THE AGS IMPROVEMENT PROGRAM*

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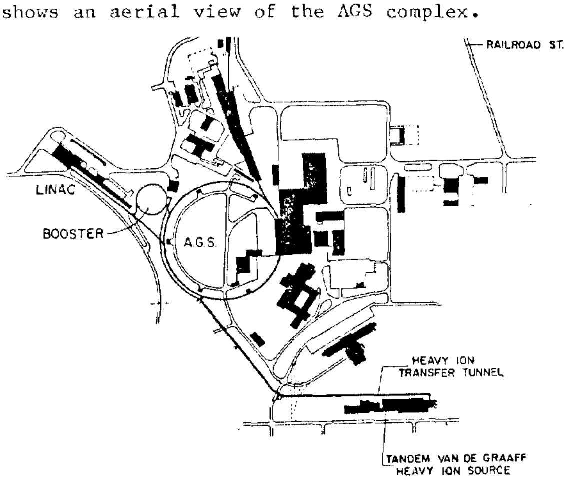
Introduction

The interest of both particle and nuclear physicists are converging on the AGS; this machine is almost ideally and uniquely suited to perform a new class of frontier experiments. Particle physicists would like to study the extremely heavy (multi-TeV) particles posited by new theories by searching for rare k-decays. Nuclear physicists want to create the extremely denser form of nuclear matter which exists within neutron stars by studying heavy ion collisions. The particle physicists require extremely intense proton beams in order to produce enough k's. The nuclear physicists require heavy ions accelerated in the top energies of the AGS. The AGS recently acquired a new capability of accelerating polarized protons to 16.5-GeV and will extend its energy to full energy of the machine. This new capability will open the way to extend the surprising lower energy result of spin-spin correlation at high momentum transfer collisions to much higher energy. The acceleration of polarized protons at the AGS is a subject of other papers in this conference.[1]

General improvement programs to increase the reliability, versatility, intensity and duty factor of the accelerator include improvement of instrumentation, vacuum systems and controls. Following successful operation of the low current polarized proton RFQ pre-injector, it is planned is to construct a new high current RFQ for general use, which will add versatility and reliability to ion sources and linac operation. In this paper, we are going to concentrate on two specific projects which would satisfy the requirements of both particle and nuclear physics. The Tandem Van de Graaff to AGS heavy ion transfer project, which is due to be completed next year, will give the AGS a capability to accelerate ions as heavy as sulfur. The ability of the AGS to simultaneously fulfill both of the above-mentioned requirements can be addressed by the construction of a booster synchrotron (it will also increase the intensity of the already unique high energy polarized proton beam). With the addition of the booster, the enhanced AGS will possess capabilities not available anywhere else in the near future. Figure 1 shows an aerial view of the AGS complex.



Heavy Ion Injection from the Tandem Van de Graaff

The BNL Tandem Van de Graaff and its ion source have been tested for pulsed operation. High current pulses of the order of 200 particle microampere was achieved with pulse length over 200 μsec without appreciable deterioration of the beam quality. Such a pulse is suited for the multiturn injection into the AGS. The preconversion AGS had been operating with 50 MeV injection corresponding to magnetic rigidity of 1.04 Tesla-meters. The output energy of the Tandem is 8 MeV/amu for oxygen which corresponds to 0.82 T-m only 20% below where the AGS operated originally. A preliminary measurement shows the machine can be operated at the field. The AGS vacuum of 10^{-7} Torr is not sufficiently low enough to prevent partially stripped ions from losing or gaining electrons through collision with residual gas atoms in the AGS. Only fully stripped ions are therefore capable of being accelerated in the AGS. Up to mass 32 (sulfur), the Tandem will meet these requirements of magnetic rigidity and charge state, and suffice as an injector. Above mass 32, the Tandem beams are not energetic enough to strip completely, and need some other means to boost the energy. For injection into the AGS, a pulsed source is required to match the acceleration cycle and maximize the intensity. Tandem instanteous current will increase by three to four orders of magnitude, but average currents will be well within the normal operating range of the Tandem. We have demonstrated this capability in the past. We installed an intershield for MP-7 (positive terminal). The intershield is expected to allow an increase in terminal voltage, and of more importance to the AGS program, will increase the stability and reliability at the terminal voltages used for injection. Light elements below oxygen will be produced in the two-stage mode of operation using only MP-7 Tandem as the injector. For obtaining fully stripped sulfur ions with reasonable efficiencies, however, the two-stage Tandem energies are not sufficient and three-stage operation will be required. For this purpose, the pulsed ion source will be installed in the high voltage terminal of the other Tandem (MP-6), and use MP-6 as an extra means to gain higher energy. A new pulsing power supply is being developed and installed in the MP-6 high voltage terminal to provide the required pulsed operation.

