The AGS Accelerator Complex with the New Fast Extraction System*

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Abstract

The delivery of a beam with chracteristics appropriate for the g-2 muon storage ring and the filling of the RHIC heavy ion collider from the AGS main ring requires a new fast extracted beam (FEB) system. The new FEB system will be capable of performing both one-turn fast extraction and single bunch multiple extraction of either a heavy ion beam or a high intensity proton beam at a rate of 30 Hz up to 12 times per AGS cycle. The new system consists of a fast multi-pulsing kicker and an ejector septum magnet with local extraction orbit bumps.

I. INTRODUCTION

Since the old fast extracted beam (FEB) and single bunch extraction (SBE) systems [1] are no longer available due to the AGS improvement program, the new FEB system [2] will serve as the AGS extraction system not just for the muon g-2 experiment [3] but also for RHIC [4] and the long baseline neutrino (ν_μ) oscillation experiment [5] as well. The AGS complex has accelerated slow-extracted (SEB) Au^{77+} beam at 11.6 GeV/c/N for the nuclear physics program and has recently increased the proton beam intensity to $6 \cdot 10^{13}$ ppp at 24.5 GeV/c for various high energy physics experiments [6].

For the g-2 experiment, which has constructed a 14 m diameter superferric muon storage ring with B = 1.5 T in order to improve the previous CERN measurement of the anomalous muon magnetic moment (a_μ) by a factor of 20, the FEB must meet the following requirements: (1) extract the bunched proton beam up to full energy and intensity to the new V-target through the U-line for 3.1 GeV/c pion production, and (2) perform single bunch multiple extraction (SBME) at 33.3 ms intervals up to 12 (or 8) times per AGS cycle. The remaining bunches, if any, have to be debunched and be slowly extracted into the SEB channel for the HEP experiments. The ν_μ oscillation experiment requires fast one-turn extraction of tightly bunched high intensity proton beam.

With the FEB system the AGS complex will also serve as an injector for RHIC. The circumference of the RHIC ring is 19/4 times larger than the AGS (C=807 m) and its harmonic number at injection is 342 compared to 12 of the AGS. The AGS will accelerate three bunches per pulse and transfer individual bunches one by one into the waiting rf buckets in RHIC through the AGS_to_RHIC (AtR) transfer line. Each RHIC ring will be filled with 57 (or 114) bunches one after another in a few minutes every 10 hours or so and accelerate heavy ions to energies of 250·(Z/A) GeV/N with the luminosity $L = 2 \cdot 10^{26}\ cm^{-2}s^{-1}$.

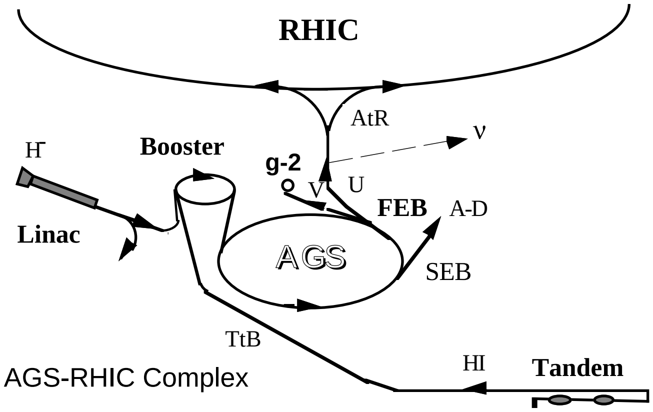

Figure 1. Schematic view of the AGS-RHIC complex.

In the fall of 1995, both the new FEB system and the AtR line are scheduled to be commissioned. The schematic layout of the AGS-RHIC accelerator complex is shown in Figure 1.

II. DESIGN OF THE FEB SYSTEM

A. Machine and Beam Parameters

Due to its high intensity operation for the g-2 experiment and the ν_μ oscillation experiment, it is important that the FEB system achieves a high extraction efficiency (>99%). On the other hand, for RHIC injection, the beam intensity is low but pulse-to-pulse and cycle-to-cycle modulations in the extracted bunched beam parameters must remain within acceptable levels since any excess will directly influence RHIC performance. Therefore, stability and reproducibility of the extracted beam parameters are crucial for RHIC injection.

