THE AGS NEW FAST-EXTRACTION SYSTEM AND THE SINGLE-BUNCH EXTRACTION TEST*

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Summary

For the neutrino physics program and for the CBA injection, a new fast extraction system has been implemented to improve the extraction efficiency and the quality of the extracted beam. Central to the new system is a new fast kicker, placed at the H5 straight section, capable of rising between bunches, $t_r < 170$ nsec, and staying constant for 2.6 μ sec with flat-top ripple less than $\pm 1.5\%$. So far, the system has been operated for longer than 3000 hours and routinely extracts 10^{13} ppp at 99% efficiency.

Experiment 745 on QCD test requires a single AGS bunch of 40 nsec. For this purpose another fast kicker was placed at the E5 straight section and powered by a new pulser to produce a half sinusoidal pulse with both a rise and fall time of 200 nsec. A single AGS bunch was extracted through the slow beam channel at 22 GeV/c leaving the remaining 11 bunches undisturbed which continued to be accelerated to 29.4 GeV/c and extracted by the H5 kicker through the fast beam channel. Because the ring circumference ratio of CBA to the AGS is $4-3/4$, some of the injected beam from the AGS has to contain 11 bunches instead of 12; consequently, this single bunch extraction mode will also be used for CBA injection.

Design of the New FEB

For several years, the old fast extraction beam (FEB) system of the AGS has provided the primary proton beam for neutrino physics in the North Area.¹ It consists of two full aperture kickers at straight section (s.s.) C15 and E15, a septum magnet at E10, and an ejector septum magnet at H10. These extraction magnets occupy four straight sections and extend over 40% of the ring, which increases the chance of obstruction of the kicked beam. In addition, the rise time of the C15 kicker is 1.2 μ sec which is slow enough to cause beam scraping by the E10 septum magnet for two or three bunches.

For the proposed Colliding Beam Accelerator (CBA) at BNL, the AGS will be used as an injector with the FEB extraction channel and the upstream part of the beam transfer line incorporated into the injection line. CBA requires a kicker capable of rising to its full strength between bunches and staying constant, with flat top ripple less than $\pm 1.5\%$, for 2.6 μ sec. In view of the tight requirements on the quality of the AGS beam for CBA injection and to free two 15th s.s. for pulsed quadrupoles for the polarized proton program, a new fast extraction system is proposed.

The new system consists of a fast kicker at H5 s.s. and an ejector septum magnet at H10 s.s. To reduce the voltage requirement on the pulsing of the H5 kicker, a C-type open magnet has been built and placed 2 inches away from the center of the vacuum chamber. Two μ sec before the extraction, a $3/2 \lambda$ local orbit deformation is created to bring the beam into the aperture of the kicker. At the extraction

time, the kicker is triggered to send the beam into the ejector septum magnet H10, which gives an additional kick to bring the beam out of the ring. The schematic layout of the system with the local orbit deformation is shown in Figure 1.

Figure 1 - The layout of the FEB components and trajectory.

The way to create the local orbit deformation is through the backleg windings (BLW's) on the AGS main magnets. In the AGSBEAM program,² there is provision for momentum change of the beam in any AGS magnet which can be interpreted as the field change introduced by the backleg windings. A reduction in particle momentum corresponds to an increase in the magnetic field. For the configuration shown in Figure 1, with six turns on the short magnet and five turns on the long magnet, 700 amperes is needed to bring the beam into the H5 aperture at 2.5" away from the vacuum chamber center line. The $3/2 \lambda$ deformation, instead of a $1/2 \lambda$ one, is chosen to minimize the tune shift introduced by the orbit bumps and to reduce the current needed for a given deformation.

At the extraction, the momentum of the AGS beam is at $p = 29.4$ GeV/c. For the design purpose, we can assume that the horizontal and vertical emittances are $\epsilon_x = \epsilon_y = 2$ mm-mrad and the momentum spread is $\Delta p/p = \pm 1.5 \times 10^{-3}$. Then the aperture requirement of the H5 kicker, the magnetic field needed, and the charging current required can all be calculated from the AGS lattice parameters.³ Another parameter to be specified is the rise time of the H5 kicker up to 99% of its strength. Because the separation between centers of the AGS bunch is 224 nsec at top energy and the bunch length is about 35 nsec, the rise time of the H5 current should be 170 nsec, allowing 10 nsec jitter in the thyatron tube and control circuit.⁴ A compilation of the design parameters of the HBLW's, H5 kicker and H10 ejector is given in Table I.

