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COMMISSIONING THE POLARIZED BEAM IN THE AGS*

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Introduction

After the successful operation of a high energy polarized proton beam at the Argonne Laboratory Zero Gradient Synchrotron (ZGS)[1] was terminated, plans were made to commission such a beam at the Brookhaven National Laboratory Alternating Gradient Synchrotron (AGS).[2,3] On February 23, 1984, 2 μA of polarized H^- was accelerated through the Linac to 200 MeV with a polarization of about 65%. 1 μA was injected into the AGS and acceleration attempts began. Several relatively short runs were then made during the next three months. Dedicated commissioning began in early June, and on June 26 the AGS polarized beam reached 13.8 GeV/c to exceed the previous ZGS peak momentum of 12.75 GeV/c. Commissioning continued to the point where 10^{10} polarized protons were accelerated to 16.5 GeV/c with 40% polarization. Then, two experiments had a short polarized proton run. We plan to continue commissioning efforts in the fall of this year to reach higher energy, higher intensity, and higher polarization levels. We will now present a brief description of the facility and of the methods used for preserving the polarization of the accelerating beam.

Facility

The whole facility can be functionally divided into two sections: a front end consisting of the polarized ion source, the 20 keV beam transport, the RFQ linear accelerator, the 750 keV beam transport, the 200 MeV linac, the 200 MeV polarimeter, and the 200 MeV transfer line to the AGS; and the hardware necessary in the AGS to accelerate and maintain the polarization of the injected protons. Figure 1 is a schematic of the whole facility and, in addition to the front end components, shows the correction dipoles, the pulsed quadrupoles and their power supplies, the internal polarimeter and high energy polarimeter which make up the AGS modifications necessary to produce a high energy accelerated proton beam.

Among all the new equipment necessary, the H^- ion source, the RFQ linear accelerator, the pulsed quadrupoles and their power supplies, and the internal polarimeter were all novel devices requiring special attention. The H^- ion source uses Cs charge exchange ionization to produce polarized H^-. This source has produced 25 μA of H^- which is several times higher than previous sources of this kind. The RFQ came on the air with almost no difficulty and was the first in the world, by a few days, to be successfully coupled to an operating accelerator. The fast pulsed quadrupoles are ferrite magnets with a 2 μsec rise time and a dI/dt of 1.3 GA per second. The internal polarimeter target assembly uses a spooling 0.003" nylon filament as a target. It is flipped into and out of the beam with a flip speed and a spooling rate of about 1 meter per second.

Besides the pulsed quadrupoles which produce a fast tune shift to pass through one type of resonance, we need pulsed dipoles to produce radial field components for correcting vertical orbit distortions which cause another type of depolarizing resonance. The AGS has 96 such dipoles equally divided among the 12 superperiods of the machine. New power supplies and regulators were designed and built to operate them in the necessary manner for polarized protons. All of the hardware was made operable over the several months of short runs as we went through the steps of 1) beam from source, 2) beam through RFQ, 3) beam to Linac, 4) beam through Linac, 5) beam through 200 MeV polarimeter, 6) beam to AGS, 7) H^- beam on AGS stripper foil, 8) bunch injected beam and accelerate, 9) measure polarization with internal polarimeter and begin corrections. Though each step had its tribulations and triumphs, we will omit a great deal of detail and only describe our experiences with depolarizing resonances.

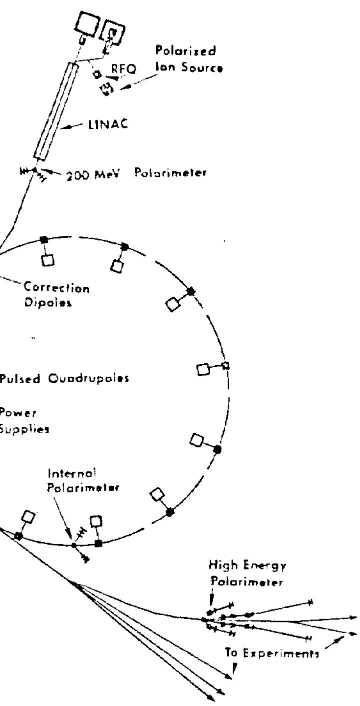

Figure 1 - AGS facility.