The following table lists the expected beam parameters and performance of the AGS Complex for FEB operation:

Table 1. FEB beam parameters.

Users	g-2	RHIC	RHIC	
Particles	Protons	Protons	Heavy ions	
Momentum	22-25	28.0	28.0·(Z/A)	[GeV/c/N]
			28.7·(Z/A) for Au^{77+}	
N_{SBE}	1,2,,8(12)	3 (19·2(·2)) for 2 rings		
N_p/bunch	5000	100	1(Au), 6(Si)	$[10^9]$
$\varepsilon^n_{h,v}$(95%)	$50\ \pi$	$20\ \pi$	$10\ \pi$	[mm-mrad]
ε_L	1.0	0.3	0.3	[eV-s/N]
(l_{bunch}	50	12	17	[ns])
$(dp/p)_{full}$	± 0.2	± 0.06	± 0.10	[%])
Oper. Mode	with SEB.	filling two rings every 10 hr.		

The basic machine parameters and performance of the present AGS proton (Au^{77+}) SEB operation are summarized in Table 2. It should be noted that for the SEB users, their

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prime interest is uniformity of the beam spill and beam intensity. In order to accelerate the high intensity proton beam without difficulties, the machine rf harmonic numbers have been changed from h=12 to 8 in AGS (from 3 to 2 in Booster) with a longer bunch length

Table 2. AGS parameters.

Circumference	$C = 2\pi R = 807.075$	[m]
Curvature	$\rho = 85.17$	[m]
Revolution Time	$t_{rev} = 2.692$	[μs]
Tune	$Q_h \cong Q_v \cong 8.7$	
Beta Functions	$\beta_{h,v} = 22.5 - 10.5$	[m]
Dispersion Function	$D_x^{max} = 2.20$	[m]
No. of Bunches	$N_b = 8$ (3 for Au^{77+})	
Gap bet. Bunches	$t_s = 336$ (224)	[ns]
Typical Intensity	$5.3\cdot10^{13}$ $(1.2\cdot10^{8})$	[ipp]
Typical AGS Cycle	3.2 (3.6)	[s]
Typical Spill Length	1.2 (1.2)	[s]
Typical Momentum	p = 24.5 (11.6)	[GeV/c/N]
Tran. Emittance	$\varepsilon^n_{h,v}(95\%) \cong 80$ (10)	[π μm]
Long. Emittance	$\varepsilon_L = 1.0$ (0.3)	[eV-s/bunch/N]
(Bunch Length	$l_b = 80$ (10)	[ns])

For design purposes, we assume that the operational FEB proton momentum range is (1) $22 < p < 29$ GeV/c, (2) the normalized transverse emittance of the high intensity beam should be $\varepsilon^n_{h,v}(95\%) = 6\cdot\sigma^2/\beta\cdot(p/m) \leq 50\ \pi$ mm-mrad, where σ is the standard deviation of the beam size due to the transverse emittance, (3) the maximum total momentum spread allowed is $(dp/p)_{full} = \pm\ 0.2$ % and the maximum bunch length is $l_b = 60$ ns. The actual measured values of ε^n, dp/p and l_b for the AGS beam are strongly dependent on the machine condition, especially the beam intensity. The high intensity values for the FEB operation have not yet been optimized [6].

For RHIC injection, the expected values of ε^n, dp/p and l_b for both protons and ions are substantially lower than the current values since the AGS Booster can deliver much more intensity than that assumed for the RHIC design parameters. The Au^{77+} beam intensity is expected to increase to meet the RHIC requirement [7].

B. Extraction Scheme

The new system consists of a fast multi-pulsing kicker at straight section G10 followed by a thick septum ejector magnet at s.s.H10 in order to utilize the existing U line and due to limited availability of straight sections. To minimize the required voltage on pulsing the fast kicker, the kicker is a C-type open ferrite magnet with a pole tip. The kicker is placed about 60 mm from the central orbit. A few ms before the extraction two extraction bumps are excited to bring the beam into the aperture of the kicker and adjacent to the septum of the ejector. At extraction, the kicker is synchronized and phased to the bunches and triggered every 33.3 ms to send one bunch at a time into the ejector, which gives an additional larger kick to extract the bunch out of the ring. In Figure 2, we show a schematic layout of the FEB extraction components and the extraction orbit bumps.

