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Expected Polarization in the Present PEP-2 Design*

Yuri Nosochkov, Michiko Minty, and Alex Chao
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94309

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In the present design of PEP-2, operation with polarized beams is not anticipated. The amount of polarization that the existing design does support is however of interest. Calculations are presented for the expected polarization for both the High Energy (HER) and the Low Energy (LER) Rings of PEP-2 arising from the Sokolov-Ternov build-up. In both rings, we find that with the detector solenoid turned on, the equilibruim polarization is less than 1% at the design operating energies. Furthermore, if a polarized beam were injected, it would depolarize in a short time.

To improve the polarization, we consider spin matching; i.e., implementing a set of spin transparency conditions on the lattice design. While to demand complete spin transparency around the entire machine is impractical, six conditions are derived to make the lattice *partially* spin transparent. Among these six conditions, perhaps only two are dominant for PEP-2. It remains to be seen whether these six (or two) conditions can be implemented into the lattice design in practice, and if implemented, whether they are sufficient to increase the polarization to useful levels. We have not studied spin rotator schemes to provide longitudinal polarization at the interaction point or their effect on the beam polarization.

Similar calculations are presented for the Beijing Tau-Charm Factory (BTCF) design, including a possible spin rotator scheme. It is found that when this spin rotator is turned on without spin matching, the polarization level is low.

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1 Polarization of the Present PEP-2 Design

The schematics layouts of the PEP-2 high and low energy rings as well as of the BTCF are shown in Fig.1. The PEP-2 lattices [1] have been designed taking into account important constraints (tunnel size restrictions, for example), but have not been optimized for maintaining beam polarization. Specifically, the design includes solenoids, skew quadrupoles, and vertical bending magnets. Past experience has shown such elements to be potentially strong depolarizers. In comparison, depolarization effects due to orbit errors are much weaker. In this study, we ignore orbit errors.

The effect of lowest order, linear depolarizing resonances is calculated using the program SLIM [2]. A thin lens approximation is used for the input lattice. The orbit distortion caused by the 5.7 T-m detector solenoid and its edge fields results in a small amount of depolarization in some nearby sextupoles.

The calculated results for the HER and LER are shown in Fig. 2. The horizontal axis is the unperturbed spin precession tune $a\gamma$, where $a = (g-2)/2$ is the anamolous g-factor. For electrons and positrons, $a\gamma =$ (beam energy E_0)/(0.44065 GeV). In either ring, the polarization is zero near betatron resonances for which $a\gamma \approx k \pm \nu_{x,y}$. These betatron resonances are much weaker than the synchrotron resonances ($a\gamma \approx k \pm \nu_s$), which overlap with integer resonances to cause the broad suppression of the polarization level.

The sign changes in P_0 (the equilibrium level of polarization) and in $\hat{n}$ (the polarization direction) near half-integer $a\gamma$. The product $P_0\hat{n}$ of course should not change sign. There is also a numerical uncertainty near half-integer resonances associated with a sign degeneracy in the eigen-analysis package. The results for P_0 shown in Fig. 2 have been slightly modified (dotted portion of the curve) by interpolation in these neighborhoods to compensate for this uncertainty.

By definition, τ_p is the time it takes the beam to acquire the equilibrium polarization of P_0 when an unpolarized beam is injected into the storage ring. If a polarized beam is injected into the ring, then the polarization would still approach P_0 with the same time constant τ_p. In this case, τ_p acts as a *depolarizing* time.

In general the expected polarization for PEP-2 is low. The best level of equilibrium polarization is 0.8% (which occurs near 9 GeV) for the HER, and 3.5% at about 2.9 GeV for the LER. If a polarized beam is injected into the HER, it would depolarize in a time < 1.5 minutes. For the LER, an injected polarized beam depolarizes in < 17 minutes.

