The AGS New Fast Extraction System for the g-2 Experiment and RHIC Injection*

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Abstract

The AGS requires a new fast extraction beam (NewFEB) system for the muon g-2 experiment and the Relativistic Heavy Ion Collider (RHIC). The proposed NewFEB system will consist of a new fast multi-pulsing kicker placed at straight section G10 and an ejector septum magnet at H10,together with local orbit bumps generated by powering backleg windings on the AGS main magnets. The new system is capable of performing single bunch multiple extraction as often as every 8 ms up to 12 times per AGS cycle, in addition to the standard single turn fast extraction. The conceptual design of the NewFEB sysytem will be discussed.

I. Introduction

Since the present fast extraction beam (FEB) and single bunch extraction (SBE) systems[1] are no longer available for the post-Booster era, the NewFEB system will serve as the AGS extraction system not just for the muon g-2 experiment[2] but also for RHIC[3] and any future neutrino physics program. The AGS Booster, nearly completed, should soon be able to increase the proton intensity in the AGS by a factor 4 and to allow the AGS to accelerate heavy ions (HI) beyond Si^{28} up to Au^{197}.

For the g-2 experiment, which is now constructing a 14 m diameter superferric muon storage ring (μ-SR) with B=1.5 T in order to improve the previous measurement of the anomalous magnetic moment (a_μ) by a factor of 20, NewFEB must meet the following requirements: (1) extract proton bunch beam up to full energy and intensity to the new V-target through the existing U-line for 3.1 GeV/c pion production, (2) perform single bunch multiple extraction (SBME) at $\sim$ 8 ms intervals up to 12 times per AGS cycle. The remaining bunches, if any, have to be debunched and go though the slow extraction beam (SEB) channel.

With the NewFEB system the AGS will also serve as an injector for the RHIC, which is now under construction. The circumference of the RHIC ring is 19/4 times larger than the AGS and its harmonic number at injection is 342 compared to 12 of the AGS. The present RHIC design assumes that the AGS can accelerate a variable number of bunches per pulse and the FEB/SBE system can be used as the extraction system for RHIC injection. The exact AGS operation mode for RHIC injection has not yet been fixed: (1) one may transfer all bunches (*e.g.*, 12/11 for protons, 3 for HI) to RHIC in a single turn (FEB, box-car stacking), or (2) one may transfer individual bunches one by one into the waiting rf buckets in RHIC (SBME). RHIC two rings will be filled with 57 bunches one after another in two minutes every $\sim$ 10 hours.

The schematic layout of the AGS-RHIC complex is shown in figure 1.

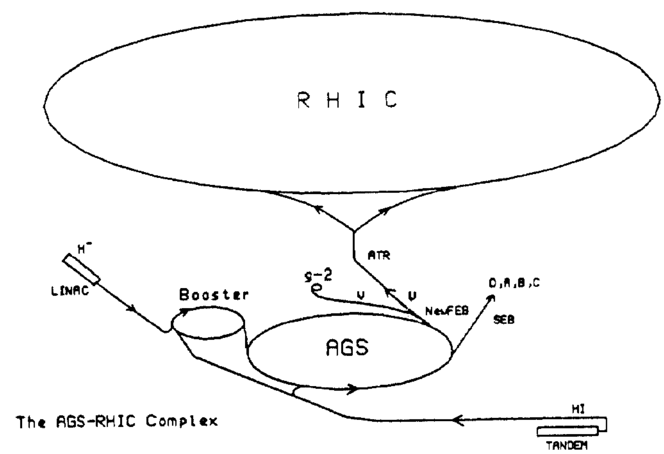

Fig. 1. Schematic layout of the AGS-RHIC complex.

II. Design of the NewFEB

A. Machine and Beam Parameters

For design purposes, we may assume that (1) p=29 GeV/c, (2) the 95% normalized emittance of the high intensity beam is $\epsilon_h^n(95) = \epsilon_v^n = 50\pi$ mm-mrad, (3) the maximum momentum spread allowed is $dp/p = \pm 2 \times 10^{-3}$. The current AGS machine parameters are summarized as follows:

