POLARIZATION SIMULATION STUDIES FOR LEP

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Abstract

This paper analyses the first-order depolarizing mechanisms responsible for the transverse polarization degree by means of simulation programs. It is shown that the Sokolov-Ternov effect causes the beam to polarize at a level of 4 to 30% with a time constant of 90 mn on well corrected standard optics. Further specific orbit manipulations (harmonic spin matching) yield up to 60% polarization using the nominal LEP wigglers and more than 70% if stronger and more asymmetric wigglers are used. First-order depolarizing mechanisms are thus shown not to prevent transverse polarization in LEP. The depolarization caused by the spin rotators and by the energy spread strongly enhanced by the wigglers is under study.

1 INTRODUCTION

Following a renewed interest from the physics community in polarized beams at the Z energy, a quantitative study was launched to estimate their feasibility. This paper is concerned with the prediction of the asymptotic transverse polarization degree, with the aim of

- understanding the energy dependance of the polarization degree and probing the Z region,
- testing the efficiency of polarization optimization techniques, the wiggler magnets being left off,
- studying the effects of the wigglers on the depolarization.

This study is done in the framework of the first-order spin dynamics, i.e. in the limit of small emittances and weak depolarizing mechanisms.

2 ENERGY SCANNING WITH SLIM

The first simulation results obtained for LEP [1] showed a strong dependance of the polarization on the integer part of the spin tune, with high polarization on several integer spin resonances. Another unpublished result predicted very low polarization.

Using the same program SLIM [2], but randomizing more systematically the optics errors, the essential features observed in [1] disappeared. Instead a periodic oscillation of the peak polarization is observed (figure 1) while a decrease like $(1+E^2)^{-1}$ could be expected from spin diffusion.

Based on [3], the Fourier analysis of the spin precession shows a potential periodic coupling between spin precession and orbital motion with the observed periodicity . The complete analysis [4] relates the spin resonance strength to the detailed closed orbit spectrum observed in the spin precession frame. It is shown that the polarization oscillation arises mainly from an insufficient model of an imperfect closed orbit.

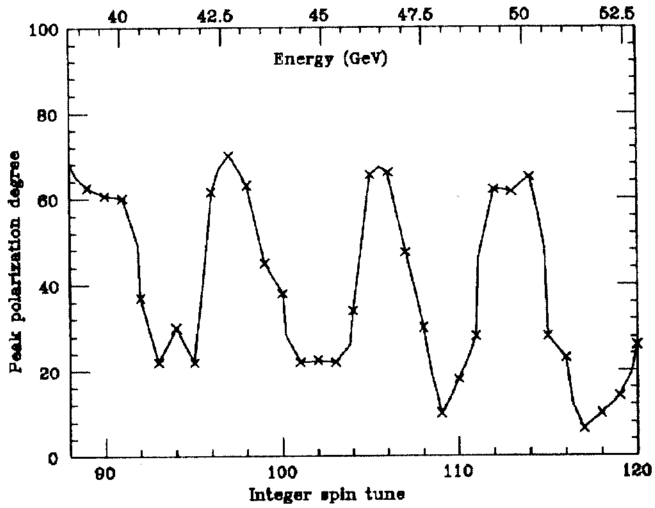

Figure 1: energy dependance of polarization

3 NATURAL POLARIZATION

Avoiding this limitation requires a significant sophistication in the handling of the optics. Luckily a new first-order polarization program SITF [5], has become available from DESY. Its optical part is inspired from PETROS [6] and thus potentially accepts a full description of an imperfect but corrected optics. Another advantage is that the lenses and magnets are treated in a better approximation (thick lens). Instead of using a model of an imperfect closed orbit, it became possible to specify realistic machine defects (strength and alignment) and to correct the resulting optics with only a few modifications.

polarization degree on uncorrected optics

The Sokolov-Ternov polarizing mechanism is much weaker in LEP than the depolarizing effects : for an rms uncorrected vertical closed orbit of 7 mm, the polarization degree is less than 1.5 % over the explored energy range, i.e. for $\nu \in [104,108]$.

polarization degree on corrected optics

Ten random optics were generated and the horizontal and vertical closed orbits corrected to reach :

$$<x>=0.93\pm0.22mm \qquad <y>=0.91\pm0.13mm$$

which is a reasonable target in practice.

