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EFFECTS OF DEPOLARIZING RESONANCES ON A CIRCULATING BEAM OF POLARIZED PROTONS DURING ACCELERATION OR STORAGE IN A SYNCHROTRON*

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Abstract

We have conducted a series of experiments with the polarized proton beam of the Zero Gradient Synchrotron (ZGS) at Argonne National Laboratory in order to: 1) Study the feasibility of adiabatically crossing intrinsic depolarizing resonances as an alternative to the fast tune-shift crossing presently used, 2) determine the amount of depolarization due to imperfection resonances which may be more important in alternating-gradient machines than in the ZGS, 3) determine whether polarized protons can be stored for times long enough to allow polarized colliding beam experiments. The results of these experiments will be presented.

Adiabatic Crossing of an Intrinsic Resonance

The purpose of this test was to determine whether the beam polarization would simply change sign without changing its magnitude when a very strong depolarizing resonance was crossed slowly enough. This was predicted by some theoretical models.[1-3] Such a spin flip could provide a relatively simple technique[2] for crossing the strong depolarizing resonances in strong focussing accelerators. This would be much easier than the quadrupole produced tune shift technique used in the weak focussing ZGS, where these resonances are not so strong.

Since all models use simplifying assumptions, which are questionable in real machines, experimental tests were deemed necessary. In particular, the energy of each particle fluctuates around the average value due to syncnroton oscillations and is not constant as assumed in the models.(Fig. 1)

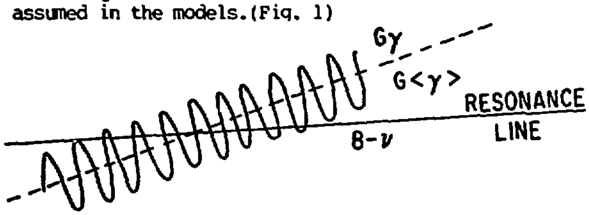
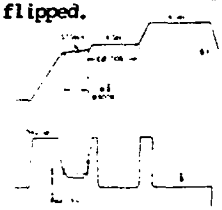


Fig. 1. Schematic representation of synchrotron oscillations

The intrinsic resonances occur at $G\gamma = k \pm \nu_y$, where k is a harmonic number associated with the machine geometry and ν_y is the vertical tune. Depolarization occurs for each k when ν passes through the value satisfying this equation. Thus as γ is increased during the acceleration cycle several such depolarizing resonances will occur.

The experimental technique was to study the $8 - \nu_y$ resonance by varying the crossing speed which is given by $\dot{\gamma}_{eff} = \dot{\gamma} + \dot{\nu}/G$. This was done by changing the acceleration ratio $\dot{B}$ and hence $\dot{\gamma}$ or by pulsing the tune shift quadrupoles such that $\dot{\nu}/G \approx -\dot{\gamma}$. The field cycle used for the experiments with reduced $\dot{B}$ is shown in Fig. 2. The beam was extracted at 4 GeV/c with an energy loss target and the polarization measured. The $8 - \nu_y$ resonance was crossed in the reduced $\dot{B}$ region just below the 4 GeV/c flattop. The height of the low $\dot{B}$ ramp was about 100 G independent of $\dot{B}$, which was large enough to accommodate the width of the resonance including uncertainties in energy and ν values. The loss in polarization was measured as $\dot{B}$ was reduced thus increasing the dwell time on the resonance. The results are summarized in Fig. 3. Notice that the final polarization (P) has a broad minimum with $P \approx -20\%$ indicating that the spin only partially flipped.



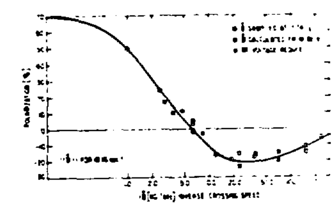


Fig. 2 Low B field cycle Fig. 3 Loss of polarization

For fast crossing, the 70% polarization is maintained and for very slow crossing the final polarization seems to approach zero. The shape of the curve might be due to the beam's momentum spread. Calculations, made prior to the experiment and including synchrotron oscillations, displayed the qualitative features of the data as shown in Fig. 4.

