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Thoughts And "Facts" From The AGS Polarized Proton Runs During The 1980's*

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Abstract. This workshop's focus is on considering ways for improving the proton beam polarization that the AGS delivers to the RHIC. This talk attempts to review the first decade of AGS polarization – the 1980's; to briefly describe some aspects of the machine situation, the depolarization avoidance strategies employed and the success achieved in AGS from the perspective of one of those involved.

THE GENERAL CORRECTING SCHEMES OF THE 80'S

First a very brief description of the 1980's polarized proton setup will be given. Reference 1 goes through this in detail. Differences with the situation in 2003 will be mentioned as we go. The intensity of the polarized beam delivered to the AGS directly from the 200 MeV Linac was at most $2x10^{10}$ protons per AGS cycle. (In 2003 we will have more than 10 times this intensity, now coming in from the Booster at about 1.5 GeV.) The initial polarization was 75%; we will have 80% this year. The initial transverse emittances of the beam, in AGS, were about 10π mmmr normalized 95%. The need for "polarization-based" measurements will be indicated occasionally in the following. Machine setup based on polarization measurements are much more time consuming and difficult than either dead reckoned setups or beam-based setups that only need beam properties such as intensity, betatron tune, and transverse emittance, which get more difficult in that order.

Intrinsic Resonances

Intrinsic resonances were handled by pulsing very fast (rise time less than the time for the protons to make one turn around the AGS) ferrite quadrupoles, located symmetrically in each of the twelve AGS superperiods at positions where the vertical betatron function is a maximum (22m), and the horizontal a minimum (10m). Only ten quads were actually used, for reasons of cost. Hybrid pulsing systems were built for the resonances occurring at 0+, 12+, 36-, 24+ and 48-, where the code being used here is e.g. "0+" means the resonance when the spin tune ($G\gamma$) is equal to the integer 0 "plus" the vertical betatron tune (which is close to 8.75 in AGS). The resonance at 24- was too weak to require a pulse. The resonance at 36+ ($G\gamma$ = 44.75) was judged too strong for jumping and strong enough to rely on spin flipping. The strengths of these

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resonances were well predicted by Courant and Ruth. The most aggressive pulsing was at 36-, with the fast (1.6μsec rise time) components requiring 12kV, and the slow part (20 μsec) requiring 2 kV. The timing of these pulses during the acceleration ramp was derived from measurements of the field in the main magnets using the AGS "Gauss Clock". Although the timing setups could be "dead reckoned", the clock was neither accurate nor stable enough to avoid using polarization measurements to both carry out the initial setup and to occasionally confirm that things were still ok later in a run. The situation has improved since the 80's. We have a new clock, a new orbit measuring system, and claim (not tested) an accuracy that would allow such a setup to be marginally possible without any polarization checks.

A second system required for the intrinsic tune jumping involved the normal AGS slow quadrupoles. These were used to shift the tunes around each jump to allow more tune headroom for the jump. The timing requirements were mild.

Imperfection Resonances

The imperfection resonances were corrected by making the machine equilibrium orbit perfect for the relevant driving harmonic. There are more than 30 resonances below 18.5 GeV. Each must be set up. The timing requirements are loose enough to be learned from the Gauss clock. Learning the two strength parameters – i.e. the amplitude and the phase of the correction – is completely polarization based. The existing system of vertical correction dipoles, eight per superperiod, was connected to stronger pulsing power supplies using a new control system. The system allowed the harmonic corrections to change with time in order to maximize the current available to the one relevant for the spin survival at that moment in the acceleration cycle. This system was pushed to its limits in order to cope with imperfections encountered below $G\gamma$ of 42. Some of the stronger of these imperfections were ultimately corrected by flipping rather than by correcting since the resulting machine was more stable and the tuning was simple. At highest energies the strength of the correction system was marginal to correct and too weak to flip. Aside from remembering the complexity of the system and the associated setup, this discussion is no longer particularly relevant. The solenoidal Partial Siberian Snake replaced this entire system in the 90's, flipping all the imperfections but also introducing its own interesting problems associated with relatively strong and uncorrectable betatron coupling which then strengthens other higher order resonances.

SPECIFIC DESCRIPTION OF THE MAJOR 1980'S RUNS

The 1980's polarized proton accelerator activity at the AGS can be described by three running periods, a pre-commissioning run in June of 1984, a commissioning run in February of 1986, and a production run in January of 1988. During the 1984 run beam was accelerated up to 16.5 GeV/c or $G\gamma=31.5$ where 40% polarization was achieved. The higher energy pulsing systems not yet available, the lower energy systems were "being commissioned".

