SLAC-PUB-3081
March 1983
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LATEST ON POLARIZATION IN ELECTRON STORAGE RINGS*

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

Introduction

The field of beam polarization in electron storage rings is making rapid progress in recent several years. This report is an attempt to summarize some of these developments concerning how to produce and maintain a high level of beam polarization. Emphasized will be the ideas and current thoughts people have on what should and could be done on electron rings being designed at present such as HERA, LEP and TRISTAN. An up-to-date review on similar subjects can be found in Ref. 1.

Polarization in an Electron Storage Ring

Consider a relativistic electron traversing a magnetic field and getting deflected by an angle θ. The spin of the electron also sees the magnetic field and as a result rotates about the field by an angle $(a\gamma+1)\theta$, where $a=(g-2)/2=0.00116$ is the anomalous part of the gyromagnetic ratio of an electron and γ is the relativistic Lorentz factor. Relative to the trajectory of the electron, the spin thus precesses by an angle $a\gamma\theta$.

In a storage ring with planar geometry, all bending magnets have fields along the vertical direction $\hat{y}$. The electron spin rotates about $\hat{y}$ by an angle $2\pi a\gamma$ as the electron completes one revolution. See Fig. 1(a). This leads us to define

$$\text{spin tune } \nu = a\gamma = E/440.65 \text{ MeV} \qquad (1)$$

where E is the electron energy. Furthermore, if all electrons have different precession phases, the net beam polarization, provided the beam is polarized in the first place, will have to be along the $\hat{y}$ direction, i.e.

$$\text{net beam polarization direction } \hat{n} = \hat{y} \quad . \qquad (2)$$

It can be shown that for any storage ring geometry, there always exists a net beam polarization direction $\hat{n}$. It is obtained mathematically by looking for a spin direction that repeats itself turn after turn as the electron circulates around the ring. In other words, $\hat{n}$ is given by the "closed" solution of spin direction. We then define two auxiliary unit vectors $\hat{m}$ and $\hat{\ell}$ so that $(\hat{n},\hat{m},\hat{\ell})$ forms a right handed orthonormal set. All three unit vectors precess according to the bending fields. The vectors $\hat{m}$ and $\hat{\ell}$ continue to precess turn after turn while $\hat{n}$ repeats itself. For a ring with planar geometry, $\hat{n}=\hat{y}$ and $\hat{m}$ and $\hat{\ell}$ lie in the ring plane.

The story began when Ternov, Lokutov and Korovina[2] and Sokolov and Ternov[3] realized that, in a planar ring, synchrotron radiation by an electron causes its spin to align with the magnetic field direction ($-\hat{y}$ for electrons and $\hat{y}$ for positrons) so that the lower quantum state is occupied more. This is a very interesting observation because due to this "radiative polarization" effect, the beam will slowly polarize itself. The net polarization theoretically will reach the level

$$P_o = 8/5\sqrt{3} = 92.4\% \qquad (3)$$

with a polarization time constant

$$T_o = 99 \text{ sec } \frac{\rho^2 R[m^3]}{E^5[\text{GeV}^5]} \qquad (4)$$

where ρ is the bending radius of the bending magnets, $2\pi R$ is the ring circumference. Again using a vector to represent the spin, we have the situation shown in Fig. 1(b); the spin slowly spirals towards $\hat{y}$. For a 3.7 GeV ring like SPEAR, $T_o = 14$ min, i.e. it takes 14 minutes for the beam to become polarized. Soon after the theoretical discovery, beam polarization was observed in several rings (VEPP-2[4] and ACO[5] around 1971, SPEAR[6] in 1975). Things looked very encouraging.

Fig. 1. (a) Spin precesses rapidly as the electron circulates around. (b) At the same time, the precession motion slowly spirals inward due to the radiative polarization mechanism.

In Fig. 2, we show the polarization data measured for SPEAR[7] in the energy range from 3.5 GeV to 3.75 GeV ($\nu = 8.0$ to 8.5). One observes that the beam polarization is lost when the spin tune satisfies some specific conditions that in general are given by

$$\nu + k_x\nu_x + k_y\nu_y + k_s\nu_s = k \quad , \qquad (5)$$

where $\nu_{x,y,s}$ are the tunes for the three orbital motions -- the horizontal betatron, the vertical betatron and the synchrotron motions, respectively, $k_{x,y,s}$ and k are integers. Equation (5) gives the spin depolarization resonance conditions. As we shall see, the depolarization resonances, which do not seem too harmful for SPEAR, become much more pronounced for rings of higher energies and what people have been doing is mostly to find clever ways to fight these resonances.

In a planar ring, a fully polarized electron with spin along $\hat{y}$ will stay fully polarized. Synchrotron radiation by this electron of course will excite its horizontal betatron and the synchrotron motions which in turn causes the electron to experience perturbing magnetic fields, but these fields are all parallel to $\hat{y}$ and do not cause the spin to precess away from $\hat{y}$. Once the beam is polarized, synchrotron radiation does not depolarize the beam even near the depolarization resonances.

