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AGS PERFORMANCE AND UPGRADES*

A Possible Proton Driver for a Muon Collider

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Abstract

After the successful completion of the AGS Booster and several upgrades of the AGS, a new intensity record of 6.3×10^{13} protons per pulse accelerated to 24 GeV was achieved. Further intensity upgrades are being discussed that could increase the average delivered beam intensity by up to a factor of six. The total beam power then reaches almost 1 MW and the AGS can then be considered as a proton driver for a muon collider.

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 few 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 GeV . At this energy space charge forces are much reduced and this in turn allowed for the dramatic increase in the AGS beam intensity.

The beam intensity in the Booster surpassed the design goal of 1.5×10^{13} protons per pulse already to reach a peak value of 2.2×10^{13} protons per pulse. This was achieved by very carefully correcting all the important nonlinear orbit resonances especially at the injection energy of 200 MeV , where the space charge tune shift reaches about 0.4, 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

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

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 kW power during 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 above 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 6.3×10^{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.

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

2 Possible Future AGS Intensity Upgrades

Currently the number of Booster beam pulses that can be accumulated in the AGS is limited to four by 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 2.5×10^{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 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 with the beam partially debunched in the AGS the beam density and therefore space charge forces are reduce by up to a factor of two.

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 elevated with respect to the AGS.

The increases in beam intensity will then have to be accelerated in the AGS. Presently, the beam intensity that can be accelerated across transition energy is limited by the very large dispersion waves produced by the transition jump quadrupoles. The large dispersion severely limits the momentum aperture. The amplitude of the required dispersion wave could be reduced significantly by using a quadrupole arrangement that generates a transition energy shift that increases linearly with the dispersion wave amplitude[3]. The present system generates a global dispersion wave where all the first order contributions to the change in transition energy cancel[4].

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 built rather inexpensively possibly using low field permanent magnets[5]. Fig. 3 also shows the possible running scenarios with an accumulator and a barrier cavity.

3 The AGS Complex as a Proton Driver

For the current scenario of a muon collider the two biggest challenges for the proton driver are delivering the required beam power and producing the required extremely short and intense bunches.

For the 250 on 250 GeV muon collider a proton beam power of about 1 MW is required which could be achieved at the AGS by accumulating four Booster beam pulses of 0.25×10^{14} protons each in the Accumulator at the maximum possible rate of 10 Hz and then accelerate the resulting 1.0×10^{14} protons in the AGS with a repetition rate of 2.5 Hz. This would require an additional upgrade of the AGS main magnet power supply which now limits the AGS repetition rate to about 1 Hz.

The relative high energy of the AGS proton beam is a distinct advantage in producing the required short and intense beam bunches since the space charge forces are significantly reduced. The goal is to produce two bunches with 0.5×10^{14} protons each and a rms length of 1 ns (0.3 m). The maximum incoherent space charge tune shift of such a bunch for a $100\pi\text{ mm mrad}$ transverse 95% beam emittance is 0.4 at 24 GeV . Although manageable this still very large tune shift illustrates clearly that the relative high proton energy is critical to the production of the required short proton bunches. At lower energy, not only does the space charge tune shift increase rapidly, but also more protons are required to produce the same number of muons per bunch.

The momentum spread of such a short bunch is very large, but again the higher energy can bring it into a manageable range. The current AGS momentum acceptance is at most $\pm 3\%$ which requires the longitudinal phase space occupied by one bunch to be less than 4.5 eVs . This in turn creates more stringent demands on the earlier parts of the accelerator cycle. In particular, Landau damping from the beam momentum spread is used to guard against resistive wall instabilities during AGS injection and also longitudinal microwave instabilities after transition[6]. Beam stability can be restored with a more powerful transverse damping system and possibly a new low impedance vacuum chamber. Also, the transverse microwave instability after transition crossing is predicted to cause beam loss unless damped by Landau damping from incoherent tune spread or possibly high frequency quadrupoles.

In summary, the required upgrades to the AGS complex to achieve the requirements for a 250 on 250 GeV muon collider consist of a 1.5 GeV accumulator and an AGS power supply upgrade to achieve 2.5 Hz operation and also possibly a Barrier Cavity system, a new AGS vacuum chamber, and upgrades to the AGS rf, transition jump, and transverse damping system. Although substantial, the cost of these upgrades is rather modest on the scale of a muon collider project.

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] V. Visnjic, Phys. Rev. Lett. **73** (1994) 2860
- [4] W.K. van Asselt et al., The Transition Jump System for the AGS, 1995 Particle Accel. Conf., Dallas, Texas, May 1995, to be published.
- [5] 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.
- [6] S.Y. Zhang, these proceedings.