PHYSICS OF THE AGS-TO-RHIC TRANSFER LINE COMMISSIONING

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Abstract

This paper presents beam physics results from the fall 1995 AGS-to-RHIC (ATR) transfer line commissioning run with fully ionized gold nuclei. We first describe beam position monitors and transverse video profile monitors, instrumentation relevant to measurements performed during this commissioning. Measured and corrected beam trajectories demonstrate agreement with design optics to a few percent, including optical transfer functions and beamline dispersion. Digitized 2-dimensional video profile monitors were used to measure beam emittance, and beamline optics and AGS gold ion beam parameters are shown to be comparable to RHIC design requirements.

1 INTRODUCTION

A description of the RHIC complex, AGS extraction, and the ATR transfer line layout and commissioning is included in the preceding paper[1]. The six weeks of 1995 ATR commissioning extracted Au^{+77} beam from the AGS, which was then fully stripped to Au^{+79} and delivered through the ATR transfer line U- and W-lines, two-thirds of the distance to RHIC.

Prototype sections of a new RHIC control system were commissioned together with AGS and RHIC extraction systems, transfer line hardware, and instrumentation. The success of this effort is indicated not only by the short time required to deliver beam through the transfer line, but also by the clarity of data that were saved in raw and processed formats suitable for instrumentation and physics post-analysis.

We first present a summary of primary instrumentation (beam position monitors and video profile monitors) used to measure transfer line and beam properties. (Other instrumentation is described in [1].) Sections on optics measurements, beam emittance measurements, and analysis follow, and results of all relevant parameters measured during commissioning are summarized in Table 3.

2 INSTRUMENTATION

Six single-plane and nine dual-plane beam position monitors (BPMs) were present during ATR commissioning. For typical operational intensities, these monitors have a resolution of approximately 10 μm, and each trajectory from all BPMs was saved with a correlated set of power supply and magnet settings for the transfer line. Beam intensities were well above the operational threshold of 10^7 nucleons per bunch for all measurements.

Eight video profile monitors, connected to four frame grabbers through a high-speed optical multiplexer, were present and available for use during commissioning[2]. The first two flags in the U-line, UF1 and UF2, are “thick” flags designed to withstand high-intensity proton beams. During this run they were also used to strip the ion beam and monitor extraction stability. The other six flags are grouped in two sets of three, placed for three-profile emittance measurements. Flags UF3,4,5 are located before the 20-degree W-line bend, while WF1,2,3 are located at the end of the W-line. Raw flag data as well as calibration data were saved together to allow later calibration analysis.

3 BEAMLINE OPTICS

Beam transfer functions between dipole correctors and downstream BPMs and profile flags were measured and compared to design. During these measurements, BPM and dipole corrector polarities and calibrations were confirmed. Beam dispersion was also measured by varying either the AGS extraction energy or the energy scale of transfer line magnet strengths.

3.1 Matrix Elements and Transfer Functions

First-pass calibration and testing of BPMs and dipole correctors was significantly simplified by the presence of physical calibration markings on the video profile flags[2]. Comparing centroid positions on these flags to positions on nearby dual-plane BPMs, polarities and alignment offsets were confirmed and corrected when necessary.

After calibration, optical transfer elements were measured by acquiring and archiving orbits with several different settings of each dipole corrector, holding all other beamline and extraction parameters fixed. Differences between perturbed and nominal trajectories could then be purely attributed to the single dipole corrector change, and compared to a simple design optics model. Typical ‘difference orbits’ in Figure 1 display close agreement between measurement and theory, and complete analysis evinces no discrepancies above the 5% level.

3.2 Line and Beam Dispersions

Two separate methods were used to measure dispersions during ATR commissioning. In the first method the ex-

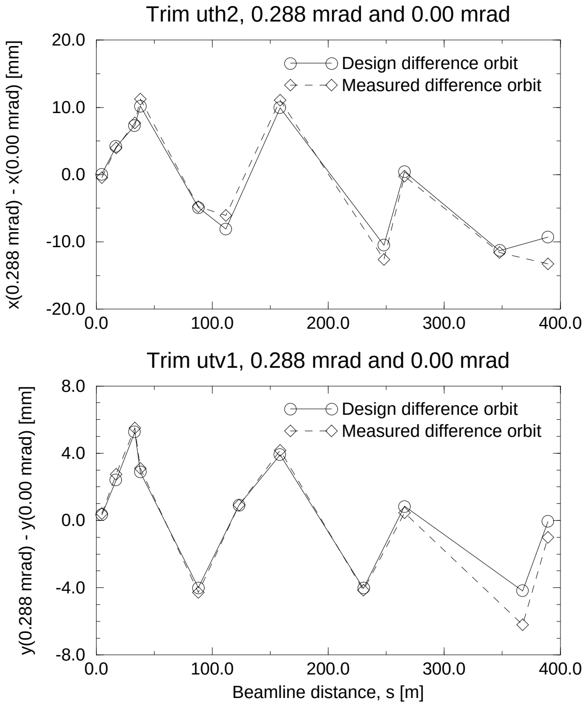

Figure 1: Orbit differences for horizontal and vertical orbits in ATR, varying trim dipoles UTH2 and UTV1, both near AGS extraction. Measurement and simulated design optics closely agree almost throughout the commissioned line.

