Presentation 61

90° Lattice and Insertions

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61.1 Machine Developments with the 90° Lattice

The three MD done so far with the 90° lattice were performed at injection energy with positrons and a central RF frequency of 4170 Hz. The betatron tunes of the model developed for this lattice have been derived from what was believed to be an optimal choice for the 60° lattice and have thus been fixed to $Q_x = 91.385$ and $Q_y = 97.285$. It is worth underlining that at the time of these MDs, the solenoids were not excited and the coupling compensation files for the 90° machine were missing, so that the skew quadrupoles were either set at their 60° values or switched off.

As will be shown in the following, these machine development sessions rapidly demonstrated some major operational difficulties which persisted for all the working conditions tried so far, namely:

\[ Q_x : .24 \Rightarrow .385 \]
\[ Q_y : .20 \Rightarrow .285 \]
\[ Q_z : .05 \Rightarrow .100 \]

It thus follows that one has to restrict oneself to report on experimental observations rather than trying to produce rational explanations for these difficulties.

61.1.1 Machine Reproducibility between MD

As far as the betatron tunes are concerned, the reproducibility of the machine was rather satisfactory. The measured variations were about $\Delta Q_x \approx 0.04$ and $\Delta Q_y \approx 0.01$.

As far as the chromaticity is concerned, contrary to the horizontal plane ($\Delta Q_x' = 0.0$), some problems were experienced with the reproducibility of the chromaticity in the vertical plane.

As a matter of fact, $Q_y'$ seems to strongly depend on the central frequency of the measurement and thus exhibits a non-linear behaviour. However, more data are necessary to confirm this experimental observation.

61.1.2 Comparison with the Model

Here again, the comparison between the predicted and the measured betatron tunes looks reasonable, although the vertical tune has a more pronounced deviation from the model than the
horizontal one ($\Delta Q_x \approx 0.02$, $\Delta Q_y \approx 0.07$). The major discrepancy comes from the chromaticities, which illustrate (as for the 60° case) that the model is missing some sextupolar component of the machine. The measured differences are:

$$\Delta Q'_x = -7.0$$
$$\Delta Q'_y = +9.0$$

This specific argument will be discussed in more details in a subsequent section.

61.2 General Experimental Observations

In this section, we shall try to summarise the main experimental observations characterizing the behaviour of the 90° lattice.

61.2.1 Closed Orbit Correction

After having set the machine to the theoretical values for the betatron tunes, the closed orbit could be corrected down to an r.m.s. of about 1.1 mm in both planes (which corresponds more or less to the values routinely achieved in operation with the 60° lattice). However, we got some experimental evidence that:

- The horizontal closed orbit is more difficult to correct than with the 60° lattice.
- Local corrections in the RF sections is very inefficient. This demonstrates that the 3 correctors presently available will not be sufficient to minimise the orbit in this region and that all possible positions should be equipped with correctors so as to avoid synchro-betatron resonances.
- The efficiency of the correction is very sensitive to the difference between the actual tunes of the machine and those of the reference Twiss file used by the correction algorithms. Such a pronounced correlation was not observed with the 60° lattice.

61.2.2 Residual Vertical Dispersion

The residual vertical dispersion has been carefully measured in a machine set to the theoretical tunes of the model and a bunch intensity of about 100 $\mu$A.

We measured an r.m.s. value of about 20 cm, which is comparable to the results obtained with the 60° lattice. However, it should be stressed that this measurement was performed without any skew quadrupole for coupling compensation.

61.2.3 Dynamic Acceptance

The horizontal dynamic acceptance of the machine has been evaluated by kicking the stored beam by means of the injection kickers and observing the decrease of the intensity as a function of time.

After having corrected the chromaticity, the dynamic acceptance of the machine could be estimated to be between 760-880 nm. This experimental result cannot unfortunately be compared with simulation results, since the latter presently only exist for a perfect machine (5000 nm). However there are first indications that the relative difference between the computed (perfect machine) and the measured dynamic acceptance behaves in about the same way for both the 60° and the 90° lattices.

61.3 Main Differences with respect to the 60° Lattice

During these dedicated machine developments, we could identify a few features which strongly depart from the usual operation with the 60° lattice. These can be summarised as follows:
• Whatever the working point, the accumulation rate is very low. The situation remains the same even with the damping wigglers switched on.

