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## AGS INTENSITY UPGRADES\*

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### Abstract

After the successful completion of the AGS Booster and several upgrades of the AGS, a new intensity record of  $6.3 \times 10^{13}$  protons per pulse accelerated to  $24 \text{ GeV}$  was achieved. The high intensity slow-extracted beam program at the AGS typically serves about five production targets and about eight experiments including three rare Kaon decay experiments. Further intensity upgrades are being discussed that could increase the average delivered beam intensity by up to a factor of four.

## 1 Recent AGS High Intensity Performance

The proton beam intensity in the AGS has increased steadily over the 35 year existence of the AGS, but the most dramatic increase occurred over the last couple of years with the addition of the new AGS Booster[1]. In Fig. 1 the history of the AGS intensity improvements is shown and the major upgrades are indicated. The AGS Booster has one quarter the circumference of the AGS and therefore allows four Booster beam pulses to be stacked in the AGS at an injection energy of  $1.5 \text{ GeV}$ . At this energy space charge forces are much reduced and this in turn allows for the dramatic increase in the AGS beam intensity.

The beam intensity in the Booster surpassed the design goal of  $1.5 \times 10^{13}$  protons per pulse already to reach a peak value of  $2.2 \times 10^{13}$  protons per pulse. This was achieved by very carefully correcting all the important nonlinear orbit resonances especially at the injection energy of  $200 \text{ MeV}$ , where the space charge tune shift reaches about 0.3, and also by using the extra set of rf cavities that were installed for heavy ion operation as a second harmonic rf system. A second harmonic system allows for the creation of a flattened rf bucket which gives longer bunches with lower space charge forces.

The AGS itself also had to be upgraded to be able to cope with the higher beam intensity. During beam injection from the Booster, the AGS needs to store the already transferred beam bunches. During this time the beam is exposed to the strong image forces from the vacuum chamber which causes beam loss from coupled bunch beam instabilities within as short a time as a few hundred revolutions. A very powerful feedback system was installed that senses any transverse movement of the beam and compensates with a correcting kick. New more powerful rf power amplifiers were build and installed immediately next to the ten rf cavities. This was needed to deliver to the beam the necessary  $400 \text{ kW}$  power during

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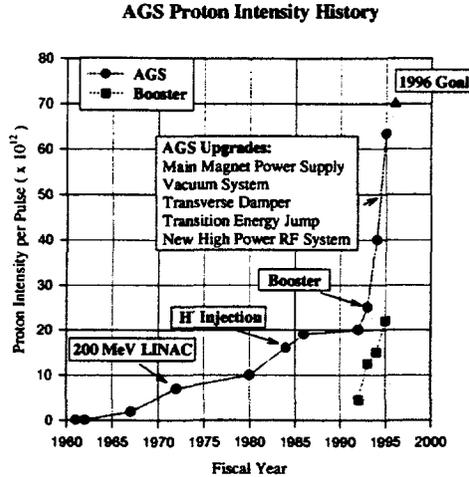


Figure 1: The history of the evolution of the proton beam intensity in the Brookhaven AGS.

acceleration and also to counteract the very large beam loading effects in the rf cavities from the high intensity beam.

During acceleration the AGS beam has to pass through the transition energy after which the revolution time of higher energy protons becomes longer than for the lower energy protons. This potentially unstable point during the acceleration cycle was crossed very quickly with a new powerful transition energy jump system with only minimal losses even at the highest intensities. However at energies higher than transition, a very rapid, high frequency instability developed which could only be avoided by purposely increasing the bunch length using a 100 *Mhz* dilution cavity.

The peak beam intensity reached at the AGS extraction energy of 24 *GeV* was  $6.3 \times 10^{13}$  protons per pulse also exceeding the design goal for this latest round of intensity upgrades. It also represents a world record beam intensity for a proton synchrotron. With a 1.6 second slow-extracted beam spill the average extracted beam current was about 3  $\mu A$ . This level of performance was reached quite consistently during the last AGS experimental run of 24 weeks during which more than  $10^{20}$  protons were accelerated in the AGS to 24 *GeV*.

## 2 Possible Future AGS Intensity Upgrades

Currently the number of Booster beam pulses that can be accumulated in the AGS is limited to four be the fact that the circumference of the AGS is four times the circumference of the Booster. This limits the maximum beam intensity in the AGS to four times the maximum Booster intensity which itself is limited to about  $2.5 \times 10^{13}$  protons per pulse by the space charge forces at Booster injection. To overcome this limitation some sort of stacking would have to be used in the AGS. The most promising scheme is stacking in the time domain. To accomplish this a cavity that produces isolated rf buckets can be used to maintain a partially debunched beam in the AGS and still leave an empty gap for filling in additional Booster beam pulses. The stacking scheme is illustrated in Fig. 2. It makes use of two isolated rf buckets to control the width of this gap. Isolated bucket cavities, also called Barrier Bucket