The lattice function in the external beam line can be calculated by the AGSBEAM program and the results have been found to be:³

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$$\begin{aligned} \beta_y &= 4.7 \text{ m} & \alpha_y &= 0.987 \\ \beta_x &= 57.46 & \alpha_x &= 5.67 \\ x_p &= 2.46 \text{ m} & x_p' &= 295 \text{ mrad} \end{aligned}$$

at the H13 s.s. where the beam is about 43 cm away from the AGS beam center line and is free from the fringe field effect. It is defined to be the beginning point of the external transport line.

Table I - The FEB Magnet parameters.

	HBLW's	H5	H10
t_{trig} (msec)	590	592	591.3
waveform	half sine	square	half sine
t_{rise}	2 msec	170 nsec	0.7 msec
aperture (V/H)	Full	0.56"/1.75"	1.0"/2.5"
θ	2 mrad	1.1 mrad	22 mrad
I	700 A	3 kA	21 kA

Where the trigger time is defined with respect to a predetermined peaker mark. If we use the extraction time of H5 as a reference, the orbit change occurs about 2 msec before extraction and the ejector magnet is excited 0.7 nsec before extraction.

The Performance of the New FEB

The kicker and modulator combination has been tested for a few months before installation. The first concern is to confirm that the position of the beam is really inside the narrow aperture of the kicker. The way to do this is to excite the HBLW's to move the beam closer to the kicker in steps. For each step, the vertical position at the H5 kicker is adjusted by the F20 vertical dipole magnet. Before we reach the kicker, there is 2 cm allowed vertical space before we pick up any indication of beam loss. But when the beam is within the magnet aperture, only 3 mm is available for vertical position adjustment. The observation is consistent with the estimate from the magnet position and beam size.

Figure 2a - The H5 waveform.
2b - The bunch structure lower trace: in the AGS ring; upper trace: in the U line.

Figure 2a shows the waveform of the H5 kicker. It clearly has achieved the required 170 nsec rise time, 2.6 μ sec flat top and $\pm 1.5\%$ stability at the top. Figure 2b shows the bunch structure recorded by the wide band current transformer, the lower trace

represents the AGS bunches in the ring which is terminated by the extraction. The upper trace is taken from the external line which is generated immediately after the extraction. The AGS baseline shows no particles left in the ring and the evenness of the external trace shows that the H5 pulse is stable. Furthermore, the first and last bunches show no sign of clipping, proving that the H5 current rises fast enough between bunches.

During the running period in the fall of 1982, the AGS accepted H^+ from the Linac and stacked them multiturn in the betatron space. The best condition achieved is 9.2×10^{12} ppp with 99% extraction efficiency. But in the fall of 1982, a new injection mode, H^- charge exchange injection, was introduced which accepted the beam into the center of the vacuum chamber and resulted in a better injection efficiency and better AGS beam quality and intensity. Within a month, the best condition achieved is 12×10^{12} ppp and 99% extraction efficiency.

A sensitive dependence on the AGS vacuum condition was observed in the early period when the outgassing of the ferrite kicker was faster. Under excessive outgassing, the beam size would grow to such a degree that the extraction efficiency deteriorated to 80% and the machine would be inactive due to the radiation monitor interlock at the H10 s.s. More pumping and lower intensity can circumvent the problem, but eventually it went away after a two week running period. Another operational adjustment required is to increase the horizontal tune by 0.08 units at around 450 msec to improve the extraction efficiency by 10%. The actual mechanism of the beam behavior has not been identified yet.

The Design and Test of the SBE

Experiment 745 requires a single AGS bunch of 40 nsec long to be delivered to the D line for their experiment on QCD test. Because the D line can only be reached through the slow extraction beam (SEB) channel and the remaining 11 bunches have to be delivered into the fast beam channel, to perform single bunch extraction (SBE) implies that we not only need another kicker to pull one bunch out without disturbing the other 11 bunches, but we also have to exercise the slow beam equipment and fast beam equipment all within one AGS cycle of 1.5 sec.

