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AGS TO RHIC TRANSFER LINE: DESIGN AND COMMISSIONING[1]

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Abstract

In the fall of 1995, we successfully completed a major milestone in the RHIC project: the first beam test of the AGS to RHIC (ATR) transfer line. The ATR serves as a test bed for the new RHIC control system. This transfer line is highly instrumented, with several types of instrumentation for characterizing the extracted beam from the AGS and for matching the beam into RHIC. We describe the design and performance of the ATR with gold ions with an eye to reaching the design criteria for RHIC operation, both in beam quality and controls.

1 INTRODUCTION

The Relativistic Heavy Ion Collider (RHIC)[2][3] is a pair of intersecting superconducting storage rings being built to study nuclear phenomena of heavy-ion collisions in the center-of-mass. The injector system for RHIC (see Fig. 1) consists of the AGS (Alternating Gradient Synchrotron), the AGS injection Booster and two linacs: a tandem Van de Graaf for heavy ions, and a linac with an RFQ for protons. The ATR transfer lines consist of four pieces described in the next section.

Beam will be injected into RHIC by single-bunch bucket-to-bucket transfers. Multiple bunches extracted during one AGS cycle will be injected into only one of the two RHIC rings; however, it will be possible to switch rings between adjacent AGS ramps by reversing the polarity of a switch magnet between the X and Y-arcs.

2 DESIGN OF THE ATR LINE

Over 770 m of transfer lines transport ions up to rigidities of 100 Tm from the AGS through 80 dipoles, 31 quadrupoles, 35 correctors, and 2 Lambertson magnets to the RHIC rings. All but four of the horizontal dipoles are combined function magnets. These transfer lines are divided into four regions as shown in Figure 1.:

- The U-line matches the beam optics from the AGS, and ends with zero dispersion. There is a beam waist of $\beta_x = \beta_y = 6$m to locate a foil for stripping the final two electrons from gold ions (Au^{+77}). An additional pair of switch dipoles almost halfway down the U-line are sometimes used to divert beam to a muon storage ring experiment unrelated to RHIC.
- The W-line transports the beam from the end of the U-line onto a left-right symmetry line of the two RHIC rings with a dispersion free combination of vertical and horizontal bends. A switch dipole after the W-line directs beam to either of the the RHIC rings, or if unpowered, into a beam dump just downstream of the switch.

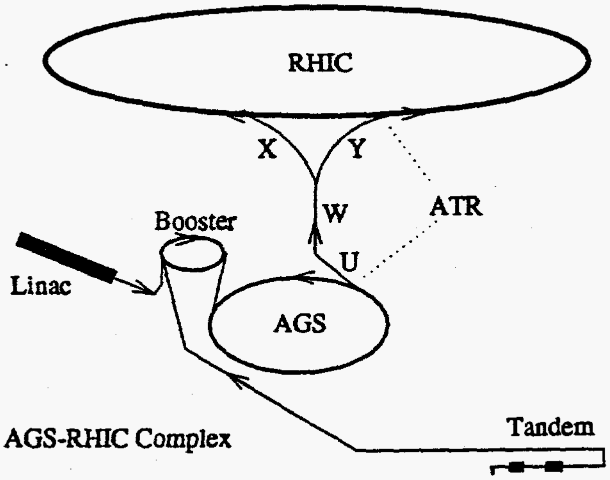

Figure 1: Layout of RHIC and the injector complex. Heavy ions originate at the beginning of the Tandem Van de Graaf, and protons at the beginning of the linac.

- The X-line bends almost 90° to the left with six tunable quadrupoles at the end to match and inject vertically into the clockwise (Blue) ring. In the second half-cell of the clockwise ring after the Lambertson magnet, four vertical kicker magnets bend the injected bunch onto the circulating orbit.
- The Y-line mirrors the X-line for the counterclockwise (Yellow) ring.

Figure 2 shows the optical functions for the U, W, and Y-lines. The functions for the X-line are identical to those of the Y-line, except that the horizontal dispersion, η_x is flipped in sign.

