DESIGN AND STATUS OF THE AGS BOOSTER ACCELERATOR*

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INTRODUCTION

A booster accelerator for the AGS was originally proposed in 1983 as an accumulator for polarized protons and shortly after as a means of also increasing the AGS proton intensity [1]. It was later proposed to also design it for use as a pre-accelerator for heavy ions from the Tandem Van de Graaff so that all ions up to Au (mass 197) could be fully stripped and accelerated in the AGS [2]. Without the Booster the maximum mass that can be directly injected into the AGS is sulfur (mass 32) [3]. The Booster is thus an essential component in the chain which will permit the AGS to act as a heavy ion injector into the proposed Relativistic Heavy Ion Collider (RHIC) [4]. The diverse requirements for the Booster impose many difficult constraints and compromises on the design. Prior to the start of construction in November, 1985, a preliminary design had emerged for a fast-cycling machine with a circumference one-quarter of the AGS using a separated function FODO lattice [5].

DESIGN REQUIREMENT

After construction started in late 1985 design groups were formed in several areas to address detailed problems. A panel of international experts reviewed the design in March 1986; their report focused on both problems of detail and the general concept of the accelerator. Further examination of the Booster design at Brookhaven resulted in the publication of a Design Manual in the summer of 1986. This manual is intended to bridge the transition from conceptual to engineering design. Comments on some areas of the design considered in the period leading to the Design Manual are given below.

Lattice: Some consideration was given to a choice of one-third rather than one-quarter the AGS circumference. This would have given the options of higher energy, longer straight sections, higher tune and reduced ramping rate. In the end this option was dropped, mainly due to the higher construction cost. Meanwhile, detailed investigation continued on the one-quarter AGS design; chromatic correction was refined [6] and such topics as space charge limit [7], resonances and instabilities [8] [9], and aperture limitations [10] were considered. The structure resonance at the vertical and horizontal tunes of 4.5 was the subject of particular attention as this is the major stopband which will be crossed due to tune depression caused by space charge. The correction system is being designed to minimize the driving term for this resonance [6]. Other lattices were considered using both separated function and combined function magnets. The latter magnets, possibly used in a hybrid lattice i.e., separate quadrupoles are also used with gradient dipoles, provide longer straight sections - an important engineering consideration for a small accelerator. A summary of some lattice options considered is given in Table 1.

Energy and Repetition Rate: An important concern of the review committee was that the 1 GeV injection into the AGS for protons envisioned in the preliminary design may not provide a sufficient improvement in AGS intensity due to space charge limitations in the larger machine. The factor $\beta\gamma^2$ was raised by a factor of nearly two by increasing the nominal energy for proton ejection to 1.5 GeV. This was achieved by keeping the same mean rate of change of flux in the magnets and thus decreasing the repetition rate from 10 Hz to 7.5 Hz. The flow of real and imaginary power to and from the main power supply was studied in detail in order to determine the voltage and phase flicker on the feeder to the laboratory. The main dipole power supply has a maximum rating of 13 MVA. Voltage fluctuations on the 69 kV feeder will be below 0.25% and phase flicker will not exceed 0.72° in the proton acceleration mode.

Injection: Three methods of injection must be provided for the various species to be accelerated in the Booster [11]. The proposed method of proton injection was investigated in detail because the preliminary design required that the injection beam pipe pass through the return leg of a dipole yoke. In addition the equilibrium orbit perturbation at injection raised the possibility of aperture limitation both vertically and horizontally due to strong coupling. The possibility of reducing some of these problems by using an injection region with four fast kicker magnets, similar to that used in SNS [12], was a major motivation in considering lattice choices with longer straight sections. In the end tracking studies indicated that aperture limitation was not severe during injection and the cost and complexity of four kickers greatly outweighed the perceived problems of the preliminary design. The design of the beam injection and ejection transfer lines has reached an advanced stage [13].

Radio Frequency System: The design of the RF system is complicated by the need for a wide frequency swing for heavy ion acceleration and effects of beam loading during proton acceleration. Initially, the heavy ion acceleration system will be designed for a harmonic number of three and will use two cavity/amplifier combinations to cover the required frequency range, one will cover the low frequency end and the other the high frequency portion of the range. The general characteristics are shown in Table 2. At a later date it will be possible to replace one cavity and amplifier in order to operate with a harmonic number of unity; this option may be necessary to increase the particles per bunch required when the AGS is serv-