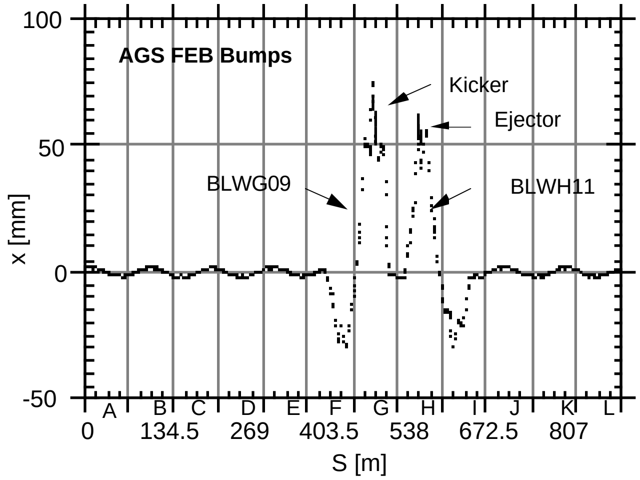

Figure 2. Layout of the AGS FEB components.

C. Fast Kicker, Ejector and Orbit Bumps

Using the 99% emittance at p=29 GeV/c and asking at least 2 mm clearance at both sides of the ejector septum (10 mm), he required separation of the circulating beam and the beam kicked by the fast kicker is $\Delta x = 30.4$ mm at H10. The kicker must deflect the beam by

$$\theta(G10) = \Delta x \,/\, \sqrt{\beta(G10)\cdot\beta(H10)}\cdot\sin(\Delta\mu) = -1.80 \text{ mrad},$$

where $\Delta\mu$ is the betatron phase advance from the kicker to the septum calculated from the AGS lattice. This corresponds to $\int Bdl = B_o\cdot l_{eff} = -0.18$ T-m. Since it is desirable to keep the maximum pulse voltage less than 40 kV, the kicker magnet is subdivided into four modules and powered by four PFN modules. The kicker has a limited aperture, 32 mm x 22 mm (w x g) and a pole tip which is shaped to maximize the good field region while keeping a gap as large as possible as shown in Figure 3.

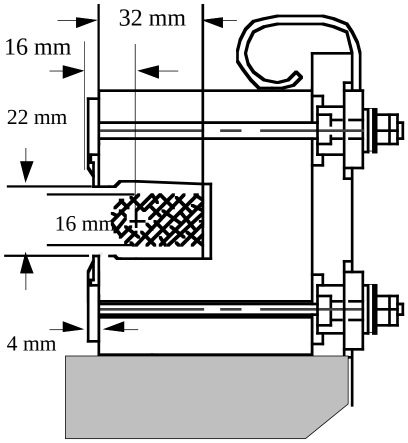

Figure 3. Geometry of the fast kicker.

The vertical field uniformity is calculated to be ± 2.5 % and the horizontal field component is 0 ± 2.5 Gauss in the cross hatched region shown in the gap. Aluminum shields have been placed on both the upstream and downstream ends of the magnet to protect the ferrite magnet core. For FEB operation, the ejector magnet also has to pulse at 30 Hz. As a result, the temperature of the copper septum will rise significantly, causing wear of the insulation. Therefore, the septum needs 10 mm thickness and is water-cooled.

Two 1 λ rather than standard 3/2 λ local orbit deformations (BLWG09 & H11) are installed to avoid the kicked beam hitting the vacuum chamber wall at s.s.G20 as seen in Figure 2. Each bump is excited by powering backleg windings on selected AGS main magnets with three independent power supplies. The basic parameters of the kicker, ejector and extraction bumps are summarized in Table 3.

Table 3. FEB magnet parameters.