tracted beam energy was varied while trajectory displacements were observed at flags and BPMs, providing a measurement of the dispersion function through the beamline. These results are shown in Figure 2.

A second dispersion measurement, corresponding to momentum-coupling coefficients in the line transfer functions, was performed by scaling all transfer line magnet strengths to different extraction energies, or γ. These measurements were unfortunately complicated by shot-to-shot extraction stability variations[1].

3.3 Apertures

The dispersion measurements of the previous section also served as aperture scans for several elements in AGS extraction and the transfer line. Variation of the AGS energy through RF radial loop parameters indicated that the total momentum acceptance of the AGS extraction septum, the limiting aperture, was $\Delta p/p = 1.1\%$. AGS extracted beam momentum width, $\sigma_p/p = 3 \times 10^{-3}$, was also measured with new AGS coalescing strategies.

The momentum aperture of the ATR transfer line was deduced from the range of variation in beamline magnet strength that did not scrape beam. With loss-free extraction in the range $\gamma = 12.1 \pm 0.1$, the ATR momentum aperture is $\Delta p/p = \pm 8.3 \times 10^{-3}$, quite close to the AGS momentum aperture without extraction bumps of $\Delta p/p = \pm 8 \times 10^{-3}$.

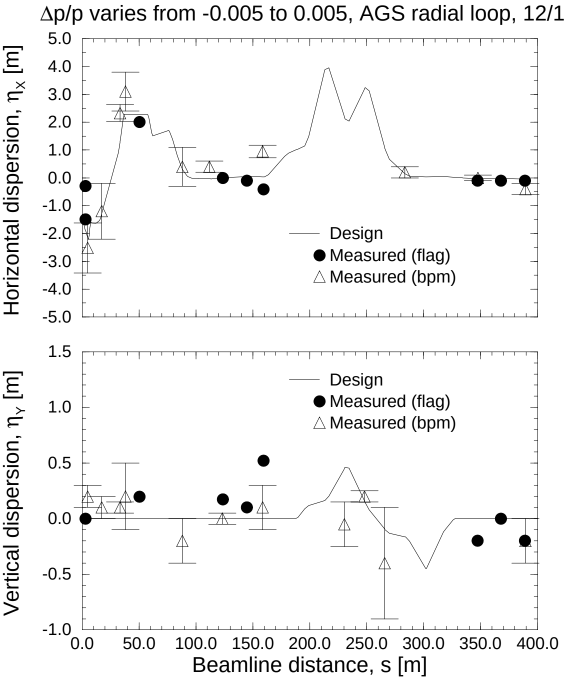

Figure 2: Dispersion functions of the ATR as measured by varying the AGS extraction energy.

4 TRANSVERSE EMITTANCE MEASUREMENTS

4.1 Methods

With the wealth of data that full two-dimensional transverse beam profiles provide, there are several methods that are used to measure transverse emittance in the ATR line. These methods can be characterized by the required number of inserted profile monitors, and by whether optics need modification during the measurement.

- Many profile locations: three or more acquired profiles, one per flag and per extraction pulse keeping extraction optics fixed. Emittance is extracted from a beam ellipse fit to the measured widths.
- Two profile locations, knobbing middle quad: using two flags, adjust a quad between the flags to set $\beta' = 0$ at the downstream flag.
- One profile location, knobbing upstream quad: a parabolic fit of beam width versus quad strength gives emittance and lattice functions at the quad.

Accurate emittance measurements required the insertion of only a single measurement flag (UF3,4,5, WF1,2,3), with either UF1 or UF2 also inserted for full stripping. Online flag calibration, and online and offline data analysis, were possible using a gaussian fit and analysis program, pictured in Figure 3 and developed during commissioning. All emittances quoted here are 95% normalized emittances.

