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POLARIZED PROTON ACCELERATION AT THE BNL AGS, 1988*

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ABSTRACT

The present status of the polarized proton acceleration at the Brookhaven AGS is described. Some details regarding the tune-up and performance during the December 1987-January 1988 physics run are given.

The intention of this paper is to provide an update on the status of polarized proton acceleration at the Brookhaven AGS. The strategy for resonance crossing at the AGS is fast passage via tune jumping of the intrinsic resonances (5 below 18.5 GeV/c) and strength reduction via magnetic correction at the imperfection resonances (30 below 18.5 GeV/c). The lowest energy synchrotron in an AHF may use similar techniques. The general description of AGS operation given last year at the Sante Fe Workshop (see Ref. 1 and other references therein) will not be repeated here.

Since that report, a polarized run occurred starting in mid-December 1987 and ending six weeks later. This run will be denoted as the 1988 run, and comparison will be drawn between it and the prior run (1986). Nearly half of the 1988 run time was required to complete the tuning out of the resonances to produce an extracted beam with greater than 40% polarization at 18.5 GeV/c. The external intensity varied between 1 and 2×10^{12} protons per pulse at a 2.8 second repetition period. The extraction energy was set by economic constraints and was slightly lower than the record set in the past (40% at 22 GeV/c). Very little time was explicitly dedicated to studies, this being a production run for high energy physics. The rate of acceleration for the 1988 run was only 60% of past runs due to problems with the main magnet power supply. This implies that resonances were crossed more slowly and hence, all else being equal, a given resonance caused more depolarization of the beam.

A one-sentence summary of the run is that the standard techniques worked as predicted. The situation was cleaner this run than last in that some of the odd effects seen last run did not reappear. The final polarization after crossing 35 corrected resonances was a little more than half of the value at injection into the synchrotron. The external polarization was not very stable, varying between 35% and 50% over a time

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period of days. The reasons for this variation were not clearly determined. Four of the imperfection resonances were passed by flipping the polarization, using the magnetic correctors to strengthen the depolarizing fields in the machine. The decision to flip rather than correct was based on the observed lack of stability in the correction for $G\gamma = 9$ (a very sharp resonance--a four "count" change in the correction current reducing the polarization by 50%). The variation in the required correction current could have resulted from a shift in the ring magnets or a change in the correcting fields, the former being more probable. Flipping eliminated this sensitivity. In what follows the performance of the various systems will be briefly reviewed.

The source produced a 500 μsec-long current pulse of 25 μAmp H^-. The RFQ transmitted 75% of the source output, accelerating the beam to 750 keV. The current at the 200 MeV end of the Linac was 10 μAmp and the polarization measured there was a very stable (78 ± 2%). These numbers are comparable to the 1986 run, the pulse width a bit longer and the polarization a bit higher. The intensity was sufficient to allow acceleration albeit unpolarized, to full energy easily; about half of the injected beam was fully accelerated.

The internal polarimeter carried a 6 mil nylon string this year (4 mil in 1986). It was used on a flat measurement magnetic porch for the polarization tuning. The porch was shifted upward ten times during the tune-up period, gradually increasing the field or momentum at which polarization was measured. Figure 1 gives a summary of the polarization tune-up period. Machine polarization is plotted against time (days), with the momentum of the measuring point stepping up as time increases. The internal polarimeter was also used while the field was ramping to scan polarization vs energy. The emittance growth caused by the target string makes this measurement somewhat difficult to interpret since the intrinsic resonances depolarize more than they would with the string "out". Measurement time (2% polarization statistics) using the internal polarimeter varied from 5 minutes at low energy to about 15 minutes at high energy. The time needed by the control system to confirm that a resonance tuning parameter had been changed as desired was a few minutes.

The fast jumping of the intrinsic resonances went as predicted. As in the past, the jump sizes were to first order not a tuned parameter, the largest being $\Delta\nu = .3$ at $G\gamma = 36-\nu$. The timing of the jumps depends critically on the calibration and stability of the Gauss clock (a clock with tick rate proportional to dB/dt where B is the main magnet field). The resonances occurred at the predicted fields to within about 50 Gauss clock counts (10 Gauss) and within experimental errors were stable. The lower acceleration rate mentioned above effectively strengthened all resonances by about a factor of 1.4. This in itself appeared to cause no problem. However, as a consequence of the slower acceleration rate, the current waveform for the fast quads did present a problem. This function rapidly shifts the tune and the beam through the intrinsic resonance and then holds the beam away from the resonance condition long enough to allow the normal acceleration rate to keep the beam away from the resonance. The decay time of the quad current was designed to hold the beam

