Beam Instrumentation for the RHIC Sextant Test*

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

Abstract

In late 1995, commissioning of the Relativistic Heavy Ion Collider will begin with beam transport through the collider's injection line. One year later, the first superconducting sextant will be commissioned. Several new instrumentation systems now under construction will operate for the first time during these single pass demonstrations. During the injection and sextant tests, they will characterize the beam delivered by the injector complex and measure the optical properties of the magnetic lattice. Several years later, collider commissioning and operations will rely upon the same systems. This paper describes the position monitors, loss detectors, profile monitors, and current transformers. Preliminary test results for individual components will be presented.

1 SYSTEM LAYOUT

Because RHIC commissioning will extend over at least 4 years, the beam instrumentation group must provide resilient systems that can be easily upgraded over the course of commissioning and operations. This is accomplished by relying on software based functionality and a fine grained hardware modularity within the confines of the usual industry standards. The systems are itemized in Table 1.

Table 1: Summary of Instrumentation Systems

Device	Number needed for injection test	Total number needed for sextant test
Position monitors	15	58
Loss monitor channels	20	64
Profile monitors	8	11
Current transformers	3	5

The AGS will serve as the injector for RHIC, providing individual bunches at up to a 30 Hz rate. Beam will range from protons at 1×10^{11} per bunch to gold at 1×10^{9} ions per bunch. The gold ions will be extracted at charge state 77 and fully stripped early in the beam line. The bunch length will be typically 20 nsec. Measurements of beam intensity, position, transverse density distribution and loss will be made at a number of locations in the ATR line.

2 POSITION MONITOR SYSTEM

2.1 Position Monitors

The RHIC BPM performance requirements, design details and fabrication techniques, and Calibration and Testing Procedures are in the literature[2],[3]. Production is underway. The calibration technique previously described has been refined with the removal of the nickel bellows spring contact from the end of the contact post. The function of the spring contact is now served by the cantilevered stripline. With the stripline thinned to about 0.8 mm at the hinge, the spring constant at the post is about 0.1 N/micron (8 oz/mil), and typical stripline deflections are about 200 microns. The BPM is calibrated by adjusting the length of the contact post. The average separation between electrical and mechanical centers is about 25 microns after calibration. The calibrated accuracy could easily be increased to a few microns if desired.

The 'glass-ceramic' cryogenic feedthrough design (which uses lithium silicate glass dielectric doped to match the expansion coefficient of stainless steel) proved reliable under cryogenic shock testing. This design is more simple, much more economical, and has better RF properties than the conventional ceramic/kovar design. The cryogenic signal cables are stainless steel outer conductor, Tefzel (ETFE) dielectric, silver-plated copper center conductor, with male SMAs both ends.

2.2 Position monitor electronics

Development of the position monitor electronics for the collider rings has already been documented[3], so this report will simply highlight performance measurements and adaptation to the single pass application. For circulating beam operation, the ring electronics acquires bunch position at a 78 kHz rate. One DSP board is dedicated to each analog detector. By taking advantage of the modular architecture, up to 6 analog detectors can be serviced by a single DSP board. This leads to significant cost savings with no performance penalty for the injection and sextant tests.

The previously reported analog detector incorporated a RF mixers in a synchronous detector. In the most recent version, the mixers have been replaced by monolithic

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samplers leading to the following improved performance for acquisition of a single bunch in a 70 mm bore BPM:

- <100 micron error over 40 dB range of intensity and ±20 mm range of position
- 5 micron RMS noise at operational intensity

The output of the front end is digitized by 16 bit ADCs in Industry Pack format. This information is then processed and buffered by a DSP board with the following specifications:

- Motorola 96002 dual port, 32 bit floating point DSP
- Static and flash memory shared by DSP and register based VXI interface
- 4 Industry Pack sites for flexible I/O interfaced to dedicated DSP port

Prototypes of both the ADC and DSP boards have been constructed and tested.