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Table 1. AGS Parameters

Circumference	C=2πR=807.075	[m]
Curvature	ρ=85.17	[m]
Revolution Time	t_{rev}=2.692	[μs]
Tune	$Q_h=Q_v=\sim 8.7$	
Beta Functions	$\beta_{h,v}^{max,(min)}$=22.5 (10.5)	[m]
Dispersion Function	D_x^{max}=2.20	[m]
No. of Bunches	N_b=12,(3 for HI)	
Full Bunch Length	t_b=35$\pm$5	[ns]
Gap bet. Bunches	t_s=224(peak-to-peak)	[ns]
Typical Intensity	$1.6\cdot 10^{13}$	[ppp]
	$3.0\cdot 10^{8}$	[Si/p]
Typical AGS Cycle	2.0(FEB),3.4(SEB)	[s]
Typical Energy	24.5,28.5(p)	[GeV]
	14.5(O,Si)	[GeV/N]
Emittance	$\epsilon_{h,v}^n=35\pi$	[μm-rad]
Momentum Spread	dp/p=0.12	[%]

For RHIC injection, the expected values of ϵ^n, dp/p and t_b for both protons and HI are substantially lower than the current values since the Booster can deliver more intensity than that assumed for the RHIC design parameters[3]. At 10-foot straight section (G10,H10), β_h and β_v are rapidly changing as well as D_x while at 5-foot s.s. $\beta_h \cong \beta_{max}$, $\beta_v \cong \beta_{min}$ and $D_x \cong D_{max}$:

location	β_h (m)	β_v (m)	D_x (m)
10-ft s.s.	19.9 to 12.0	12.0 to 19.9	2.09 to 1.63
5-ft s.s.	22.1	10.5	2.17

Figure 2 shows the wall monitor display of the bunch structure in the AGS after the third bunch is extracted for the SBE operation.

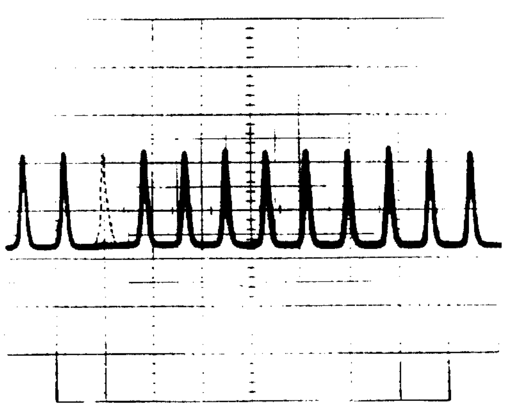

Fig. 2. Display of the bunch structure in the AGS

B. Fast Kicker

The full horizontal beam width, is usually defined by $w_f = 2\sqrt{\epsilon_h\beta_h/\pi + (D_x dp/p)^2}$, assuming that the dp/p distribution is symmetric, and the transverse and longitudinal emittances are uncorrelated, where $\epsilon_h = \epsilon_h^n \cdot (m/p)$. Hence, at p=29 GeV/c, using the 99% emittance we have w_f(H10)=16.4 mm. Assuming that we need 2 mm separation at both sides of the septum of the ejctor magnet (SMH10), and $\sim$ 10 mm septum thickness, then the required separation of the circulating beam and the beam kicked by the fast kicker at G10 (FKG10) is δx=30.4 mm. The FKG10 must deflect the beam by

$$\vartheta(G10) = \delta x(H10)/\sqrt{\beta_h(G10)\beta_h(H10)}\sin(\delta\mu)$$

=-2.00 mrad, where $\delta\mu$ is the betatron phase advance from FKG10 to SMH10, and which corresponds to $\int Bdl = B_0 \cdot l_{eff} = -0.19$ T-m.

We consider a C-typé ferrite magnet with a limited aperture, w(idth)=38.5 mm and g(ap)=17 mm, to minimize the required voltage on pulsing the FKG10. Choosing l_{eff}=2.0 m, we find the magnetic field is B_0=0.95 T, the magnet current, $I = B_0 \cdot g/\mu_0$=1.29 kA and the corresponding total magnet inductance, $L_{mag} = \mu_0 \cdot l_{eff}/g$=5.69 μH.