In the measurements using the pulsed quadrupoles we triggered the pulse early so that the resonance was crossed on the trailing edge of the $\nu(+)$ waveform rather than during the fast rise. This is shown in Fig. 5. Results for 3 different trailing edge lengths are shown in Fig. 6. The normal $\dot{B} \approx 19$ kG/s was used. The maximum reversed polarization was about - 20% as in the low $\dot{B}$ case. It appears that energy spread and possibly other influences prevent complete spin flip in the ZGS even when the strong $8 - \nu_y$ resonance is crossed very slowly. Thus it is unlikely that 100% spin flip can be achieved in any machine. Probably strong focussing accelerators will have to use tune-jump quadrupoles to maintain polarization.

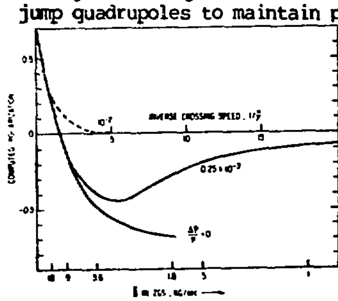


Fig. 4 Calculated curves

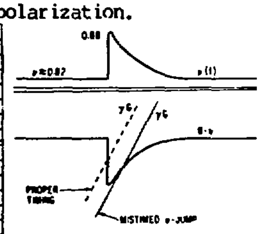


Fig. 5 Quadrupoles timing wave form

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Depolarization Produced by Imperfection Resonances

The imperfection resonances characterized by γG = integer are a somewhat controversial subject and had never been detected previous to this experiment. Some theoretical models[4] indicated that they did not exist at all, whereas others suggested that they may be very serious in strong focussing synchrotrons. The imperfections in synchrotrons cause vertical orbit distortions which might cause depolarization when $G\gamma$ = integer is passed during the acceleration cycle.

We studied these by again reducing the $\dot{B}$ of the ZGS in the neighborhood of the resonance which increased the dwell time. We then produced vertical orbit bumps by pulsing pole face windings (PFW) in Octant III of the ZGS. The ZGS magnetic field cycle is shown in Fig. 7. A reduced $\dot{B}$ window was centered at the position of the $\gamma G = 6$ or $\gamma G = 7$ resonance. Most measurements were done at $\gamma G = 6$ since it is most isolated from neighboring intrinsic resonances. The

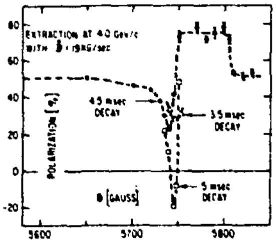

Fig. 6 Polarization

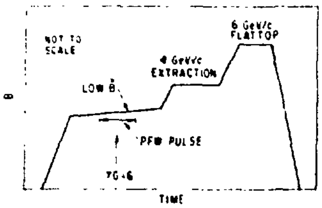

Fig. 7. ZGS field cycle for imperfection resonances

orbit distortion produced is shown in Fig. 8 and the sensitivity of orbit distortion to PFW current in Fig. 9. The PFW excitation current was a square wave pulse whose length could be varied from 30 ms to 1 s. The polarization was measured for different crossing speeds, pulse lengths, pulse positions, and pulse magnitudes.

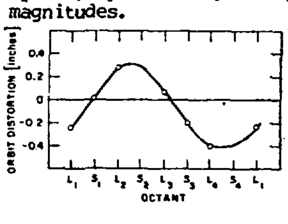

Fig. 8. PFW orbit distortion

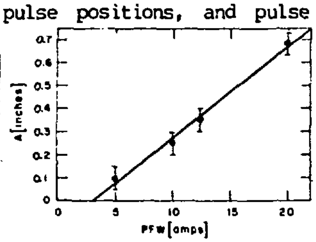

Fig. 9. Orbit distortion as a function of PFW current

The polarization as a function of PFW current is shown in Figs. 10, 11, 12 for $\gamma G = 6$, and in Fig. 13 for $\gamma G = 7$. The $\dot{B}$ window with $\dot{B}$ = 200 g/s has a length ΔB = 100 G and thus a length $\Delta T \approx 0.5$ s; similarly when $\dot{B}$ = 100 g/s, ΔB = 100 g, and when $\dot{B}$ = 50 g/s, ΔB = 40 g. A PFW current of 2 A is required to make the polarization equal to the injected beam polarization. This indicates that there is a 6th harmonic ZGS orbit distortion which is exactly compensated by 2 A. For large currents the polarization decreases and eventually changes sign. The degree of spin flip depends on the magnitude and length of the magnetic pulse and on the value of $\dot{B}$. Comparison between Fig. 10 and 13 suggests that the $\gamma G = 7$ resonance is about 10 times stronger then the $\gamma G = 6$ for the same PFW bump. This is probably because our pulsed orbit distortion has a strong first harmonic while the focussing fields have an 8-fold periodicity. The combination of $\sin 8\theta$ and $\cos\theta$ terms leads to strong 7th and 9th harmonics. Without a PFW pulse, the depolarization due to $\gamma G = 7$ is relatively weak which suggests that there is normally little 7th harmonic perturbation in the ZGS. The measured depolarizations agree, within about a factor of 2, with simple theoretical predictions.[5]

