A vertical mid-arc separation system for an 8 $e^+ \times$ 8 e^- bunch operation of LEP2 with 90°/60° phase advance optics

W. Kalbreier, G. Roy, F. Ruggiero
CERN - SL Division
CH-1211 Geneva 23

1 INTRODUCTION

A scheme for vertical separation at the mid-arc encounters in LEP was proposed a few years ago [1] and later abandoned for the long-range horizontal separation scheme known as pretzel. Since for LEP2 a luminosity increase by at least a factor four is required, the vertical separation proposal is now revisited, based on the new 90°/60° optics, as a possible solution to the insufficient bunch currents achieved so far with the current pretzel scheme[2]. This vertical mid-arc separation would reuse the unipolar pretzel separators, after some minor modifications and a rotation of 90° around the longitudinal axis. In total eleven pretzel separators will become available for this purpose, so that an additional five units would have to be built to provide the required sixteen units for the eight arcs of LEP.

2 MOTIVATION

Since a vertical orbit offset in sextupoles creates coupling between the transverse planes of motion, it is advantageous to remove the sextupoles located inside the closed separator bump. Unfortunately a reduction of dynamic aperture by about 25% in this configuration was observed in simulations for the 1990 study, so that leaving the sextupoles in place had to be considered. However, it was shown that the resulting coupling could be cancelled by an adequate choice of bump polarities. The remaining effect is then the vertical dispersion arising from the vertical orbit, with a RMS value of $D_y = 6\ cm$ in the arcs.

With the new 90°/60° lattice in operation in LEP since 1993, the bump spans three arc-cells; it has been shown that the reduction of dynamic aperture with missing sextupoles (figure 1) is much smaller than in the previous study. The chromaticity correction also benefits from this configuration and this allows us to envisage the removal of the sextupoles located inside the bump, therefore ensuring that no coupling is generated. In turn the symmetry of bump polarities is now used to minimize the vertical dispersion generated. Since sextupoles are missing in three out of thirty-one cells per arc, the strengths of the remaining sextupoles increase by about 10%.

Figure 2 shows the geometry of the lattice around the mid-arc point, with normal dipoles replaced by injection dipoles (half as long and twice the field of normal dipoles) at both ends of the bump in order to make room for the separators. The closure of the bumps relies on the precise vertical phase advance of the arc cells and virtually cannot be tuned otherwise.

3 SEPARATION

The criterion chosen for the amplitude of the vertical bumps is that the total horizontal beam-beam tune shift from the eight mid-arc collision points should be lower than the horizontal beam-beam tune shift from the four experimental IPs when the beams are separated. This criterion, for typical LEP injection conditions with emittance wigglers powered, requires a full separation of 2 $\times$ 9.8mm at 20 GeV, equivalent to $8\sigma_x$. At 90 GeV the vertical separation is about 2×2.3mm, equivalent to only $1.6\sigma_x$. The total separation is actually larger than this thanks to the "energy sawtoothing effect". The two beams, having slightly unequal energies in the arcs, follow different orbits in the horizontal plane, providing a natural horizontal separation about equal to the vertical separation. In terms of beam-beam tune shift the total contribution of all eight mid-arc encounters is $(\xi_x)_{\text{mid-arc}} = 0.016\ (0.021)$ per mA of bunch current at 20 GeV (90 GeV, with sawtooth effect).

4 SEPARATOR LAYOUT

After the experience with the pretzel separators when exposed to a severe synchrotron radiation flux, the unipolar mid-arc separators (see table 1) are constrained to an operation at positive polarity only, with a limitation of the electric field strength to about 1 MV/m in order to minimize the rate of beam-induced electrical breakdowns. Furthermore, the units should be protected by vertical collimators to reduce the flux of multiply scattered synchrotron radiation photons hitting the separator electrodes. With a vertical aperture of the standard LEP vacuum chamber of 70 mm, the separator electrodes should be further retracted by at least 30 mm, so that the minimum inter-electrode gap height is some 100 mm.

