WORKSHOP ON ACCELERATION OF POLARIZED PROTONS: SUMMARY REPORT*

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The workshop sessions were attended by approximately 25-30 people from many laboratories and universities. From the beginning, we decided to concentrate the discussions on polarized protons in circular accelerators and storage rings because of the limited time. Topics such as polarized electrons were discussed only when the subject was relevant to proton phenomena. There was much very pertinent theoretical work reported during this symposium and workshop (Ruth,[1] Courant,[2] Chao,[3] Stefan[4]). Of major interest was the possible applicability of the new idea of "spin matching" for crossing depolarizing resonances. On the experimental side, some remarkable new data were presented by the SATURNE II Group (Grourod).[5] They have successfully crossed both intrinsic and imperfection depolarizing resonances by the spin flip method with minimal depolarization--the first group to do so. They also obtained some results which apparently cannot be explained with our present understanding of spin phenomena. The workshop concluded that more experimental measurements are needed to understand the physics and that such studies would be very important for the future acceleration of polarized protons at KEK and the AGS.

The workshop included status reports from the four laboratories which have programs of polarized particle acceleration--or approved projects to accelerate polarized protons. Although the full reports will be published in the proceedings, it is worthwhile to list some excerpts from the presentations:

1. SATURNE II[5]--Accelerated protons to 2.4 GeV with 80% polarization. They corrected two resonances, $\gamma G = 2$ and $\gamma G = 7-\nu_z$, and spin flipped through stronger resonances $\gamma G = 3,4,5,6$ and 7 and $\gamma G = \nu_z$ and $8 - \nu_z$. Unexpected data for $\gamma G = 2$, $\gamma G = \nu_z$ and $\gamma G = 8 - \nu_z$ caused most of the disucssion in the workshops. Details of the discussion will be presented later in this paper.
2. AGS[6]--The present schedule is to accelerate polarized protons in late 1983. Not planning to spin flip; will correct imperfection and jump intrinsic resonances. They, however, do not exclude the possibilities of spin flipping through the resonances.
3. KEK[7]--At present they are approved only for the ion source development; however, they expect to be approved soon for the whole project. Their present schedule calls for acceleration through the

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booster by 1983 and in the main ring by 1984. They are planning both resonance jumping and spin flipping. A question was raised about their present plans for crossing a large intrinsic resonance in the booster in view of the new data from SATURNE II.

There was at least one case where the scheme works in computer simulation (DESY Workshop) and there was one case of the AGS (resonance at 60-ν), where the scheme has difficulties. It certainly is a worthwhile idea to investigate further.

Most of the discussions were concentrated on the only real experimental data available; namely, the results from SATURNE. The naive theory of spin resonance crossing says that for an isolated resonance, the resultant polarization after crossing a resonance can be expressed

$$\frac{P}{P_o} = 2e^{-\frac{\pi\,\varepsilon^2}{2\alpha}} - 1 \tag{3}$$

where P_o, P = the polarization before and after resonance

ε = strength of the resonance

$\alpha = G\frac{d\gamma}{d\theta} \mp \frac{d\nu_z}{d\theta} = \left(G\frac{d\gamma}{dt} \mp \frac{d\nu_z}{dt}\right)\frac{1}{\omega}$

θ, ω = turning angle and angular velocity of the proton around the ring

The $\mp$ chosen appropriately for the particular intrinsic resonance:

$$G\gamma = kP \pm \nu_z$$

If ε^2 is small or α is large so that $\pi\varepsilon^2/2\alpha \ll 1$ then $P \cong P_o$. If ε^2 is large and α is small so that $\pi\varepsilon^2/2\alpha \gg 1$ then $P \cong -P_o$ and the spin is flipped. In other words, for the given resonance spin flip can be achieved by reducing α, or by increasing ε.

There are two pieces of data available from SATURNE II, one for $\gamma G = 2$, an imperfecton resonance and the other for the $\gamma G = \nu_z$ and $8 - \nu_z$ intrinsic resonances. For the $\gamma G = 2$ data (Figure 2 of Reference 5), one can see some important features. As predicted by theory, they were able to correct the imperfection resonance by exciting corresponding harmonics. Also, they could make the imperfection stronger and flip the spin as predicted by the theory. Now, according to the theory, if one increases the driving perturbation further, the polarization of the protons should still stay reversed and approach 100% spin flip. The data, however, show that the polarization starts oscillating similar to optical interference patterns. Somewhat different but possibly related behavior is seen for the $\gamma G = \nu_z$ and $\gamma G = 8 - \nu_z$ intrinsic resonances. As shown in Figure 3 of Reference 5, they had to introduce finite $\frac{d\nu_z}{dt}$ in order to obtain spin reversal. In other words, contrary to the theory, they had to increase α in Equation (3) to completley reverse the spin. Table I presents the data for crossing $\gamma G = \nu_z$. These data are also shown in Figure 1 in graphic form.

