13th International Conf. on High Energy Accelerators, Novosibirsk, USSR, 8/7-11/86. CONF-860870--4

BNL 38494

POLARIZED PROTON ACCELERATION AT THE BROOKHAVEN AGS*

BNL--38494

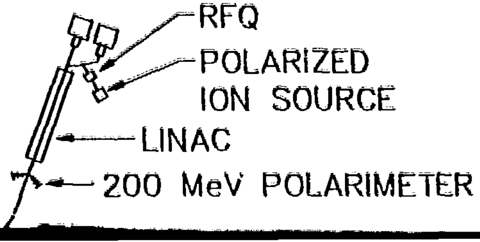
DE86 015080

L.A. Ahrens
Brookhaven National Laboratory
Associated Universities, Inc.
Upton, New York 11973 USA

Abstract

At the conclusion of polarized proton commissioning in February 1986, protons with an average polarization of 45%, momentum of 21.7 GeV/c, and intensity of 2×10^{10} protons per pulse, were extracted to an external polarimeter at the Brookhaven AGS. In order to maintain this polarization, five intrinsic and nearly forty imperfection depolarizing resonances had to be corrected. An apparent interaction between imperfection and intrinsic resonances occurring at very nearly the same energy was observed and the correction of imperfection resonances using "beat" magnetic harmonics discovered in the previous AGS commissioning run was further confirmed.

This paper reports on phenomena encountered in accelerating polarized protons beyond the 16.5 GeV/c at 40% polarization achieved in the first AGS commissioning run of June 1984,[1] up to 21.7 GeV/c at 45% polarization in February of 1986. The accelerator configuration remained basically unchanged (Fig. 1), as did the schemes for maintaining polarization; both subjects are well covered in Ref. 1 and will not be repeated here. Some general motivation will be given for the phenomena reported.



are well known[2] and indeed the project to accelerate polarized protons at the Brookhaven AGS[3,4] was developed against a reasonable model for these obstacles, namely the depolarizing resonances. These resonances occur whenever the spin precession frequency of the proton is nearly equal to a frequency present in the transverse magnetic fields the particle experiences as it circles the ring. The focusing fields seen by off-axis particles and essential to transverse stability result in resonances referred to as "intrinsic," and the fields due to the fact that the machine is not perfect magnetically result in "imperfection" resonances. The resonance conditions are given by $G\gamma = KP \pm Q_v$ and by $G\gamma = K$ for the intrinsic and imperfection resonances respectively; where $G = (g-2)/2 \simeq 1.79$, g = the anomalous magnetic moment of the proton, K is any integer, P is the ring periodicity (12 at the AGS), and Q_v is the vertical betatron tune ($\simeq 8.75$ at the AGS). In order to accelerate from injection ($\gamma = 1.2$) to an extraction momentum of 22 GeV/c ($\gamma = 23.5$), six intrinsic and nearly 40 imperfection resonances were crossed. While the depolarization strength of the intrinsic resonances are calculable (given the lattice and the beam emittance), the strengths of the imperfection resonances depend both on the lattice and on the errors in the positioning of the 240 main ring magnets, and are neither known a priori nor will they remain constant over long periods of time.

The intrinsic resonances are "corrected" by shifting the resonance condition rapidly, moving the vertical tune of the AGS using 10 ferrite quadrupoles having rise times of a few microseconds and fall times of a few milleseconds. A large tune shift keeps the protons far from resonance except during the jump. One price paid for this is that the beam

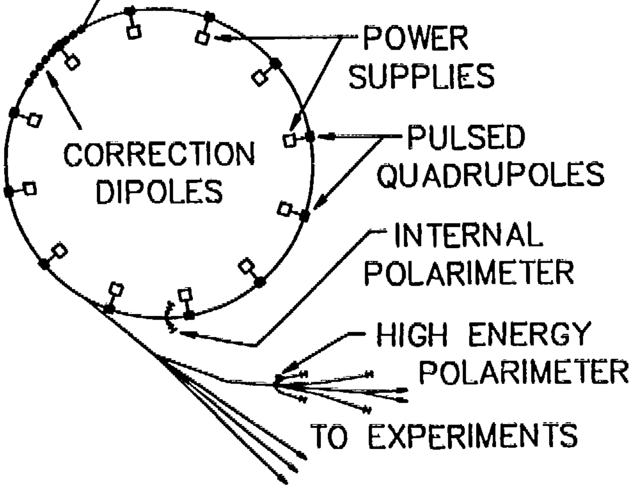


Fig. 1 - AGS facility, polarized proton configuration.