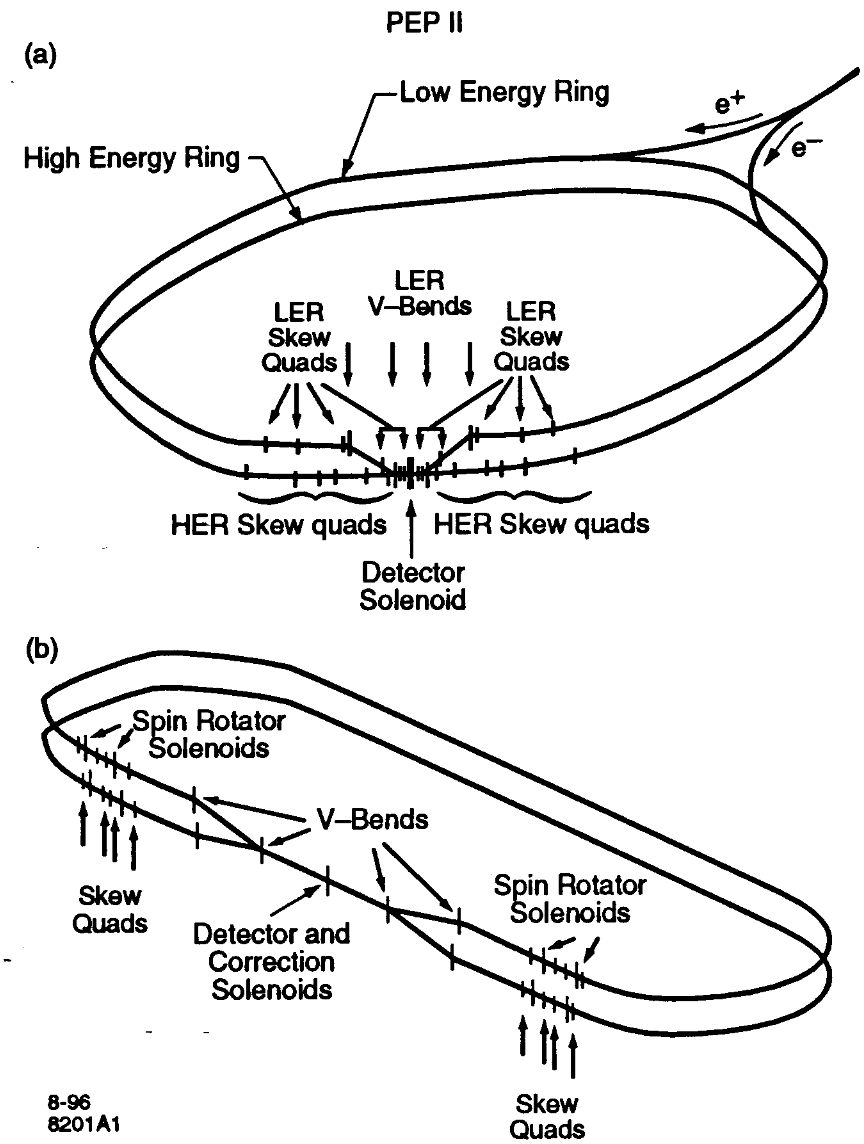

Figure 1: Schematics layouts (not to scale) for (a) PEP-2, and (b) BTCF.

2 Partial Spin Transparency

To increase the spin polarization for PEP-2, one might impose a "spin match" constraint on the lattice design. This means that the lattice must fulfill a set of "spin transparency" conditions. For example, consider a lattice which consists mostly of "arc sections", which are planar and have $\eta_y = 0$ ($\eta_{x,y}$ and $\beta_{x,y}$ are the dispersion and the beta-functions), and no x-y coupling. Let the remainder of the lattice consist of a shorter "insertion section", which can contain x-y coupling and $\eta_y \neq 0$. The insertion section may include quadrupoles, skew quadrupoles, vertical and horizontal bending magnets, and solenoids. It may also contain the interaction region (IP) and spin rotators, if any. For complete spin transparency, the machine must be spin transparent at all locations where synchrotron radiation is emitted, i.e., at all horizontal and vertical bending magnets. In general this is impractical if not impossible to fulfill, with the exception of some special cases.

