Particle Accelerators, 1990, Vol. 29, pp. 121–126
Reprints available directly from the publisher
Photocopying permitted by license only

THE AGS BOOSTER MAIN RING POWER SUPPLY SYSTEM*

A. SOUKAS, K. HUGHES, J. SANDBERG, F. TOLDO and S. Y. ZHANG
Brookhaven National Laboratory, Upton, New York, U.S.A.

Abstract

The AGS Booster[1] is being designed as a very versatile particle accelerator. Its primary function is to be a high quality injector to the currently operating Alternating Gradient Synchrotron (AGS). The Booster/AGS combination will produce proton intensities greater than $5x10^{13}$ protons per pulse (ppp), and accelerate heavy ions, with mass up to 200, to a maximum energy of 15 GeV per atomic mass unit (Gev/amu).

The power supply for the Booster Main Ring (BMRPS) has to accommodate a wide range of cycles and a wide range of operating parameters. The cycles range from storage for several seconds to rapid cycling at 7.5 Hz. The peak output power is 18 MW.

This paper will describe the AGS Booster machine powering requirements, the choice of power supply, the a.c. circuit tie-in and its associated problems and some of the details of the design of the BMRPS.

MACHINE REQUIREMENTS

The Booster will enable proton intensity improvements in the AGS by operating at an energy of 1.5 GeV ($B\rho$=7.5 Tm). This will increase the space charge limit in the AGS which is presently operating at an injection energy of 200 MeV, and an intensity of $1.6x10^{13}$ ppp. The present proton injector to the AGS is a 200 MeV linac which provides H^- unpolarized and H polarized beams. This linac will be one of the injectors to the Booster.

The high mass heavy ion improvement to the accelerator complex will be possible since the Booster is being designed to have better matched magnetic fields at injection and a very hard vacuum system attaining pressures in the 10^{-11} torr range. The injector for heavy ions into the Booster will be the presently operating Tandem Van de Graaf/Heavy Ion Transfer Line[2], which for gold ion species can operate at 210 MeV.

The Booster operation is very closely tied to the AGS operating

* Worked performed under the auspices of the U. S. Dept. of Energy.

cycles. The AGS operates in two distinctly different high-intensity proton cycle modes namely, slow extracted beam (SEB), and fast extracted beam (FEB). The cycle times for these at an energy of 28.5 GeV, are approximately 3.0 and 1.4 seconds. Also, the AGS serves polarized beam users and heavy ion beam users with somewhat altered SEB modes. Thus, depending on the operating mode of the AGS, the Booster cycle must be capable of being varied from a fast cycling mode, to a slower heavy ion mode, or to a dc storage mode.

Fig. 1, shows the cycles for the AGS and the Booster for four major operating modes. Figure 1a shows high intensity proton operation and figure 1b shows polarized proton and heavy ion operation. The harmonic number in the AGS is 12 and that of the Booster is 3. Therefore, it takes 4 transfers from the Booster to fill up all the available phase space in the AGS. This is accomplished (fig. 1a) by four successive Booster acceleration cycles which take approximately 0.53 seconds. To increase the polarized proton beam intensities that are presently source current limited, the Booster will be capable of an accumulation mode for a period greater than 2 seconds. This necessitates a very stable, accurate dc field which is ramped up to 1.5 GeV as quickly as possible. Because heavy ion experiments are not intensity demanding, the requirements for this mode of Booster operation is a cycle up to a high energy ($B\rho$=18 Tm), in a p.r.f. that fits within the AGS cycle time. These are shown in fig. 1b.