5 HIGH-VOLTAGE SUPPLY

The mid-arc separators will be connected to High Voltage generators which cannot be placed directly into the LEP tunnel, since they contain some electronic components which can be damaged by synchrotron radiation. Several variants of possible locations of the generators have been studied, such as excavating a new cave next to the mid-arc positions or installing the generators in the existing underground caves located at the even interaction points, requiring long High Voltage cables of about 1500 m length. A detailed cost analysis has revealed that these variants are almost comparable in price. Practical arguments, however, clearly favor the last option. One gener-

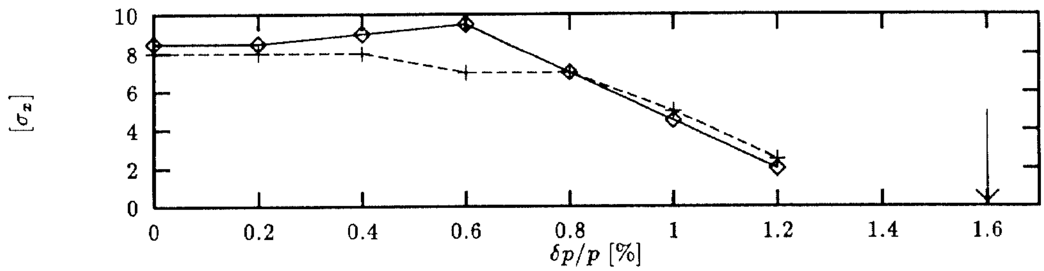

Figure 1: Comparison of the dynamic aperture with (solid line) and without (dashes) the sextupoles of the mid-arc bumps. This study was made on the physics optics used in 1993 with no radiation effects and the bumps were actually turned off. The limit of the RF bucket is shown at $\delta p/p = 1.6$ %

Table 1: Main parameters for mid-arc separation for LEP2 with a 90°/60° lattice.

Separator length	3.38 m
Electrode length	3.00 m
Electrode gap	100 mm
Nominal operating voltage	100 kV
Nominal field strength	1 MV/m
Nominal deflection at 90 GeV	33 μrad
Total separation at 20 GeV	$\approx$ 20 mm or 8.0 σ_x
Total separation at 90 GeV	$\approx$ 4.6 mm or 1.7 σ_x (without sawtooth)
Number of separators	16

ator would be able to power the two adjacent arcs simultaneously, and an intervention for repair could take place without need of access to the LEP machine.

6 SYNCHROTRON RADIATION SCREENING

Experience with the vertical separation system and the horizontal pretzel separation system has shown that the separator electrodes must be screened against synchrotron radiation in order to achieve the low rate of electrical breakdowns ($\leq$ 0.001 per hour and per unit) necessary for a reliable collider operation.

In a dedicated LEP machine experiment at injection energy, separators of the vertical separation system were operated at a gap height reduced by a factor 1.5 with respect to standard operation[3]. It was shown that each breakdown resulted in a complete loss of the beam, and the breakdown rate at 2.5 MV/m increased by a factor 400, limiting the bunch currents to an unacceptably low value of below 0.2 mA. This was the first evidence in LEP separators of electrical breakdown induced from the relatively low flux of synchrotron radiation produced in the quadrupoles of the low beta insertions, where the contribution from the high intensity flux from the arc dipoles is negligible.

From 1991 onwards with the installation of the horizontal pretzel separators, located at the entrance of the LEP arcs, the synchrotron radiation induced separator sparking became a major problem[4]. It was found that collimating of the synchrotron radiation would reduce the spark rate by only a factor two. This was completely insufficient when operating the unipolar separators at the negative design polarity where a spark rate of the order of 6 per hour per unit was observed. Operating the pretzel separators at positive polarity cured this problem, since the spark rate became as low as $< 7 \times 10^{-4}$ per hour per unit.

Since the separator electrodes of the mid-arc scheme will be positioned well beyond the vertical aperture of the vacuum chamber of 70 mm, no direct synchrotron radiation photons from the main dipoles will hit the electrodes. Thus, only scattered photons have to be taken into account. For photons confined in the vacuum chamber at least two reflections at the wall are needed in order to reach the separator electrodes. The intensity of this flux could be reduced by a factor of two by a pair of vertical collimators adjacent to each separator[5].

At 90 GeV the critical energy of the photons will be 540 keV for the standard dipoles and twice this value for the adjacent double field units. Photons of such high energy will not be absorbed either in the vacuum chamber wall or in the attached lead shield (8 mm horizontally and 3 mm vertically). After one scattering these photons could hit the electrodes, so that some additional vertical lead shielding at the vacuum chamber near the separators will be necessary. A wall thickness of 22.5 mm (45 mm) will reduce the photon intensity at the critical energy by about a factor 10 (100)[5].