However, a real storage ring is not planar. The ring may be nonplanar by design -- we will see later a few such examples -- or even if it is planar by design, it may contain imperfections that distorts the planar geometry. In either case, depolarization resonances will be excited by synchrotron radiation. To see that, consider a nonplanar ring that has a vertical dispersion somewhere. A synchrotron photon emission at this location causes the electron to execute a vertical betatron oscillation. The vertical motion introduces the electron to experience horizontal magnetic fields in the quadrupole magnets. The spin of the electron will then rotate around the horizontal $\hat{x}$ axis and be forced to precess away from the nominal direction $\hat{y}$. Another mechanism of depolarization occurs when $\hat{n} \neq \hat{y}$, then even horizontal or synchrotron motions excited by synchrotron radiation depolarize the beam. Since synchrotron emissions are random events, this causes a diffusion of spin directions. This diffusion effect counteracts the radiative polarizing effect and at balance the beam will have a net polarization lower than 92.4%. The diffusion is the strongest near a depolarization resonance.

* Work supported by the Department of Energy, contract DE-AC03-76SF00515.

Invited talk presented at the Particle Accelerator Conference, Santa Fe, New Mexico, March 21-23, 1983.

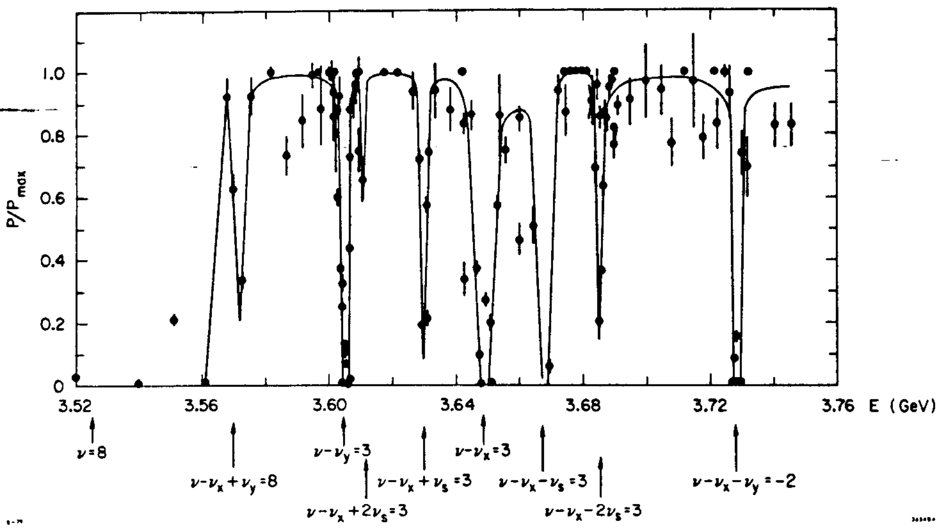

Fig. 2. SPEAR polarization normalized to $P_{max} = 92.4\%$ versus beam energy.

The reason the depolarization resonances are more enhanced for higher energy rings is that for a given distortion of the ring, the spin precession is directly proportional to the particle energy. If all rings have similar closed orbit distortions, the higher energy rings will suffer more. Very roughly, let us write[8]

$$P = 92.4\% \; \frac{1}{1 + (\alpha E)^2} \qquad (6)$$

where α is determined by the amount of distortion of the ring with $\alpha = 0$ for a perfect ring. Depolarization, being a diffusion effect, introduces into the denominator a factor $1 + (\alpha E)^2$. If we do the best to stay away from depolarization resonances and take $P \approx 85\%$ for SPEAR, then for a similar closed orbit distortion, i.e. similar value for α, we will get something like $P \approx 37\%$ for 15 GeV rings like PEP or PETRA, 14% for 30 GeV rings like HERA and TRISTAN, and a mere 3% for 70 GeV LEP. Clearly something will have to be done to improve this situation. See Fig. 3.

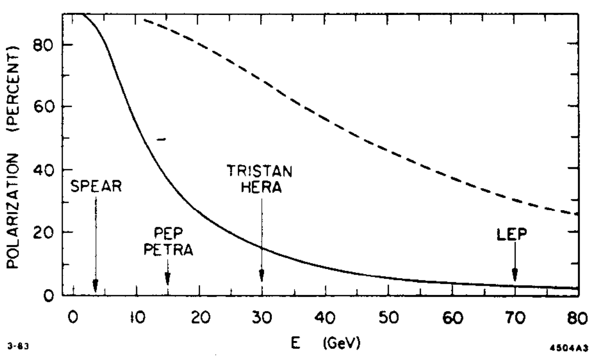

Fig. 3. Rough estimate of the achievable vertical beam polarization as a function of storage ring energy. The solid curve is to scale from SPEAR data. The dashed curve is to scale from PETRA data after "harmonic matching" (see later).

