IMPLICATIONS OF POLARISED BEAMS ON LEP DESIGN AND CONSTRUCTION

B.W. Montague

1. Introduction

A recent study\(^1\) has shown that there are good hopes of obtaining polarised \(e^+e^-\) beams in LEP Version \(^2\) (Pink Book) up to \(\sim 50\) GeV by relatively orthodox techniques, and even up to \(90\) GeV if more radical methods such as Siberian Snakes are admitted. Presentations and discussions at the Polarisation Symposium in Lausanne indicated a lively interest in spin physics with \(e^+e^-\) collisions around the \(Z_0\) pole, and confirmed the recommendation of the Les Houches Summer Study\(^3\) that nothing in the LEP design should prejudice the use of polarised beams. For the LEP e-p option polarised electrons are much more important than for e\(^+\)e\(^-\), and probably vital for a large and important part of the e-p physics programme.

To implement this recommendation certain decisions must be taken before the LEP parameters are frozen and, in preparation for possible polarised-beam operation, a longer-term programme must be established. The purpose of this note is to draw attention to the essential features and their implications.

2. Early Decisions

Phase I operation of LEP will most likely be concentrated around the \(Z_0\) energy at about \(46\) GeV per beam. Polarised beams will be useful here to distinguish between the "standard model" (with one \(Z_0\)) and extended gauge theories with more than one \(Z_0\). There could therefore be some interest in having polarisation even at a fairly early stage of Phase I operation. The main issues to be settled in order for this to be possible are discussed below.
2.1 Betatron tunes $Q_x, Q_z$

Depolarisation occurs when the spin-procession frequency $\nu$ resonates with various combinations of betatron frequencies and closed-orbit harmonics. In the present context the most dangerous resonant conditions are:

(a) $\nu \approx Q_z, Q_x$ (betatron resonances)
(b) $\nu \approx k + k_z Q_z$ (betatron plus c.o. harmonics)
(c) $\nu \approx k$ (c.o. harmonics)

where $k, k_z$ are positive or negative integers, $k$ being the order of the relevant vertical closed-orbit harmonic. The main depolarising effects arise from radial fields associated with vertical motion, the horizontal motion being important mainly in the neighbourhood of $\nu = Q_x$.

At 46 GeV the spin tune $\nu = \gamma(\kappa-2)/2$ is about 104.5. LEP Version 8 of the Pink Book has betatron tunes $Q_x \approx 70.3, Q_z \approx 74.5$ well removed from $\nu$, making it possible in Ref. 1) to hold out hope for polarised beams using relatively orthodox correction methods. Version 9 with a 90° phase advance per cell does not permit this optimism since the vertical tune $Q_z = 102.3$ is very close to $\nu$.

To see why this is so we look at Fig. 1 which shows the ratio of the $k$-th harmonic $z_k$ of the orbit distortion to its peak value $\hat{z}$ in an uncorrected machine with a normal error distribution; the $Q$ values are taken at the quarter integer for a proper comparison. For $Q_z = 74.25$, the orbit harmonics $z_k$ corresponding to the $Z_o$ energy region are well below 1% of the peak orbit distortion $\hat{z}$. Correction of these harmonics requires only weak fields which would have a very small effect on the orbit, if appropriately distributed. In contrast, the current Version 9 tune $Q_z \approx 102.25$ is dangerously near to the $\nu = Q_z$ resonance and, in addition, would require correction of very strong orbit harmonics close to betatron frequency down to a level which is probably not attainable. A change of the tune to $Q_z = 114.25$ (as suggested by A.M. Rutton) might be sufficient to avoid the effects of the $\nu = Q_z$ resonance (a) above but still leaves strong orbit harmonics driving resonances of type (b) and (c).
It should be kept in mind that Fig. 1 shows approximate expectation values based on average statistics for a large number of machines, and that any particular machine may have an harmonic spectrum differing considerably from this in a completely unpredictable manner. The above estimates should therefore be interpreted conservatively.

The permissible orbit errors relevant to the integer resonances \( \nu = k \) are shown in Fig. 2. It is assumed that the depolarisation time \( \tau_d \) must be at least ten times the polarisation time \( \tau_p \) and the energy such that the spin tune \( \nu \) is at least 1.5 units away from the nearest systematic integer resonance \( k = mS \), where \( S \) is the superperiodicity and \( m \) an integer. The lower curve shows the maximum harmonic amplitude admissible. The upper curves for the two extreme \( Q_z \) are obtained by folding the lower curve with the corresponding harmonic spectra of Fig. 1; they show the peak closed-orbit deviation \( \tilde{z} \) for a hypothetical uncorrected machine with normal statistical errors having the harmonic amplitudes of the lower curve. For \( Q_z = 74.25 \), the required \( \tilde{z} \) near the \( Z_0 \) energy is not so much less than might be obtained in practice with a well-aligned machine before correction, implying that reduction of specific harmonic amplitudes by a relatively modest factor of 3 to 5 could already be effective. With \( Q_z = 114.24 \) however, the harmonic correction would be more difficult by a further factor of at least 4.