For PEP-2, we therefore consider making the machine only partially spin transparent, and seek spin transparency only for those bending magnets located in the arc sections. With this partial trans- parancy, depolarization will however still occur due to radiation in the bending magnets of the insertion section. Whether implementing partial transparency suffices to bring the PEP-2 polarization to a useful level remains to be seen.

We derive the partial spin transparency conditions by following the general approach developed in Ref.3. We designate the equilibrium polarization direction at position s by $\hat{n}(s)$. Let $(\hat{n}(s), \hat{m}(s), \hat{\ell}(s))$ be the right-handed orthonormal vector system at position s, and let all three unit vectors precess according to the magnetic bending fields. Spin transparency against synchrotron radiation in the arc section requires that integrated spin precession through the insertion section to vanish. This means

$$\int_{\text{insertion}} ds\ \hat{\ell}(s) \cdot \vec{B}_{\perp}(s) = \int_{\text{insertion}} ds\ \hat{m}(s) \cdot \vec{B}_{\perp}(s) = 0 \qquad (1)$$

Assuming the lattice is such that $\hat{n} \approx \hat{y}$ in the arc sections, we find six transparency conditions for spin transparency against synchrotron radiation

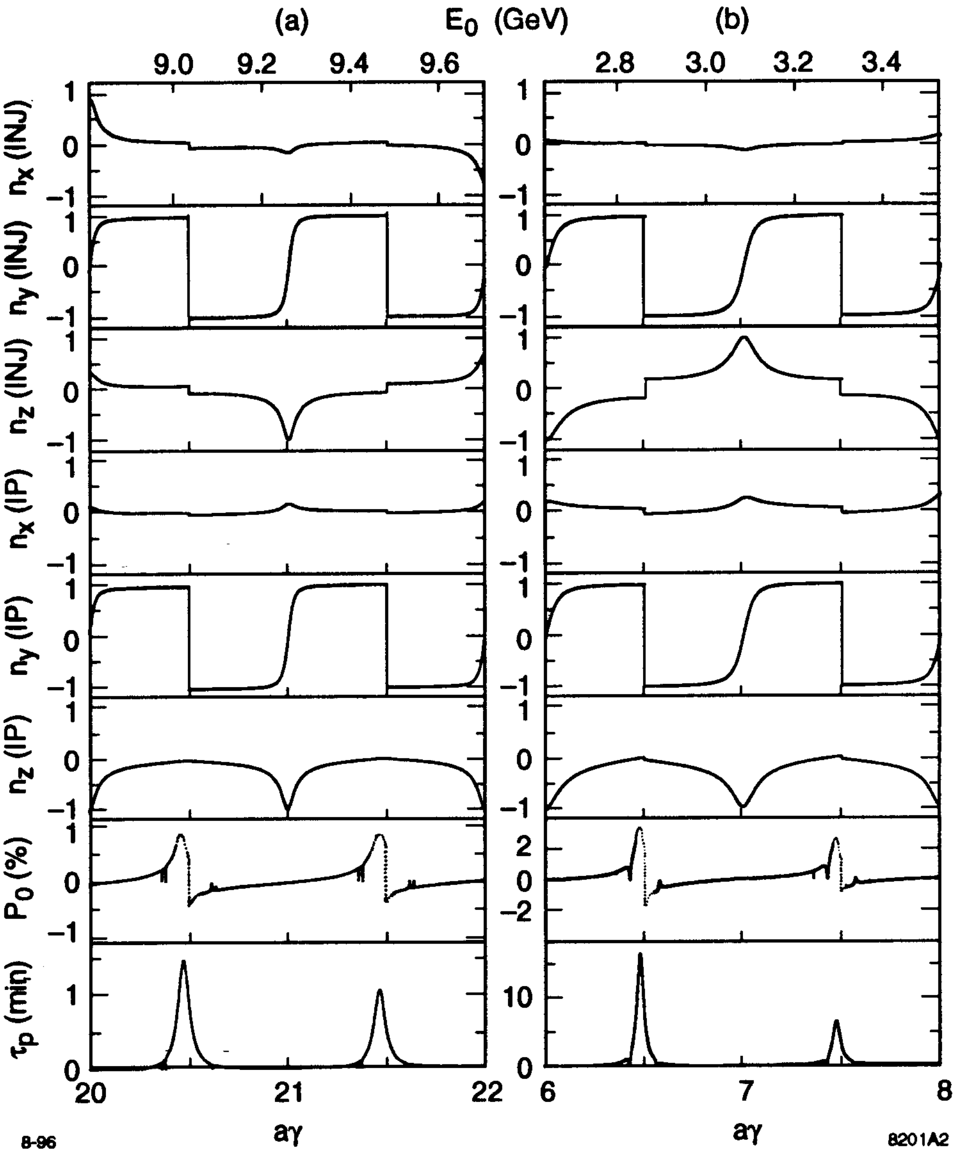

Figure 2: For the PEP-2 (a) HER and (b) LER, the equilibrium polarization direction $\hat{n}$ at the injection point, $\hat{n}$ at the IP, the equilibrium level of polarization P_0, and the polarizing time τ_p are plotted as a function of $a\gamma$ (bottom scale), or the beam energy E_0 (top scale). The nominal beam energy is 9.01 GeV and 3.10 GeV for the HER and LER respectively.

in the arc sections:

$$\int_{\text{insertion}} ds \begin{Bmatrix} \hat{\ell}(s) \\ \hat{m}(s) \end{Bmatrix} \cdot [\hat{y}\ G_Q(s) + \hat{x}\ G_{SQ}(s)]\sqrt{\beta_x(s)} \begin{Bmatrix} \sin\psi_x(s) \\ \cos\psi_x(s) \end{Bmatrix} = 0$$