Longitudinal Polarization and Spin Transparency

Before we describe how to cure the problem associated with nonplanar distortions, let us mention another difficult problem that people are trying to solve. Namely one would like to have a beam with its polarization along the direction of motion of the beam. Since the natural beam polarization is along $\hat{y}$, we need to somehow rotate the polarization into the longitudinal direction $\hat{z}$ at the point where beams collide.

In fact, the solution to the two problems are closely related. The principle involved in solving both problems has been called the spin transparency conditions.[9] In this section, I will describe how the transparency conditions solve the longitudinal polarization problem and in the next section, I will describe how the same principle is applied to rings with imperfections.

It may seem easy to design an insertion that provides a longitudinal polarization at the collision point. All one has to do is to install a few horizontal and vertical bending magnets on one side of the collision point so that the polarization is rotated from $\hat{y}$- to $\hat{z}$-direction and then do a similar trick on the other side of the collision point to restore the polarization from $\hat{z}$- back to $\hat{y}$-direction. In the rest of the ring, polarization will be along $\hat{y}$ as if nothing had happened. The idea is schematically drawn in Fig. 4. The trouble with such a scheme is that one has forgotten about the depolarization effects which now must be considered because the ring is no longer planar.

Indeed, in a "spin rotator" scheme just described, the depolarization resonances will in general be greatly enhanced by the added insertion. The result typically is that the resonances become so strong that the beam polarization will be even much smaller than what Fig. 3 promises. (This is true even if the rotator is perfectly built.) What happens is that the rotator necessarily contains vertical bending magnets. This means there is necessarily vertical dispersion in the ring and, as we explained before, synchrotron radiation causes spin to diffuse and polarization will be lost.

The question is then how to have a spin rotator while at the same time it does not drive spin diffusion. Recalling that the spin diffusion comes from emission-excited orbital oscillations, one obvious solution is to somehow minimize the orbital excitation due to synchrotron radiation (by minimizing the vertical dispersion and by using weak and long rotator magnets). If we can decouple the orbital motion from synchrotron radiation, there will be no spin diffusion. This idea has been tried to some extend but was not very successful because it is simply an extremely difficult thing to do.

Fortunately there is another way out. The trick is to let the orbital motions be excited by synchrotron

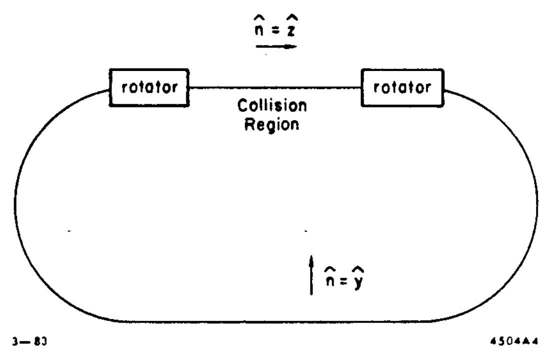

Fig. 4. A schematic design of a spin rotator.

radiation as much as they wish, but somehow design the storage ring so that the spin precessions made in the troubled regions add up to zero as a net result. In other words, by cleverly designing the storage ring, the depolarization terms are arranged to cancel one another so that as an electron executes emission-excited orbital oscillations, its spin precesses away but always comes back to the nominal direction whenever the electron completes one revolution. Consequently there will be no spin diffusion due to synchrotron radiation. The conditions on the storage ring lattice for this to occur is called the spin transparency conditions. The design procedure that allows these conditions to be implemented in the storage ring lattice is called spin matching.[9] In practice, one just inserts the rotator as in Fig. 4 and then adjust quadrupole strengths in appropriate regions so that the transparency conditions are satisfied.

It turns out that the strongest depolarization resonances are the linear ones including the integer resonances $\nu = k$ (or more precisely, the synchrotron sidebands of the integer resonances, but ν_s is usually very small) and the betatron sideband resonances $\nu \pm \nu_{x,y} = k$. Most of the transparency conditions worked out so far are aimed at eliminating these resonances. As an example, the transparency conditions for a storage ring that consists solely of horizontal and vertical bending magnets and quadrupole magnets are given in Table I.

In Table I, s is the location where the transparency conditions are imposed; $\eta_{x,y}$ are the horizontal and vertical dispersion functions and $\eta'_{x,y}$ are their derivatives; $\hat{n}$, $\hat{m}$ and $\hat{\ell}$ are the spin vectors defined before; G is the quadrupole gradient; $\beta_{x,y}$ and $\psi_{x,y}$ are the betatron functions and phases; C is the circumference of the ring. Take $\nu + \nu_x = k$ resonance for example. To eliminate this resonance, we have two sets of conditions to choose from. The first set, namely $\eta_x = 0$ and $\eta'_x = 0$, is simply the conditions for not exciting a horizontal betatron oscillation due to a photon emission at s. If this cannot be achieved, then we would demand the second set of conditions, which essentially means the integration of spin perturbation around one revolution vanishes.

