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RECENT EXPERIENCE IN ACCELERATING POLARIZED BEAM AT THE AGS*

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INTRODUCTION

The most recent operation of the AGS for polarized protons occurred in December, 1987 and January, 1988. The primary purpose during this period was to tune up the accelerator as soon as possible and to provide a usable polarized beam for high energy physics. We succeeded in providing 1-2 x 10^{10} polarized protons per pulse at 18.5 GeV/c with an average polarization of 43 ± 3% and a peak of 52%. The conditions for this run differed in some respects from the previous run done in 1986.[1] Due to problems with the main ring power supply, we were forced to use a back-up MG set which was only capable of 60% of the normal field rate of rise. This, of course, enhanced the effect of the depolarizing resonances. A second difference was the fact that a complete horizontal and vertical realignment of the ring magnets was done during the 1987 summer shutdown. In addition, the fast pulsed quadrupole positions were readjusted with respect to the equilibrium orbit. It had been suspected that misalignment of these quads was responsible for large transverse emittance growth in both planes. We will look at the effects of these differences, but the bottom line is that the "standard correction techniques" worked as expected.

SYSTEMS AND "STANDARD CORRECTION TECHNIQUES"

Compared to a standard accelerator, there are several additional systems needed for polarized proton acceleration:

(1) Fast pulsed quadrupoles to tune jump the "intrinsic" depolarizing resonances. The resonances are characterized by $G\gamma = nP \pm \nu_y$ where G is the proton anomolous magnetic moment, P the periodicity of the accelerator (12 for the AGS), n an integer, and ν_y the vertical tune (number of vertical betatron oscillations per revolution). These are intrinsic resonances because they arise from the accelerator focusing field which are necessary to keep the beam in the accelerator during the acceleration process. The fast quads change ν_y before a resonance is reached and keep ν_y displaced from the resonance until this point in the acceleration cycle is passed.

(2) Pulsed dipole magnets to compensate for vertical closed orbit distortions which cause "imperfection" resonance depolarization. These are imperfection resonances because the closed orbit distortions are due to imperfections in construction or alignment of the ring magnets and are not necessarily inherent in an accelerator. These are characterized by $G\gamma = n$, where n is an integer.

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We also again used the technique of slowly adjusting the machine tune before the fast jump so that a larger jump can be made without driving the tune into an integer or one-half integer stopband. With the AGS nominal tune of 8.75 and the need to make a fast jump of +0.3 in tune, we would normally go to 9.05 and therefore lose beam at the 9.0 integer stopband. The fix is to slowly lower the tune to 8.55 before the jump, and then end up at 8.85. In the earlier runs, this was used at several intrinsic resonances since it appeared to reduce the emittance growth which apparently was produced by the fast non-adiabatic quadrupole pulse. This was not necessary during this last run and this tune shift was used only as described above on one resonance.

The realignment of the AGS was partially motivated by our desire to reduce closed orbit errors for polarized protons and because we thought that the large emittance growth observed in the 1986 run might be due to misalignment between the equilibrium orbit and the fast pulsed quads. The misalignment of the dipoles could produce a non-adiabatic kick to the beam leading to the observed growth. After the main ring realignment, we pulsed the fast quads and the effect on the equilibrium orbit was measured. From this we could deduce the quad offset and physically reposition the quads. During the run we maintained the radial beam position at the quad centers. Figure 2 compares the emittance growth between these two runs. The greatly reduced emittance reduced the depolarization at the intrinsic resonances and improved the beam efficiency.