$$\int_{\text{insertion}} ds \begin{Bmatrix} \hat{\ell}(s) \\ \hat{m}(s) \end{Bmatrix} \cdot [\hat{y}\ G_Q(s)\eta_x(s) + \hat{x}\ G_Q(s)\eta_y(s) + \hat{x}\ G_{SQ}(s)\eta_x(s) - \hat{y}\ G_{SQ}(s)\eta_y(s)] = 0 \qquad (2)$$

where the first equation represents four conditions and the second equation represents two; G_Q and G_{SQ} are gradients of quadrupole and skew quadrupole magnets.

The conditions (2) are not easy to implement into well-advanced lattice designs such as those for PEP-2 or KEK-B. At this stage, implementation will necessarily require a re-optimization of the orbital dynamics.

Judging from the fact that the betatron resonances seem weak in Fig. 2, it may be possible that one only has to observe the second equation of Eq.(2), whose driving terms pertain to the synchrotron sidebands. (The first equation represents driving terms for the betatron sidebands.) It is therefore conceivable that one may reduce the six conditions to two, and the partial transparency conditions can be correspondingly simplified.

3 Polarization of the Present BTCF Design

As mentioned, polarization is not a key requirment for PEP-2, even though it might allow for some useful experiments. In comparison, polarization plays a more critical role [5] for the BTCF. For this reason, we have also preliminarily studied the polarization at the BTCF. The polarization characteristics of the BTCF lattice as presently designed is shown in Fig.3(a). In contrast to the PEP-2 designs, this lattice does maintain high polarization (only slightly reduced from the ideal value of 92.4% due to the vertical bending magnets). The main difference from PEP-2 is that BTCF detector has compensating solenoids adjacent to it. The stronger depolarizing resonances observed in Fig.3(a) are horizontal betatron sidebands; they are driven by the detector and its compensating solenoids.