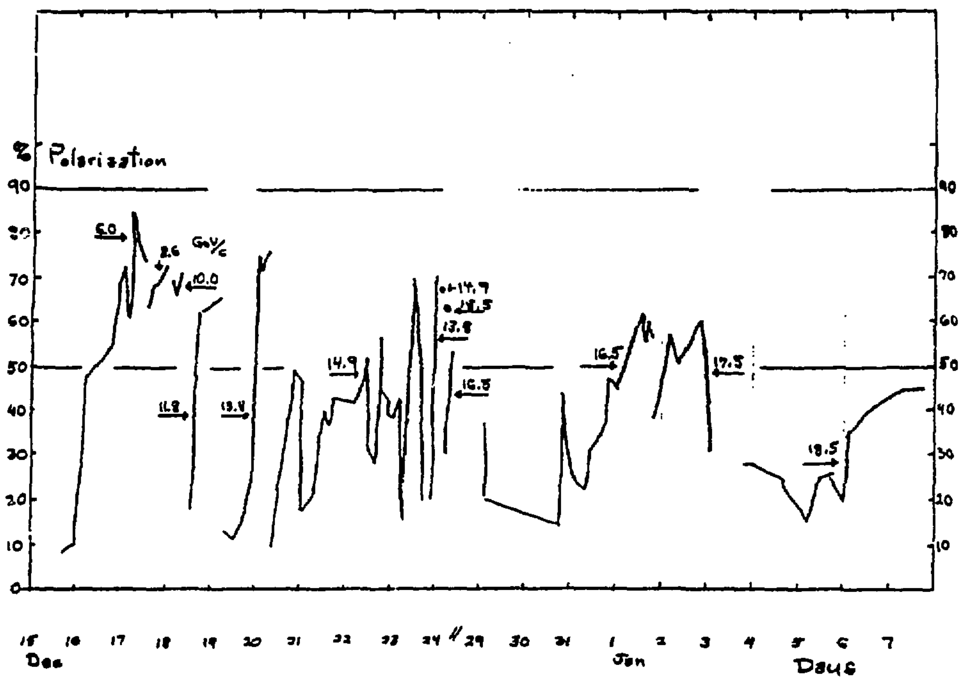

Fig. 1. Polarization at Measuring Porch Momentum vs. Time.

a fixed distance from resonance, assuming the normal acceleration rate. With the lower $d\gamma/dt$ of this run, the decay time was marginal, especially at $G\gamma = 24+\nu$. The plateau of that resonance timing curve was very narrow.

In order to allow large tune jumps (>.25) and yet avoid integer and half integer stop bands, the machine tune can be slowly adjusted prior to a given resonance crossing. In the past this technique was needed at a few intrinsics, and in particular was used in an odd fashion in 1986 at $G\gamma = 0+\nu$ (reducing the vertical tune so that the fast negative going jump actually pushed the tune down through the half integer ($\nu_v = 8.5$) for a few milliseconds). These "slow" quad maneuvers appeared to reduce somewhat the large emittance growth experienced during the 1986 run (see below). For the 1988 run, slow tune manipulations were needed only at $G\gamma = 36-\nu$ where the technique was used in the expected way, namely pushing the vertical tune down to 8.55 to allow a positive jump of .3 up to 8.85. During the 1986 run, moving the vertical tune very close to 8.5 while in the vicinity of $G\gamma = 36-\nu$ improved polarization and led to speculation that the nearby resonances were overlapping. An attempt to repeat this maneuver this run yielded no change in polarization.

The inherently nonadiabatic nature of pulsing the ferrite quads at the intrinsic resonances leads to transverse emittance growth in both planes. The growth seen in 1986 far exceeded that expected from the fast variation of the betatron functions and was suspected to be caused by a lack of alignment between the equilibrium orbit and the quad centers. The pulsing quads were suspected to be kicking the beam. Prior to the 1988 run, the main ring magnets were surveyed and repositioned both vertically and horizontally. Following this the effect of pulsing the ferrite quads on the beam equilibrium orbit was measured and the quad offsets deduced. The quad positions were then readjusted. Finally during the run the radial position of the beam, which is controlled by the acceleration program, was fixed and monitored to assure that the quad-centered radius was maintained. The result from all this effort was a great reduction in the emittance growth observed. Figure 2 compares the emittance growth in the vertical plane for the 1988 and 1986 runs. The horizontal growth was similarly reduced. The smaller beam sizes reduced depolarization at the intrinsic resonances and improved extraction efficiency.