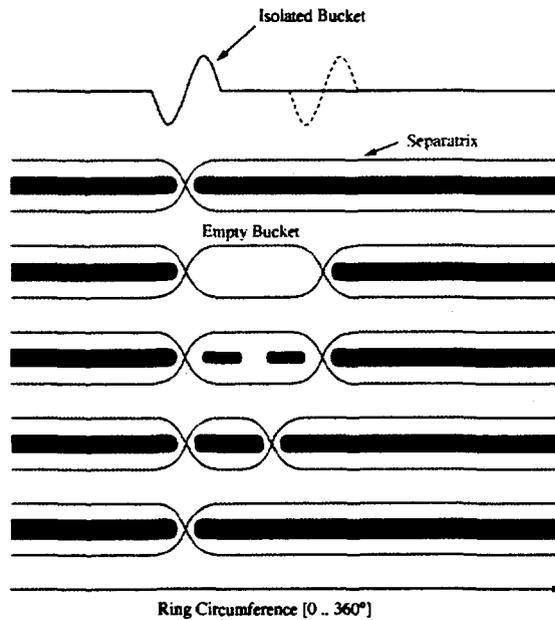


Figure 2: Time domain stacking scheme using a barrier bucket cavity. The evolution of the longitudinal beam structure during the stacking process are shown from top to bottom.

cavities, have been used elsewhere[2]. However, for this stacking scheme, a much higher rf voltage would be needed. An additional important advantage of this scheme is that while the beam is partially debunched in the AGS the beam density and therefore space charge forces are reduce by up to a factor of two.

As more Booster beam pulses are accumulated in the AGS the reduction in the overall duty cycle becomes more significant. For fast-extracted beam operation (FEB) already the accumulation of four Booster pulses contributes significantly to the overall cycle time. With the addition of a 1.5 GeV accumulator ring in the AGS tunnel, shown in Fig. 3, this overhead time could be completely avoided. Such a ring could be build rather inexpensively possibly using low field permanent magnets[3]. Fig. 3 shows the possible running scenarios with an accumulator and a barrier cavity. Using the design values for the Booster and AGS beam intensities of  $1.5 \times 10^{13}$  and  $6.0 \times 10^{13}$ , respectively, an average beam current of  $10 \mu A$  could be achieved for slow-extracted beam with a duty cycle of 50 %. For fast-extracted beam the average beam current would be  $20 \mu A$  with repetition rate of 1 Hz.

### 3 Conclusions

With the era of the Relativistic Heavy Ion Collider (RHIC) approaching at Brookhaven the AGS will need to serve as an injector for RHIC delivering high brightness Gold and polarized proton beams. However, due to the 10 hour beam storage time in RHIC the AGS is available for about 80 % of the time for multi-GeV slow and fast extracted beams. With modest

### AGS WITH ACCUMULATOR RING

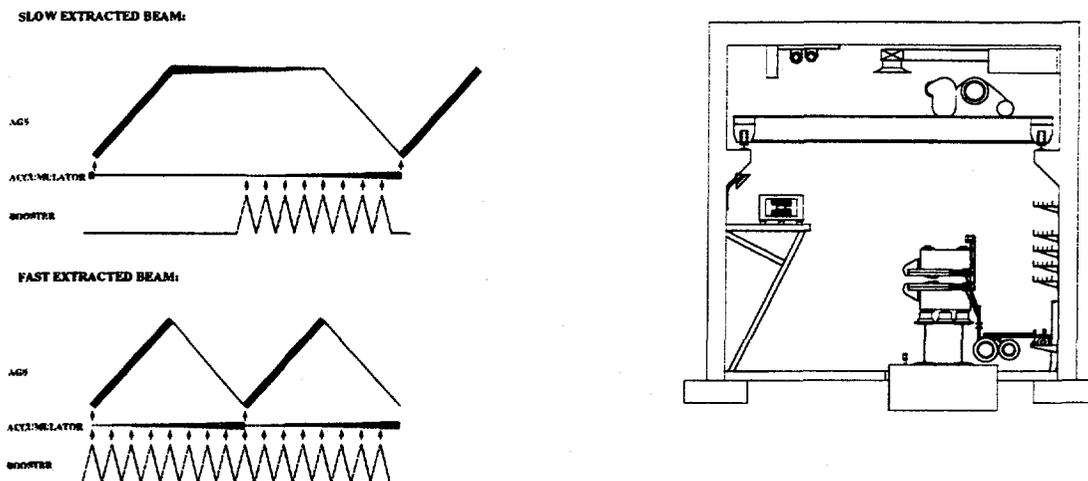


Figure 3: A 1.5 GeV accumulator in the AGS tunnel can be used for both slow-extracted beam (SEB) and fast-extracted beam (FEB) to improve the machine duty cycle. On the left operation scenarios for these two modes are shown. On the right the location of the 1.5 GeV accumulator in the AGS tunnel is shown. The low field combined function magnets are shown on the left side of the tunnel cross section vertically displaced with respect to the AGS.

upgrades of the AGS its current high intensity performance could be greatly improved and would open up the possibility for a next round of high precision experiments.

## References

- [1] M. Blaskiewicz et al., High Intensity Proton Operations at Brookhaven, 1995 Particle Accel. Conf. Dallas, Texas, May 1995, to be published.
- [2] J.E. Griffin et al., IEEE Trans. on Nucl. Sc. Vol. NS-30, No. 4, (1983) 3502
- [3] K. Bertsche et al., Temperature Considerations in the Design of a Permanent Magnet Storage Ring, 1995 Particle Accel. Conf. Dallas, Texas, May 1995, to be published.

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