Lattice modifications for the LEP energy upgrade

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Abstract

In its second phase LEP will operate at energies high enough to produce W^+/W^- pairs. This requires both the use of a low emittance lattice (90° phase advance per cell) and the installation of superconducting cavities to provide the necessary RF power. The present layout would not allow to reach the required energy, because the quadrupoles of the insertions are not strong enough. The LEP insertions have therefore to be redesigned. To accomodate the additional cavities, the RF regions have also to be modified. As a result, the original symmetry of the machine will be broken. The lattice modifications imposed by these constraints are discussed.

1 INTRODUCTION

The objective of the LEP 2 project is to operate the machine at energies high enough to produce W^+/W^- pairs. Both the inherent reduction of cross section for these events and the increased radiation at higher energy require two major modifications of the present machine. First the luminosity has to be maximized, which can be achieved by using a low emittance lattice (90° phase advance per arc cell). Secondly, superconducting cavities have to be installed to provide the necessary RF power to compensate for the larger energy losses (1.85 GeV at 90 GeV).

In 1988, a first study on a possible layout for the energy upgrade was published [1]. However, since the overall length of the superconducting units has increased, they would no longer fit into the layout originally proposed. On top of this, experimental evidence of a strong coupling in LEP showed that the initially proposed betatron tunes would not be suitable. It thus follows that a completely new design had to be considered.

2 GENERAL BOUNDARY CONDITIONS

The boundary conditions which have been retained for the present study are the following:

- The final layout should allow for an energy of 100 GeV.
- The low-β insertions should be tunable within a range comparable to that of the present LEP ($5.25 < \beta_x^* < 1.25$ m and $0.21 < \beta_y^* < 0.05$ m).
- The necessary layout modifications should be accomodated with a minimum of additional quadrupoles, power converters and modifications of the vacuum system.
- The highest achievable level of compatibility with other projects such as the operation with eight bunches (Pretzel [2]) and polarization should be aimed at.

2.1 Constraints from the magnets

The major incompatibilities of the present LEP 1 magnets with an operation at 100 GeV can be summarized as follows:

- The steel-concrete cores of the injection dipoles, which have twice the field of the arc dipoles, will saturate progressively above 65 GeV and will have to be replaced above 75 GeV.
- The superconducting quadrupoles (QSC) of the low-β insertions should operate satisfactorily up to about 75 GeV, beyond which they will have either to be pulled back (with a corresponding increase in β^*), or replaced. Since shifting back these magnets would lead to a reduced luminosity, LEP 2 will be equipped with new superconducting quadrupoles of the same length but with a gradient increased from 36 to 55 T/m.
- The first two doublets of the high-β insertions (QL1 and QL2) can only operate up to 65 GeV and 74 GeV respectively.

As far as the sextupoles are concerned, there is no basic limitation. The choice of 90° phase advance simply requires a rearrangement of the sextupoles circuits in order to work with four (instead of six) sextupole families.

2.2 Constraints from the RF sections

Originally, it was foreseen to bring modules of two SC units down in the tunnel and to assemble a total of 8 cavities in situ. This procedure implied not only to open the cryostats but also the vacuum, exposing the cavities to contamination in the tunnel.

The resulting degradation in the SC cavities performance would not be tolerable. It has therefore been decided to assemble cavities in modules of 4 units on the surface and to close the beam vacuum with valves. The latter will only be opened once the cavities are installed in the machine and good vacuum conditions have been established. The addition of the valves and the related transition parts have a non-negligible impact on the layout since the overall length required for the cavities has increased substantially. As a consequence, the present spacing between the quadrupoles in the RF sections (22.3 m) is insufficient to accomodate two modules of SC cavities and a completely new design of these regions has to be considered.

3 RF REGIONS

Presently, the straight sections around all four even interaction points (IP) are the same. Such a symmetry will be broken with the installation of the SC cavities. The number of SC cavities required to reach energies comfortably above the W-pair production threshold will evidently depend on the performance achieved in operation. However, since the Cu cavities will remain in the machine, the layout of the RF regions around IP2/IP6 will be different from that around IP4/IP8. It thus follows that the actual fourfold symmetry of the machine will be reduced to a twofold symmetry.

3.1 *Installation of SC cavities around IP2 and IP6*

Considering the space already occupied by the conventional Cu cavities, the layout modifications around IP2/IP6 are minor and rather straightforward. The basic scheme is to install on each side of the IP:

- 2 × 4 cavities between QS4 and QS5 (already installed on the left of IP2 and used for LEP operation).
- 2 × 4 cavities between QS5 and QS6, which implies to move the quadrupole QS6 about 1.7 m away from the IP.

The total number of SC cavities to be installed around both IP is therefore 64 (32 around each interaction point).

3.2 *Installation of SC cavities around IP4 and IP8*

Around each of these two IP, it is planned to leave enough space to accomodate up to 2 × 44 SC cavities. The scheme presently envisaged is:

- 4 cavities between QS10 and QS11 (leaving some space for a separator of the pretzel scheme).
- Fill the five half cells between QS5 and QS10 with 8 cavities each (2 modules).

Due to the increased length of the new SC units, this installation is not compatible with the actual layout. The major modifications are:

- The distance between two quadrupoles in the periodic RF section has been increased from 22.3 m (LEP 1) to 26.1 m (LEP 2). The corresponding increase in the β-functions remains below 10%.
- The drift space of 34.9 m between QS4 and QS5 has been reduced to about 11.0 m

4 LOW-β INSERTIONS (EVEN IP)

The major modification related to all low-β insertions concerns the back-up solution. Its present purpose - to allow physics at reduced luminosity without superconducting quadrupoles - will be modified. Only one of the two existing QS2 magnets will be kept so as to allow a back-up operation, but only at injection energy. In addition, this single QS2 magnet will also be used above 85 GeV to reinforce the QS1 doublet such as to produce the required focusing strength.