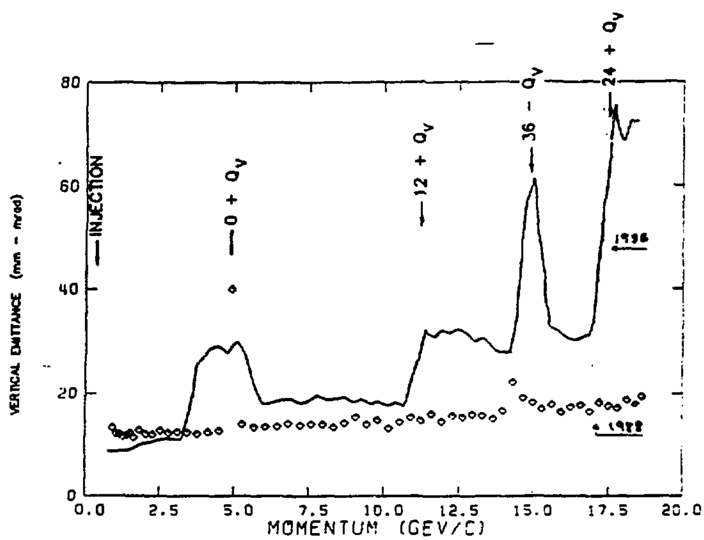

Fig. 2. Vertical emittance growth during the accelerator cycle, 1986 run compared to 1988 run.

The correction of the imperfection resonances generated no surprises. As in the past the resonances near $G\gamma = 36-\nu$ (namely $G\gamma = 27$, 28 and 29) were more effectively corrected by tuning magnetic harmonics at $N = 36-G\gamma$, rather than at $G\gamma$ (namely 9, 8 and 7 respectively). The interaction between the relatively large orbit distortions at these "beat" harmonics and the fields of the machine lattice produced the magnetic harmonic necessary to correct the resonance.[2] As mentioned above, four of the imperfections were flipped in an attempt to attain a more stable machine. Except for $G\gamma = 9$, this strategy seemed to have a neutral effect on machine performance.

The actual amplitudes and phases needed for correction at the imperfections presumably give a picture (a Fourier analysis) of the errors in the machine. Figure 3 gives these values for the 1986 and 1988 runs. The amplitudes are normalized by momentum (which assumes the errors come from the main ring magnets). The machine was realigned between these runs which one might think would randomize these values. Quite to the contrary, the amplitude data suggests that there is a strong correlation between the two runs. However, the phase information seems to show no such strong correlation. This remains a puzzle.