Preserving Polarization

There are basically two types of depolarizing resonances, one a so-called "intrinsic resonance" which is due to the natural periodicity of the accelerator and two, an "imperfection resonance" which is due to misalignments which lead to closed vertical orbit distortions. These are characterized by

$G\gamma = kP \pm \nu_y$ intrinsic, and
$G\gamma = k$ imperfection, where
G = $g/2 - 1$ anamolous magnetic moment
k = integer
P = periodicity of the accelerator (=12 in AGS)
ν_y = vertical machine tune (number of betatron oscillations per revolution)
γ = relativistic energy factor

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Discussion and derivation[4] have appeared many times before so we will not say anymore here other than that the intrinsic resonance can be corrected for by a fast vertical tune shift (ν_y) and the imperfection resonance by a radial magnetic field at the proper harmonic.

The magnitude of the correction efforts can be seen from Figure 2 which shows the AGS calculated resonances.[5] The X's are intrinsic resonances and the lines represent the imperfection resonances.

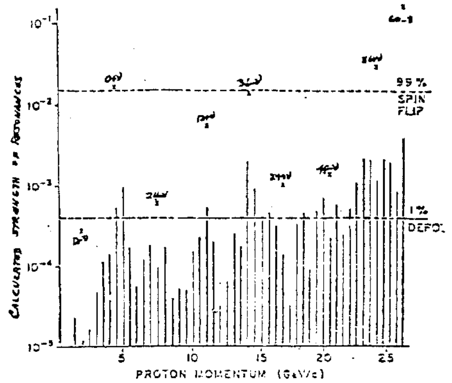

Figure 2 - Calculated AGS resonance strengths.

Initially we had thought we would only have to correct about four or five imperfection resonances and four or five intrinsic resonances to reach 16.5 GeV/c. However, the real world was different. We had to correct essentially all 30 imperfection resonances as well as the intrinsic ones. Since the imperfection resonances were much stronger than anticipated, we had to proceed in smaller steps and measure polarization after a few resonances before going on. We operated the AGS with a front porch as well as a flat top and we moved these flats to higher and higher energies as we proceeded in steps from 3.7 GeV/c to 6 to 10.3 . . . to 16.5 GeV/c. The flats were set to values just above the few resonances we were correcting and the polarization was measured on the flats. This gave us better counting rates in the internal polarimeter.

Let us first consider the correction for the intrinsic resonances. Figure 3 shows some typical corrections in tune energy space for an intrinsic resonance. The resonance line is crossed in less than one turn (~ 2 μsec) and the tune (ν_y) remains a fixed distance from the resonance as the correction pulse decays at a rate comparable to the change of energy during the normal acceleration cycle (1.2-2.9 msec depending on the strength of the correction 0.125-0.30 tune units).

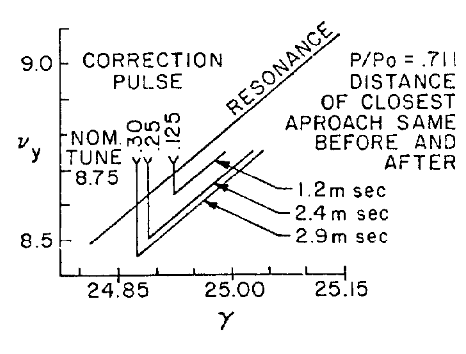

Figure 3 - Typical corrections in tune energy space.

The description of what occurs can be seen in the following examples of passing through intrinsic resonances.

In tuning through $G\gamma = 0 + \nu_y$, an intrinsic resonance, one sets a reasonable amplitude and then varies the time at which the quadrupole is energized. In this particular case we set the quads to produce a tune shift of 0.2 units. We then started to search in time near the calculated position of the resonance. The abcissa in Figure 4 is the number of "Gauss clock counts" (a magnetic field generated number) which is proportional to the momentum of the accelerated beam. We see in this resultant curve a spin flip region at 8400 Gcc and the region where we have successfully jumped the resonance at 8635 Gcc. The bump at 8250 Gcc is still not understood, but the flip and correction pattern is exactly what one expects from a resonance. The ordinate is a measure of the relative polarization as measured with the internal polarimeter. The location of the resonance was in excellent agreement with the predicted number of Gauss clock counts. Once the resonance is located one can examine the effect of amplitude changes. An increase from 0.2 units to 0.25 units of time resulted in a wider plateau but with no increase in surviving polarization.