The 1986 Polarized Run

The 1986 run produced the highest energy polarized beam, 45% at 21.7 GeV/c or $G\gamma$=41.5 of the 80's. (This run is described in reference 1.) The acceleration rate available in the AGS was the nominal 2 Tesla/sec from the Siemens motor generator set (which will not be true for the 1988 run). During the course of the '86 run the correction systems described above were pushed to their limits. Their reliability was better understood, and diagnostic systems to help "Operations" – which for this run was mostly physicists – respond to problems were being developed.

Maintaining the beam intensity and if possible the emittance through the intrinsic jumping was a major effort. The fast quads produce an inherently nonadiabatic change to the orbit betatron motion. Though some concern was expressed over the implications of this for emittance growth due to the implied changes to the machine beta functions, we did not worry about putting the beam on the axis of the quads during the jumps, in particular in the horizontal plane. As a result, each pulsing excited significant oscillations in both the vertical, and the horizontal planes. The shifting of the tunes to provide maximum headroom for the fast tune shift complicated this situation because the horizontal and vertical tunes would sometimes cross slowly – adiabatically – before and after each tune jump. As a result the beam transverse emittances were systematically swapped (slow quad setup), increased (fast quad kicks), and then swapped again (slow quad recovery) around the intrinsic jump. This was not understood at the time though the fascinating transverse size evolution as seen by the ionization profile monitor (IPM) was known. Figure 1 shows the trajectories in tune space of the vertical betatron tune.

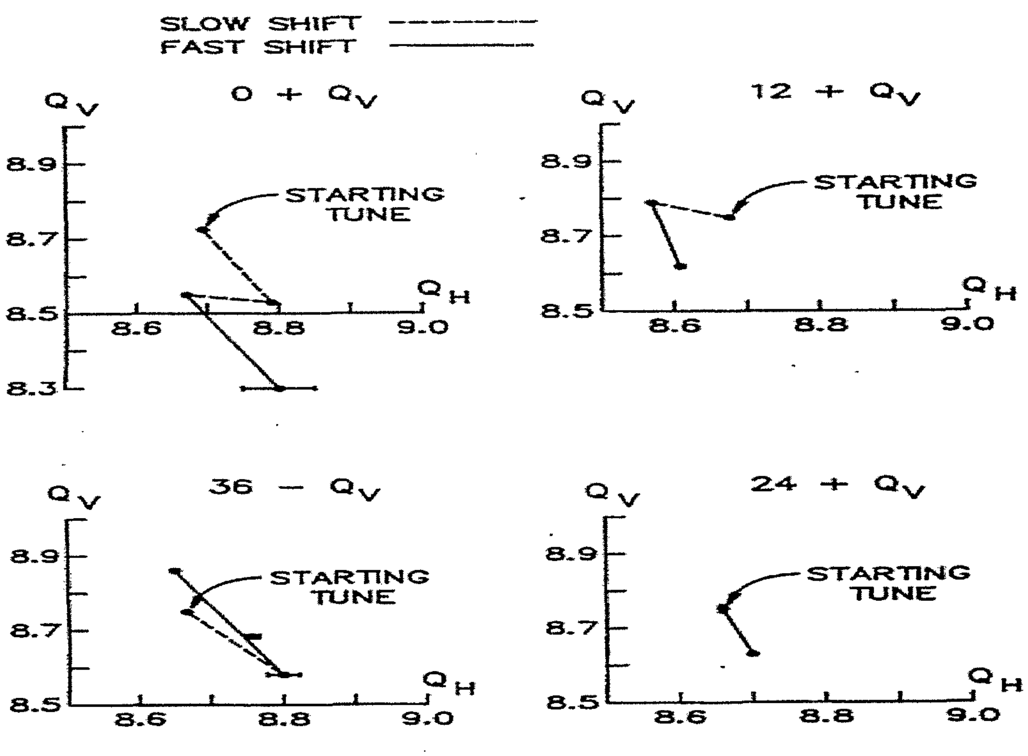

FIGURE 1. AGS Horizontal Betatron tunes as set up during the 1986 run.

Figure 2 gives one snapshot of the vertical emittance evolution. These figures are from a talk given in 1987 (ref 2). There is no discussion of the behavior of the horizontal tunes, which must also jump, though only half as far as the vertical and of course are involved in the emittance swap.

