PERFORMANCE OF THE RHIC INJECTION LINE INSTRUMENTATION SYSTEMS*

T. J. Shea, R. L. Witkover, P. Cameron, R. Connolly, W. A. Ryan, G. A. Smith, E. Zitvogel
Brookhaven National Laboratory, Upton, NY 11973

Abstract

The beam injection line from the Alternating Gradient Synchrotron (AGS) to the Relativistic Heavy Ion Collider (RHIC) transports proton and heavy ion bunches. This line and the RHIC first sextant currently contain the following complement of beam instrumentation: stripline position monitors, ionization loss monitors, video profile monitors, and commercial current transformers. Over several years, these systems have been designed and bench tested to assure a desired performance level. Using data from laboratory tests and the recent single pass beam tests, attained performance will be reported. Finally, experience from the beam based tests will be applied to the design criteria for the future collider ring instrumentation.

1 BEAM PARAMETERS

The beams delivered by the AGS to RHIC (AtR) transfer line will include 10^{10} polarized protons and 10^{11} non-polarized protons (28 GeV/c) as well as 10^9 fully stripped gold (Au^{+79}) ions at 10.8 GeV/u, extracted as individual bunches at a 30 Hz rate[1]. The nominal bunch length is 20 nsec. Normalized emittance is 10 pi-mm-mrad. The AtR line is divided into sections starting with “U”, which leads into “W” where it switches to the “X” or “Y” arcs to either of the 2 RHIC rings. The upstream part of the U-line branches off to the “V” line in which up to 5 x 10^{12} protons per bunch are brought to the “g-2” experiment.

2 BEAM POSITION MONITORS

The AtR position monitor system consists of shorted stripline electrodes[2] and gated, self triggering samplers[3]. This system was designed to measure the position of individual bunches injected into RHIC. Because the transfer line provided a convenient test bed, the injection electronics was based on a prototype of the collider ring implementation.

2.1 Accuracy and Stability

Installation of the electronics for transfer line and first sextant commissioning has provided opportunity to monitor stability in the real accelerator environment. The most recent results are shown in Figure 1. Each point is the mean vertical position of 100 single bunch samples. The position is calculated relative to an arbitrary orbit. The bunch contains about $8*10^{11}$ protons within a 30 ns length while the simultaneous reference pulse (measured on a different position channel) simulates a centered bunch of similar intensity. As shown, the vertical drift of the extracted bunches is less than ±30 microns while the drift of the electronics is less than ±6 microns. The physical aperture of the electrode is about 69 mm and the typical position of the measured bunch was about 2 mm from center.

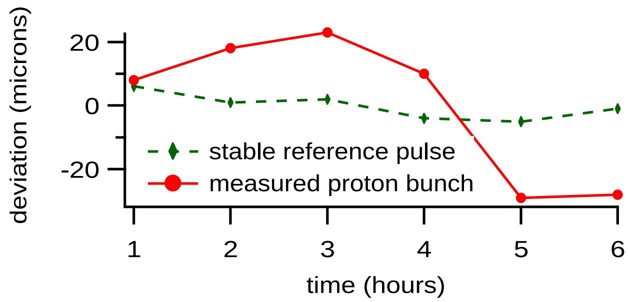

Figure 1: Average vertical position vs. time.

2.2 Noise

The noise performance of the sampling electronics has been characterized in the accelerator environment by measuring the distribution of simulated, single bunch acquisitions. With signal amplitudes near full scale, this distribution is gaussian with a width <5 microns rms. When measuring the collider’s closed orbit, a sampler of this type will average the turn-by-turn data to provide a 100 Hz update rate with a noise floor of <200 nm. Early in the 1997 proton run, we measured the vertical position of several hundred bunches extracted from the AGS. The resulting histogram is shown in Figure 2. The 20 micron rms width of this measured distribution is comparable to that due to electronic noise at these signal amplitudes (about one fifth of full scale). This

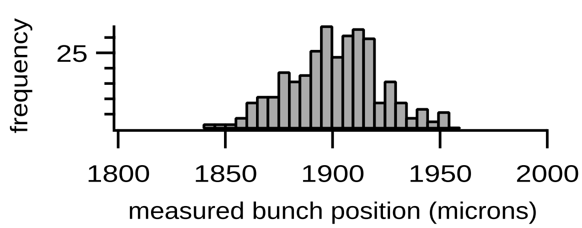

Figure 2: Histogram of vertical positions.

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leads us to believe that the short term vertical extraction jitter of the AGS is less than 20 microns.

2.3 Future Work

In order to set the interval between calibrations, long term stability must be characterized. This will be done during the 1997 proton run at the AGS. Late in the AtR commissioning, a significant number of mistriggers were observed. During the 1997 sextant test, it was confirmed that the sampler’s 70 MHz bandwidth was too wide to smooth the complex structure of coalesced bunches. Initial results show that the problem has been resolved by reducing the bandwidth to 20 MHz, but further optimization of the trigger circuit is desired.