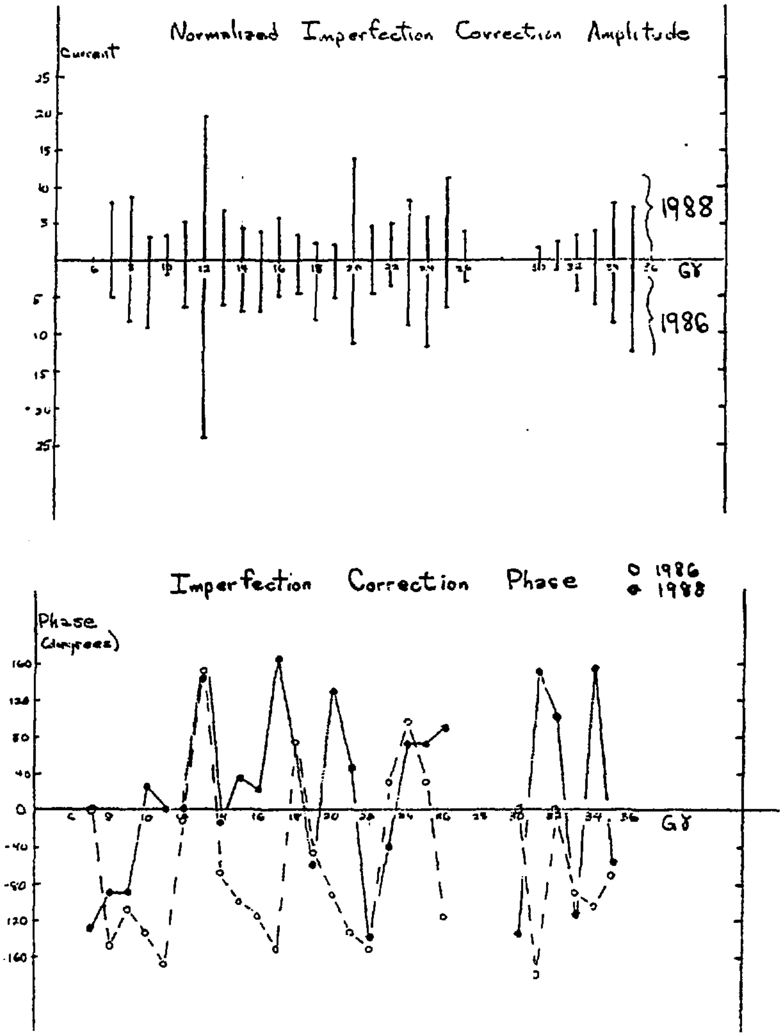

Fig. 3. Amplitude and phase of imperfection correction.
1986 run compared to 1988 run.

In tuning an imperfection resonance, a parameter emerges which is very useful for predicting the likelihood of being able to correct or flip that resonance, namely the width of the curve of polarization vs correction harmonic strength. This curve is just a scaled version of the Froissart-Stora curve of polarization vs resonance strength for resonance crossing at a fixed rate. The inverse of the width of this curve is a measure of the sensitivity of the intrinsic resonance to this harmonic and is a function of the lattice, the acceleration rate and the machine tune, but not of the magnitude or phase of the error harmonic present in the machine. If a particular resonance sensitivity is sufficiently high that the harmonic correction system available can span the interval from full correction to full flip, then it is guaranteed that the resonance can be successfully crossed. Even if this is not true, the sensitivity is a great help in planning the tuning procedure. A table of intrinsic resonance sensitivities for a proposed synchrotron where resonances are to be corrected by tuning out the imperfection fields would be a valuable addition in judging the difficulty of tuning-up such a lattice. Figure 4 gives the widths measured at the AGS in 1986 and 1988. The width plotted is the full width in units proportional to the magnetic harmonic applied at the point where the polarization has decreased to half of its peak value. The different acceleration rates for the two runs account for most but not all of the difference between the curves.

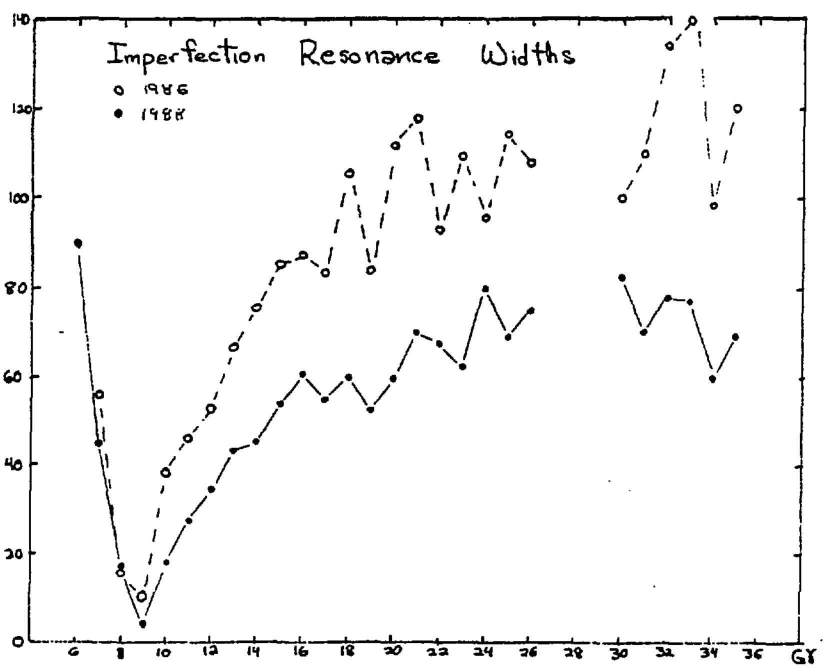

Fig. 4. Width of Imperfection correction curves.
1986 run compared to 1988 run.

In conclusion the 1988 run held no large surprises, neither good nor bad, in obtaining a polarized beam at 18.5 GeV/c. Nevertheless, many questions are not fully answered. The emphasis at the AGS in the immediate future is to expedite the tune-up procedures, and increase the final polarization and its stability. It remains an exciting but lower priority task for the future to push the polarized acceleration up to the momentum limits of the AGS.

Acknowledgments

The production of a polarized beam at the AGS requires the dedicated efforts of a large team of people at BNL and strong, continued support from the University of Michigan. The present program rests on past contributions from those institutions and also from Argonne National Laboratory and the Universities of Rice and Yale. I especially appreciate the continuing efforts and guidance of Larry Ratner.

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