POLARIZATION FOR THE BY-PASS SLAC/PEP COLLIDER*

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It was suggested (by J. Rees and R. Schwitters) that one can collide the store e^+ beam in PEP with the e^- beam from SLAC to reach a center-of-mass energy higher than that achieved by the PEP colliding beams. Although the future of this PEP/SLAC collider is not yet certain, it is useful to first explore its physics possibilities.

One possible version of the SLAC/PEP collider utilizes a by-pass at the interaction point; the stored beam is displaced vertically by a set of vertical bending magnets every time the linac beam arrives. The arrangement of the by-pass magnets is shown in Fig. 1. One feature of this by-pass scheme that makes it attractive is that the amount of the vertical displacement of the by-pass can be chosen so that, as suggested by B. Richter and R. Schwitters (PEP-175), the spin polarization of the stored beam is made longitudinal at the point of interaction.

In this note, we have studied the various depolarization effects of the stored e^+ beam due to the perturbation of the by-pass magnets.

We first note that it is not desirable to have the e^+ beam go through the by-pass for all revolutions. The polarization for this case has been studied before (PEP-263) and was found to be unfavorable. The

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reason for a strong depolarization is that there is strong synchrotron radiation in the region of the by-pass magnets where there exists a large vertical dispersion which couples the vertical betatron noise directly into the spin motion. The present by-pass scheme, however, requires the beam to go through the by-pass only when the linac beam arrives, i.e., at a rate of 180 hertz. As a consequence, the depolarization rate is decreased by a factor $N=f_0/180 \text{ hz} = 757$, with f_0 the revolution frequency of the beam in PEP and N the number of revolutions for each by-pass. With this large reduction factor, the depolarization effect due to synchrotron radiation in the by-pass magnets becomes negligible. Depolarization due to synchrotron radiation in the rest of PEP will be the same as the normal PEP without by-pass and should not be a serious problem away from depolarization resonances.

We have also studied a few other possible depolarizing mechanisms caused by the by-pass. A summary of the results is given below. We have not included in this work the beam-beam depolarization effects.

1) Excitation of Synchrotron Oscillation by the By-Pass:

As the stored e^+ bunch passes through the by-pass, the longitudinal position of the bunch falls behind because of the longer path length involved. Also, due to the synchrotron radiation loss in the by-pass magnets, the mean energy of the bunch is shifted toward a lower value. At 15 GeV, the shift in longitudinal position $(\Delta l)_0$ is about 9 mm, and the shift in energy is about $(\Delta E/E)_0 = 2 \times 10^{-3}$. These shifts excite the synchrotron oscillation of the bunch in its subsequent motion.

In the ideal case, the excitation of synchrotron oscillation does not depolarize, because the spin and the synchrotron motions are not coupled. In reality, field errors (such as those associated with a vertical closed orbit distortion) cause the spin motion to couple with the synchrotron motion, and excitation of synchrotron oscillation may cause loss of polarization.

For simplicity, let us assume the excited synchrotron oscillation is damped before the e^+ bunch passes through the by-pass again N turns later. Let us denote the polarization vector at the end of each by-pass (position P in Fig. 1) by

$$\vec{s} = \hat{y} + \alpha \hat{z} + \beta \hat{x} \quad (1)$$

$|\alpha|$ and $|\beta| \ll 1$.

The reduction in polarization is given by $\Delta P = (\alpha^2 + \beta^2)/2$.

The coupling between the spin and the synchrotron motions is most conveniently described in terms of an 8×8 matrix, M , which is the transformation matrix for one revolution around position P of the vector $(x, x', y, y', z, \Delta E/E, \alpha, \beta)$ (PEP-257).

Let E_k ($k=I, II, III, IV$) be the eigenvectors of the matrix M . The contribution to the spin components from the by-pass excitation $(\Delta \epsilon)_0$ and $(\Delta E/E)_0$ is given by projecting these perturbations onto the spin eigenstate. The result is

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$$\begin{pmatrix} \Delta\alpha \\ \Delta\beta \end{pmatrix} = 2 \operatorname{Im} \sum_{k=I, II, III} \left(\left(\frac{\Delta E}{E} \right)_0 E_{5k}^* E_{7k} - (\Delta t)_0 E_{6k}^* E_{7k} \right) \quad (2)$$

where E_{ik} is the i -th component of the vector E_k , and Im means taking the imaginary part.