TABLE I

Resonances	Transparency Conditions that Eliminate the Resonances		
$\nu + \nu_x = k$	$\eta_x(s) = 0$	or	$\int_s^{s+C} ds\ (\hat{m}\cos\psi_x - \hat{\ell}\sin\psi_x)\cdot\hat{y}\,G\sqrt{\beta_x} = 0$
	$\eta'_x(s) = 0$		$\int_s^{s+C} ds\ (\hat{m}\sin\psi_x + \hat{\ell}\cos\psi_x)\cdot\hat{y}\,G\sqrt{\beta_x} = 0$
$\nu - \nu_x = k$	$\eta_x(s) = 0$	or	$\int_s^{s+C} ds\ (\hat{m}\cos\psi_x + \hat{\ell}\sin\psi_x)\cdot\hat{y}\,G\sqrt{\beta_x} = 0$
	$\eta'_x(s) = 0$		$\int_s^{s+C} ds\ (\hat{m}\sin\psi_x - \hat{\ell}\cos\psi_x)\cdot\hat{y}\,G\sqrt{\beta_x} = 0$
$\nu + \nu_y = k$	$\eta_y(s) = 0$	or	$\int_s^{s+C} ds\ (\hat{m}\cos\psi_y - \hat{\ell}\sin\psi_y)\cdot\hat{x}\,G\sqrt{\beta_y} = 0$
	$\eta'_y(s) = 0$		$\int_s^{s+C} ds\ (\hat{m}\sin\psi_y + \hat{\ell}\cos\psi_y)\cdot\hat{x}\,G\sqrt{\beta_y} = 0$
$\nu - \nu_y = k$	$\eta_y(s) = 0$	or	$\int_s^{s+C} ds\ (\hat{m}\cos\psi_y + \hat{\ell}\sin\psi_y)\cdot\hat{x}\,G\sqrt{\beta_y} = 0$
	$\eta'_y(s) = 0$		$\int_s^{s+C} ds\ (\hat{m}\sin\psi_y - \hat{\ell}\cos\psi_y)\cdot\hat{x}\,G\sqrt{\beta_y} = 0$
$\nu = k$			$\int_s^{s+C} ds\ \ \hat{m}\cdot(\eta_x\hat{y} + \eta_y\hat{x})\,G = 0$
			$\int_s^{s+C} ds\ \ \hat{\ell}\cdot(\eta_x\hat{y} + \eta_y\hat{x})\,G = 0$

At a first glance, the conditions listed in Table I are not practical at all. To completely eliminate depolarization resonances, it is necessary to impose the transparency conditions at all s where synchrotron photons can potentially be radiated. Since synchrotron radiation occurs at all bending magnets, the total number of transparency conditions must be very large, namely 10N, where N is the number of bending magnets.

Fortunately these 10N conditions are often either trivially satisfied or they degenerate into a much smaller number of conditions. For a planar ring, for instance, they are all satisfied because $\eta_y = 0$, $\eta'_y = 0$ and $\hat{m}$ and $\hat{\ell}$ are orthogonal to $\hat{y}$. For a rotator ring as shown in Fig. 4, it can be shown that there are only 10 nontrivial conditions to fulfill. The transparency conditions make the ring design difficult but certainly does not make it impractical.

Before going on to discuss rings with imperfections, it is worthwhile to mention one interesting related development: With the recent advent of mini-β^* lattices in various storage rings, the detector solenoids are deprived of having compensating solenoids adjacent to them. Although it helps the luminosity, this way of operation is very harmful to the beam polarization. So the question is how to make a detector solenoid spin transparent. It was found[10] that the depolarization due to the detector solenoid can be removed by inserting compensating solenoid at strategic locations. Those locations are away from the interaction region so that the compensating solenoids do not interfere with the mini-β^* installations. In addition, they are dispersion free and they have the property that the trajectory of a particle executing free horizontal betatron oscillation has equal slopes at those locations as at the detector solenoid. By implementing such a spin matching scheme, the detector solenoid is made spin transparent.

Ring with Imperfections

Now let us turn to the case of a distorted ring. Since in this case the depolarization comes from unknown imperfections, the 10N transparency conditions do not degenerate. To eliminate depolarization, therefore, one needs 10N knobs and the problem again seems impossible to manage. To see how this difficulty is overcome, note that the depolarization caused by imperfections is relatively weak -- at least compared with that caused by a rotator and only as bad as Fig. 3 shows. Consequently, the 10N conditions only need to be approximately satisfied. An inspection of the transparency conditions shows that there is indeed a way to do just that.