5 HIGH-β INSERTIONS (ODD IP)

For the LEP 2 project, the design of the new high-β insertions turns out to be of major importance. It should be underlined that the future betatron tunes of the machine are not yet completely defined and will largely depend on our experience with the LEP 1 layout. Remembering that collimation considerations impose relatively tight constraints on the phase advance in the low-β insertions, it thus follows that any significant tuneshift (e.g. new working point) will have to be achieved exclusively in the odd straight sections. The future layout of the high-β regions should thus not only allow to reach 100 GeV, but also provide sufficient flexibility such as to cope with a relatively large tuning range (e.g. $\pm$ 1 unit in tune) in both planes. A solution maintaining the present insertion characteristics, both for the β-ratio and the β^* at the IP, has been found feasible provided a total of 8 additional quadrupoles be acquired. Aperture considerations would also favour the installation of a special vacuum chamber at each odd insertion. Considering that all these additional expenses are only balanced by the potential to allow for some rather unlikely experiments around these IP, it was decided to relax the constraint on the β values at the IP and to opt for a solution where the first two doublets are moved away from the IP [3]. Such a solution (roughly sketched in Fig. 1) proved to fulfill all the constraints imposed. Its main merits are:

- Increased separation at the IP ($\delta \approx 13$ mm).
- More favourable residual beam-beam tuneshifts.
- No additional quadrupoles necessary.
- No special vacuum chamber required.

These arguments were felt strong enough to definitively adopt this solution as the future layout for LEP 2. It should be mentioned that, if necessary, this insertion could be modified (by purchasing additional components) such as to provide physics conditions comparable to those presently available in LEP.

6 NEW LAYOUT AND MACHINE COMPONENTS

The new geometry described in the preceding sections has a non-negligible impact on many other components of the machine. It is then necessary to reposition existing elements, but also to find suitable locations for the additional equipment related directly to LEP 2. This aspect of the work is progressing satisfactorily and convenient solutions for most of the items to be considered are already available. The relevant modifications are regularly updated in a database [4]

7 COMPATIBILITY WITH OTHER PROJECTS

It should be stressed that the changeover from the present machine to the LEP 2 layout cannot be completed during one single shutdown period. It thus follows that the modifications will be spread from 1992 until 1994 where LEP 2 should be operational. This implies that, during this long period, the intermediate layouts have to remain compatible with the other projects running in parallel such as the Pretzel scheme, transverse polarization and possibly an experimental spin rotator. However, it seems that the proposed layout and its related planning offer a satifactory solution to the constraints mentioned above.

8 PRELIMINARY SCHEDULE

A large effort in coordination is required to schedule the modifications and minimize the number of major interventions on the layout of the machine.
However, independently of this programme, the timetable for the modifications will follow directly from the availability of the RF power, new SC cavities and the required cryogenics (the cavities have to be cold when beam is circulating in LEP). To the present knowledge, the schedule of installation will be the following:

- 1992: Layout around IP2 already modified, space for 32 SC cavities available but 12 will be installed ($E \leq 62$ GeV).
- Shutdown 92-93: Modify layout around IP6 such as to accomodate 32 cavities (64 SC cavities in the machine, $E \approx 75$ GeV). The geometry of the odd points will also be modified during this shutdown.
- Shutdown 93-94: Modify low-β insertions and RF regions around IP4 and IP8. 192 SC cavities installed ($E \approx 90$ GeV).
- 1994: LEP 2 operational.

9 CONCLUSION

As shown in this paper, the energy upgrade of LEP implies several basic modifications with respect to the present machine. First, the optics of the machine will change from 60° to 90° phase advance to allow for reduced emittances and therefore an increased luminosity [5]. Secondly, with the present layout, most of the insertion quadrupoles would saturate before reaching the required energy, so that a new design of both the insertions and the RF sections proved to be necessary. The proposed new geometry includes the constraints imposed by the quadrupoles and the new SC cavities but also accounts for the necessary modifications of the separators and the beam instrumentation. The installation work will be achieved in steps during the coming shutdown periods and it is foreseen that the layout of the LEP 2 machine will be available in the beginning of 1994.

10 REFERENCES

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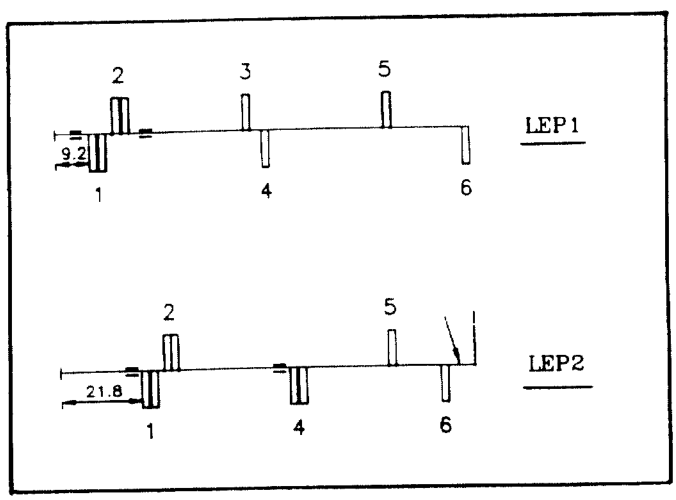

Fig. 1 LEP 2 insertion for the odd interaction points.