JITTER CONTROL AND SCRAPING IN THE 12-VIEW AHF HEBT*

Barbara Blind and Andrew J. Jason, LANL, Los Alamos, NM 87545, USA

Abstract

The HEBT of the proposed Advanced Hydrotest Facility (AHF) [1] is designed to deliver 50-GeV protons to an object from 12 directions, 15° apart. Individual beam bunches extracted from a synchrotron are split with 11 sets of septa such that, nominally, the same number of particles arrives from each direction. Extraction-kicker jitter can be expected, and can result in beam-intensity fluctuations in the 12 lines to the object. The HEBT tune is chosen to minimize this effect, with interesting consequences for the beam-splitting process. Beam splitting in each set of septa is initiated by a wire septum, with some particles hitting the wires. Particle-tracking simulations predict that activation of beamline components due to these affected particles can be kept low with sets of scrapers. They also predict that the scraping scheme is not sensitive to beam-position jitter from extraction-kicker jitter, or to average-energy jitter. Details of the jitter study and the scraping study are discussed.

OVERVIEW

The jitter study assessed the problems caused by jitter, identified possible remedies, and provided a means for establishing tolerances. The scraping study assessed the feasibility and effectiveness of a scraping scheme. Both studies relied heavily on code developed at LANL.

The HEBT layout is shown in Fig. 1. Each set of septa splits the beam into two parts. Beam splitting is initiated by wire septa and each set of septa will be referred to by its wire septum (WS). Septum sets WS1 and WS2 split the impinging beam in half. The vertically oriented septum sets WS3V send 2/3 of the impinging beam into the lower channel, where it is subsequently split in half by septum sets WS3H, and 1/3 into the upper channel. A septum set WS1 or WS2 is referred to as a two-way splitter, while a unit composed of a septum set WS3V and a septum set WS3H is referred to as a three-way splitter.

JITTER STUDY

To minimize beam-intensity fluctuations in the 12 lines to the object, corrective measures must be taken. In the about 1748 m from the start of the extraction line to the entrance of the line-12 lens system [1] the particles encounter 126 dipoles and 182 quadrupoles, and beamline errors lessen the effectiveness of the corrective measures.

Extraction-Kicker Jitter

The synchrotron has two extraction kickers. Kicker jitter causes horizontal beam-position jitter in the HEBT, which can change the splitting ratios (percentages of beam entering the two channels of a septum set) and thus the beam intensities in the 12 lines to the object.

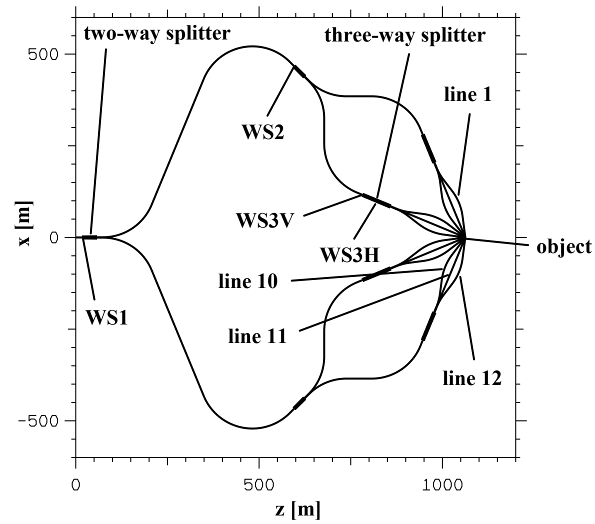

Figure 1: Layout of 50-GeV AHF HEBT.

All jitter is made up of correlated (same magnitude, same sign) and anti-correlated (same magnitude, opposite sign) deflection-angle errors in the two kickers. Correlated (anti-correlated) errors of 0.01 mrad per kicker move the beam centroid to the 0.298-rms (0.055-rms) ellipse of the nominal beam and can conceivably change the splitting ratio of WS1 from 50/50 to 60/40 (52/48), and thus cause significant beam-intensity fluctuations.