3 BEAM LOSS MONITORS

Beam loss monitoring is one of the most important diagnostic tools in setting up the AtR transfer line. The loss monitors were designed to be sensitive at least one decade below nominal for low intensity studies. During the AtR commissioning in November 1995, the actual beam intensity varied from 10^6 to 2 x 10^7 Au^{79} ions, well below the design range, yet the system was able to monitor the losses. Modified Tevatron ion chambers[4] are mounted on the vacuum flanges downstream of each magnetic element. To limit the number of electronic channels while providing complete coverage, signals from the 120 detectors were grouped into 56 outputs. A number of ion chambers are mounted on movable stands to allow locating them where special attention was required.

The ion chamber consists of a 113 cc glass bulb filled with argon at about 725 milli-Torr. Each chamber is calibrated using a cesium-137 source. The mean sensitivity in the middle of the plateau for the AtR chambers was found to be 19.6 pA/R/hr at the nominal operating voltage of 1450 Volts. Ninety-five percent were within (1.5 pA/R/hr of the mean. The ionization current from the detector is fed to a low leakage gated integrator and read out using the standard RHIC MADC[5]. Non-tribo-electric cable was used to reduce noise due to mechanical motion. The circuit input is designed to pre-integrate the electron signal so that its rise time is in the millisecond range, (comparable to the ion collection time) greatly reducing noise from the kicker magnets which are time coincident with the beam. An isolated signal connector prevents a ground loop with the HV connector shield. These features resulted in the noise level of about 10 pA observed during the AtR commissioning.

4 VIDEO PROFILE MONITORS

The Video Profile Monitor[6] (VPM) consists of a high resolution video camera observing the light emitted by the beam hitting a phosphor screen. A VME-based frame grabber-image processing system acquires and processes the data from any 4 of the 12 cameras in the system. VPMs were used because multiwires were too expensive and would not meet the spatial resolution requirement and scanning wires cannot acquire the data on a single bunch. By using low mass phosphor screens to minimize scattering, profiles have been simultaneously measured at 4 locations for the single bunches. All of the 12 camera outputs are brought to a central processing location over wideband analog fiber-optic links to preserve resolution, since coax cable would degrade the high frequencies over the 1700-foot length of the furthest runs. For the initial AtR commissioning 8 VPMs were installed. For the RHIC First Sextant test in December 1996 the Y-line VPMs and a temporary unit at the end of the sextant were also used.

The .002" thick phosphor screen (Gadolinium Oxy-sulfide doped with Terbium Gd2O2S:Tb, deposited on an aluminum substrate) is mounted at 45^o and inserted by a pneumatic drive. The drive, a 4" viewing window, and 2 lamp ports are mounted on the same 8" conflat flange, eliminating alignment errors. The flange is mounted on a vacuum tee with the window facing the floor. A first surface mirror mounted at 45^o transfers the image to the camera. Typical optical path length is 3 meters. The phosphor has been tested and shown to fully decay within the 33 ms camera frame period. The batch of screens made for the AtR tests were found to “orange peel” when put under vacuum. This was traced to a change in the concentration of the potassium silicate which allowed water vapor to be trapped under the phosphor. While no quantitative problems resulted from this effect, the original recipe was used in later screens. The running period with the gold beam did not produce any damage to the screens but none was expected for the low intensity and short duration of the run.

All of the VPMs used Pulnix TM-7cn CCD cameras except UF1 which was in the AGS ring tunnel and exposed to much higher radiation. Typical CCD camera lifetime is 100 to 700 Rad. Cidtek manufactures a charge injection device (CID) based camera which typically can tolerate 20 kRad., which was used for UF1. During the high intensity running for the g-2 experiment the Cidtek camera (3710D) failed after 1 week, even though it was behind 0.5 m of heavy concrete, which appears to have been consistent with the rated dose. A newer model Cidtek camera rated at a mega-rad is now available and will be considered along with a Dage radiation hardened vidicon model. The cameras in the transfer line are typically mounted in 14-inch diameter holes bored into the tunnel wall to provide shielding in the lower radiation environment.

Since the light is emitted in a <2 msec pulse, the camera must either acquire the full frame at once as in the Cidtek, or have a period in which the odd and even fields overlap as in the Pulnix. The camera must be synchronized to start the scan just after the screen has decayed. By mis-timing the camera, a picket-fence like image appeared on the vertical display as every other line was blank. Because of the 3 decade range of intensity in the expected beams, a means of adjusting the light into the camera was required. A typical lens will only adjust over a range of about 40:1. A simple device was built using small solenoids to flip 4 neutral density filters into the light path between the camera and the lens, providing a range of 20,000:1. This worked very well over the wide range of studies, shapes, and intensities.