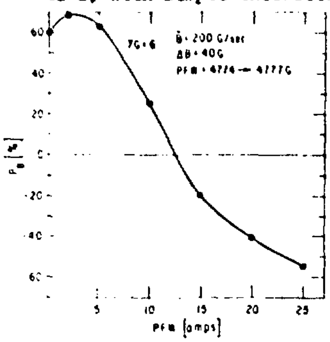

Fig. 10. Polarization at $\dot{B}$ = 200 g/s, $G\gamma = 6$

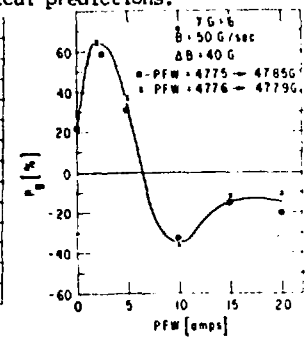

Fig. 11. Polarization at $\dot{B}$ = 50 g/s, $\gamma G = 6$

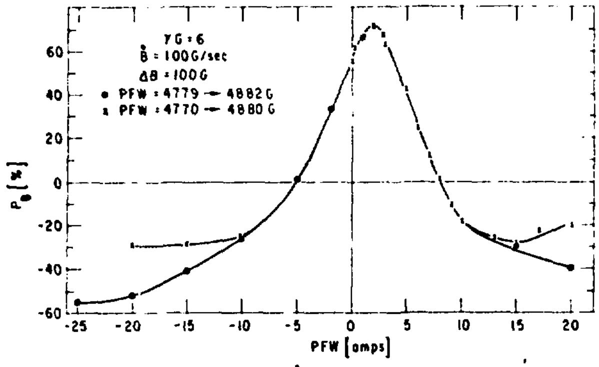

Fig. 12. Polarization at $\dot{B}$ = 100 g/s, $G\gamma = 6$

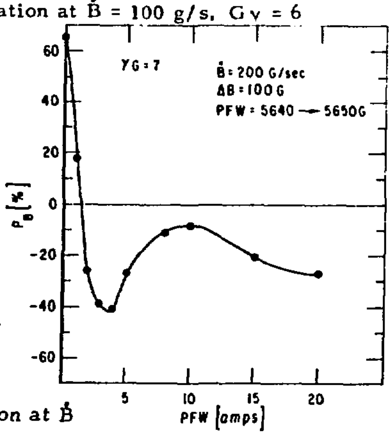

Fig. 13. Polarization at $\dot{B}$ 200 g/s, $\gamma G = 7$

Additional measurements of higher harmonics have been made at the normal $\dot{B}$ (18 kG/s); we see small effects which might give a total depolarizations of up to 5% to 10% withan uncertainty of ±5%. Since the effect is spread over 11 resonances, the systematic uncertainties of measuring 1% effects make it difficult to be absolutely certain of this effect. We intend to pursue this further by evaluating the effect by passing through these resonances with a factor of 10 reduction in $\dot{B}$. The 12 GeV/c polarization is lower than would be expected from the depolarization of the intrinsic resonances only.

We thus see that even in the weak focussing ZGS, imperfection resonances exist and may have some deleterious effect on polarization. The simple theory predicts tolerable orbit distortion for the ZGS of

$$z_k \leq \frac{3.5\ mm}{k^2\ (1 + k)}$$

and for the strong focussing CERN PS of

$$z_k \leq \frac{40\ mm}{k^2\ (1 + k)}$$

This apparent factor of 12 less sensitivity in the PS may be misleading. The expectation value of z_k for a given magnet misalignment is proportional to $\sqrt{(R/P)}\ (n/m)$ (n is field gradient, m the number of magnets), and this factor is 85 times larger in the PS than in the ZGS. Thus in the PS the depolarization from these resonances may be 10 times larger than in the ZGS (~ 50-60% between 6 GeV/c and 12 GeV/c). The PS would then require a very sophisticated correction system for vertical orbit distortions.