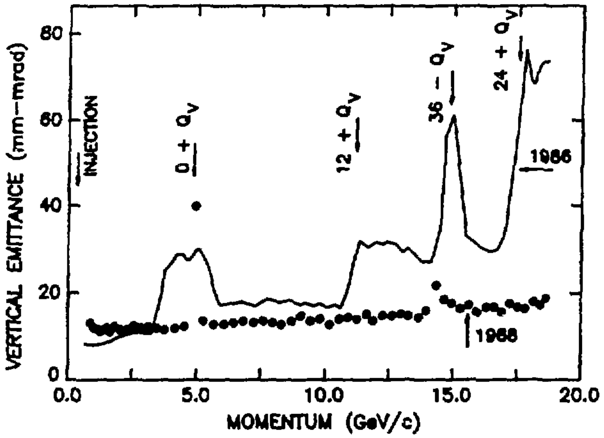

Figure 2. Emittance comparison

EXPERIENCE WITH THE IMPERFECTION RESONANCE CORRECTIONS

In contrast to the intrinsic resonances, here the timing is preset and the amplitude of the closed orbit vertical correction is varied. The fields of the 96 correction dipoles are energized with the appropriate harmonic correction at the energy where the resonance occurs $\left(E = \frac{nM_p}{G}\right)$. Since the vertical orbit distortions of harmonic number n is driven by imperfection fields of harmonic n, we must correct by cancelling the n^{th} harmonic of the horizontal imperfection field. Since there are two parameters, namely, amplitude and phase, we apply orthogonal corrections of sin $n\theta$ and cos $n\theta$ in an iterative process. This then assures us that our correction vector has the correct amplitude and phase to minimize the alignment error. It was hoped that the survey and realignment would reduce the necessary corrections even though we know that survey errors of the order of mils could cause significant problems. The results were a mixed bag and we infer that survey techniques must be significantly improved to be able to address this problem. Figure 3 shows the ratio of the correction amplitudes for the 1988/1986 run and shows that less correction was needed on fifteen and more on twelve resonances--a sort of random change. One significant occurrence was the twelve-fold enhancement of the 29th harmonic. The correction was large enough so that we decided to correct $G\gamma = 29$ with $n = 7$ harmonic, the so-called "beat harmonic" technique described in References 1 and 2 and one of our "standard techniques". This was also used on $G\gamma = 27, 28$. Even though the amount of correction, i.e., whether we needed more or less appears to be random, there is a strong correlation between the two runs as far as the change in amplitude as a function of energy (Figure 4).

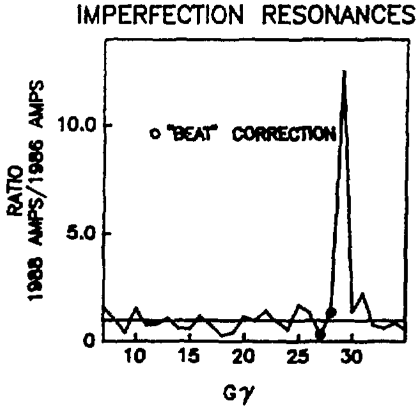

Figure 3.

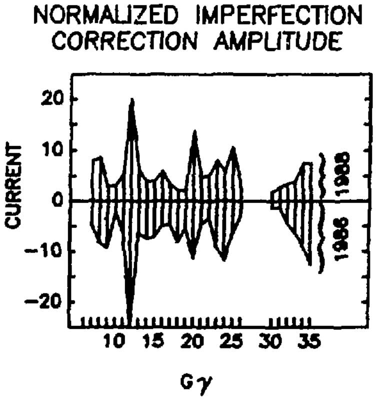

Figure 4.

On the other hand, the phase correction shows no correlation (Figure 5). It would appear that the phase and the amplitude required is changed by the realignment in a random manner and without essentially improving the closed orbit distortions. However, the shape of the amplitude versus energy curve seems to be unaffected by the realignment and shows a strong correlation between runs.

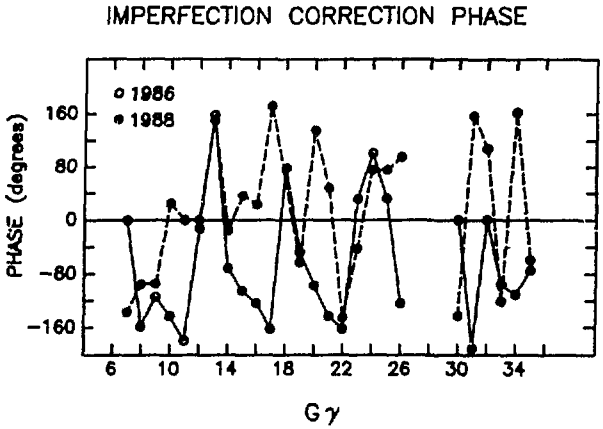

Figure 5.

SUMMARY

The 1988 run led to no surprises and to the continued successful use of our standard techniques. We saw no great benefits from realigning the ring magnets and guess that this might require precisions of the order of 0.001" to show improvements. We had sufficient corrections to accommodate the slower rate of rise, but we were getting close to the limit for $G\gamma = 24 - \nu$. We did see an improvement in the emittance growth on the fast quad pulse and conclude that it is desirable to have these quads as close to the beam axes as possible. The beam polarization as determined by the internal polarimeter is shown in Figure 6 and in contrast to the 1986 run we see no strong evidence for a large loss at 13 GeV/c. We do see a change in slope after a few days shutdown which is unexplainable. We hope to be able to re-establish that level as we eventually bring the polarized beam energy up to the design goal of 26 GeV/C.

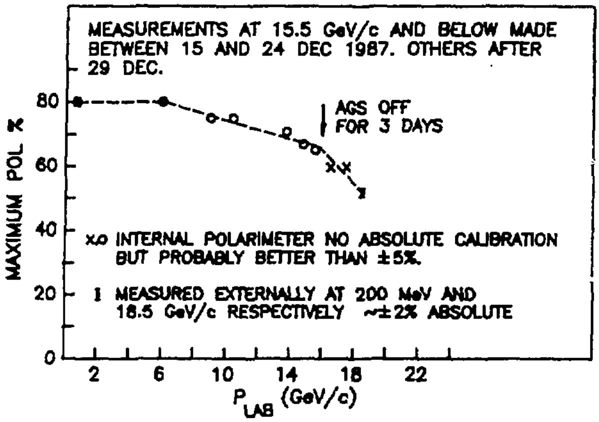

Figure 6. Maximum polarization as a function of energy.

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2. K.M. Terwilliger, et al., IEEE Trans. on Nucl Sci., NS-32, 2635 (1985).