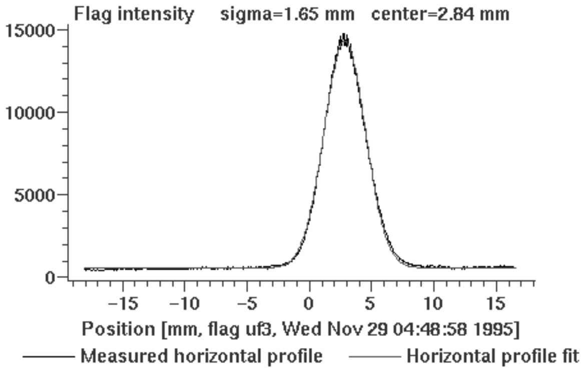

Figure 3: A typical gaussian fit to a horizontal profile monitor projection, here flag UF3 in the middle of the U-line.

4.2 Emittance Blowup and Error Sensitivity

The rms angular beam size increase, $\Delta\sigma'$, from passage through a profile flag at an optical beta function of β_i gives an emittance growth of $\Delta\epsilon \approx 5.911(\beta\gamma)\beta_i\Delta\sigma'^2/2$. Emittance growths from single flags are calculated in [3] and summarized in Table 1. Thick flag UF1 was initially used for ion stripping in the ATR commissioning, as it is suitable for tuning and monitoring extra stability. Emittance measurements were later performed with either or both of thick flags UF1 and UF2 inserted.

	Thick flag UF1	Thick flag UF2	Thin flag UF3,4,5 WF1,2,3
$\Delta\sigma'$ [μrad]	57	57	19
$\Delta\epsilon_x$ [π mm-mrad]	7.1	0.8	0.1–1.3
$\Delta\epsilon_y$ [π mm-mrad]	0.4	0.7	0.1–1.2

Table 1: 95% normalized emittance growth parameters for profile measurement flags in ATR. Thin flag emittance growths vary with optical beta function.

For multi-flag emittance measurement methods, errors in optics or flag calibration of 15–20% can give unphysical imaginary emittances as calculated from measured beam widths[4]. During sextant test commissioning in 1996, we plan to test alternate optics in ATR that include nominal 60° phase advances between flags, and additional systematic emittance measurements will be performed.

4.3 Results

Emittance measurement results are summarized in Table 2, with averaged measurements of AGS 95% normalized emittances giving $\epsilon_x = 10.3\ \pi$ mm-mrad and $\epsilon_y = 9.5\ \pi$ mm-mrad. These data, acquired over approximately one month of shifts, represent a variety of emittance measurement methods and insertion combinations of the two thick stripping flags UF1 and UF2. Consistent emittances were measured at the end of the U- and W-lines.

Flag UF1	Flag UF2	$\epsilon_x[\pi$ mm-mr]	$\epsilon_y[\pi$ mm-mr]
⟨in⟩	⟨in⟩	20.1 ± 2.2	8.6 ± 4.2
⟨in⟩	⟨out⟩	19.9 ± 1.0	8.1 ± 1.5
⟨out⟩	⟨in⟩	10.3 ± 0.5	9.5 ± 0.6
Design	Design	10.0	10.0

Table 2: Average 95% normalized transverse emittance measurements $\epsilon_{x,y}$ of Au ion beam extracted from AGS during 1996 ATR commissioning for various insertion combinations of profile flags UF1 and UF2.

Comparison of these emittance measurements with flags UF1 and UF2 each individually inserted gives an average difference of 10 π mm-mrad horizontally, with no vertical emittance growth. This is approximately consistent with calculation of emittance growth from UF1 as given in Table 1, which indicate large horizontal and small vertical emittance differences between these configurations.

5 SUMMARY

The fall 1995 commissioning of the ATR transfer line successfully measured a variety of beamline and AGS extracted gold ion beam properties as summarized in Table 3. Measured beamline optics are within 5% of design, with reasonable matching to AGS extraction optics. Extracted beam σ_p/p is 0.3%, with an AGS septum momentum aperture of 1.1%. Gold ion beam properties as delivered by the AGS such as emittances, bunch length, and beam size were all close to RHIC design. The beam intensity was only a factor of four or five below design requirements.

	measured	design	units
Energy	10.33	10.83	GeV/amu
Intensity (low)	10^7	10^9	ions
(high)	2.5×10^8	10^9	ions
σ_p/p	3	0.271	10^{-3}
bunch length	20	17	ns
95% emittance ϵ_x	10.3±0.5	10	π mm-mrad
95% emittance ϵ_y	9.5±0.6	10	π mm-mrad

Table 3: Comparison of AGS extracted beam in 1995 with Au^{+77} beam to RHIC design requirements[5].

6 REFERENCES

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[4] S. Peggs and N. Tsoupas, "The Phase Advance Between ATR Flags", RHIC AP note 79, December 1995.

[5] "RHIC Design Manual", October 1994.