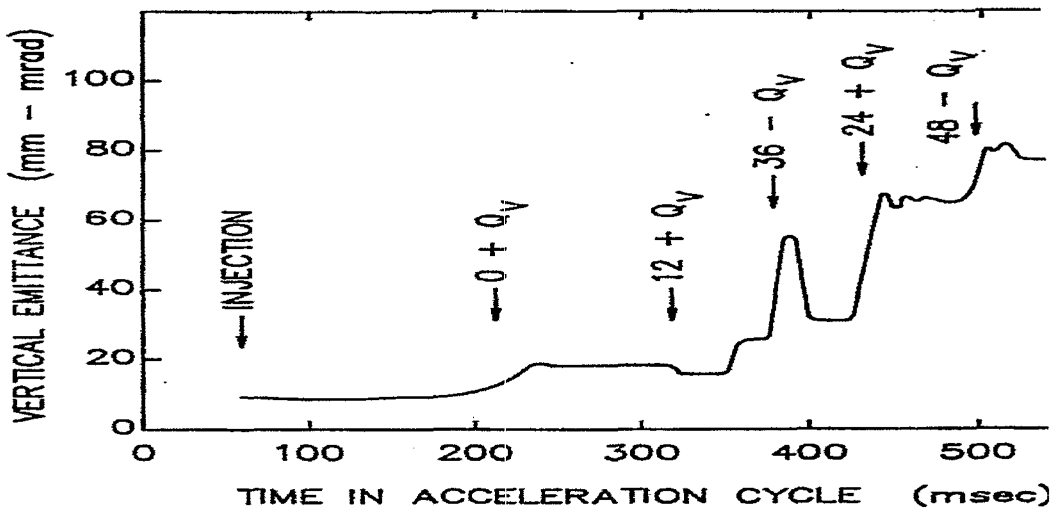

FIGURE 2. Typical vertical normalized emittance (95%) during the 1986 run.

The solution given in these figures was arrived at empirically, to first of all allow beam survival, and then to minimize emittance growth. We well understood that emittance growth was a bad thing for the intrinsics. Note that for the 0+ jump, the vertical tune crossed the half-integer line at 8.5, actually crossed it twice, once very fast going down, and then more slowly on the recovery side of the fast pulse. That this line can be crossed is consistent with earlier AGS experience, at least at injection.

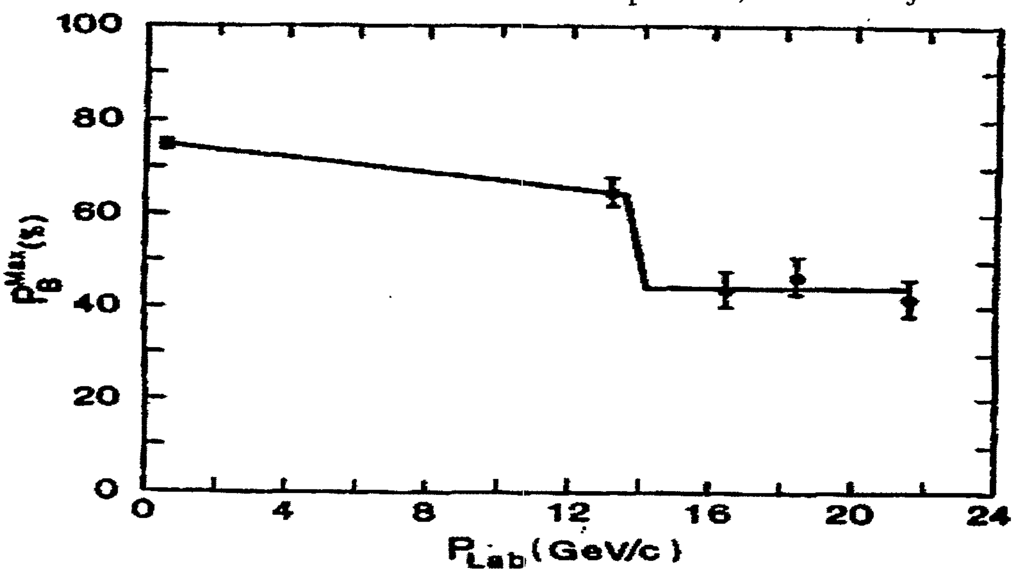

FIGURE 3. Polarization (figure 40 from ref 1) measured using extracted beam for the 1986 run.

Figure 3, again from reference 1, gives measurements of the polarization using a polarimeter in an extracted beam line for the 1986 run. The measurement at 13.3 GeV/c corresponds to extraction at Gγ=25.5, and at 16.5GeV/c to Gγ=31.5. The drop between these points is associated with the region near the strong 36- resonance. Aside from this and despite or because of the large emittance growth, there is no measurable polarization loss later in the cycle.