Again take the $\nu + \nu_x = k$ resonances for example. The two integral conditions in Table I of course really mean 2N conditions because the integrals are functions of s. However, if $\nu + \nu_x$ is exactly equal to k, the integrals become independent of s and the 2N conditions reduce to 2 conditions. This means two knobs are sufficient to eliminate the resonance, at least in principle, when the resonance condition is exactly fulfilled.[9] This means that not all of the 2N knobs are equally sensitive and, even somewhat away from a resonance, the same two knobs will still do the job approximately. To optimize beam polarization, therefore, one simply locates the dominating nearby depolarization resonances, tweaks the right knobs in the right direction and then the beam polarization will greatly improve. The question left -- admittedly a highly nontrivial one -- is what are the most effective knobs for each resonance. A number of clever schemes have been suggested.[9] One of them[9,11] has been applied to PETRA and it worked like a charm.

To see how it worked, let us assume n_y has been carefully minimized around the ring. An inspection of Table I then shows that the harmful depolarization resonances are $\nu \pm \nu_x = k$ and $\nu = k$, and they are driven because $\hat{m}$ and $\hat{\ell}$ are not orthogonal to $\hat{y}$, or equivalently $\hat{n}$ is not parallel to $\hat{y}$. The idea is therefore to correct $\hat{n}$ so that it becomes parallel to $\hat{y}$. The most effective knobs to do so are the m-th Fourier harmonics of the vertical closed orbit, where m is the nearest integer to the spin tune ν. The PETRA team had four knobs that corrects the 37th and the 38th sine and cosine harmonics ($\nu \approx 37.6$). The needed corrections hardly changed the over-all vertical closed orbit and yet by tweaking them, beam polarization has dramatically improved from 20% to 80%. It is estimated that $\hat{n}$ deviates from $\hat{y}$ by $\sim 1^o$ before correction and $\sim 0.3^o$ after correction. Figure 5 shows the measured beam polarization as a function of two of the harmonics. Polarization is obviously very sensitive to these knobs.

The technique used on PETRA has been called the harmonic matching.[11] Applying it to a range of beam energy, the beam polarization obtained is shown in Fig. 6. Note that there is still strong depolarization much closer to the resonances. This presumably is partly due to incomplete harmonic matching, but more importantly also due to the n_y effects.

If we extrapolate the PETRA data (85% at 15 GeV) to higher energy rings with imperfections, assuming a similar harmonic matching is applied and using Eq. (6), we find the dashed curve shown in Fig. 3.

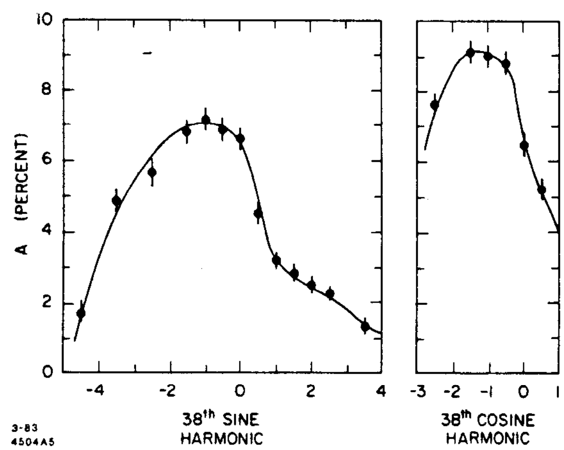

Fig. 5. Beam polarization versus the 38th harmonics of the vertical closed orbit distortion in PETRA. The harmonics are in arbitrary units. The parameter A is the asymmetry measured by the polarimeter; A = 10% corresponds to about 70% of polarization.

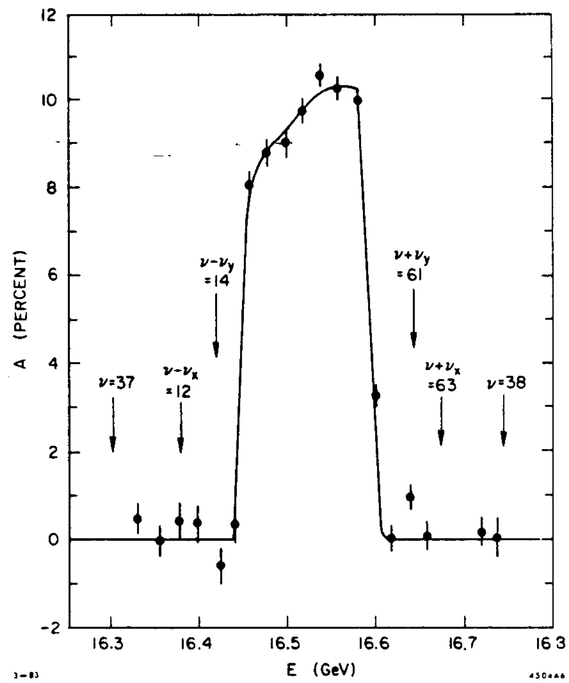

Fig. 6. PETRA polarization after harmonic matching.