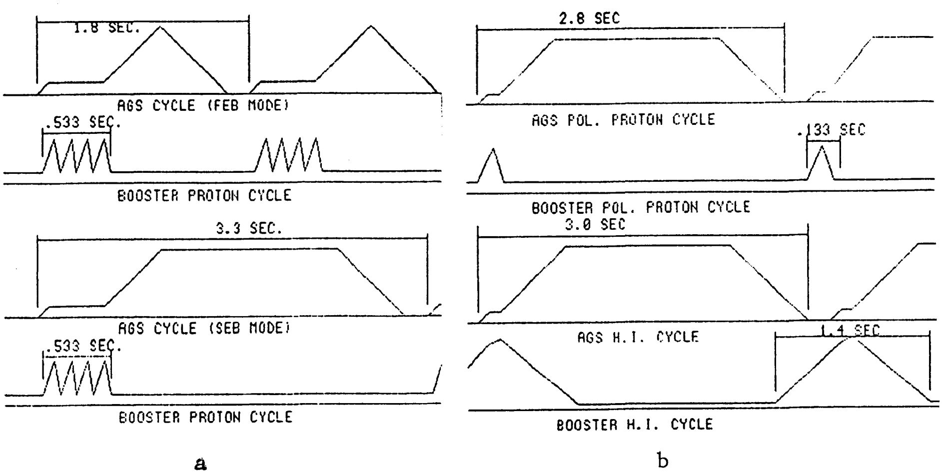

FIGURE 1 AGS and Booster cycles

In designing the BMRPS, the above, sometimes conflicting, requirements have to be taken into account. In addition, in order to minimize switchover time between the various modes,a pulse-to-pulse modulation scheme has been adopted. This places additional flexibility demands on the Booster and the BMRPS. Taking the various design requirements into consideration, the choices for a power supply configuration are either a multiple number of systems that are switched in and out, or a single system that is programmable for the various cycles. We have chosen the latter schemes as the most flexible and cost effective.

Peak voltage/current requirements for the output of the BMRPS are: 5400 volts and 2500 A for proton acceleration and 1500 volts and 5700 A for heavy ion acceleration. The BMRPS consists of a series of adjustable, programmable modules that are capable of operating from full positive to full negative voltage or in a by-pass mode.

AC LINE TIE-IN

For economic as well as technical reasons,it was decided by the project to power the Booster off the ac line directly without other energy storage. A pulsed power supply operating directly off the utility power lines, however, presents a dynamic load that causes a certain amount of disturbance to the power system. These may show up as voltage/phase amplitude variations (termed "flicker")and as instabilities in the power generation or transmission systems. The amount of disturbance is directly proportional to the dynamic load KVA and inversely proportional to the "stiffness" or short circuit capacity (SCC) of the power system. Powering accelerators directly off a power grid has been studied many times previously.[3,4,5,6] The big differences presented by the Booster load are its faster p.r.f., up to 7.5 Hz, as well as several other frequencies which will be employed. The topology of the LILCO (Long Island Lighting Company) generation and distribution system presents several unique problems not encountered in previous machines.

An analysis was performed at BNL to determine the possible disturbances to the Lab by pulsing the Booster on the local 13.8 kV distribution bus. This indicated that a connection to this bus was unacceptable.An acceptable solution found was based on a tie to one of the 69 kV buses entering the Lab site.[7,8] The SCC at this point is 2300 KVA, thus making the flicker disturbances small.

Following this, an analysis was performed by the power company to investigate effects such as power system dynamic oscillations, voltage fluctuations on the grid, torsional oscillations, system instabilities and harmonic effects.[9] Both time and frequency domain techniques were used in the analysis. Several distinct problems were identified. When operating near 1.0 Hz, the Booster could excite power oscillations between various machines tied together by the LILCO network. The network exhibits a sharp resonance very near this frequency and at several others up to 5 Hz, depending on the oper-ating conditions, i.e., which generators may be up and which feeders may be inoperative. Because a nuclear generating station (Shoreham) is located near the BNL site (approximately 10 km),power fluctuations were high there and could be troublesome especially at start-up or low power operation. The potential problems would be mostly in the instrumentation area. Also, the Shoreham nuclear plant has its lowest torsional oscillation mode near 10 Hz. All other areas of the study indicated no large adverse effects.

In order to connect the Booster to the grid the following were agreed to between BNL and LILCO: 1) BNL would tie into the grid at 69 kV, 2) A relay would be installed at the BNL site boundary to monitor operation near a frequency of 1 Hz and above 8 Hz.

The tie-in which satisfies both the power company and the Lab requirements, was performed via a dedicated 20 MVA, 69/13.8 kV transformer connected to a 69 kV BNL site alternate feeder line. Future enhancements of the Booster ac feed are being planned via the use of a dynamic reactive power compensator and ac line harmonic filters, if necessary.

DC RECTIFIER MODULES

To minimize the ac effects and to enhance the dc performance of the Booster, the BMRPS is built as a series group of 6 each, 24 phase, silicon controlled rectifier (SCR thyristor) modules. The scheme is shown in figure 2. On the ac side, this scheme reduces the line harmonics and minimizes the reactive power variation. On the dc side, the improvement provided is in the output ripple and in the response time or bandwidth. Also, provided the phases can be kept balanced, the size of the ripple filter is reduced.