The fundamental obstacles to maintaining polarization while accelerating particles in a synchrotron

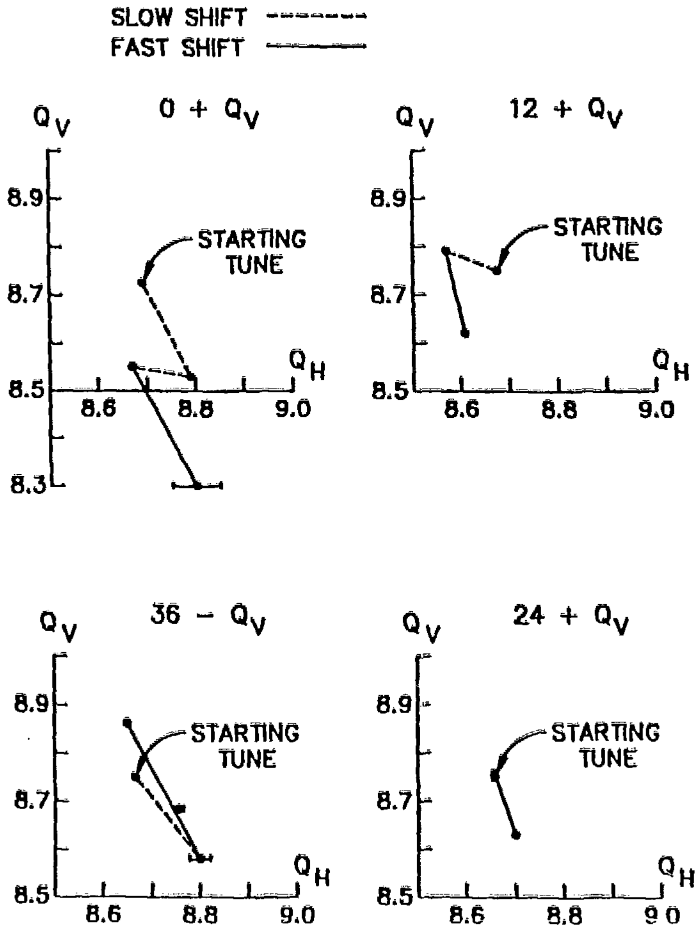
must also cross many of the normal transverse resonance lines. This will cause some increase in transverse emittance which, if especially severe, can cause beam loss, but more relevantly results in a strengthening of the intrinsic resonances occurring later in the acceleration cycle due to the emittance growth. The fast quadrupoles also enlarge the stop band at $Q_v = 8.5$ and the nonadiabatic nature of the jump coupled with the fact that the equilibrium orbit is not perfectly centered in the quads provides another source for emittance growth.

To allow some control over the trajectory to be followed by the beam in tune space in the vicinity of an intrinsic resonance, strings of "slow" quadrupoles (rise times of order 10 milliseconds) can be powered according to a variable function. These were originally set to drive the tunes in opposition to the motion caused by the fast quads, allowing a doubling of the maximum shift for a given maximum excursion in tune space. The final programs were the result of tuning the slow quad currents to minimize the emittance growth (using an ionization profile monitor[5] to measure beam size). The resulting tune space motion deviated substantially from the expected pattern and is shown in Fig. 2. The emittance growth was substantial (Fig. 3); nevertheless, this was the best solution of those tested. The emittance plotted is

---

*Work performed under the auspices of the U.S. Department of Energy.

derived from beam size measurements, without taking into consideration changes in the Twiss parameters due to the slow quads. The horizontal plane showed similar growth and in particular showed growth at points where the vertical emittance apparently shrinks. Except at $G\gamma = 36-\nu$, which is mentioned below, there was no significant polarization loss at the intrinsic resonances after correction; the strengths were in reasonable agreement with the calculation.



In the earlier AGS commissioning,[1,6] strong effects were observed near $G\gamma = (12*3 - Q_v)$, namely using $K = 9$ at $G\gamma = 27$ and $K = 8$ at $G\gamma = 28$. The present tuning measured depolarizing responses near $(12 + Q_v)$ namely $K = 9$ at $G\gamma = 21$, and more interestingly, for K far away from the tune, beating against the very strong AGS 60th harmonic periodicity at $G\gamma = (37, 38, 40,$ and $41)$ using $K = (23, 22, 20,$ and $19)$ respectively. For this range of harmonics, the effectiveness of the beat correction was comparable to that of the natural harmonic. It should be noted that since the tune enters into the effectiveness of the beating (for K near Q_v), the imperfection resonance corrections are tune dependent.

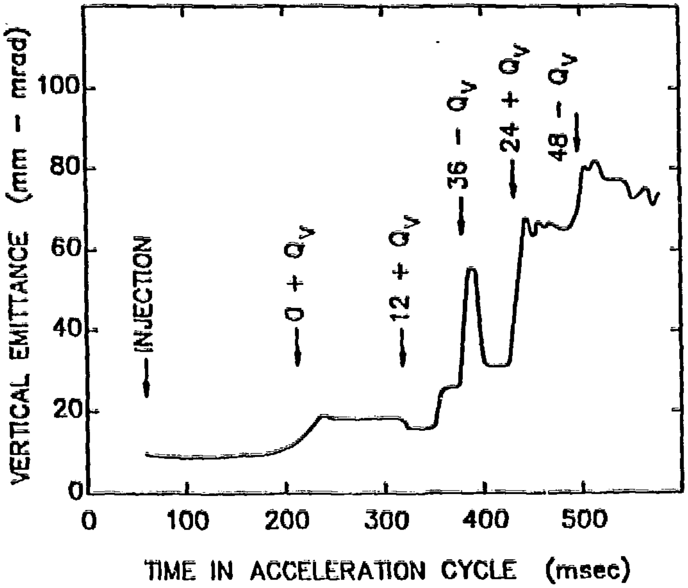


Fig. 3 - Vertical emittance growth due to intrinsic resonance corrections.