Maintaining polarization while producing longitudinal polarization at the IP using a spin rotator is still an issue however. One possible spin rotator de-

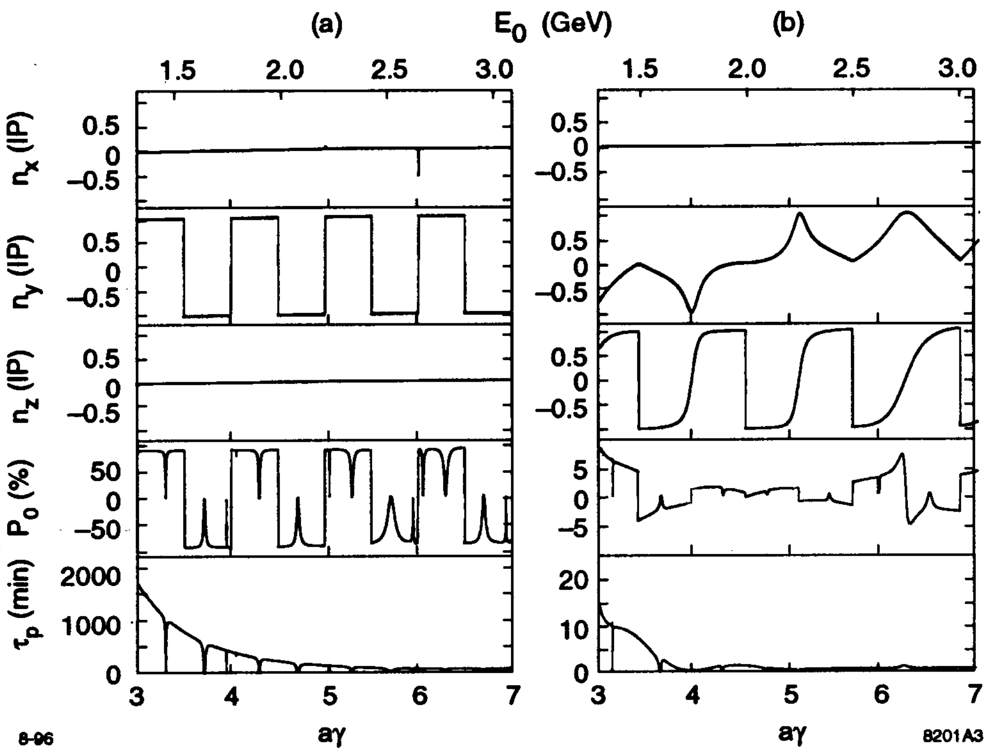

Figure 3: For BTCF, $\hat{n}$ at the IP, P_0, and τ_p are plotted as a function of $a\gamma$ and E_0. The nominal beam energy is 2 GeV. (a) is when the spin rotator scheme is turned off. (b) is when it is turned on.

sign employs two pairs of solenoids, one on each side of the IP. The solenoids rotate the spin by 90° around the longitudinal direction while horizontal bending magnets between each solenoid pair and the IP rotate the polarization by 90° about the vertical direction. Orbital coupling caused by the solenoids are corrected by near-by skew quadrupoles.

Calculated results with this spin rotator scheme are shown in Fig. 3(b). Here each solenoid is 1 m long and has a strength of 5.23 T. The bending angle between one solenoid pair and the IP is 21.47°. To have an exact 90° spin rotation at 2 GeV by these bending magnets, this angle was changed to 19.83° in our run for the case of Fig.3(b). With the spin rotator turned on, the polarization drops to a very low level and τ_p is small. Note that the spin tune is noticeably different from $a\gamma$ in Fig.3(b). No spin matching has been implemented in these cases.

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[5] Paul Tsai, private communications 1996.