2.1 *Instrumentation*[4]

The charge in each bunch transferred from the AGS to RHIC is 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 are current transformers, specifically the Integrating Cur-

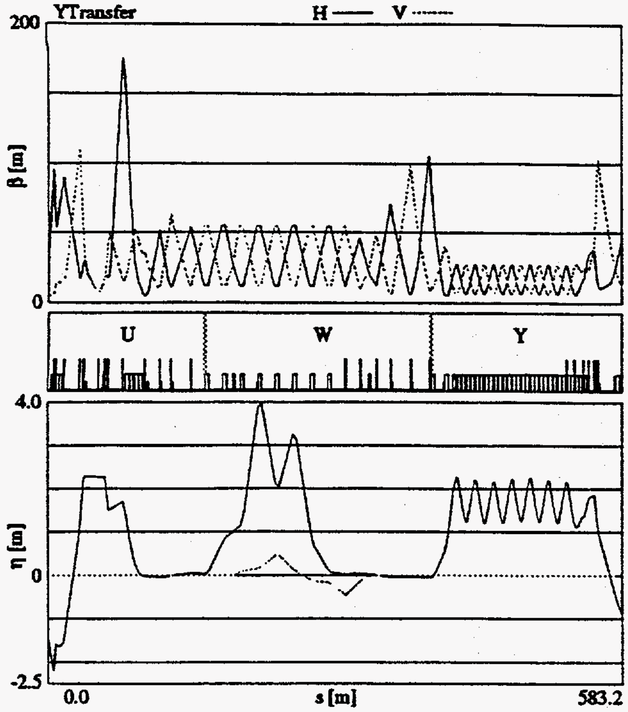

Figure 2: Optical functions for the U-W-Y beam lines from the AGS into the counterclockwise ring of RHIC. The tall elements are quadrupoles, and the shorter elements are dipoles.

rent Transformer type developed by Unser[5] for LEP and purchased off-the-shelf from Bergoz. This design incorporates two toroidal transformer cores and is particularly suited to measuring the charge in short beam bunches.

Beam loss monitoring is one of the most important diagnostic tools in setting up the ATR. Beam loss monitors for the ATR and RHIC are argon filled ion chambers of essentially the same design as used in the Tevatron at FNAL. Ion chambers mounted on the vacuum flange downstream of each magnetic element detect the ionizing radiation produced by beam loss. Because the number of readout channels is limited, some detectors are daisy-chained on a single signal cable. The ionization current is collected by a low leakage gated integrator and read out using the standard multi-channel ADC designed by the RHIC Controls Section. Special non-tribo-electric cable is used to reduce noise due to mechanical motion which would compromise the pico-amp sensitivity of the system. An input circuit stretches the electron signal's rise time to milliseconds thus reducing induced noise from the kicker magnets which are time coincident with the beam. The shield of the ion chamber signal connector is isolated from the enclosure to prevent a ground loop with the HV connector shield. The result of these precautions is that a noise level of under 10 pA was observed during the ATR commissioning, allowing measurement of the beam 2 decades below the nominal design intensity.

Stripline beam position monitors (BPMs) are distributed along the ATR with 24 planes in the U and W-lines and another 12 planes in each of the X and Y-lines. The signals from these BPMs are carried through phased-matched heliax cables out of the tunnel to a VXI-based sample-and-hold system[6]. The outputs of the analog circuits are then digitized and converted to positions which are written into VME memory. The position resolution is about 10μ for bunches of $\geq 10^7$ charges.

Beam profile information is measured by digitizing images on phosphorescent flags[7] which can be remotely inserted into the beam at various locations along the ATR: one (UF1) at the beginning of the U-line, one (UF2) near beam waist in both the horizontal and vertical about 50 m into the U-line, three (UF3, UF4, UF5) at the end of the U-line, three (WF1, WF2, WF3) at the end of the W-line, two at the end the X-line, and another two at the end the Y-line. The first two flags in the U-line are 1 mm thick Al_2O_3:Cr and are designed to withstand high current beams (6×10^{13} protons per AGS cycle) for the muon ring experiment. The remaining 10 flags are made of 1 mil thick Al coated with 2 mils of Gd_2O_2S:Tb phosphor and are designed to withstand RHIC beam intensities. These thin flags are designed so that up to four profiles might be taken for a single extracted bunch with minimal blowup from multiple scattering. Profiles are read by CCD cameras except for the first location where a CID camera is used because of its higher tolerance for radiation. Up to four flags may be simultaneously digitized with VME frame grabbers. The following paper[8] discusses emittance measurements using these flags.

For future running a thin gold foil for stripping the final electrons from the extracted Au^{+77} ions will be installed in the U-line just downstream of flag UF2. Three pairs of collimator jaws will also be installed in the U-line to aid in momentum spread measurements.

2.2 *AGS Extraction*

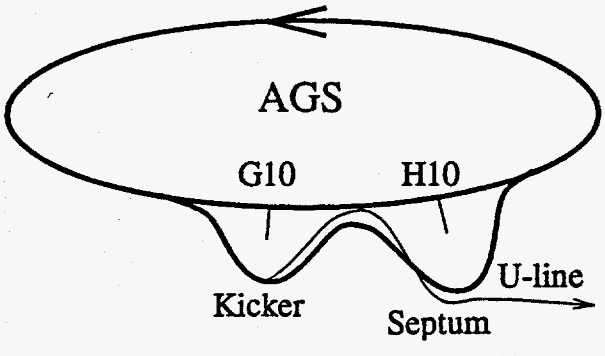

Figure 3: Schematic of the extraction orbit.