The 1988 Polarized Run

The 1988 run was explicitly to be a production run. We had 2.5 weeks to tune up the machine, and then 3 weeks for physics. Extraction at 18.5 GeV/c (Gγ=35.5) avoided the higher energy trouble with the imperfection corrections and the 48- intrinsic. Interpretation of the results of the run are complicated by a failure with the Siemens motor-generator set, which forced the run to occur with the lower acceleration rate associated with the backup power supply, the Westinghouse. (If you think I have slipped a decade and am describing the 2002 run, you are wrong, but your confusion is understandable. So the resonances are all stronger because the acceleration rate is cut in half. In some ways this made the machine setup easier. Tolerances and adjusting room for timing the imperfection resonance corrections and the slow quadrupole tune shifts were relaxed by this factor of two. We had learned enough about the cause for the emittance growth in '86 to fix it. Both the vertical positions (beam based quad repositioning) and the horizontal position (care for the radial position) were corrected. As a result the emittance growth essentially disappeared. Figure 4, from reference 3, compares the emittance growth in the two runs.

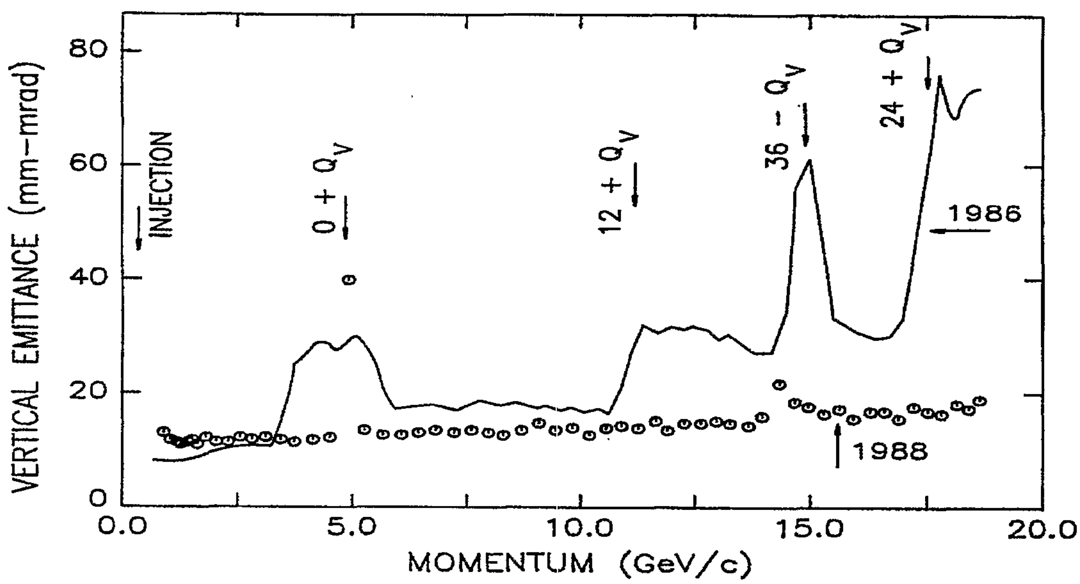

FIGURE 4. Comparison of the vertical emittance growth (normalized, 95%) between 1986 and 1988.

The slow tune shifts to gain jump headroom proved unnecessary except for 36-, and the shift there followed the book, with the vertical tune slowly pushed down to 8.55 and the jump moving it to 8.85.

The systematic tuning done for the 1986 run was repeated for the 1988 run. Despite a resurvey of the ring vertically, the required harmonic corrector strengths to eliminate polarization loss at the imperfections was about the same. Measuring polarization using the internal polarimeter with certainty was a continuing problem. Once we were high enough in momentum to use the external polarimeter, we chose to do so, despite the cost associated with setting up extraction. The measurements were better.

At the end of the tune-up period, beam with polarization of 45% was available for the physics experiment in the extraction line. Over the rest of the run we continued a program of tuning behind the experiment; varying slightly the corrections at the most sensitive resonances while watching the polarization of the extracted beam in an attempt to further increase the delivered polarization. The logbooks, which still exist, display the results of this effort. Scan after scan show the polarization being smoothly optimized above 50%. However, this did not produce any long-term improvement in the beam polarization. At the end of the running period we were still no better than at the beginning. Whether we were missing a critical knob, or were just forever slipping due to tiny changes in the many corrected resonances is not known.

A measurement at the end of the run using the internal polarimeter and collecting data simultaneously over many contiguous gates from just after 0+ till extraction showed only a smoothly falling asymmetry, with no structure to suggest a single point of polarization loss.

ACKNOWLEDGMENTS

These polarization- maintaining systems were complicated to build and to maintain. I would acknowledge the teams of engineers and technicians at BNL, at the University of Michigan, and elsewhere who made them happen.

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