Injection into the AGS is accomplished through an electrostatic septum. The ions are stacked multiturn into transverse betatron phase space using collapsing orbit bumps similar to the method formerly used for the proton injection. Since the present AGS rf system only handles 2 to 4.5 MHz, the rf system has to be extended to accommodate slow heavy ions. The old preconversion rf cavity is being modified to resonate between 0.5 to 2.1 MHz to preaccelerate the ions in the 12th harmonic. Table I shows the expected performance parameters for oxygen and for sulfur ions.

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Table I
Expected Performance for Direct Tandem-AGS Injection

	oxygen	sulfur
Source Current	100 pμA	200 pμA
Source Pulse Length	220 μsec	220 μsec
Stripping Efficiency		
at Tandem Terminal	30%	3.7%
at Final Tandem Energy	100%	6 %
AGS Injection, Acceleration	60%	40 %
AGS Intensity per Pulse	2.5×10^{10}	2.5×10^{8}
Energy	15 GeV/amu	
	2-Stage Tandem	3-Stage Tandem

The AGS Booster[2]

The AGS Booster is a rapid cycling synchrotron that acts as a booster injector to the AGS for both protons and heavy ions up to uranium and as an accumulator and injector for polarized protons. This machine is capable of accelerating protons at 10 Hertz to 1 GeV. The size of the machine is one fourth of the AGS and located between the 200 MeV linac and the old 50 MeV injection line. Heavy ion injection would be accomplished by extending the Heavy Ion Transfer Line along the AGS tunnel to the booster area. The AGS booster has three objectives. They are to increase the space-charge limit of the AGS, to increase the intensity of the polarized proton beam by accumulating many linac pulses, and to preaccelerate heavy ions from the Tandem to inject into the AGS. For high intensity proton injection, the space charge limit is proportional to $\beta\gamma^2$ for given invariant emittances. Therefore, by raising the proton injection energy of the AGS from its present 200 MeV to the booster energy of 1 GeV, one will increase the space-charge related intensity limit by a factor of four. This would result in an accelerated proton intensity of $4\text{-}5 \times 10^{13}$ protons/pulse. For polarized proton acceleration, the accumulator aspect of the ring will result in an increase of intensity by a factor of 20-30. The presently available intensities are approximately 10^{10} per pulse in the AGS. Much higher intensities are required to fully explore the physics of spin-dependent phenomena. By accumulating many linac pulses of polarized protons and injecting them into the AGS, we will accelerate approximately $2\text{-}3 \times 10^{11}$ polarized protons in the AGS. For the case of heavy ion operation in the AGS, the booster ring allows for acceleration of all heavy ions in the periodic table. The booster ring with vacuum of 10^{-11} Torr will accelerate heavy ions to a momentum equivalent to 5Q/A GeV/c/amu. At this energy the charge stripping efficiency prior to injection into the AGS is greater than 40% for all ion species and therefore overcomes the problem of charge number changing during the acceleration cycle of the AGS. The accelerated beam intensity of 2×10^{9}/pulse for Au, as an example, is a factor of 10^3 greater than presently available at high energies. For example of Au, the accelerated beam intensity is at the calculated space-charge limit of the booster ring.

In order to allow efficient, synchronous bucket-to-bucket transfer of beam from the booster of the AGS, the size of the ring should be integer/12 of the AGS ring. The design chosen is a booster with a circumference of 1/4 AGS (201.6 m) with the objective of making it simple, relatively inexpensive, and capable of accelerating heavy ions to a magnetic rigidity $B\rho$ = 16.7 Tesla-Meter at a 1 Hz rate.