The Problem of Energy Spread

So far, the situation looks rather encouraging; the longitudinal polarization can indeed be provided by a rotator insertion and imperfections can be effectively corrected by harmonic matching. However, these developments are based on linear theories. Life becomes difficult when nonlinear effects are involved, and one nasty nonlinear effect is that associated with having a large spread in particle energy (and therefore in spin tune). Since the energy spread is larger for higher energy rings, this problem is expected to be most serious for LEP.

Nonlinear effects excites the nonlinear depolarization resonances. In particular, a finite spin tune spread excites synchrotron sidebands of all linear resonances. One indication of this already happening at SPEAR was in fact shown in Fig. 2: the linear $\nu - \nu_x = 3$ resonance has two synchrotron sidebands on its each side. The widths of these sideband resonances can be related to that of the $\nu - \nu_x = 3$ resonance by Bessel functions using a frequency modulation analysis.[12-14] From such an analysis, one can define an enhancement factor d which is essentially the ratio of the total width of all the Bessel function synchrotron sidebands to the width of the linear resonance located at the center. Taking into account of this depolarization enhancement, Eq. (6) becomes something like

$$P = 92.4\% \; \frac{1}{1 + (1+d)(\alpha E)^2} \; . \qquad (7)$$

An accurate estimate on d is very difficult. Here let me just show in Fig. 7 the result of one such attempt.[13] According to Fig. 7, HERA is not going to suffer from the multiple synchrotron sidebands up to 40 GeV or so, while LEP beyond 70 GeV looks rather dismal. For instance, we find $d \approx 10$ for LEP at 80 GeV. If we take the dashed curve of Fig. 3 and take into account of the enhancement, the polarization drops to ~3%.

What can we do to improve this situation? One way is to do a much more precise harmonic matching so that the coefficient α in Eq. (7) is reduced by an order of magnitude. Another idea[13] was to use a special-purpose wiggler (the "dipole-octupole" wiggler[15]) to curtail

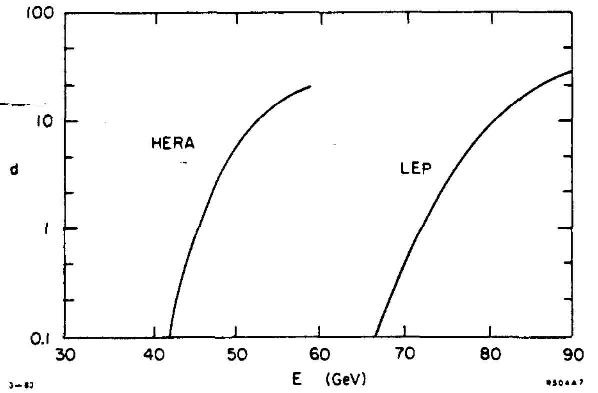

Fig. 7. A rough estimate of the enhancement factor d (log scale) as a function of beam energy for HERA and LEP.

the energy (spin tune) distribution of the beam. Still one more suggestion[16] is to insert a "spin chromaticity corrector" into the ring. Such an insertion consists of horizontal and vertical bending magnets and requires the implementation of the transparency conditions, just like the rotator does. After it is inserted in the ring, the spin tune of an on-momentum particle is still $a\gamma_0$; but for an off-momentum particle, the spin tune is not $a(\gamma_0 + \Delta\gamma)$ but some value closer to $a\gamma_0$. This device thus reduces the spin tune spread for a given energy spread. It is conceivable that a spin chromaticity corrector can be incorporated into a rotator.

If all ideas fail, there is still one last resort. It employs a powerful scheme called the Siberian snakes.[17] For this scheme to work, we need a "double snake" scheme in which the storage ring looks like that sketched in Fig. 8. There are two opposite regions where the snake insertions -- again consist of horizontal and vertical bending magnets -- are installed. With such a snake scheme, all particles have spin tune $\nu = 1/2$ irrespective of their energies. As a result, there is no spin tune spread and therefore no depolarization enhancement. There are complications involved in a ring with double snake, however. First of all, the transparency conditions need to take care of both insertions. Secondly, one half of the ring (say, the half with $\hat{n} = \hat{y}$) will have to be made up of sharp bends while the other half (with $\hat{n} = -\hat{y}$) ring is made up of smooth bends, as shown in Fig. 8. This is so that the radiative polarization -- that provides the beam polarization in the first place -- does not have a zero net effect. At present, it is not yet clear how these complication weigh against their potential benefits and this remains an unanswered question for LEP as far as beam polarization is concerned.

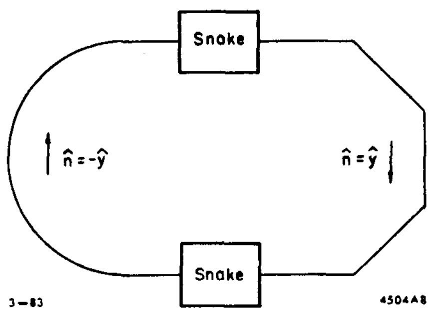

Fig. 8. A double-Siberian-snake ring. The two snake insertions are different -- one is of the "first kind," the other of the "second kind."