Single bunches are extracted horizontally from the AGS as shown in Fig. 3. During the flattop of the acceleration cycle, two horizontal bumps are ramped to move the orbit into the gap of a fast kicker magnet at the peak of the first bump and close to a septum magnet at the peak of the second bump. At the maximum bump amplitude the septum magnet is then pulsed. Finally the kicker is fired to kick the desired bunch inward so that after 3/4 of a betatron pe-

riod the bunch will arrive at the extraction channel of the septum.

3 COMMISSIONING

In the fall of 1995, we commissioned the U and W-lines, taking beam beam to the dump just downstream of the switch magnet with gold ions of momentum 11.2 Gev/c/nucleon ($\gamma = 12.1$).

The beam intensity at the beginning of the run started at about 5×10^6 ions per pulse from the AGS. At the end of the heavy-ion run the intensity was increased to about 2.5×10^8 ions per bunch. Several things were done to improve the intensity, in particular, doubling the tandem output and two levels of bunch coalescing in the Booster and AGS. More work will be done during the next heavy-ion run to increase the desired intensity per bunch to the RHIC design value of 10^9 gold ions per bunch.

A very important change in the AGS complex was developed and very successfully tested during this run: context-switching between AGS cycles. With context-switching we were able to do most of the commissioning by stealing only an occasional AGS cycle for the ATR. The result was that the ATR tests had an almost negligible impact on the fixed target program. Context-switching has also proven to be very useful for other machine studies of the Booster and AGS.

Setting up extraction from the AGS took about four hours with dedicated beam time. Next the AGS and Booster were switched into a context-switching "ping-pong" mode where only one of every 11 cycles were extracted to the ATR; the remaining 10 cycles were used for slow extracted beam to the fixed-target experiments. Later this mode of operation was shifted to a "pulse-on-demand" context-switching. In the pulse-on-demand mode, we used fewer than 200 cycles per 8-hour shift ($< 2.5\%$) throughout the rest of the AGS heavy-ion run.

Initial threading of beam down the U-line was very quick, although some time was taken to adjust timing and settings for the instrumentation. Due to the small beam currents, only the flags and loss monitors were used. The beginning of the W-line took longer to thread since there are a combination of horizontal and vertical bends without any flags. There is a 20° bend of 8 widely spaced gradient dipoles with a narrow-aperture vertical bend between the second and third. The night shift made an aperture scan versus current in the horizontal bend and were able to determine the correct current setting for the momentum.

3.1 AGS extraction stability

After beam coalescing was introduced, there were only two bunches in the AGS, one with half the current of the other. This limitation was due to the pulse length of the extraction kicker in the booster. The larger current bunch was then extracted into the ATR for further studies. In this running mode, the radial feedback loop to the rf system within the AGS would not lock if the bunch intensity was smaller than about 4×10^7 ions (indicated by the dashed line in Fig. 4). Fig. 4 shows the position measured on the flag, UF1, at the beginning of the U-line versus bunch intensity. The vertical position of the extracted beam is very stable, but the horizontal position shows some jitter, and even an apparent current dependence. We believe that this current dependence may be related to the radial feedback loop. If the current dependence is unfolded, then the orbit variations appear to be within ±0.5 mm at UF1. This variation should be correctable by the transverse damping system which allows for a 2 mm injection variation of the transverse orbit at a $\beta_{\max} = 150$ m, which when translated back to UF1 corresponds to errors of about ±0.7 mm.

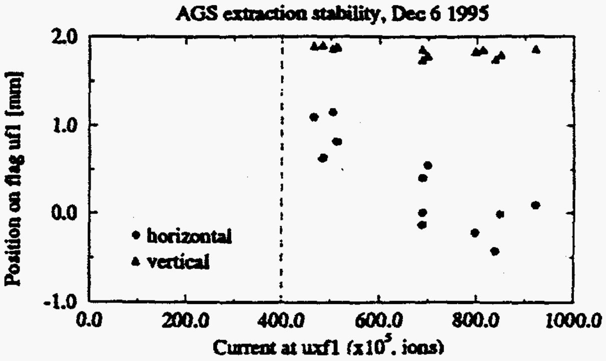

Figure 4: Stability of AGS extraction: position measured on flag UF1 at the beginning of the ATR versus intensity.

More information about the controls and physics analysis will be found in the following paper[8].

4 ACKNOWLEDGMENTS

This paper is dedicated to the memory of Horst Foelsche who inspired much of the design and construction of the ATR. We would also like to acknowledge the fine work of the installation and operations groups.

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