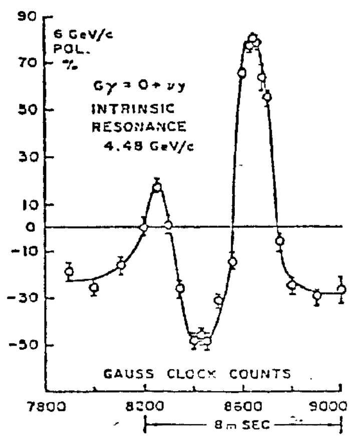

Figure 4 - Intrinsic $G\gamma = 0 + \nu_y$ resonance correction.

The $G\gamma = 36-\nu_y$ (Figure 5) has a much wider semi-correction before the spin flip and looks qualitatively different. These differences are probably not due to the nature of the resonance but rather to some anomoly in the correction pulse.

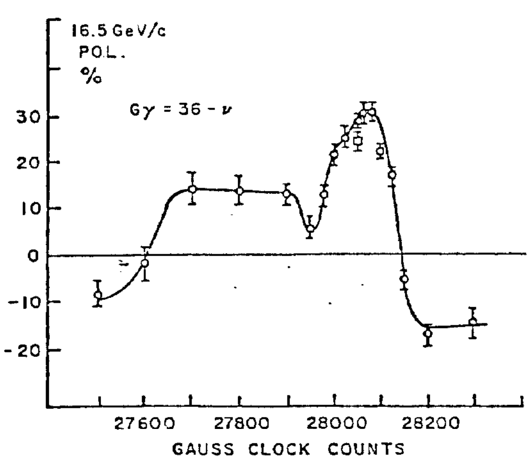

Figure 5 - Intrinsic $G\gamma = 36 - \nu_y$ resonance correction.

The correction technique for the imperfection resonance is a little more complex. Since the vertical orbit distoration of harmonic number k (k is an integer) is driven by horizontal imperfection fields of harmonic k, we correct these $G\gamma = k$ resonances by cancelling the kth component of the horizontal imperfection field. We correct by pulsing the 96 dipoles with the appropriate amplitude and phase to minimize depolarization.

In the following figures we show that a sine correction is determined by varying the sine amplitude at a fixed arbitrary cosine correction. Then we vary the cosine while set to the best value of the sine amplitude. Since the sine and cosine are orthogonal our correction vector should have the correct amplitude and phase. Notice that in Figures 6, 7, and 8 for $G\gamma$ = 7, 8, 9 the width of the correction becomes narrower and narrower indicating that the resonance strength increases, while the setpoint values (abcissae) are a relative measure of the amount of vertical orbit distortion in the accelerator. The 9th is strongest since it is the closest to the AGS vertical tune of 8.75.

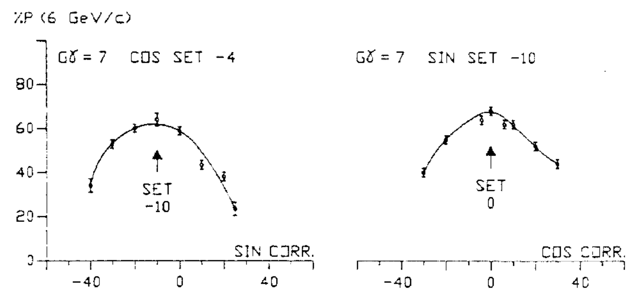

Figure 6 - $G\gamma$=7.

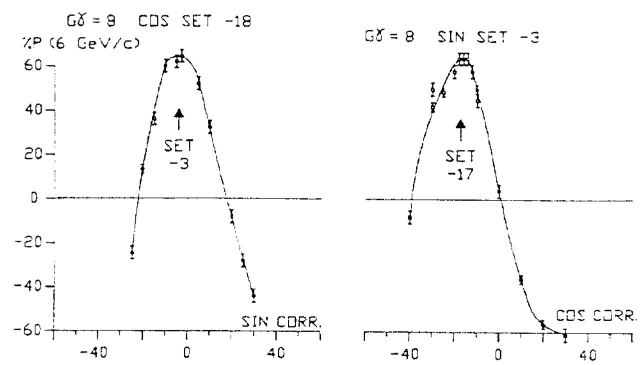

Figure 7 - $G\gamma$=8.