In order to achieve clean bunch-to-bunch extraction, the kicker fall time must be as rapid as the rise time. The total duration is $T_0=t_{rise}+t_{flat}+t_{fall}$=160+40+180=380 ns and the pulse waveform is essentially half sine. The recharge time must be a few ms. The minimum pulse voltage to perform the full field in t_{rise}=160 ns is $V=L_{mag}$dI/dt=$B_o \cdot l_{eff} \cdot w/t_{rise}$=45 kV. Since we have to add the additional stray inductance and it is also desirable to keep $V \leq\sim$ 30 kV, the magnet will be subdivided into several shorter modules and powered in parallel. If the pulser is to be mounted outside the ring due to the high radiation environment, it will have to be a *matched* pulse forming network (PFN). The magnet is loaded with capacitance so it behaves like a transmission line of the correct impedance. The PFN storage voltage will be twice the maximum pulsing voltage and it has to be oil insulated.

C. Ejector Magnet

A new out-of-vacuum ejector septum magnet (SMH10) has been built for standard FEB operation and its magnetic properties have been intensively analyzed. However, for NewFEB operation the ejector magnet has to stay a DC mode over 100 ms, the septum thickness must be increased from the current value of 2.3 mm to $\sim$ 10 mm. If the magnet is water-cooled, $\sim$ 5 mm thickness might be sufficient.

D. Orbit Bump

Local orbit deformations are needed to move the circulating beam into the aperture of the fast kicker and also to bring the beam adjacent to the septum of the ejector. These bumps are generated by powering backleg windings on selected AGS main magnets so arranged that the tune shifts and stopbands at Q_h=8.5 are minimized. We first consider two standard 3/2 λ horizontal bumps, one (BLWG10) for FKG10 and another (BLWH10) for SMH10. With this configuration, a tracking study shows that the available space for the kicked beam is rather marginal around G17. So we make modifications to create a hybrid (2λ) bump (BLWGH), eliminating some backleg windings and doubling kicks at some.

In figure 3 , we show a schematic layout of the NewFEB extraction components (BLWGH, FKG10, SMH10) and the particle trajectories with and without FKG10 and SMH10 on.

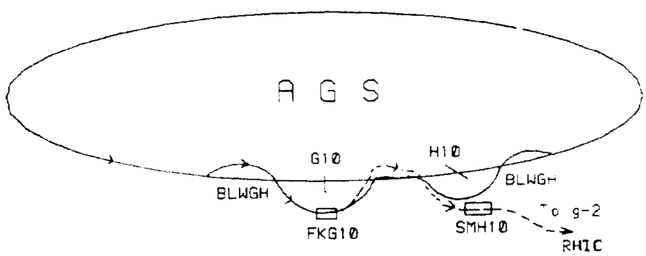

Fig. 3. Schematic layout of the NewFEB components.

II. Simulation

To find out the extracted beam parameters at the middle of straight section H13, *i.e.*, the entrance of the U-line, a simulation was performed with a simple model of the AGS, using the accelerator modeling program MAD which includes quadrupolar and sextupolar components of the main combined function magnets and the NewFEB extraction components. First, we run MAD to obtain the desire orbit at FKG10 and at SMH10, making fine adjustments of BLWGH. Then, the particle with initial conditions (x, x') at the beginning of s.s.G10 is traced through the lattice and receives an appropriate kick (1.6 mrad) at FKG10 and an additional kick (20 mard) at SMH10 up to the middle of s.s.H13, where the beam should be about $\sim$ 43 cm away from the central orbit, free from the fringing field of the ring magnets. The simulation results on the extracted beam parameters at s.s.H13 are summarized as follows:

$x = 43.8$ cm	x'=63.8 mrad		
α_x=-5.75	β_h=46.4 m	$\alpha_y = 0.83$	$\beta_v = 3.6$ m
D_x=1.24 m	D'_x=0.19		

Due to its high intensity operation for the g-2 experiment, it is important that the NewFEB system can achieve a high extraction efficiency ($\geq$99%). On the other hand, for RHIC injection, stability and reproducibility of the extracted bunched beam parameters are crucial since any change (pulse-to-pulse, cycle-to-cycle) of the extracted beam parameters will directly influence RHIC performance.

III. Summary and Plan

The basic conceptual design is made on the NewFEB system at the AGS, which is capable of performing SBME for the g-2 experiment and RHIC injection. It is expected that detailed engineering design work will start soon since the μ-SR and RHIC are scheduled to be completed in 1994 and in 1997, respectively. Further simulation studies of the NewFEB extraction and beam transfer from the AGS to RHIC (ATR) will be needed to specify tolerances of the NewFEB system components as well as the overall required AGS capability as the injector for RHIC.

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