The rectifier system is is laid out in a 2 station symmetrical arrangement. Each module has a nominal output voltage of 1000 volts dc. The two center units on each station, have a 6000 ampere peak (3500 ampere rms) rating, while the other 4 modules have a peak rating of 3000 amperes (1750 amperes rms). All the modules are equipped with SCR by-pass switches, which have a 6000 ampere rating. Heavy ion acceleration will use the 2 high current modules, while the other 4 modules are by-passed. Proton acceleration will utilize all 6 modules. The operation of the modules will be sequential, with the by-pass SCR's shorting out or by-passing modules when they are not required. They will also be used for fault protection, such as over current or over voltage. All SCR's used in the rectifier and by-pass systems are 100 mm devices. Single units of 3 kV peak inverse voltage rating are used in each leg of a bridge.

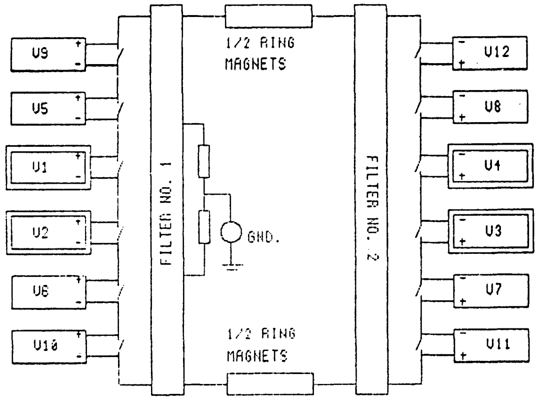

FIGURE 2 BMRPS scheme

Modules of 24 pulse output are obtained by driving two 12 pulse modules from a ± 7.5° phase shifting transformer. The 12 pulse units are obtained via extended delta primary to Y secondary, ± 15° rectifier transformations. Much care was taken in the specification of the absolute impedance of all transformers (3%), as well as in the balance between phases and between one unit to another. (±4%).

The Booster load consists of separated function dipole and quadrupole magnets that are connected in series (140 mHy and 100 mOhm total). The horizontal and vertical tunes are adjusted independently via the use of 2 bipolar power supplies powering isolated trim windings on the main ring quadrupoles. The ring magnet connection is a 2-feed, folded bus arrangement with a loop break 180° from the power feed point.

Other elements that are part of the BMRPS are 2 LCRC passive filters, 2 transformer coupled active filters, 3 reference magnets (1 dipole, 1 H quad, 1 V quad), a DCCT for the accurate measurement of the current, and 3 gauss clocks that measure the magnetic fields in the 3 reference magnets. The latter will be used for cycle set-up, and will be distributed to enable other machine functions such as injection, acceleration and extraction to be timed.

CONTROLS

The control of the 6, 24 pulse rectifier modules will be by 6 voltage functions generators driving 6 real-time voltage feedback loops. In addition, a current regulating loop will be closed around the "first" rectifier module.(V1, V2) All the function generators are vector driven, with 16 bit DAC output outputs. The digital power supply interface and certain interlock and control functions will be performed via programmable logic controllers (PLC's). These will be interfaced to Device Controllers (microprocessors) in the AGS hierarchical Apollo based control system.

REFERENCES

1. W.T. Weng, Progress With the AGS Booster, 1988 Summer Study on HEP in the 1990's. Snowmass, Colo., 6/88.
2. C. Gardner, et al., Operational Experience with Heavy Ions at BNL: An Update, IEEE Trans. Nucl. Sci., NS-36, 1989.
3. J.A. Fox, Static Power Supplies for Pulsed Loads, IEEE Trans. on Nucl. Sci., NS-16, 6/69.
4. R. Cassel, J.E. VanNess, Direct Powering of the 200 GeV Synchrotron Magnets from the Utility System, op. cit NS-16, 6/69.
5. R. Cassel, Power supply for NAL Main Ring, op. cit NS-20, 1973.
6. A. Rohrmayer, Operation of Accelerators Directly Off The Utility System, op. cit., NS-14, 6/67.
7. M. Meth, Preliminary Study of AC Power Feeders for the AGS Booster, AD Tech. Note No. 220, 10/85.
8. M. Meth, Line Flicker for 1.5 GeV Proton Operation, Booster Tech. Note No. 54, 7/86.
9. N. W. Miller, et. al., A Study of the Effect of the Brookhaven AGS Booster Synchrotron on the LILCO Power System, GE Systems Development and Engineering Dept., Schenectady, N.Y., 3/88.