7 OPTICS PERTURBATIONS

The perturbations to the optics due to the vertical electrostatic bumps are very small. Since the sextupoles located inside the bumps are removed in our scheme there is no coupling generated and vertical dispersion is minimized by choosing the symmetry of the polarities of the bumps. The RMS value along the whole ring can be kept below $D_y = 3\ cm$. This can be compared to typically measured

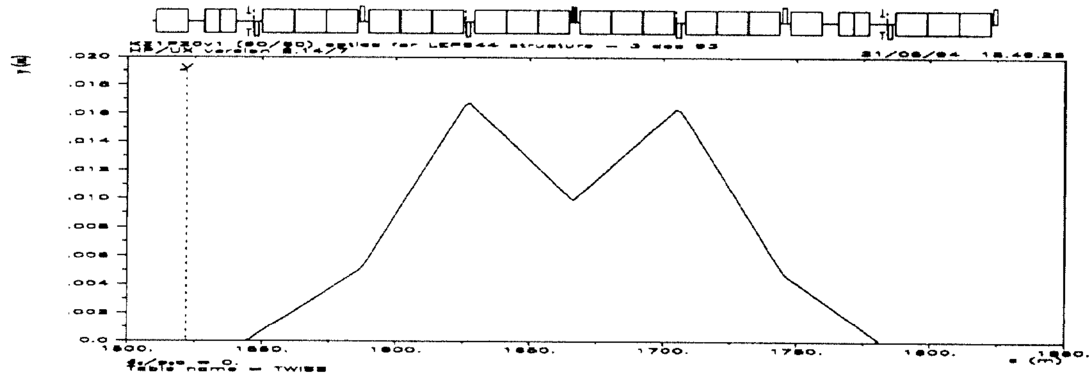

Figure 2: Vertical orbit in the mid-arc region. The separators and the stronger injection-type dipoles replacing normal dipoles can be seen on the diagram.

values of 5 to 6 cm in LEP in 1993. In the accelerating cavities the vertical dispersion is also kept to low values so that the excitation of synchro-betatron resonances through the Sundelin effect is not a problem. Tunes and chromaticities hardly change compared to the nominal LEP machine.

The introduction of the other beam perturbs the optics through the beam-beam kick at the separated encounters. This vertical kick produces a small residual vertical orbit of opposite sign for electrons and positrons. It is small enough that we do not need to foresee a cure – one additional separator at the mid-arc point – for this. Side effects of this vertical orbit are, however, seen in the form of coupling and vertical dispersion. The coupling generated is of the order of $|C| \approx 7. \times 10^{-5}$ for the resonance width which translates into an emittance ratio through this effect of $\epsilon_y/\epsilon_x \approx 1. \times 10^{-6}$, which is negligible for LEP. The vertical dispersion is also very small but, caused by an electrostatic effect, it has opposite sign for electrons and positrons, which makes it hard to correct. There are no sizable electron-positron tune splits and chromaticity splits are negligible.

8 FURTHER IMPROVEMENTS

In order to benefit from the higher β_y at the defocusing quadrupoles, it was suggested[6] to try and shift the mid-arc collisions by half a cell. This is easily achieved by shifting the pretzel bunches at injection by about 88 RF buckets. The nominal interactions points, where "normal" bunches meet "normal" bunches and "pretzel" bunches meet "pretzel" bunches, are not perturbed while the "mid-arc" crossing points, where "normal" bunches meet "pretzel" bunches, are translated by half this quantity. The potential problem of this scheme is that the beam-crossing frequency is no longer unique and would require the experiments to open a larger acquisition window of about 263 ns. This has already been envisaged for the bunch-train project at LEP for which a window opening up to 500 ns is possible.

9 CONCLUSION

We have looked at the possibility of replacing the current pretzel scheme in LEP, where maximum current at injection will limit the luminosity at high energy, with a scheme with local vertical separation at the center of each of the eight LEP arcs. The required separation is well within reach of the current pretzel separators which can be reused. The optics perturbation are very small compared to the large effects of pretzel; this is a consequence of removing the sextupolar elements within the span of the bumps. Some small perturbations have been identified but should not cause problems for operation of LEP2. Installation of the separators has been studied and is feasible. The major advantage of this scheme over the pretzel scheme is in its simplicity and therefore ease of operation. Spanning only short regions of the LEP arcs guarantees minimal perturbations of the optics and would gain back some of the flexibility currently missing with the pretzel scheme.

10 REFERENCES

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