Beam-Beam Depolarization

Another important nonlinear depolarization mechanism is that due to the beam-beam collisions. As two beams collide, the very nonlinear space charge force kicks the spins as well as the trajectories of particles. Both the direct kicks on spin and the beam-beam excited nonlinear betatron motions are harmful to beam polarization if the beam intensity is high enough. The relevant nonlinear depolarization resonances are those involving ν_x and ν_y in Eq. (5).

To get an indication of the order of magnitude of the problem, one can insert a linearized beam-beam force in an otherwise spin-transparent ring to see how much it makes the ring opaque.[18] Such a calculation involves a linear theory in which the beam intensity is specified by the beam-beam tune shift parameter $\Delta\nu_{BB}$. The result of this calculation for PETRA predicts depolarization if $\Delta\nu_{BB} > 0.01$, which is about a factor 3 lower than what is required for a good luminosity.

Since this calculation is based on a linear model, and all linear depolarization effects can in principle be eliminated by spin matching techniques, the actual situation may not be as bad. Indeed, there are profound theoretical works[18,19] saying that the real beam-beam depolarization is not ~0.01 but ~0.03, right where it is needed for luminosity.

Figure 9 shows the experimental results taken at PETRA.[1,18] It demonstrates that it is possible to keep the beam polarization while maintaining a respectable luminosity. At $\Delta\nu_{BB} = 0.023$, a polarization of 80% was measured. On the other hand, as the beam intensity increases toward a higher luminosity, the beam polarization does suffer. In other words, the beam-beam depolarization is not bad, but bad enough to hurt.

It has been suggested[20] that it might be possible to impose a set of transparency conditions to make the ring spin transparent against the beam-beam perturbation. Such conditions would look dissimilar to those shown in Table I because they have to fight against nonlinear resonances. On the other hand, they are applied only at one location -- the collision point -- of the ring. Meanwhile, progress is being made[21] on the theory of the beam-beam transparency conditions.

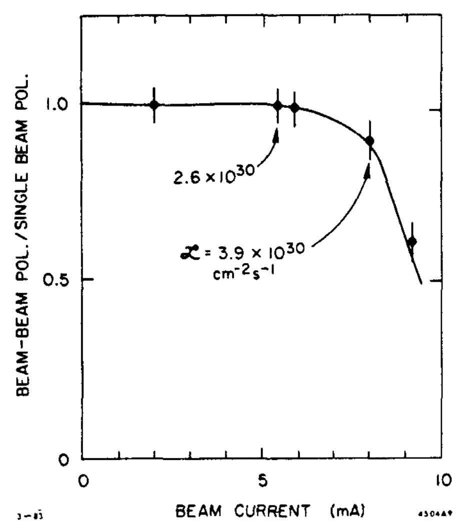

Fig. 9. Beam-beam caused depolarization vs beam intensity measured at PETRA. $\mathcal{L}$ is the luminosity.

Polarimeter

The problems discussed so far are related directly to the storage ring. We now turn to the techniques devleoped for measuring and for flipping the beam polarization.

The data for SPEAR in Fig. 2 and for PETRA in Figs. 5 and 6 are both taken by Compton polarimeters.[7,22] The device, sketched in Fig. 10, utilizes a laser that provides circularly polarized light in the visible frequency range. One shines the laser light against the electron beam and collects the Compton back-scattered photons. The up-down asymmetry of the back-scattered photons, now in the x-ray range, is directly related to the vertical polarization of the electron beam. The electrons that scatter the laser photons are knocked out of the acceptance of the ring. The counting rate is about 100 counts per second. To measure beam polarization to an accuracy of ~1%, it takes ~2 minutes.

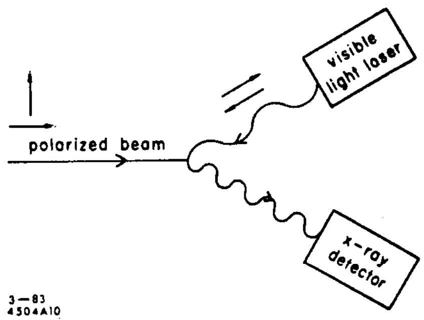

Fig. 10. A Compton polarimeter.