The equilibrium values of α and β at position P satisfy the condition

$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \underbrace{\begin{pmatrix} \cos 2\pi N \nu & \sin 2\pi N \nu \\ -\sin 2\pi N \nu & \cos 2\pi N \nu \end{pmatrix}}_{\text{spin precession for N turns } (\nu = a\gamma = \text{spin tune}).} \begin{pmatrix} \alpha \\ \beta \end{pmatrix} + \underbrace{\begin{pmatrix} \Delta\alpha \\ \Delta\beta \end{pmatrix}}_{\text{kick contribution from by-pass given by Eq.(2).}} \quad (3)$$

We have assumed that the mixing (due to non-linearities) in the spin precession phase can be ignored in N turns. Eq.(3) can be solved to yield the loss of polarization

$$\Delta P = (\alpha^2 + \beta^2)/2 = (\Delta\alpha^2 + \Delta\beta^2)/(8 \sin^2 N\pi\nu). \quad (4)$$

It is clear that whenever the spin tune is equal to an integer divided by N , we have $\Delta P \rightarrow \infty$, and the stored beam will be depolarized. With N a large number, this means there are many resonances per spin tune unit. The distance between resonances is 0.58 MeV in energy. However, the width of each resonance is inversely proportional to N , and a dense population of resonances does not necessarily imply losing beam polarization at all energies.

Not so obvious from Eq.(4) is the fact that $\Delta\alpha$ and $\Delta\beta$ become large when the resonance condition, $\nu \pm \nu_{x,y,s} = k$, is fulfilled. This is simply because near those resonances (N does not appear here) the coupling between spin motion and the subsequent orbital motion following the excitation of the synchrotron motion of an electron is strong.

A sample PEP run with an rms vertical orbit distortion of 1.2 mm shows that the depolarization effect is not at all serious away from resonances; typically with $\Delta P \sim 10^{-8}$. The resonance widths around $\nu = k/N$ are typically 4 orders of magnitude less than the distance between resonances. The spin tune spread associated with the energy spread of the beam does not enter, because the synchrotron oscillation does not last for N turns.

2) Static Error in $\int B d\hat{z}$:

In case the value of $\int B d\hat{z}$ is not exactly equal to zero, the by-pass would excite vertical betatron oscillations. This in turn excites the spin motion, causing the polarization to deviate away from the nominal direction $\hat{y}$ (even without any field errors in the rest of PEP, because the vertical betatron motion, unlike the synchrotron motion, is intrinsically coupled to the spin motion).

Again, assuming the betatron oscillation damps out in N turns, the excitation caused by $\int B d\hat{z} \neq 0$ gives a contribution

$$\begin{pmatrix} \Delta\alpha \\ \Delta\beta \end{pmatrix} = \begin{pmatrix} -(v+1) & \Delta y' \\ 0 & \end{pmatrix} + 2 \operatorname{Im} \sum_{k=I, II, III} \begin{pmatrix} \Delta y' E_{3k}^* E_{7k}^- & \Delta y E_{4k}^* E_{7k}^- \\ \Delta y' E_{3k}^* E_{8k}^- & \Delta y E_{4k}^* E_{8k}^- \end{pmatrix} \quad (5)$$

to the spin components, where Δy and $\Delta y'$ are the displacement and slope at position P due to static by-pass field errors. The corresponding loss of polarization ΔP is given by Eq. (4).

The sample run shows that this depolarization effect is also negligible. Depolarization occurs at resonances $v = k/N$ and $v \pm v_{x,y,s} = k$, just like the previous case. If we assume $\Delta y = 1$ mm and $\Delta y' = 0.1$ mrad, the loss of polarization away from resonances is found to be typically $\Delta P = 10^{-5}$.

3) Jittering in fBd1 :

Random kicks caused by jittering in fBd1 is also studied. The difference from the previous effect is that in this case the fBd1 error is not the same every time the by-pass is affected. As a result, the vertical kicks give rise to a diffusion in spin motion. The diffusion rate is then directly related to a depolarization lifetime τ_D :

$$\tau_D = \frac{1}{2NT_0} \left\{ 4\langle \Delta y^2 \rangle \left[\left(\text{Im} \sum_k E_{4k}^* E_{7k} \right)^2 + \left(\text{Im} \sum_k E_{4k}^* E_{8k} \right)^2 \right] + \langle \Delta y'^2 \rangle \left[\left(2 \text{Im} \sum_k E_{3k}^* E_{7k} - v - 1 \right)^2 + \left(2 \text{Im} \sum_k E_{3k}^* E_{8k} \right)^2 \right] \right\} \quad (6)$$

Resonances occur at $v \pm v_{x,y,s} = k$; the resonances $v = k/N$ do not occur here. This depolarization mechanism does not require field errors other than those in the by-pass. In (6), T_0 is the revolution period.

If we let Δy and $\Delta y'$ have rms jittering of 0.1 mm and 0.01 mrad, respectively, we find that the depolarization time is of the order of $\frac{1}{2}$ hr. away from resonances. (The polarization time is 20 min. at 15 GeV.) It seems that jittering in fBd1 should be minimized in order to maintain a good polarization with the by-pass scheme.

Fig. 1 By-pass