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Table 1

Some Lattice Options Considered for the AGS Booster

General Type	No. of Super Periods	Approx. Tune Qx, Qy	Phase Adv Per Cell (deg)	Systematic Stopbands Order 2	3	4	Dipole Length m	Comment
Separated fn	6	4.8	72	3,6,9	4,6,8	4,5,6	2.4	Standard lattice in the design manual.
Separated fn	8	6.8	102	4,8	5,3,8	4,6,8	2.7	High periodicity, high tune and longer straight sections. Disadvantage is high quadrupole gradient.
Combined fn	12	4.8	72	6,12	4,8	3,6	2.9	An attractive design but judged to have some problems as a polarized proton accumulator.

ing as an injector into RHIC. A considerable design effort has gone into the conceptual design of the acceleration system for protons. In particular, a compromise must be found between the ramp rate, bucket size and maximum RF voltage. The system that evolved maintains a minimum bucket size of 1.0 eV sec (plus safety factor) and uses two cavities simultaneously. With some light-ion species the same cavities may also need to complete acceleration to the specified maximum energy. The details of the system are given in Table 2.

Vacuum Chamber: The vacuum system requirements are set by heavy ion acceleration - changes in the charge state caused by collision with residual gas molecules will cause a loss of accelerated particles. A goal of 3×10^{-11} torr has been set for the maximum pressure [14], to achieve this level will require a method of baking each component to 200°C in situ. The vacuum chamber cross-section in the dipole magnets is roughly oval, the sextupole moment of the magnetic field caused by the eddy currents during the maximum ramping rate (proton acceleration) has a magnitude roughly comparable to the natural chromaticity and must be corrected. The random component of the sextupole field caused by variations in the vacuum chamber has been investigated and tolerances set on the chamber dimensions.

PRESENT STATUS

During the period fiscal years 1986 and 1987 approximately 15% of the estimated total construction cost of ~$29 M was received. This funding profile has, of course, influenced the technical progress. Instead of building the tunnel and conventional civil engineering support facilities, emphasis has been placed on completing detailed design. Three dipole magnet prototypes have been tested [15] and the yoke laminations ordered. R&D is proceeding on the vacuum chamber design and the RF cavities. A start has been made on the conceptual design of the computer control system. It is expected that the Title II phase of conventional construction will be completed by the summer of 1987 and a start can be made on the tunnel in the fall of 1987. A new 20 MVA transformer is on order to upgrade one of the main laboratory substations in anticipation of the increased electrical load of the Booster. A summary of the present design parameters is given in Table 3.

ACKNOWLEDGEMENT

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Table 2

Booster RF Systems

Species:	p	p↑	S^{14}	Au^{33}
RF Amplitude				
Injection	90 kV	7.35 kV	0.61 kV	1.6 kV
Ejection	90 kV	40 kV	17 kV	17 kV
Harmonic Number	3	3	3	3
RF Frequency				
Injection	2.5 MHz	2.5 MHz	0.446 MHz	0.206 MHz
E/A	200 MeV	200 MeV	4.69 MeV	1.07 MeV
Ejection	4.11 MHz	4.11 MHz	4.13 MHz	3.06 MHz
Phase Space Area/A	≥1.0 eV-s	0.3 eV-s	0.066 eV-s	0.066 eV-s
Intensity (per bunch)	10^{13}	3×10^{11}	5×10^{9}	8×10^{9}
Total Gap Impedance (f_{rf} = 4.1 MHz)	<24 kΩ	-	-	-
Accelerator Time	62 ms	≤0.5 s	≤0.5 s	≤ 0.5 s
Maximum Power Delivered to Beam	156 kW	-	-	-
Maximum $\dot{B}$	9.5 T/s	-	-	-
$\dot{B}_{inj}$	1.5 T/s	-	<0.15 T/s	<0.15 T/s

Table 3

Summary of Booster Characteristics

Circumference	201.78 m (1/4 AGS)
Avg. radius	32.114 m
Magnetic bend radius	13.75099 m
No. of particles/pulse	protons, 1.5 - 3 x 10^{13} polarized protons, 10^{12} C S I Au 54 15 6.6 3.2 x 10^{9} ions
Lattice type	separated function, FODO
No. of superperiods	6
No. of cells	24
Betatron tune, x, y	4.82, 4.83
Number of magnets	36 dipoles, 48 quads
Magnet type	iron-dominated, water-cooled Cu conductor
Dipole length (magnetic/physical)	2.4/2.34 m, excl. coils
Quad length (magnetic/physical)	0.50375/0.472 m, excl. coils
Vacuum chamber, dimensions	70 x 152 mm, dipoles 152 mm (circular), quads
Acceleration time	62 ms, protons & polarized protons 500 ms (max.) heavy ions
Repetition rate	7.5 Hz (4 pulses/AGS pulse), protons 1 Hz (1 pulse/AGS pulse), polarized protons 1 Hz (1 pulse/AGS pulse), heavy ions