HEBT Tune

There are two possible methods for dealing with kicker jitter, an active method and a passive method.

The active method returns the beam to the axis with two additional kickers in the synchrotron or extraction line, so that there is no beam-position jitter due to kicker jitter in the HEBT. This is conceptually easy, but it may only be possible in case the kicker jitter is reproducible.

The passive method employs a nominal HEBT tune where correlated kicker jitter does not cause position jitter at any of the horizontal wire septa, by setting R_{12}=0 from the symmetry point of the kickers to WS1, from WS1 to WS2, and from WS2 to WS3H. This passive method only protects against beam-intensity fluctuations due to correlated components of kicker jitter and causes the maximum possible fluctuations due to anti-correlated components, and the method is not fully effective in the presence of beamline errors. Also, with constraints imposed on the transfer-matrix elements a larger number of independently adjusted quadrupoles is needed than without.

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Beam-intensity fluctuations due to average-energy fluctuations are minimized by setting $R_{16}=R_{26}=0$ at WS1, WS2 and WS3H. This does not guard against fluctuations due to second-order chromatic aberrations.

Description of Simulations

The 47,825-particle input beam used had a momentum distribution with momentum deviations of up to ±0.175%. The transverse coordinates were Gaussian distributed, with 0.047 π-cm-mrad √6-rms emittances. The beam was tracked from the synchrotron extraction region through line 12 (see Fig. 1), which provides information about the beam intensities in lines 10, 11 and 12.

Random sets of beamline errors were assumed. The (uniformly distributed) errors that do not cause beam steering were quadrupole rolls to ±0.2°, gradient errors in strings of quadrupoles to ±0.1% and gradient errors in individually powered quadrupoles to ±0.01%, as well as multipole errors (normal and skew sextupoles, octupoles, decapoles and duodecapoles) in quadrupoles to ±0.1% of the quadrupole field at 80% of the 1.0-inch or 1.5-inch aperture radius and in dipoles to ±0.01% of the dipole field at 80% of the 0.75-inch half gap. The (Gaussian distributed) errors that do cause beam steering were dipole-field errors of 0.1% (rms), dipole rolls of 1.0 mrad (rms), and quadrupole transverse misalignments of 0.25 mm (rms). Steerers periodically returned the beam to the axis, and beam-position monitor readings had errors of 0.25 mm (rms). The code removed the particles not being sent to line 12. Each beamline with a set of errors was tuned so that, in the absence of jitter, 8.333% of the input beam arrived in each of lines 10, 11, and 12.

Jitter-Study Results

The simulations showed that the beam-intensity fluctuations are roughly proportional to the amount of jitter. Without beamline errors, the fluctuations are only about ±1% per 0.01 mrad of correlated kicker jitter, but ±10% per 0.01 mrad of anti-correlated kicker jitter. With beamline errors, the fluctuations can reach ±5% per 0.01 mrad of correlated kicker jitter and again ±10% per 0.01 mrad of anti-correlated kicker jitter. Without (with) beamline errors, the fluctuations are around ±2% (±5%) per 10 MeV of energy jitter.

The simulations showed that the beam-intensity fluctuations due to several types of jitter can roughly be added up. Kicker baseline shifts act like a turn-dependent combination of correlated and anti-correlated kicker jitter. Persistent 300-V baseline shifts in the 50-kV kickers act like 3.0% of anti-correlated kicker jitter and 0.8% of correlated kicker jitter and can lead to fluctuations of up to ±30%. Short-term 300-V baseline shifts act like 4.1% of anti-correlated kicker jitter and 0.8% of correlated kicker jitter and can lead to fluctuations of up to ±34%.

With all types of jitter, factor-of-two beam-intensity fluctuations are easily possible. Thus, an active method for dealing with kicker jitter is strongly recommended.