The other phenomenon to be reported involves an apparent interaction between the intrinsic resonance at $G\gamma = 36 - Q_v$ and the imperfection resonance at $G\gamma = 27$. The centers of these two resonances occur at

Fig. 2 - Tune shifts at intrinsic resonances.

Essentially every imperfection resonance was strong enough to require a correction using the 96 dipole array. A flavor of this work is given by Fig. 4, where the magnitude of the current required for each resonance is plotted. The maximum current of which the system is capable corresponds to approximately 110 counts on the figure, so the high energy resonances were just barely correctable. As described in Ref. 6, a given imperfection resonance $G\gamma = N$, which is conventionally corrected using a magnetic harmonic proportional to $\sin(N\theta + \phi)$, (θ the tuning angle around the ring, ϕ the phase of the imperfection), is also augmented by and correctable using magnetic harmonics having N replaced by another integer K, satisfying $N = (P*M \pm K)$ with P the machine periodicity and M any integer. The effectiveness of the resulting "beat" interaction depends both on how close K is to the vertical tune Q_v, and on the details of the lattice, since it is the equilibrium orbit distortion at the Kth harmonic (proportional to $[Q_v^2 - K^2]^{-1}$) that beats against the machine periodicity to produce the effect.

= 27. The centers of these two resonances occur at very nearly the same energy and time. The corrections used for either overlap the other (slow quad tune shifting pulse and the dipole correcting pulse). Therefore one expects to iterate tuning somewhat to maximize surviving polarization. Such tuning could not eliminate a 20% loss of polarization in this region of the acceleration cycle. It was found, however, that by reducing the vertical tune, essentially to 8.5, and thereby increasing the spacing between these two resonances slightly, the loss of polarization was significantly reduced, perhaps by 25%.

Finally a few comments are made updating the techniques used to measure the polarization and tuning strategies. The internal polarimeter was used to simultaneously measure polarization over many intervals throughout the acceleration cycle. With this technique it was possible to rapidly confirm that corrections made throughout the cycle, and in particular early in the cycle, had not drifted greatly. The measurement was made without flat tops on the ring magnet power supply cycle.

For the accurate polarization measurements necessary for tuning, the external polarimeter proved to be more reliable and in the long run quicker than the internal polarimeter once the cycle had been corrected up to momenta where extraction was available. This was true despite the care necessary to avoid extracting on a resonance, and the retuning of the extraction beam line and external polarimeter as the momentum was stepped along from resonance to resonance.

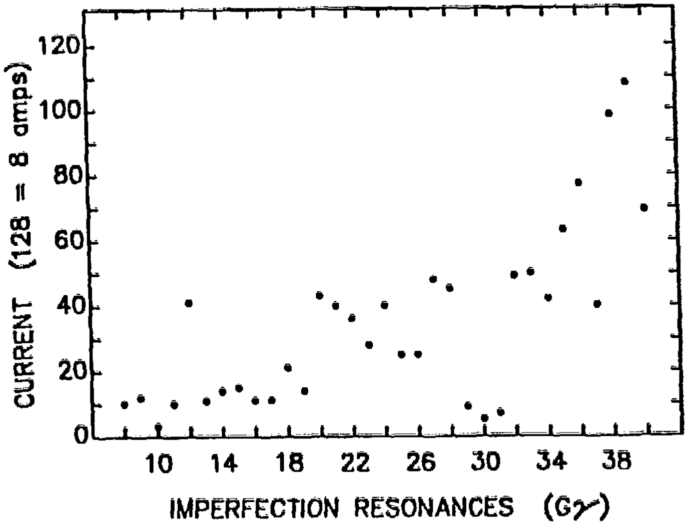


Fig. 4 - Maximum dipole current required to correct imperfection resonances.

The work described above reflects the dedicated efforts of many colleagues over several years at Brookhaven, Argonne, and the Universities of Michigan Rice and Yale.

References

1. L.G. Ratner, et al. IEEE Trans. on Nucl. Sci. NS-32, 1656 (1985).
2. E.D. Courant and R.D. Ruth. Brookhaven National Laboratory Report 51270, ISA 80-5 (unpub.)
3. K.M. Terwilliger, et al. IEEE Trans. on Nucl.

DISCLAIMER

3. K.M. Terwilliger, et al. IEEE Trans. on Nucl. Sci. NS-28, 2031 (1981).
4. L.G. Ratner, et al. IEEE Trans. on Nucl. Sci. NS-30, 2690 (1983).
5. H. Weisberg, et al. IEEE Trans. on Nucl. Sci. NS-30, 2179 (1983).
6. K.M. Terwilliger, et al. IEEE Trans. on Nucl. Sci. NS-32, 2635 (1985).