4. JINR (Dubna)[8]--Polarized deutrons were accelerated in their synchro-phasatron up to 8 GeV, where they met the first resonance of $\gamma G = \nu_z$. Several runs of bubble chamber exposure were taken and the data is being examined.

Some other contributed papers relevant to polarized proton acceleration presented at the workshop sessions were: an investigation of the effect of an asymmetric ν jump (Turrin[9]) and a general study of polarization precession in quadrupoles and sextupoles (Carey[10]).

The discussion sessions focussed on three major topics: resonance crossing theory, the analysis of the so-called "spin transparency (or matching)", and the interpretation of the SATURNE II data.

The applicabilities of "Siberian Snakes" and their limitations had been discussed by Courant in the plenary session and his paper[2] is published in these proceedings. His conclusion is that with some minor complications, the Siberian Snake scheme should enable one to accelerate polarized protons to the energy of ISABELLE or the Tevatron.

The problem of resonance "criss-crossing", accelerating the protons back and forth across a single resonance several times (as by synchrotron oscillations) was considered. The general consensus was that if one went back and forth slowly enough, nothing would happen to the spin; however, because of the particles in the center of the vertical phase space, some depolarization would be expected to occur with intrinsic resonances. In the special case of a perfectly symmetric back and forth crossing the polarization will remain the same regardless of the speed of the crossing.

Some very interesting preliminary work on the analysis of crossing a two-resonance system was presented by Ruth. Interference effects should be observable if the resonances are close enough.

The idea of spin matching (or transparency) was discussed (Chao, Steffen).[3,4] The basic idea is that if one makes

$$\oint ds \, {\cos \atop \sin} \left(\Psi_{spin} - \Psi_{betatron}\right) G \sqrt{\beta} = 0 \qquad (1)$$

For intrinisc resonances

$$\oint ds \, {\cos \atop \sin} \left(\Psi_{spin}\right) G \Delta y_{closed\ orbit} = 0 \qquad (2)$$

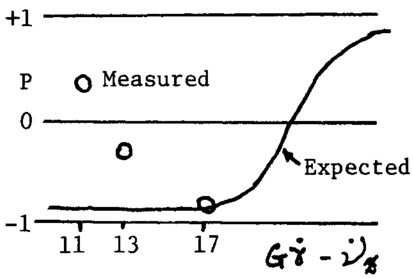
For imperfection resonances

then the strength of the resonance vanishes and there would be no problem crossing the resonances. The second condition could be satisfied by harmonic dipole excitation. At the ZGS and SATURNE II, the second conditions were satisfied by exciting vertical correction dipoles, and the same procedures are planned for the AGS and KEK. The first conditions for the intrinsic resonance are harder to achieve. Although they may be relatively easy to accomplish at a single given energy and a given resonance (in electron storage rings, where one is concerned with only certain energy regions, the scheme is particularly useful), they are harder to satisfy when one has to accelerate through a resonance or cross a number of them.

Table I

ν_z	$\alpha\omega$	P(measured)
- 4	~ 17	~ - 0.80
0	~ 13	~ - 0.20
+ 2	~ 11	~ + 0.30

Figure 1



The workshop participants discussed the possible causes of these important discrepancies and a few conjectures were suggested. One possibility is that the phenomena may be related to the synchrotron motion of the protons. Possibly similar phenomena, but more limited, were observed at the ZGS[11] and it was noted then that the effect could be simulated by synchrotron motion and energy spread. In the SATURNE data however, the "side bands" spacing does not appear to be related to the synchrotron oscillation frequencies. Another suggestion was that the phenomena were caused by the interference of two resonances (Ruth[1]). There are possibilities of some weaker higher order resonances close by which may have caused the problem.

It was evident that more experimental data are needed to resolve these questions and accelerator time to experiment is scarce. Many experiments to interpret the above mentioned hypotheses were suggested. The workshop concluded with the strong plea to get more experimental data and adopted the following recommendation:

"The initial very exciting SATURNE II results on resonance crossing with the polarized protons have raised questions about our understanding of the process. We believe it is extremely important that further studies be undertaken at SATURNE to investigate the phenomena in considerable depth. As well as being of general interest, the results of such studies certainly will be important for the imminent KEK and AGS polarized protons resonance crossing programs."

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