The lattice chosen is FODO arrangement with bending magnets missing from every other cell. The magnets are a separated function since this will minimize end effects in a lattice which has such a small packing factor. Making end effect corrections for both bending and focusing in a combined function magnet could be quite difficult. Combined function magnets would also be larger and more costly than window-frame dipoles. The dipoles of the lattice have an aperture of 3.25" x 10" with a field of about 1.6 kG (0.7 kG for heavy ions) at injection. Magnetic field cycle requirements are 4 kG at 10 Hz rate for protons and 12 kG at 1 Hz rate for heavy ions. The heavy ion acceleration aspect is the determining constraint on the magnet specification. The power supply requirements for both cases are almost identical. This range of fields, appreciably below saturation levels, makes the design of magnets of storage ring quality straightforward. The tune and the aperture of the ring are chosen to avoid depolarizing resonances, to match the admittance of the AGS and to be flexible enough to accommodate research and development of devices and techniques for the acceleration and storage of polarized protons. The parameters of the AGS Booster ring is given in Table II.

Table II
AGS BOOSTER PARAMETERS

INJECTION	PROTON		HEAVY ION
T	200 MeV		1-7.5 MeV/amu
B - ρ	2.15		> 0.71 T-m
Δ p/p	2×10^{-3}		10^{-3}
Top Energy	1 GeV		p = 5Q/A GeV/c
Top B	5.66		16.7 T-m
Rep. Rate	10		1 Hz
Circumference		201.6 m	
Bend. Radius		13.75 m	
Periodicity		12	
No. Cells		24 FODO	
(One missing dipole every other cell)			
Phase Advance		71.25°	
Tune		4.75	
β max/min.		12/3.7 m	
η max		2.3 m	
Transition		4.74	
Straight Section		12/3.7 m	
(No./length)		12/1 m	
# Dipoles		36	
Length		2.4 m	
Max. Field	4		12 K-Gauss
# Quads		48	
Length		0.5 m	
Max. Grad.	33		96 T/m
# Harmonics[a)]		3	
Frequency	2.5-3.9		0.178-2.5 MHz
T Gain/Turn	17.5		8.5Q keV
Acc. Phase		30°	

a) For heavy ion 1st harmonic will be considered at a later date.

Table III
AGS BOOSTER HEAVY ION DATA

Element	A	Qin	T MeV/amu	β	B T-m	Iin μ-Amp	N $\times 10^9$
C	12	6	7.5	0.1262	0.793	82.0	22.0
S	32	14	4.7	0.1002	0.716	20.0	6.7
Cu	64	21	2.9	0.0782	0.75	11.0	4.7
I	127	29	1.65	0.0595	0.813	6.0	3.2
Au	197	33	1.0	0.0463	0.863	5.0	2.2[a)]

[a)] Space-charge limited for $\Delta\nu = 0.1$

The frequency swing of the rf accelerating system in the booster must cover the frequency range from 0.18 to 4.29 MHz. This allows capture and acceleration of protons from the 200 MeV linac and operation with the slowest of the heavy ion particles like gold (v/c = 0/04). For practical reasons this frequency range is divided into three parts, the first two parts for heavy ion work and the highest for proton acceleration. The heavy ion work and the highest for proton acceleration. The heavy ion acceleration is subdivided to match the characteristics of the ferrite selected. The third system for the proton acceleration will be the same range with the AGS cavities.

To inject the 200 MeV H^- beam into the booster ring, it must pass through a hole in the yoke of a ring bending magnet. It will then be deflected by the field of this magnet to a position that is tangent to the displaced beam orbit at the location of the stripping foil. The foil is located immediately downstream of the ring bending magnet close to a horizontal beta maximum. The heavy ions are injected multiturn into the transverse betatron phase space through an electrostatic thin septum at a long straight section.

We employ the simplest most straightforward extraction and beam transfer scheme of bucket-to-bucket transfer. The heavy ion beams will be stripped once more before being injected into the AGS. The data for typical heavy ion species are given in table III.

Future Projects

The stretcher ring for the AGS is one of the key elements in the future project. The stretcher ring is a small aperture full energy ring residing inside the AGS tunnel specially designed for efficient slow extraction of the beam. It will double the duty factor to almost 100%, and reduce the electric power requirement by an appreciable amount. Modification to the AGS to accommodate it to be the injector for the proposed Relativistic Heavy Ion Collider[3] (RHIC) is also in the future of the AGS.

References

[1] L.G. Ratner et al. Commissioning the polarized beam in the AGS, Conference session VB (1985).

[2] AGS Booster Conceptual Design Report, BNL Informal Report 34989 (1984).

[3] RHIC and Quark Matter, BNL Informal Report 51801 (1984).