SCRAPING STUDY

To minimize the number of particles interacting with the wires of the wire septa, the beam is focused with large spot sizes transverse to the wires. Nevertheless, a fraction of the beam hits the wires of WS1, WS2, WS3V and WS3H. Scrapers are planned to, ideally, remove those of these affected particles that would otherwise be lost in downstream beamline elements, without removing any of the unaffected particles.

Description of Simulations

The beam was tracked from the upstream end of WS1 through each of the 12 lines to the respective lens-system entrance. Particles hitting the wires experienced multiple Coulomb scattering, and energy loss and straggling. Particles undergoing nuclear interactions were simply dropped from the beam. They should be easy to scrape, due to their large scattering angles. The scrapers were described as zero-length elements that cleanly remove all particles hitting them. Particles outside the magnet apertures were also simply removed.

The scraping scheme was developed using a HEBT without beamline errors. To facilitate the effort, poor-quality wire septa that generate large numbers of affected particles were assumed. The 2,362 2-mil-wide 2-mil-deep wires of each 3-m-long wire septum were randomly misaligned by up to ±5 mil.

First, effective scraper locations were established. Later, the minimum number of scrapers needed to avoid losses in downstream elements was determined. In the final configuration, there were four one-plane scrapers and four two-plane scrapers in each two-way splitter, and eight one-plane scrapers and ten two-plane scrapers in each three-way splitter.

Some Peculiarities of Beam Splitting

The first wire septum splits the beam in half. Affected particles lie at the edges of the two beam halves. Those particles that are given only small scattering angles will remain close to these edges. They are impossible to remove but do not cause activation.

Because of the tune of the HEBT, chosen to minimize the effects of kicker jitter, the edges generated by upstream wire septa re-emerge at downstream wire septa. Fig. 2 shows the beam entering WS2 of lines 1 through 6. The particles are shown looking upstream. Unaffected particles are shown in gold, affected particles generated by WS1 are shown in red. All affected particles from WS1 will be routed towards lines 4 through 6.

Fig. 3 (left) shows the beam entering the second scraper downstream of WS2 of lines 1 through 6, a one-plane scraper. Affected particles generated by WS2 are shown in blue. This scraper removes particles that would otherwise hit the downstream deflectors of the two-way splitter. Fig. 3 (right) shows the beam entering the third scraper downstream of WS2 of lines 1 through 3, a two-plane scraper. As predicted, there are no affected particles generated by WS1 (red particles).

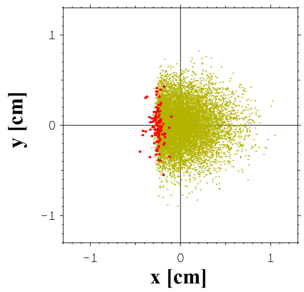

Figure 2: Beam entering WS2 of lines 1 through 6.

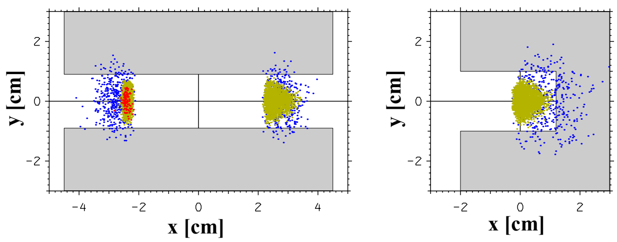

Figure 3: Beam entering a one-plane scraper downstream of WS2 of lines 1 through 6 (left) and a two-plane scraper downstream of WS2 of lines 1 through 3 (right).

Fig. 4 shows the beam entering WS3H of lines 4 and 6 (left) and the beam entering WS3H of lines 1 and 3 (right). Affected particles generated by WS3V are shown in black. The two equivalent locations have very different beams. To cut the beams in half, they need to be cut along lines with different intensities and more particles of the beam shown at left interact with the wires than of the beam shown at right. Thus, unequal numbers of particles must be sent into equivalent channels in order to achieve equal numbers of particles in all 12 lines. This effect should be less pronounced for good-quality wire septa than for the wire septa assumed for the study. As a further consequence of the HEBT tune, some equivalent scrapers have different apertures and some beamlines can be scraped more efficiently than others, with fewer affected particles surviving.

