact parameter in horizontal and vertical plane. The collimator block is surrounded by shielding.

beam onto the collimator one needs to produce a horizontal displacement of 65 mm at the location of the BES block. The beam impact parameter depends on the velocity of this bump. Initially this speed was fixed due to fixed rise-time of the magnet power supply. A variable speed ramp of the magnets was introduced to allow gradual changes of the impact parameter. Moreover, a feedback system using the loss detectors is under development, it will allow consisten beam grazing on the collimator during the measurements with minimum impact parameter.

Eight ion chamber beam loss monitors (BLM) are located along the next superperiod following the collimator. They are one meter away from the beam pipe and are located inside or outside the ring depending on the corresponding magnet polarity. Their signals are connected to a data acquisition system and plotted via a Graphic User Interface (GUI). Fast beam loss detectors will be installed facing the collimator; they are read through the same acquisition system as the BLM's. A layout of the experiment is shown in Fig. 2.

The beam intensity loss during the bump is measured with current transformers. Typically measurements are done with a beam loss about 10^{10}. This data is used for measurement normalization.

3 FIRST RESULTS

The first series of measurements was carried out during the spring run in April 2000. Measurements were taken with and without the carbon and Silicon targets. The bump velocities were varied for all three cases.

3.1 Impact Parameter

We used the profile monitor installed in the surface of the collimator to measure the impact parameter of the beam. When the beam is put into the collimator using the local bump, the impact parameter is given by

$$b_{max} = 1.5A_x(\pi D_x/A_x)^{2/3}$$

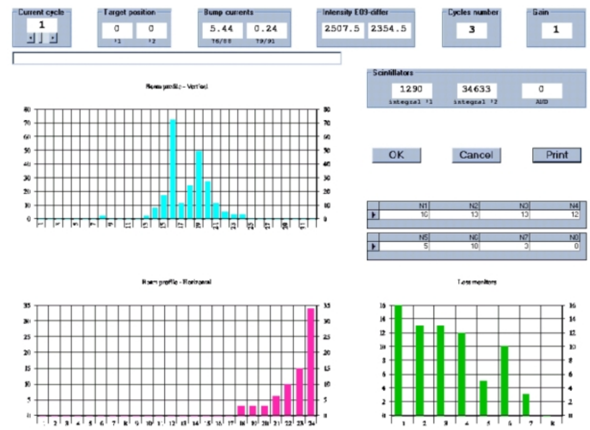

Figure 3: The data received by the main diagnostics is assembled in one graphical display. On the left, the signal coming from the profile monitors is displayed. The signal coming from the scintillators and beam loss monitors can be found on the right of the display.

where A_x is the amplitude of betatron oscillations and D_x is the drift velocity given in mm per turn [4]. The maximum drift velocity that the bump can provide is $D_x = 0.0175$mm per turn. With an amplitude A=30mm at the flat top the impact parameter is about 65mm. When the drift velocity is slower, the impact parameters is also slower and the final collimation efficiency decreases. For the slowest bump, the drift velocity is $D_x = 0.0003$mm/turn, which translates to an impact parameters of 45μm.

To increase the impact parameter in the collimator and improve the cleaning efficiency, a thin target is introduced into the beam which enhances the beam divergence by multiple Coulomb scattering. This approach has been chosen for the SNS accumulator ring collimation system [1] where the primary collimator consists of movable thin scrapers. With an increase in the angular divergence α_{rms}, the increment of the impact parameter becomes:

$$\Delta A = \sqrt{A^2 + \beta^4 \cdot \alpha_{rms}^2} - A.$$

The first target is made of carbon and produces a scattering angle of α_{rms}=0.4mrad which gives for 95% of the beam, the impact parameter about 15-17mm.

We simulated the impact parameters on the collimator for the three cases, with a fast bump, a slow bump and a Carbon target. The average impact parameter agreed with the analytical estimates. We then measured it with the profile monitor and obtained comparable data. Unfortunaley the resolution of the profile monitor is not enough to measure impact parameters smaller than a couple of millimeters.