The polarization degree was then computed around the Z energy, which is estimated to $46GeV$ per beam or $\nu=104.5$. Figure 2 shows the average over the 10 machines of

- the peak polarization observed between two integer spin tunes

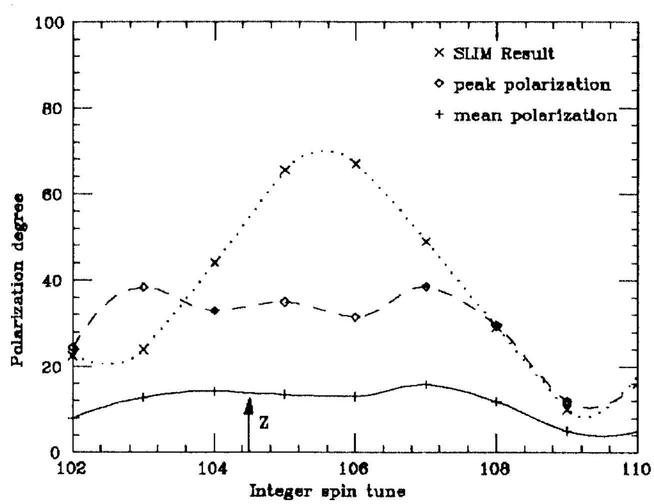

Figure 2: polarization around the Z

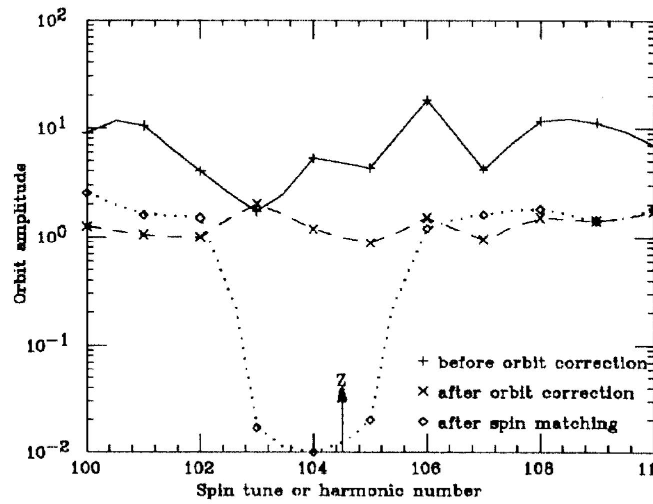

Figure 3: harmonics of the orbit

- the mean polarization over the fractional spin tune range .4 to .6 for each integer spin tune,
- the peak polarization degree as measured using SLIM (refer to the previous chapter)

The mean polarization is computated over a spin tune spread corresponding to the LEP beam energy spread; it is a naive indication of the strength of higher order effects.

The polarization degree is found significantly less than predicted by SLIM and the strong spin tune dependance has almost disappeared. There is still a depression at the "systematic" integer resonances [4], which should thus be avoided. Table 1 summarizes the results obtained at the Z energy:

Polarization	*peak*	*mean*
Average over 10	19.3%	14.2%
Peak over 10	32.9%	22.4%

Table 1: Statistics of polarization

The polarization level on a corrected optics appears sufficient to initiate an optimization phase.

harmonic spin matching

It is a method to compensate individual spin resonances. In first-order spin dynamics, three families of spin resonances, integer , synchrotron and betatron are responsible for depolarization.

The computation by SITF of their respective strengths shows that the betatron resonances have a negligible effect up to a polarization level of 70%. Depolarization is dominated by the synchrotron satellites of the integer resonances. These observations are indeed consistent with the PETRA experience [7] where over 80% polarization was achieved by the sole compensation of a few integer resonances.

Following [8], the driving term of the synchrotron resonance is given by :

$$J_s = \oint (\vec{m} + i\vec{l})(\vec{e}_y D_x + \vec{e}_x D_y) K(s) ds$$

where $\vec{n}, \vec{m}, \vec{l}$ is the spin base, $\vec{e}_x, \vec{e}_s, \vec{e}_y$ the orbital frame D_x, D_y the dispersions and K the gradient.

This integral is more transparent if the spin base is expressed as a function of the unperturbed spin base $\vec{n}_0, \vec{m}_0, \vec{l}_0$ of the perfect machine :

$$J_s = \oint K[e^{i\psi} D_y - D_x |\vec{dn}|] ds$$

where $\vec{dn} = \vec{n} - \vec{n}_0$ and ψ is the spin phase advance.

Whilst the effect of the dispersion D_y tends to cancel out, the effect of the tilts of the spin axis is additive. Higher polarization may thus be obtained by compensating the integer resonances responsible for $\vec{dn}$ through closed orbit manipulation.

The simulations show equally no correlation between the small residual rms orbit (0.7 to 1.2 mm) and the polarization, as well as no correlation between the rms vertical dispersion (or the vertical emittance) and the polarization. These observations suggest that the spectrum of the perturbations is more important that their rms strengths.