The back-scattered photons have an up-down angular spread $\sim 1/\gamma$. For a 50 GeV ring, this angle is $\sim 10^{-5}$ rad, which is rather small, but by properly arranging the detector geometry as well as the beam optics, it should be a straight-forward matter to extend the Compton polarimeter technology to HERA, TRISTAN and LEP.[7,22]

The Compton polarimeter can also be used to detect longitudinal beam polarization. The cross-section of the back-scattered photons no longer has an azimuthal angular dependence (i.e. up-down asymmetry), but its dependence on the polar angle is different for the two helicities of the laser light. By measuring the differential cross-section of the back-scattered photons while flipping the helicity of the laser light, the longitudinal polarization of the beam can be extracted. Again, the technique does not look fundamentally difficult if and when applied to the higher energy rings.

Spin Flipper

One question that has yet to be answered is how to provide longitudinally polarized beams of both helicities. It is easy to imagine that, if this is to be accomplished by the spin rotator, the rotator design will have to be very involved. It turns out that it might be possible to get around this problem by a neat technique developed at VEPP-2M.[23] The way it is done is to apply a high frequency (around 8 MHz) perturbing magnetic field to the polarized beam and slowly sweep the frequency ν_d through a depolarization resonance. If the sweeping speed is chosen properly, the beam polarization will make a beautiful 180° flip after the sweep is completed. In VEPP-2M, the perturbing magnetic field is provided by a weak solenoid, while the depolarization resonance is $\nu - 2\nu_s = \nu_d$. For the higher energy rings like HERA and LEP, the perturbing field is most likely replaced by a transverse magnetic field but otherwise a very similar technique can be used to flip the beam polarization.

If this technique works out and there is no obvious reason why it does not, a spin rotator needs to provide only one helicity. The other helicity can be obtained by the spin flipper. After the beam polarization is flipped, the natural radiative polarization will act against the beam polarization, but it takes one polarization time for this to take place and, in the meantime, the beam does process the other helicity. Another advantage of this scheme is one can selectively flip the polarization of one of the two beams or to have different polarizations for different bunches in the same beam.

Summary

To sum up, the over-all situation is a healthy one:

(1) The linear theory of beam polarization and depolarization is substantially understood. Thanks to the transparency conditions proper design of spin manipulators (rotators, Siberian snakes, spin chromaticity correctors, etc.) becomes possible and corrections for rings with imperfections have been reduced to a problem of finding the most effective correction knobs.

(2) Experts are working on the nonlinear theories. Their results so far are encouraging. Nonlinear depolarization effects associated with large energy spread seem to be a problem for LEP but there is no lack of clever schemes to choose from for defeating these effects. The beam-beam depolarization is only marginally harmful and there are again preliminary ideas of how to fight it.

(3) Polarization monitoring seems to require only a reasonable extension of the present technology.

References

1. G. Voss, talk given at the 5th Int. Symp. High Energy Spin Physics, Brookhaven (1982).
2. I.M. Ternov, Yu. M. Lokutov and L.I. Korovina, Sov. Phys. JETP 14, 921 (1962).
3. A.A. Sokolov and I.M. Ternov, Sov. Phys. Dokl. 8, 1203 (1964).
4. V.N. Baier, Sov. Phys. Ups. 14, 695 (1972).
5. D. Potaux, Proc. 8th Int. Conf. High Energy Accelerator, CERN (1971), p. 127.
6. U. Camerini et al., Phys. Rev. D12, 1855 (1975).
7. R. Schwiters and J. Johnson, talks given at the Workshop on Polarized Electron Acceleration and Storage, DESY report M-82/09 (1982).
8. J. Buon, DESY report M-82/09 (1982).
9. Talks by K. Steffan, A. Chao, R. Rossmanith, R. Schmidt, K. Yokoya, P. Coteus, S. Holmes, and A. Skuja, DESY report M-82/09 (1982).
10. D.P. Barber et al., DESY report 82-076 (1982).
11. H.D. Bremer et al., DESY report 82-026 (1982).
12. Ya. S. Derbenev, A.M. Kondratenko and A.N. Skrinsky, Part. Accel. 9, 247 (1979).
13. Talks by J. Buon, A. Kondratenko and K. Steffan, DESY report M-82/09 (1982).
14. A.M. Kondratenko and B.W. Montague, CERN-ISR-TH/80-38 (1980).
15. A. Hofmann, J. Jowett and S. Myers, IEEE Trans. Nucl. Sci. NS-28, 2393 (1981).
16. K. Yokoya, KEK report, submitted to Part. Accel. (1983).
17. Ya. S. Derbenev and A.M. Kondratenko, Proc. 10th Int. Conf. High Energy Accelerator, Protvino, Vol. 2 (1977), p. 70.
18. Talks by E. Courant, A. Kondratenko, J. Kewish, and K. Steffan, DESY M-82/09 (1982).
19. A.M. Kondratenko, Sov. Phys. JETP 39, 592 (1974).
20. K. Steffan, DESY M-82/09 (1982).
21. J. Buon, private communication, being prepared for publication (1983).
22. Talks by R. Rossmanith, R. Prepost, G. Baum and M. Preger, DESY M-82/09 (1982).
23. Ju. Shatunov, DESY M-82/09 (1982).