The way to accomplish this is to put a fast kicker at E5 s.s. and kick the beam into the F5 septum magnet and into the F10 ejector magnet to reach the D

Figure 3 - The schematic layout of the combined SBE and FEB and their trajectories. (The $1/2 \lambda$ orbit deformations are shown for simplicity, they are in fact all $3/2 \lambda$ deformation.)

line. A simplified schematic layout of the extraction components and the trajectories is given in Figure 3. Because of the symmetry property of the AGS lattice, the F5-F10 pair arrangement is almost identical to the H5-H10 arrangement. The only difference is now the E5 kicker has to deflect the beam inward in order to produce an outward displacement at the F5 septum magnet. Again, because of E5 s.s. is identical to the H5 s.s. optically, a spare H5 kicker magnet can be used as the E5 kicker, only now the polarity of the leads has to be reversed to be able to kick inward.

The pulser is identical to the first section of the H5 pulser^{4,5} and is basically a LC discharge circuit to produce a half sinusoidal current waveform with peak current of 2800 amp and half-period of 400 nsec. In the final design, the capacitance used is $C = 0.011 \mu\text{f}$ and the inductance of the magnet and the lead is $L = 1.5 \mu\text{H}$, implying that

$$t_r = \pi/2 \sqrt{LC} = 200 \text{ nsec} \quad (1)$$

$$Z = \sqrt{L/C} = 12 \Omega \quad (2)$$

$$V = ZI = 12 \times 2.8 = 34 \text{ kV} \quad (3)$$

Another change to be made before the system is complete, is that the original design for the FBLW's to produce orbit deformation in the F5 and F10 region is to stay constant for 1 sec for the slow beam spill. Now the power supply of FBLW's has to be modified to give a short pulse in order to bring the beam back to central position for further acceleration to full energy. By changing the discharge capacitance we can control the FBLW's to deliver a waveform of rise time $t_r = 60 \text{ msec}$ and fall time $t_f = 80 \text{ msec}$. To help understand the sequence of events, Figure 4 is given to show the timing of the respective systems.

Figure 4 - The timing sequence of the combined SBE and FEB operations.

Figure 4 shows that the single bunch extraction (SBE) occurs at 500 msec corresponding to a momentum of 22 GeV/c and the regular fast extraction on the remaining bunches occurs at 600 msec corresponding to a momentum of 29.4 GeV/c. The actual parameters for the EBLW's, FBLW's and the E5 kicker during the test are summarized in Table II. F5 and F10 have to be turned on two msec before extraction and they provide 1.2 mrad and 15 mrad deflection respectively.

During the test, the machine was tuned to run at an intensity of $2 - 3 \times 10^{12}$ ppp. Shown in Figure 5a is the E5 waveform at 2800 A with a half-period of 400 nsec, which is short enough not to disturb the adjacent bunches. Figure 5b shows the 11 AGS bunches

in the U line; the missing 6th bunch has been delivered to the D line. The clean extraction is evident since there is no visible perturbation to the adjacent bunches. We have also demonstrated that the trigger system can easily lock onto any bunch we choose.

Table II - The SBE magnet parameters.

	EBLW's	FBLW's	E5
t_{trig} (msec)	490	432	492
waveform	half sine	half sine	half sine
t_{rise}	2 msec	60 msec	200 nsec
aperture(V/E)	Full	Full	0.56"/1.75"
θ	2 mrad	1.5 mrad	0.9 mrad
I	560 A	420 A	2.8 kA

Figure 5a - The E5 waveform.

5b - The bunch structure in the U line.

Because the circumference ratio of the CBA ring to that of the AGS ring is 4-3/4, in the injection to CBA some of the AGS pulses can only contain 11 bunches. This single bunch extraction will also be used to produce 11 bunches for CBA injection.

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References

1. L. Blumberg, et al., BNL Fast Shaving Extraction System, Proc. IXth Intl. Conf. on High Energy
2. G.H. Morgan, AGS Internal Report, GHM-1, June 1, 1966.
3. W.T. Weng, The New AGS Fast Extraction System, BNL 51310, September 1980.
4. W.T. Weng, et al., The AGS Fast Kicker Magnet System, Trans. Nucl. Sci., Vol. 28, p. 2896 (1981).
5. W. Frey, August 1983, private communication.

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