3 Loss Monitor System

An array of ion chambers will be used to monitor losses. While each quadrupole and dipole will have an associated BLM to assure uniform coverage, several units will be connected in series to reduce the number of readout channels. The detectors will be based on the argon-filled glass ion chamber originally developed for the Tevatron by Shafer, however, the external packaging will be modified. Dual HV and signal connectors have been added to daisy-chain units on the same channel. Rexolite rather than Teflon insulation will be used in the connectors to reduce radiation damage. The signal connections will be insulated from the outer aluminum case to break the ground loop formed by the shields on the signal and HV cables. The operational characteristics are unchanged and will still be biased in the 2 kV range. The signal will be pre-integrated on the cable capacitance with a time constant of several msec. Gated integrators of the type used in the Booster[4], will condition the signal for digitization. The integrator outputs will be sent to a VME based multiplexed ADC for conversion. For troubleshooting purposes a number of status bits and flags are planned in the system design.These will be used as primary indicators of the system's integrity should problems arise.

4 Profile Monitors

To allow monitoring of the AGS extraction process and computation of the emittance, measurements of the beam profile will be available at 12 locations in the ATR. The detectors will be CCD cameras viewing phosphor screens. Frame grabbers will acquire images from up to 4 cameras simultaneously via a wideband multiplexer. Since the bunches will be extracted at a maximum rate of 30 Hz, the system will allow the measurement of the emittance of individual bunches, although some dilution will occur.

A prototype unit has been installed in the Booster -to-AGS (BTA) line and tested with protons of low and high intensity and with 108 Au+33 beams. The system is estimated to have a resolution of better than 0.25 mm in the high resolution mode. This prototype is interfaced to a commercial beam profile unit, the LBA-100A, which includes a frame grabber, CPU, and software to analyze and display the data Data acquisition at 30 Hz is possible if the computations are not activated. In the normal mode, data from every fourth pixel is stored and displayed. While the LBA-100A provides a wide range of capabilities as a stand-alone unit, the IEEE-488 interface does not provide the data transfer rate desired for this system. VME-based frame-grabbers with front-end processing capability will be used in the final system. Figure 2 shows frames taken at 30 Hz with the Booster extraction at 7.5Hz. No image is visible in frames with no Booster pulse, verifying that the system can see individual ATR bunches.

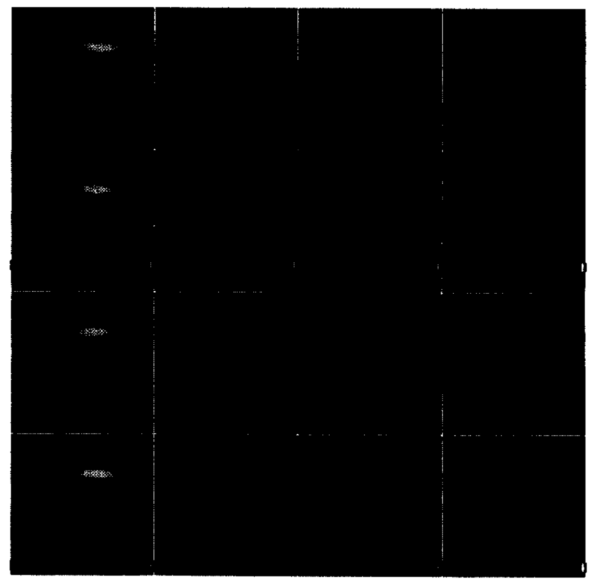

Figure 1. Results of profile monitor test

4.1 The Phosphor Screens

To allow measurement of individual bunches, the phosphor chosen for the screens was gadolinium-oxy-sulfide doped with terbium, which fully decays in 1 msec. This phosphor is used at BNL in the NSLS, ATF and the tests described above, and at Cornell's CESR. Lifetime tests at SLAC showed failure by "flaking" after moderate beam exposure, however, it is now believed that this has been eliminated by use of a different binder. The phosphor is deposited to a thickness of 0.002" on a 0.001" aluminum foil to allow the insertion of multiple screens with minimum scattering of the beam.