• A systematic intensity limitation occurs when the bunch intensity reaches about 180 μA. This instability threshold is again independent of the settings of the machine (betatron or synchrotron tunes). On one occasion, it has been observed on a spectrum analyzer, that around the maximum intensity, all the lines corresponding to the sidebands of $Q_s$ were strongly and equally excited.

• At maximum bunch intensity, it is not possible to measure the tunes without experiencing systematic beam losses (even with the lowest possible excitation level of the Q-meter). However this behaviour disappears once the intensity has been reduced down to about 100 μA/bunch.

• The emittances of the beam could be roughly estimated with the help of the BEUV system (visible synchrotron light). Although the emittances were smaller than those measured with the 60° lattice, they remained larger than expected.

Presently, there are no explanations to the unexpected difficulties encountered during these machine developments. The only "obvious" difference with respect to the 60° parameters is that, for a given $Q_s$, one has to work with twice the RF voltage (different momentum compaction factor).

61.4 The 90° Lattice and the "missing sextupole"

As already mentioned in a previous contribution, both the 60° and the 90° machines showed discrepancies between the computed and the measured chromaticities, which are usually explained by a "missing sextupole" component in our model of the machine.

Fortunately, the measured "missing sextupole" of both lattices is quite different, so that it might help to try to identify its location in the machine. The relevant measured chromaticities are:

<table>
<thead>
<tr>
<th></th>
<th>60°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta Q_x'$</td>
<td>-20.0</td>
<td>-7.0</td>
</tr>
<tr>
<td>$\Delta Q_y'$</td>
<td>+20.0</td>
<td>+9.0</td>
</tr>
</tbody>
</table>

We shall now consider three different hypothesis and check how they fit with the measured data.

61.4.1 Problem in the lattice sextupoles

This assumption implies that some of the lattice sextupoles do not work properly (e.g. erroneous excitation or wrong polarity). In such a case, the measured chromaticity behaves like:

$$ Q' \approx \sum \beta_s K_s' D_s $$

where the subscript "s" stands for sextupole. Comparing the parameters entering this equation for the two lattices with:

$$ \beta_s(90°) \approx \beta_s(60°) $$

$$ K_s'(90°) > 2K_s'(60°) $$

$$ D_s(90°) \approx 0.5 D_s(60°) $$

implies that the ratio of the measured chromaticities should be:

which is not consistent with our measurements!
61.4.2 Problem with a sextupolar component in the dipoles

Contrary to the previous case, one should now consider average values for both the $\beta$ function and the dispersion. Restricting ourselves to the arcs of the machine (the insertions are the same for the two machines), one has:

\[
K'(90°) = K'(60°)
\]
\[
Q(60°)/Q(90°) = 2/3
\]
\[
< \beta(90°) > = (2/3) < \beta(60°) >
\]
\[
< D(90°) > ≈ (4/9) < D(60°) >
\]

which yields:

\[
Q'(90°) ≈ (8/27) Q'(60°)
\]

a value rather consistent with the measured data. This result therefore indicates that the "missing sextupole" is likely to come from a spurious sextupolar component in the dipoles.

61.4.3 Problem due to the low field at injection

It is well known that the LEP sextupoles are designed to cope with a high excitation level. At injection energy, the currents required for the sextupoles of the 60° lattice are so low that one could imagine that they deviate from the expected strength and thus do not provide the predicted compensation. The situation is rather different with the 90° lattice, since the sextupoles excitation is more than twice larger.

It thus follows that the measured difference of chromaticities between the two lattices might not be real. In such a case, it is clear that the two hypothesis described previously would not hold anymore.

These three examples confirm the necessity of further detailed studies concerning the problem of the "missing sextupole".

61.5 Incompatibilities with the present LEP insertions

A first layout study on the possibility of upgrading the energy of LEP up to 100 GeV has been performed about 4 years ago by F. Pilat [1].

At that time it was already recognised that the present LEP layout could not reach the required energy, mainly because most of the insertion quadrupoles would saturate well below 100 GeV.

However, the main difference between this study and the present situation is that, by the end of 1986, the projected SC cavities could be fitted in the layout with only minor modifications of the RF sections.

61.6 New constraints from the SC cavities

More recent considerations have demonstrated that the modules of four SC cavities had to be mounted and closed in a clean area before their transport to the LEP tunnel (protection of the inner surface against dust). This procedure requires the installation of additional valves on both sides of the modules which significantly increases the overall length of these units (see Figure 61.1).

