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SPIN MATCHING FOR POLARIZED PROTONS*

Alexander W. Chao
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

So far, there seem to be at least three ways to accelerate polarized protons to high energies without losing polarization:

1. To cross the depolarization resonances rapidly during acceleration so that the polarization is nearly unchanged.
2. To cross the depolarization resonances slowly (adiabatically) so that the polarization does a 100% flip after crossing.
3. To install Siberian snakes (preferably double-snakes) so that the spin tune $\nu_{spin} = 1/2$ and there is no resonance crossing during acceleration.

The first two approaches are widely employed in ZGS[1] and SATURN[2] and are seriously considered for AGS[3] as well. The third approach is considered for higher energy proton synchrotrons such as ISABELLE.[4]

Here we suggest a fourth possible way to accelerate polarized protons. The basic idea[5-8] is borrowed from the works done on electron storage rings. The jargons involved are "spin transparency" and "spin matching," etc.

In the proton language, the question being asked is what are the conditions on the accelerator lattice that make the depolarization resonance widths[9] $\varepsilon = 0$. Suppose we can "spin match" the lattice so that at the moment of crossing a resonance during acceleration, the resonance being crossed is made to have zero width, then there will be no loss of polarization due to the resonance crossing.

In Table I, we have listed the conditions for eliminating the widths of various depolarization resonances. These conditions are called the "transparency conditions." The symbols used in Table I are

ν_{spin} = spin tune

$\nu_{x,y}$ = betatron tunes

ψ_{spin} = spin precession phase = $\nu_{spin} \int_0^s ds'/\rho(s')$

$\psi_{x,y}$ = betatron phases

$\beta_{x,y}$ = beta-functions

$y_{c.o.}$ = vertical closed orbit distortion

G = quadrupole gradient

$\hat{n}$ = nominal direction of beam polarization.

Note that the integrals listed in Table I all resemble the k-th Fourier component of some quantity ($G\sqrt{\beta_x}$, $G\sqrt{\beta_y}$ or $Gy_{c.o.}$) near the corresponding resonances. For example, near the resonance $\nu_{spin} + \nu_x = k$, the quantities $\sin(\psi_{spin} + \psi_x)$ and $\cos(\psi_{spin} + \psi_x)$ resemble — but not quite identical to — $\exp(iks/R)$, etc.

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Table I The Transparency Conditions for Eliminating Various Depolarization Resonances

Resonances	Transparency Conditions
$\nu_{spin} + \nu_x = k$	$\left\{ \oint ds \begin{matrix}\cos\\ \sin\end{matrix} \left(\psi_{spin} + \psi_x\right) G\sqrt{\beta_x} = 0 \right.$ or $\hat{n} \parallel \hat{y}$
$\nu_{spin} - \nu_x = k$	$\left\{ \oint ds \begin{matrix}\cos\\ \sin\end{matrix} \left(\psi_{spin} - \psi_x\right) G\sqrt{\beta_x} = 0 \right.$ or $\hat{n} \parallel \hat{y}$
$\nu_{spin} + \nu_y = k$	$\oint ds \begin{matrix}\cos\\ \sin\end{matrix} \left(\psi_{spin} + \psi_y\right) G\sqrt{\beta_y} = 0$
$\nu_{spin} - \nu_y = k$	$\oint ds \begin{matrix}\cos\\ \sin\end{matrix} \left(\psi_{spin} - \psi_y\right) G\sqrt{\beta_y} = 0$
$\nu_{spin} = k$	$\oint ds \begin{matrix}\cos\\ \sin\end{matrix} \left(\psi_{spin}\right) Gy_{c.o.} = 0$

In an ideal situation, or in case the lattice is only slightly perturbed, the polarization direction $\hat{n}$ is nearly parallel to $\hat{y}$. The conditions for eliminating the $\nu_{spin} \pm \nu_x = k$ resonances are therefore automatically obeyed — at least approximately — and these resonances are only weakly driven.

The conditions for $\nu_{spin} \pm \nu_y = k$ resonances, on the other hand, are automatically satisfied only if k is not a multiple of the lattice superperiod S. In case k is a multiple of S, we have the "intrinsic resonances" and, in the present approach, it is necessary to "spin match" the lattice in such a way that the transparency conditions are satisfied. This can be achieved, at least in principle, by two sets of adjustable quadrupoles (one set if the accelerator has a mirror symmetry). The quadrupole strengths are determined by an on-line control program before crossing the resonance and reset to their original values after crossing. If it turns out desirable that the values of ν_x and ν_y be maintained, four sets of quadrupoles will be needed. Small shifts on ν_x and ν_y, however, should not be considered absolutely forbidden. Note that these spin-matching quadrupoles are not pulsed. Rather, the changes on their strengths are turned on and off adiabatically as the beam is accelerated through the resonance so that the disturbance on the orbital motions of the particles is minimized.

The imperfection resonances $\nu_{spin} = k$ play an increasingly important role as the energy of the proton synchrotron increases.[4] These resonances are eliminated by controlling the "k-th Fourier component" of the quantity $Gy_{c.o.}$. Since the vertical closed orbit distortion is not known precisely enough, this can be achieved only by empirically tweaking two orbit correcting knobs.

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