4.2 CCD Camera

The camera will be capable of synchronization with the pulsed beam at up to 30 Hz, with light integration over the full frame rather than one field. Several cameras are being evaluated. Radiation sensitivity is a major concern with

CCD cameras. In the BTA testing, slight deterioration was observed at 150 R dose. To minimize the exposure, an optical system has been designed which allows the camera to be located away from the beam pipe and at floor level. In the worst locations18" thick concrete blocks and excavations in the tunnel walls will provide additional shielding.

4.3 *Optical System*

A simple optical system has been designed which allows the camera to be placed 12-15 feet from the phosphor screen. A single mirror bends the light from a vertical to a horizontal path and into a 385 or 500 mm lens, depending on beam line location. An array of 4 solenoid driven neutral density filters separates the lens and CCD camera which allows remote adjustment of the light level in steps of 2, 4, 10 and 100. Calculation, including depth-of-field, lens resolution, pixel size and CCD bandwidth shows a typical resolution of 0.12 mm, which is more than sufficient for the expected beam sizes.

4.4 *Signal Transmission*

The 4 frame grabbers will be located in a single VME crate at a central location, allowing a 16-to-4 wideband multiplexer to select which units are acquired. This requires signals to be brought from as far as 1200 feet without degrading the bandwidth and hence resolution. This will be done by using wideband analog fiber optic links previously developed for the Booster position monitors. Bandwidth is 20 MHZ, linearity is better than 1 percent with the noise floor less than 1LSB at 8 bits.

4.5 *Software*

The control software consists of a low level driver-like code running in front end computer and a device manager that runs in user level computer. Reliability and flexibility are the most important goals of the control software. Any outside access, including those by the analysis modules and interactive user action though GUI, will be through the manager, and the communication will be in the form of GLISH, an inter-process communication system and language developed at LBL, SSC and BNL. With GLISH, the high level modules can be assembled at run time through a Glish script. One side benefit of using GLISH in communication is the easy scriptability of user interaction.

The analysis modules have to provide corrections to the phosphor screen scattering effect, beam emittance calculations and beam phase space distribution characterization. Automatic procedures to do phase space matching may also be included. To match the capability of the hardware system, the analysis will be for three or four flag, one shot measurement as well as the quadrupole ramping measurement method. The multi-flag measurement calls for the correction of scattering effect of the flags, which has been studied and can be measured experimentally. The beam phase space density distribution, and hence any percentage emittance, can be reconstructed for any distribution with elliptical symmetry using Abel inversion technique.

5 CURRENT TRANSFORMERS

The charge in each bunch transferred from the AGS to RHIC will be measured at five strategic points along the transfer line. These are: (1) just after extraction from the AGS; (2)just after stripping and collimation; (3) immediately before entry into one of the two injection arcs; (4) at the end of each arc just before injection into RHIC. The detectors will be current transformers, specifically the Integrating Current Transformer (ICT) type developed by Unser[5] for LEP. This design incorporates two toroidal transformer cores and is particularly suited to measuring the charge in short beam bunches. By passively stretching the initial pulse, the signal is converted downward in frequency prior to applying it to the transformer. This overcomes the core losses at high frequencies, while preserving the relative charge and, in addition, allows the electronics to be located further from the detector. While the temporal beam signal is lost in this technique, precision measurements are made possible over a wide range of beam intensities. Each ICT will be mounted over a ceramic break in the beam pipe and covered by a copper enclosure to provide a path for the beam induced wall currents. Triaxial cable will be used to bring the signal to the electronics. The use of this kind of cable will allow the transformer outputs to remain isolated electrically from the beam pipe and building grounds and yet provides for adequate shielding from noise generated by nearby high current beam kickers and other devices. The signal processing electronics needed for the ICT signal will be resident in the Eurocrates which also contain the BLM electronics. Processing consists of an accurately timed and compensated integration of the stretched charge signal and subsequent digitization.

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7 REFERENCES

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