The compensation of the near-by integer spin resonances is obtained by a direct "measurement" and cancellation of the offending closed orbit harmonics, observed in the spin precession frame. It is thus an idealization of the heuristic approach carried in the control room, where the direct measurement is not available to the required accuracy. Resonance compensation has been done on one typical optics (figure 3).

Using four correctors, the compensation of resonances 104 and 105 yields:

Mean polarization	34% (was 20%)
Peak polarization	46% (was 27%)

The more sophisticated method developed for PETRA [9], based on machine symmetry, causes too large orbit deformations due to a difficult compensation of harmonic 106. Modified so as to use 8 families of 8 symmetric correctors, it yields :

Mean polarization	48% (was 20%)
Peak polarization	58% (was 27%)

4 POLARIZATION WITH WIGGLERS

nominal wigglers

The study may appear to be academic because the natural polarization time in LEP at 46 GeV is 5 hours, i.e. much too long.

LEP is equipped with wiggler magnets to control the damping times and the emittances at low energy. Although the polarization was not a major issue at that time, it had been decided to adopt an asymmetric design [10] which would decrease the polarization rise-time without enhancing too much the energy spread. This compromise yielded :

$$P_\infty = 70\%(was \quad 92\%)$$
$$\tau_p = 90mn(was \quad 300mn)$$
$$\sigma_\epsilon = 60MeV(was \quad 33MeV)$$

Simulation on the same basic optics but with the wigglers on shows little influence of the wigglers on the polarization level. This is clearly explained by A. Blondel in [12]: considering the transparency integrals and the Derbenev-Kondratenko formula, the wiggler magnets positionned at zero dispersion can be shown to further damp the already small depolarization due to betatron resonances but not to change the main depolarizing terms related to the integer resonance and its synchrotron satellites.

After harmonic spin matching, the wigglers are found to disturb sufficiently the harmonic 104 of the closed orbit (edge effect ?) so as to result in a loss of 10% in polarization degree, presumably recoverable. It thus appears in principle possible to achieve 60% of peak polarization with a rise-time of 90 mn.

However the spin matching process which is deterministic in the simulation may only be carried out empirically in the control room. Depending upon the number of orbit harmonics corrected, it may be estimated to take between 8 and 16 hours and even more if a more refined spin matching would be attempted (compensation of harmonics of the dispersion,...)

The implementation of harmonic spin matching at LEP would thus certainly be hampered by the duration of the operation (optics reproducibility, breakdowns,...)

dedicated wigglers

It became soon clear that the polarization rise-time must be improved, even if the beam energy spread is increased. A new dedicated scheme has been proposed [12] with the following characteristics :

$$P_\infty = 88\%$$
$$\tau_p = 36min$$
$$\sigma_\epsilon = 84MeV$$

Simulating ten perturbed corrected optics shows again no influence of the wigglers before spin matching and the same strong correlation between polarization and tilt of the spin axis $\vec{dn}$ (figure 4), calling clearly for a compensation of the near-by integer resonances.

Harmonic spin matching carried on a typical optics gives

$$72\% \quad polarization$$

The closed orbit harmonics 104 and 105 are compensated using closed orbit bumps in place of individual correctors; the advantage of the method is to localize the perturbations. Further work [11] shows that another improvement may be gained with the same tools, by using interferences between resonances. The best polarization level achieved so far reaches 85%.

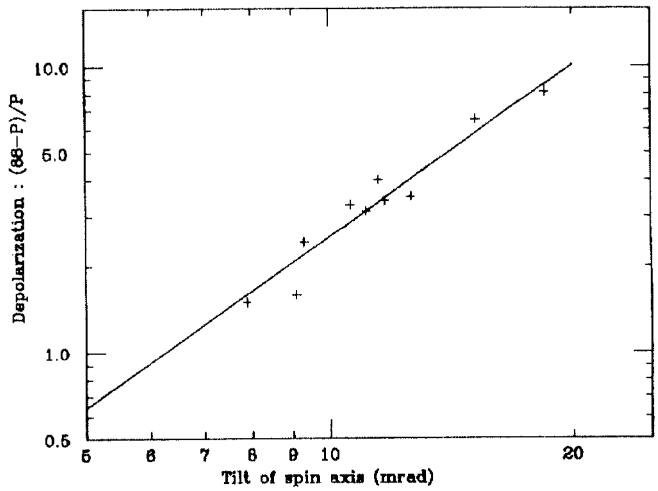

Figure 4: depolarization versus tilt of spin axis

5 CONCLUSION

It has been shown that, in spite of the high energy, a significant polarization degree may be reached in LEP. The rise-time is however too long and strong wigglers are necessary to shorten it. They however enhance the beam energy spread which in turn causes a depolarization not included in the first-order dynamics; this subject is presently under study.

6 ACKNOWLEDGEMENTS

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