A SAMPLE OF DEPOLARIZATION RESONANCE CORRECTION FROM THE
INITIAL COMMISSIONING OF THE POLARIZED BEAM AT THE AGS*

CONF-8409162-7

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BNL--35448

DE85 004158

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Abstract. A description of the response to correction for several resonances is presented. Different behavior is seen between resonances of the same class, i.e. either intrinsic or imperfection resonances show different behavior within their own genre. A brief description of the facility and present status is also given.

1. Introduction

For orientation purposes, we give a brief description of the polarized beam facility. The whole facility can be functionally divided into two sections: (1) 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 and 200 MeV polarimeter and the 200 MeV transfer line to the AGS; (2) the hardware necessary in the AGS to accelerate and maintain the polarization of the injected protons. Fig. 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 the high energy polarimeter which make up the AGS modifications necessary to produce a high energy accelerated proton beam.

Fig. 1. AGS Facility.

The ion source produces polarized H^- with a peak output to date of 25 nA in a 400 nsec FWHM pulse. It is then injected at 20 keV into an RFQ which accelerates the beam to 750 keV with about an 80% transmission efficiency. After acceleration to 200 MeV in the Linac, the polarization is measured using a PC^{12} scattering. Polarization to date has been about 70-75%. Beam is then injected into the AGS and accelerated. A peak intensity of 10^{10} polarized protons per pulse has been accelerated and a physics run was made at 16.5 GeV/c with a beam polarization of about 40%. The major problem in acceleration is to preserve the beam polarization.

To understand what the problems are in preserving the polarization of an accelerated beam, let me remind you of what depolarizes the beam.

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

and $\begin{matrix} GY = kP \pm \nu_y & \text{intrinsic} \\ GY = k & \text{imperfection} \end{matrix}$

where $\begin{matrix} G & = & g/2 - 1 & \text{anomalous magnetic moment} \\ k & = & \text{integer} \\ P & = & \text{periodicity of the accelerator } (\approx 12 \text{ in AGS}) \\ \nu_y & = & \text{vertical machine tune (number of betatron oscillations per revolution)} \\ \gamma & = & \text{relativistic energy factor} \end{matrix}$

Discussion and derivation have appeared many times before so we won't 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 fast vertical tune shifts for crossing the intrinsic resonances are generated by ferrite quadrupoles with a 2 μ sec rise time and a 3 msec decay time.

For the imperfection resonances we generate a harmonic correction at the appropriate energy using 96 dipole magnets. Searches are then made around the resonances and the relative polarization of the beam is measured by an internal polarimeter as a function of the correction amplitude or timing. The resonance correction curves Fig. 4 to 8 and 10 that will be shown are in arbitrary units for polarization. The absolute value of the polarization was measured at 16.5 GeV/c during the physics run with a double-arm spectrometer looking at PP elastic scattering and gave the 40% value quoted earlier and this is the polarization value seen in Fig. 9.

Fig. 2 shows the calculated energy and strength of both the imperfection and intrinsic resonances that we expected to correct in the AGS. As can be seen, we expected to correct only about a half dozen imperfection and four intrinsic resonances below 16.5 GeV/c. However, the real world was a little different and we had to correct some thirty imperfection resonances as well as the four intrinsic ones.

Fig. 2. Predicted AGS resonances.

Fig. 3. Typical corrections in tune-energy space.

Fig. 3 shows some typical corrections in tune-energy space for an intrinsic resonance. The resonance line is crossed in less than one turn (~ 2 μ sec) 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).

2. Examples of Resonance Jumping and Correction

The description of what occurs when we try to correct for resonances can best be seen in the following examples of passing through both imperfection and 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 abscissa in Fig. 2 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.

Fig. 4. Intrinsic $G\gamma=0+\nu_y$ Resonance Correction.

Fig. 5. Intrinsic $G\gamma=36-\nu_y$ Resonance Correction.

The $G\gamma = 36 - \nu_y$ (Fig. 3) 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 anomaly in the correction pulse. The odd behavior occurs before the main correction pulse and is, therefore, earlier in time.

This means that the first interaction of the correction pulse and the resonance takes place when the trailing edge of the pulse reaches the resonance. Some oscillatory behavior near the end of the decay pulse could account for these differences.

The case for the imperfection resonances is different and they indeed show varied properties. The correction technique for the imperfection resonance curve shown in Fig. 6 is a little more complex. Since the vertical orbit distortion of harmonic number k is driven by horizontal imperfection fields of harmonic k , we correct these $GY = k$ resonances by cancelling the k th component of the horizontal imperfection field. We correct by pulsing the 96 dipoles with the appropriate amplitude and phase to minimize depolarization. We first had done the cos correction with an arbitrary sine correction and then we set the cos at its peak of -5 and did the sin correction. Since these are orthogonal, our correction vector should have the correct amplitude and phase. Notice that the resonance is 6 units FWHM. For contrast, Fig. 7 shows a resonance correction with almost 120 units FWHM for $GY = 19$.

Fig. 6. Sine and cosine harmonic corrections for $GY = 9$ imperfection resonance. Narrow and strong.

Fig. 7. $GY = 19$ correction. Wide and weaker.

Fig. 8. $GY = 30$. Zero correction needed.

Another type of resonance correction is seen in Fig. 8 for $GY = 30$. On one side we see a flat level value of polarization for 60 units of correction, but on the other polarity we see a relatively weak but definite depolarization. For this resonance zero correction was appropriate.

The variations we see in these imperfection resonances are functions of their strength and were expected. However, though we anticipated that there might be some new behavior similar to what had been seen at Saturne, we were surprised by the strength of the response that we see in Fig. 9. $GY = 27$ is an imperfection resonance, but attempts to correct with the 27th harmonic failed. Indeed, the driving force here is due to the "intrinsic" betatron oscillations in the accelerator. To see this we note that the basic tune of the machine is 8.75 which is very close to 9 and further we note that the 27th imperfection is then very close to the very strong intrinsic $GY = 36 - \nu_y$. As seen in Fig. 9 the correction required was the 9th harmonic and this fully restored the polarization. Other resonances where the difference were close to 8.75 such as differences of 7, 8, and 10 as well as 9 were influential in correcting depolarization, although they were not always the major component (e.g. $GY = 26 = 36 - 10$, $GY = 29 = 36 - 7$ Fig. 10).

Fig. 9. $GY = 27$ corrected with 9th harmonic.

Fig. 10. $GY = 29$ corrected with 7th harmonic.

Acknowledgments

The work described here was made possible by the dedicated effort of very many talented people at Brookhaven, as well as the important contributions by Argonne National Laboratory and the Universities of Michigan, Rice, and Yale.