Since it seems rather improbable that polarisation could be obtained at the \( Z_0 \) energy with a high-tune LEP, the Pink Book betatron tunes (or something near to them) should be retained for Phase I operation, at least as a working option. If, for economy reasons, only one tune is foreseen for Phase I, the lower one of the Pink Book seems perfectly appropriate. The high tune concept was introduced into LEP to improve the performance in the upper energy range; the justification for retaining it as the sole option around 50 GeV must be rigorously scrutinised. One of the arguments could be the possible cost saving in installing initially only the smaller number of sextupole busbards necessary for a 90° lattice as compared with a 60° lattice. Later installation of the additional busbards around the 30 km circumference of an operational machine would be such a major operation as to inhibit any question of polarised beams for an indefinite period.
2.2 Closed-orbit correction

Immediate decisions under this heading are rather painless. All that is required at present is to ensure that the spaces foreseen in the lattice for pick-up electrodes and small correcting dipoles remain available in the future. Only some of these spaces are so far dedicated to normal closed-orbit correction but others, strategically positioned, will be required for the necessary harmonic correction schemes.

2.3 Polarising wiggler

The natural polarisation time in LEP at 45 GeV is about 9 hours and a wiggler is required to reduce this to an acceptable value. Two examples are given in Ref. 1); one of these requires a short superconducting dipole of 5T, rather similar to that already operating at Daresbury. The requirements for a polarisation wiggler are sufficiently close to those for a synchrotron-radiation source that the same wiggler system could be used for both. A few metres of straight section at the ends of the arcs should be reserved for this, pending a more detailed design.

2.4 Spin rotators

Effective use of polarised beams in LEP requires that the polarisation be rotated into the longitudinal direction at the interaction points. This can only be achieved at high energies by the use of alternating vertical and horizontal bending magnets, with a consequent displacement of the vertical orbit from the median plane.

Such spin-rotator sections would clearly not be incorporated in the initial LEP design and would only be installed once it had been established that transversely-polarised beams can be obtained. It must then be possible to introduce the spin rotators within the confines of the existing LEP tunnel and with the minimum disruption of operation.

The scheme proposed leaves the horizontal projection of the orbit essentially unchanged and confines the vertical orbit displacements to the dispersion-suppressor sections either side of the interaction region(s) where longitudinal polarisation is required. These vertical bumps have to be of
opposite sign on each side. Two variants have been examined, one with separated vertical/horizontal bending, the other with combined bending in the two planes using dipoles rotated about the beam axis. The combined-bend rotator looks more favourable geometrically and would require peak vertical orbit displacements typically around 300 mm.

To leave open the possibility of adding such spin rotators at a later date, the space above and below the magnetic elements in the dispersion-suppressor sections should be kept free of pipes, cables etc. The tunnel layout shown in the Pink Book would appear to accommodate such modifications, though some magnetic elements would probably require special supports because of the limited floor clearance. It would in any case be advantageous to allow, if possible, a margin over the ±300 mm vertical displacement, in order to leave some flexibility for optimising the basic design of the rotators.

3. Preparation for Polarised Beams in Phase I

In addition to the immediate precautions discussed in Section 2 some further studies will be necessary during the period of detailed design and construction of LEP.

3.1 Special correction requirements

Normal orbit correction methods are inappropriate for reducing the amplitudes of harmonics near the spin precession frequency, for which special schemes must be developed. The total correction strength required is quite small but the positions of pick-ups and corrector dipoles required to suppress particular harmonics will require detailed study. Suitable computer algorithms for analysing the harmonic spectrum and calculating the corrections need to be developed.

Correction of the vertical dispersion and the spin chromaticity is closely related to orbit correction. Detailed analytic work will be necessary to establish the required relations between these quantities for simultaneous correction by the same system.

3.2 Polarimetry

A fast polarimeter will be required to detect, measure and optimise the polarisation of the beams. The only suitable method known to date is
Compton scattering from a circularly-polarised laser beam, which has been used at SPEAR and at PETRA. Extension of this method to LEP energies appears feasible but will require some detailed study and development. Much of this design work is largely independent of the LEP machine itself and could usefully be undertaken by a laboratory outside CERN with the necessary interest and expertise in the subject.

3.3 Design of spin rotators

The basic scheme of Ref. 4) requires further study and refinement before it can be considered satisfactory. In particular, the vertical dispersion at the ends of the section must be matched to zero and the energy bandwidth should be extended by compensation of spin chromaticity or, possibly, a limited degree of variable geometry. The possibility of using a mixture of separated and combined vertical/horizontal bending should be examined. Some reduction in the overall length of the rotator and in the orbit displacement might be feasible if the constraints on magnetic field strength and synchrotron radiation were relaxed somewhat.

4. Conclusions

The most important requirement for polarisation in LEP is that a low betatron tune, near to that of the Pink Book Version 8, be available early in Phase I operation. Provision should be made for special orbit correction schemes and polarising wigglers. The space above and below the magnets in all the dispersion-suppressor regions should be kept free of permanent installations such as pipes, cable runs etc. to a distance of at least 300 mm, for later addition of spin rotators.

With these requirements satisfied, studies should proceed on methods of harmonic orbit correction, laser polarimetry and improved spin rotators, in order to establish at an early stage the feasibility of polarised beams in LEP and to prepare for their implementation in physics operation.

References
FIG. 4 RATIO OF 4th ORBIT HARMONIC TO PEAK AMPLITUDE
(normal errors)

\[ Z_k = 2Q \frac{\sin \pi Q_z}{\pi (Q_z^2 - k^2)} \]

\[ Z_k / \bar{Z} \]

\[ Z_0 \]

\[ W_z \]

\[ \frac{1}{Q_z} \]

\[ 74.25 \]

\[ 102.25 \]

\[ 44 \]

\[ 66 \]

\[ 88 \text{ GeV} \]

\[ \text{GeV} \]

Gepr.
Ges.

BWM 16.10.80