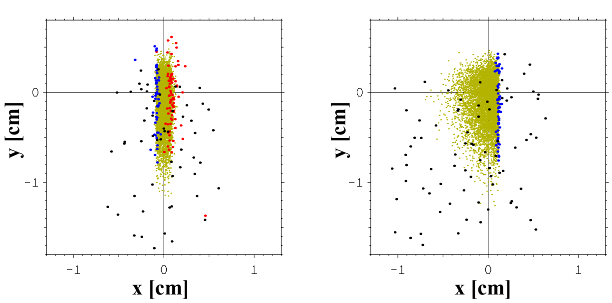

Figure 4: Beam entering WS3H of lines 4 and 6 (left) and WS3H of lines 1 and 3 (right).

Fig. 5 shows the beam entering the line-4 lens system. Affected particles generated by WS3H are shown in turquoise. The location, in phase space, of each set of affected particles indicates its origin at either a horizontally or a vertically oriented wire septum.

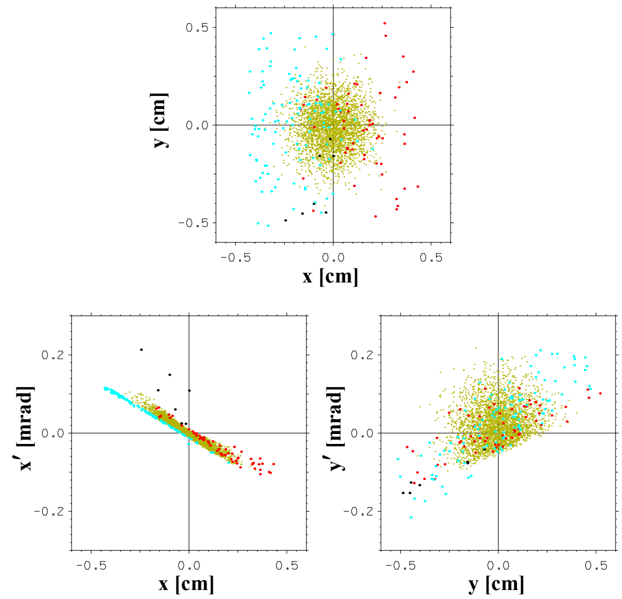

Figure 5: Beam entering line-4 lens system.

Scraping-Study Results

The simulations showed that the scraping scheme should perform acceptably well. Of the input-beam particles, some 20.3% became affected particles. Of these, only about 11.1% arrived at the lens systems, and many were near the unaffected beam. Only one unaffected particle hit a scraper. Two affected particles were lost in arc dipoles, but 90 of them unavoidably hit the septum material of the septa immediately downstream of the wire septa. As possibly unacceptable consequence of the three-way-splitter tune, 16 unaffected particles hit the septa immediately downstream of wire septa WS3H. Each particle represents some 5 pA of average beam current.

PERFORMANCE OF HEBT WITH SCRAPERS AND JITTER

The scraping-study simulations were repeated, with the input beam shifted to represent extraction-kicker jitter and average-energy jitter. It was found that the scraping scheme is not sensitive to such jitter. About the same fraction of the affected particles is removed by scrapers as without jitter. The number of affected particles hitting beamline elements and the number of unaffected particles removed by scrapers remain small. Unaffected-particle hits of the septa immediately downstream of wire septa WS3H increase and are observed at other such septa. The beam-intensity fluctuations agree with the results of the jitter study, for beamlines without errors.

REFERENCES

[1] Andrew J. Jason et al., “Beam-Distribution System for Multi-Axis Imaging at the Advanced Hydrotest Facility,” Proceedings of the 2001 Particle Accelerator Conference, 3374 (2001).