Polarization Survival Time

In view of both the effects of intrinsic and imperfection resonances it is highly probable that to achieve higher energies than 12 GeV/c, we will have to use colliding beam devices. We have performed the following experiment on the ZGS, to determine survival time and the effects of resonance tails.

The polarized beam was accelerated to 3.25 GeV/c which is as far as possible from any known resonance, and allowed to circulate on a 21 s flat-top. The ZGS repetition rate was 22.62 s. We used an operational sequence of two pulses with beam extracted at the beginning of flat-top and the next six pulses at the end of flat-top. The spin was flipped on alternate pulses, so that this sequence gave one measurement of "early" polarization and three of "late" polarization. This gave about the same number of events for measuring both "early" and "late", since the factor of three compensated for the beam loss and reduced extraction efficiency due to vacuum scattering beam growth during the 21 s flat-top. A preliminary analysis of the data indicates about a ±1/2% systematic error. No effect can be seen at this level. The statistical accuracy was about 0.1%. This upper limit corresponds to a rate of depolarization of 0.025%/s and would give a loss of polarization of 45% in a half hour run. Since this is an upper limit, it is a rather encouraging result which indicates that non-resonant depolarization may not make storage rings impossible.

We next moved the flat-top closer to the resonance ($G\gamma = 6$) and we were able to map its extent. This is shown in Fig. 14. The extimated width of the resonance is $\Delta B_{FWHM} < 10$-G and $\frac{\Delta B}{B} = \frac{\Delta \gamma}{\gamma} \approx 2 \times 10^{-3}$.

Note that the resonance effect drops 3 orders of magnitude in 30 G. Since the storage field is 400 G away, the effect of the resonance on storage is negligible. Further experiments will be done to try to improve the upper limits quoted here.

References

1. L. Teng, "Depolarization of a Polarized Proton Beam in a Circular Accelerator," NAL Note FN267 (1974). Abridged version in "Proc. of the Summer Studies on High Energy Physics with Polarized Beams," ANL/HEP 75-02 PX111.

2. J. Faure, et al., "Acceleration de Protons Polarises a Saturne," Particle Accelerators, 3(1972), p. 225.

3. M. Froissart, R. Stora, "Depolarization d'un Faisceau de Protons Polarises dans un Synchrotron," Nucl. Inst. Meth., 7 (1960) p. 297.

4. Ernst, V., Nucl. Inst. Meth. 60 (1968), p. 52.

5. R. L. Martin, et al., "Investigation of Beam Depolarization Due to an Imperfection Resonance," ANL/ARF Note AE15-15 and CERN PS/DL/Note 76/12.

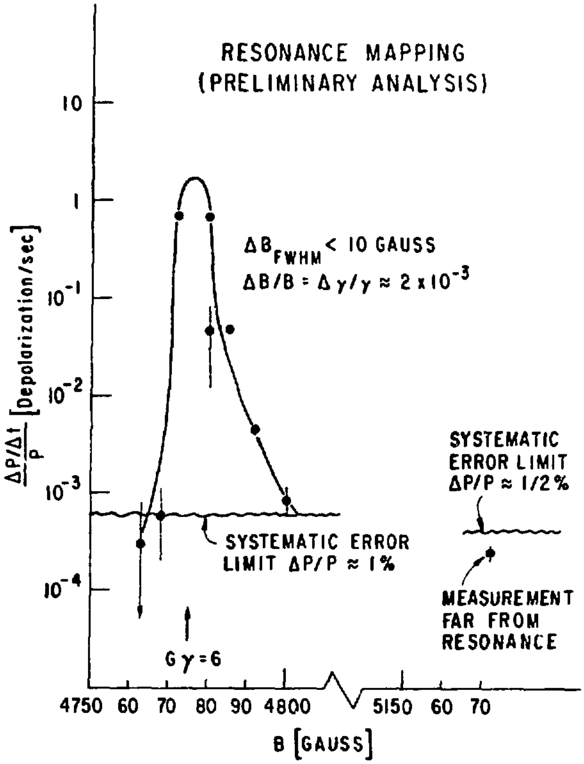

Fig. 14. Resonance mapping