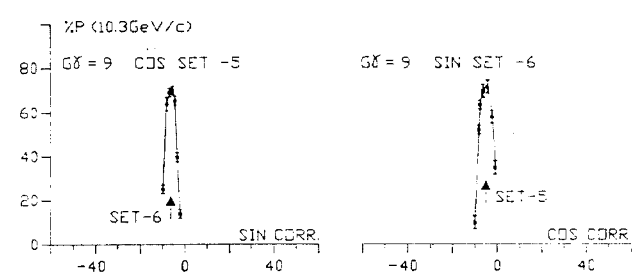

Figure 8 - $G\gamma$=9.

We also found what we have called a "beat" resonance depolarization. This is like an imperfection resonance which is dependent on the periodicity of the accelerator and is driven especially hard when the integer values are close to the vertical betatron tune. These resonances are given by $G\gamma$ = kP ± n. Values of n = 7, 8, 9, 10 (close to tune = 8.75) were found to be important, especially at $G\gamma$ = 27 = 3 x 12 - 9 (k = 3, P = 12, n = 9). This had to be corrected by using the 9th harmonic, rather than the 27th. The control algorithm had provisions for using two different harmonics at any value of $G\gamma$ so we could try 9th or 27th or both together, as shown in Figures 9 and 10.

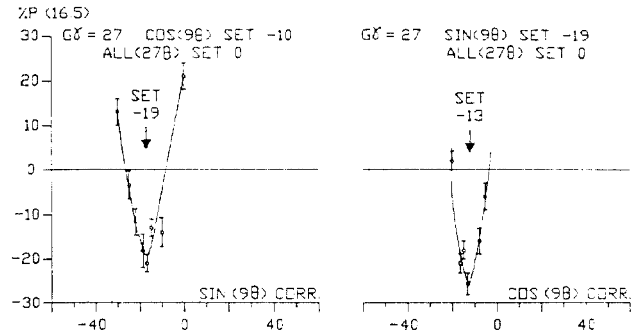

Figure 9 - $G\gamma$=27(9θ) cor.

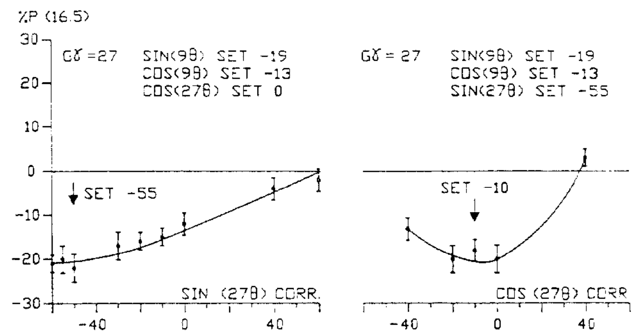

Figure 10 - $G\gamma$=27(9θ+27θ) cor.

For the physics run at 16.5 GeV/c, we corrected 24 imperfection resonances and 3 intrinsic resonances. Figure 11 shows the rising magnetic field during acceleration (bottom trace), the 3 fast quadrupole pulses for jumping the intrinsic resonances (middle trace), and the 24 pulses in one of the 96 energized dipoles for correcting the imperfection resonances (top trace).

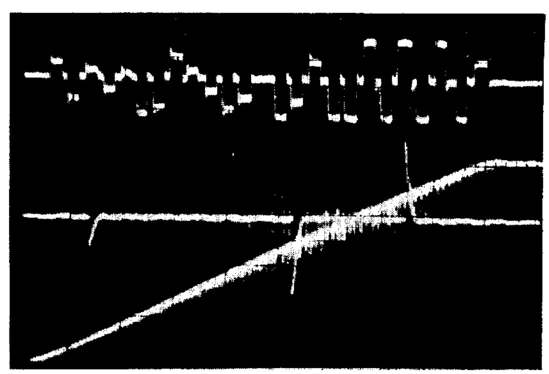

Figure 11 - resonance corrections.

Acknowledgments

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