	Kicker	Ejector	Bumps
Aperture [mm]	32 x 22	72 x 25	Full
Length [m]	2.4	2.1	(1 λ)
θ_{max} [mrad]	2.0	22.0	2(4)/pair
Waveform	half sine	half sine	half sine
B_{max} [T]	0.1	1.0	0.05(0.1)
$t_{basewidth}$	380 ns	2 ms	6 ms
I_{max} [kA]	2.0	23	1.0
Tolerance [%]	< 0.9	< 0.09	< 0.8

D. Beam Instrumentation

In order to observe possible beam scraping during the FEB extraction, two pairs of fast beam loss monitors are installed at s.s.G10. One pair is connected to a beam inhibit system. The present beam position monitor (PUE) and ring long radiation monitor (RLRM) systems are not sensitive to a gold beam and will be upgraded with a wider dynamical range and a better absolute measurement capability.

III. SIMULATION

To investigate the circulating and the extracted beam parameters at the middle of s.s.H13 (the entrance of the U-line), simulation studies were performed with a model of the AGS (MAD). We ran MAD to obtain the desired orbit at the kicker and at the ejector, making adjustments of the extraction bumps at a desired working point $\{Q_h, Q_v\} = \{8.74, 8.78\}$. Then, the particles with initial conditions {x, x'} at the beginning of s.s.G10 are traced through the lattice and receive an appropriate kick at the kicker and an additional kick at the ejector up to the middle of s.s.H13, where the beam should be about 45 cm away from the central orbit, free from the fringe field. The simulation results show that the optical parameters ($\beta_{h,v}$, $\alpha_{h,v}$, D_x, D_x') at s.s.H13 are sensitive to fine bump tuning due to both the non-linear field components at high field of the AGS combined-function main magnet and fringe field effects from the septum to s.s.H13. The results on the extracted beam parameters are summarized in Table 4.

Table 4. Extracted beam parameters.

ELEM NAME	DIST [M]	ßh [M]	αh [1]	x [mm]	x' [mrad]	Dx [M]	Dx' [1]	ßv [M]	αv [1]
ssH13	78.68	39.69	-4.85	449.	65.6	1.13	0.183	4.23	1.01

VI. CONCLUSIONS AND OUTLOOK

The new FEB extraction system is under construction at the AGS, which is capable of performing single bunch multiple extraction at a rate of 30 Hz up to 12 times per AGS cycle for the g-2 experiment and RHIC injection. In March 1995, the fast kicker system was successfully tested to extract single bunched proton beams to the SEB line for a test of the g-2 prototype detector at p = 24 GeV/c with $2 \cdot 10^{12}$ ppb. The full new FEB system is scheduled to be commissioned for the AtR-line in September 1995 and for the V-line in January 1996. The muon storage ring and RHIC are expected to be completed in 1996 and in 1999, respectively. For high intensity proton operation, it is important that the FEB system achieves a high extraction efficiency. On the other hand, for RHIC injection, stability and reproducibility of the extracted bunched beam parameters are crucial. Further machine studies and simulation studies will be needed to optimize beam parameters for the FEB operation.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

[1] W.T. Weng, “The AGS New Fast Extraction System and the Single Bunch Extraction”, *IEEE Trans. Nucl. Sci.* NS-30, No. 3 (1983).

[2] M. Tanaka and Y.Y. Lee, “The AGS -Booster Complex for the g-2 Experiment and RHIC Injection”, *1993 IEEE Part. Accel. Conf.* (Washington, D.C.), p. 360

[3] AGS Experiment 821, “A New Precision Measurement of the Muon g-2 Value at the Level of 0.35 ppm”.

[4] BNL-52195, “Conceptual Design of Relativistic Heavy Ion Collider”, May 1989.

[5] AGS Experiment 889, “Proposal for a Long Baseline Neutrino Oscillation Experiment at the AGS”.

[6] M. Blaskiewicz et.al., “High Intensity Proton Operations at the Brookhaven Hadron Complex ”, this conference.

[7] L. Ahrens et.al., “Heavy Ion Acceleration Strategies in the AGS Accelerator Complex”, this conference.