Most VPMs use a 500 mm f/5.6 Maksutov-Cassegranian reflector lens except for a 1000 mm f8 reflector lens at UF1, a 400 mm f5.6 refractor at UF2 and a 300 mm f5.6 refractor at WF2. About half of the cameras were rotated 90^o to match the beam aspect ratio. The actual beam orientation was reestablished in the computer generated display. The lens, camera, and filter array are mounted using commercial optical hardware on a precision rail, allowing rapid replacement.

The overall resolution is limited by depth of field, camera resolution, and lens resolution. Phosphor screen grain size, air waves, and mechanical vibrations are not significant for the AtR beam sizes. Depth of field is a factor because the screen is tilted at 45^o and can be significant if the beam is well off center or large vertically. Camera resolution is limited by the number of pixels, by fiber transmission system bandwidth, and by electronics bandwidth. The resolution was calculated to be better than 0.25 mm using measurements and manufacturer's data for the cameras and lenses.

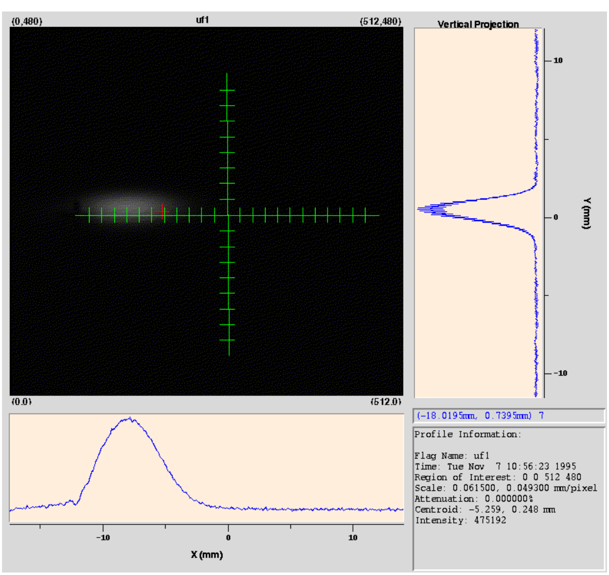

Figure 3: Beam on UF1. Scale tics are in mm.

Measurements of the fine fiducial marks on the screen were consistent with the estimate.

The acquisition and processing of the video data is done using 4 Imaging Technology Inc. IMA-VME-4.0 boards with 4 AMVS-HS acquisition modules, 2 CMCLU-HS Convolver arithmetic modules, and 2 CMHF-H histogram/feature extractor modules. The system is run under VxWorks. Forty-eight 512x512 pixel frames, plus base frames for subtraction and computational results can be stored on board. A 128x128 subset of the can be generated from a 4x4 convolution of the full frame or a region-of-interest (ROI). The computations available include: Pixel-by-pixel base frame subtraction of full frame data, centroid of the full frame, H and V projections, and sum of all pixels. The AtR data only used the full 512x512 frames for a single bunch. Figure 3 shows one set of results from the AtR tests.

5 BEAM CURRENT MONITORS

Beam current was monitored used the commercial Integrating Current Transformers (ICT) manufactured by Bergoz[7]. Three of the 5 units were installed for the AtR test with the Y-line unit added for the First Sextant Test. The X-line unit was temporarily installed at the end of the sextant. These devices use passive integration to filter a fast current pulse before it enters the core, reducing the effect of core losses and simplifying the electronics design. Initially, noise from the extraction kicker pulser interfered, but by passing the signal cable through a ferrite core (multiple turns) reliable signals were obtained even for 10^7 gold ions.

6 REFERENCES

[1] S. Peggs, “RHIC Status”, these proceedings.

[2] P. R. Cameron, et. al, “RHIC Beam Position Monitor Characterization”, Proc. 1995 Particle Accel. Conf. 95CH35843.

[3] W. A. Ryan and T. J. Shea, “A Sampling Detector for RHIC Position Monitor Electronics”, Proc. 1995 Particle Accel. Conf. 95CH35843.

[4] R. E. Shafer, et al, “The Tevatron Beam Position and Beam Loss Monitoring Systems”, Proc. 12th Int'l Conf on High-Energy Accel., Aug 1983, p609

[5] R. Michnoff, “The RHIC General Purpose Multiplexed Analog-to-Digital Converter System“, Proc. 1995 Particle Accel. Conf. 95CH35843, p2229

[6] R. Witkover, “Design of the Beam Profile Monitor System for the RHIC Injection Line”, Proc. 1995 Particle Accel. Conf. 95CH35843, p2589

[7] Bergoz Precision Beam Instrumentation, 01170 Crozet, France