3.2 Loss distribution

The beam is moved to the edge of the collimator at different velocities by changing the bump programming. For

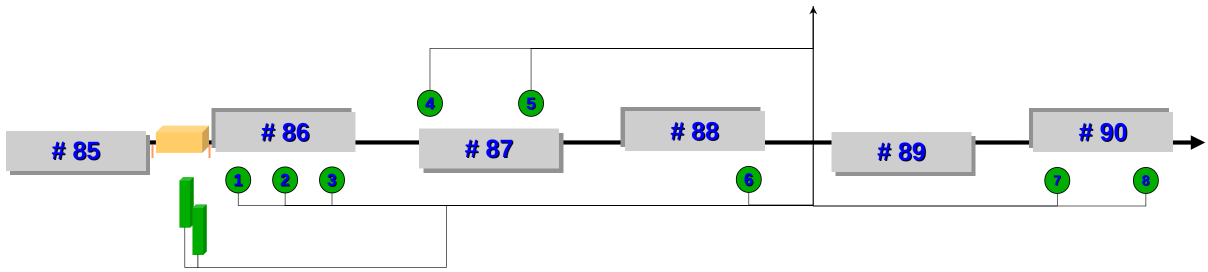

Figure 2: Layout of the experiment. The collimator is located between magnets #85 and #86. From magnet unit #85 to#90 , eight beam loss monitors have been installed as indicated in the figure and connected to a dedicated data acquisition system. Two scintillators will be located near the collimator.

each setting, the fraction of halo particles absorbed at the collimator can be inferred from the secondary particle flux measured by the loss monitors.

From the signal of the eight beam loss monitors, and assuming the same detection yield for all detectors, we can deduce the location of the losses downstream of the collimator and compare with simulation. By changing the measurement parameters, as the depth of the target or the bump velocity, we can reduce the sensitivity to calibration errors. The Carbon target was horizontally plunged into the beam at various depths. At each position the BLM signal was recorded. The signal normalized to the number of protons lost is plotted in Fig. 4. We can see a change of regime

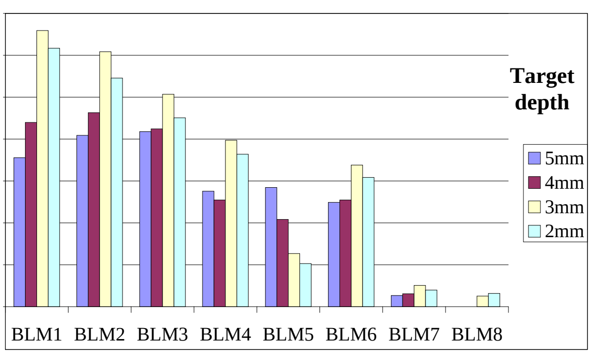

Figure 4: Data coming from all eight beam loss monitors when the carbon target is introduced into the beam.

when the target is introduced deeper than 3mm inside the beam.

Simulations with the target and without the target have proven that some out-scattered protons with a kinetic energy above 800 MeV stay in the machine and travel as far as magnet unit #87. Indeed, the signals recorded by BLM7 and BLM8, facing magnet #90 are almost negligible. Nevertheless, we see considerable signal from BLM6. This can be due to unexpected losses in magnet #89 or detecting secondary particles flux produced in magnet #87. The relative high signal of BLM6 may also be due to a larger detection yield. Unfortunately, there is no direct calibration between the protons absorbed in each element of the ring and the signal detected by the instruments. Cross-calibration of all eight BLM detectors is under way. More detailed simulations will help identify the location of the losses.

4 FUTURE PLANS

The next series of measurements is planned for the Fall run 2000. By this time, the fast beam loss monitors will be installed in the machine. We plan to configure the scintillators to work as a telescope focusing the collimator to avoid counting of background signals and secondary particle flux coming from losses in the magnets. All forty BLM will be integrated in the acquisition system to be read at the same time as the measurements are performed. The position of the target and local bump parameters will also be read by the same system. A new tungsten target of similar characteristics as the one planned for the SNS is being prepared to be used during measurements and compared against Carbon and Silicon. Also, a very thin crystal will be tested as a primary scraper and compared to amorphous targets [5].

These experiments will provide information to improve the SNS ring collimation design. Besides benchmarking the simulation codes, we plan to validate the use of thin scrapers and crystals as primary targets, check their performance under operational conditions and their resistance to radiation.

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REFERENCES

[1] N. Catalan-Lasheras et al.,“Optimization of the Collimation System for the SNS Accumulator Ring”, this proceedings

[2] T. Trenkler, J.B. Jeanneret, SL Note 94-105 (AP)

[3] N. Catalan-Lasheras, “Transverse and Longitudinal Beam Collimation in a High-Energy Proton collider”, PhD. thesis

[4] M. Seidel,“The proton collimation of HERA”, PhD. Th., DESY94-103

[5] Y. Chesnokov et al.,“Using Bent Crystals for Loss Localisation in IHEP Accelerator”, this proceedings