61.7 Low-β insertions (even IP)

The first general statement about the new low-β insertions is that the principle of the back-up solution is not felt necessary anymore.

Remembering that above 75 GeV, the present SC quadrupole (QSC) has to be replaced by a more powerful SC quadrupole (QSCC), there exist basically two solutions for the low-β insertions:
• The 'cold option', where the present QSC would be installed directly behind the new QSCC magnet. This solution would therefore have two SC quadrupoles following each other and would thus make the QS1 doublet available for other purposes.
• The 'warm option', where the present QS1 doublet remains in use (QSC magnet is not used). Around 90 GeV, a small additional magnet (e.g. a QS2 from the back-up solution) would then have to be installed next to the doublet to reach 100 GeV.

Both options have been carefully studied and corresponding solutions for the layout exist. From a pure optical point of view, both solutions appear almost comparable. However, financial and operational considerations presently favour the 'warm option'.

61.7.1 New layout for IP2 and IP6

These two IP require a specific installation, since it is foreseen to maintain the Cu cavities at their present locations. The basic scheme is therefore to install (both around IP2 and IP6):
• 2 × 4 cavities between QS4 and QS5 (already installed on the left of IP2).
• 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 IPs is therefore 64 (32 around each interaction point).

61.7.2 New layout for IP4 and IP8

Around each of these two IP, it is planned to foresee enough space to possibly accommodate up to 2 × 44 SC cavities. The scheme presently envisaged around each IP is:
• 4 cavities between QS11 and QS10 (leaving free space for a separator of the pretzel scheme).
• Fill the 5 half cells between QS10 and QS5 with 8 cavities each (2 modules).

Due to the increased length of the new SC units, this installation is therefore not compatible with the present LEP layout and the insertions have thus to be modified.

The outstanding differences 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).
• Due to the increased length of the RF section, the drift of 34.9 m between QS4 and QS5 (LEP 1) has been reduced to about 11.0 m.
• The RF section which used to be located between QS6 to QS11, now extends from QS5 to QS11.

The corresponding modifications are roughly sketched in Figure 61.2.

61.7.3 Symmetry of the machine

It is worth underlining that due to these different installation schemes, the present fourfold symmetry of the machine will be reduced to a twofold symmetry (IP2/IP6 are different from IP4/IP8).

61.8 High-β insertions (odd IP)

For the high-β insertions, the LEP energy upgrade has even more severe implications than for the low-β regions. As a matter of fact, the following magnets will then reach their limits:

<table>
<thead>
<tr>
<th>Magnet</th>
<th>Energy</th>
</tr>
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<tbody>
<tr>
<td>QL1</td>
<td>65 GeV</td>
</tr>
<tr>
<td>QL2</td>
<td>74 GeV</td>
</tr>
<tr>
<td>QL4</td>
<td>97 GeV</td>
</tr>
</tbody>
</table>

F. Pilat [1] proposed a solution consisting in shifting the first two doublets of the insertion about 6.6 m away from the IP. However, the tunability of such an insertion turns out to be too limited for our purposes. Actually, the tunability criterion is an essential one since:
• The phase advance in the arcs is fixed (90° for LEP 2).
• The phase advance in the low-β insertions is almost fixed by collimation considerations.
It thus follows that potential tune shifts for a new working point have to be performed in the high-β insertions.

61.8.1 Modified high-β insertions

The new layout under consideration maintains the present insertion characteristics and should also favour the compatibility with the installation of a pretzel scheme.

For the reasons mentioned above, special care has been given to the range of tunability of this insertion. The main modifications to be considered are:
• Replace the QL1 doublet by a triplet (MQA magnets).
• Replace the present QL2 doublet (MQ magnets) by a MQA doublet.
• Replace QL3 (presently MQA) by a MQ magnet and move it by about 9.0 m towards the IP.
• Replace QL4 (presently MQA) by a MQ doublet (e.g. the present QL2 doublet).
Remembering that one MQ magnet is available from the back-up solution (QS2), such a scheme implies the acquisition of 8 additional MQA magnets. On top of this, aperture considerations require the installation of a special vacuum chamber from QL1 to QL4.

However, our present feeling is that the additional constraints of this type of insertion are well compensated by the potential advantages of such a layout, especially from a tunability point of view. This is illustrated in Figure 61.3, where the tunability of a Pillat-like insertion is compared with that of the new layout.

61.8.2 Beam dumping system for LEP 2

As far as modifications around the odd IP is concerned, it should also be mentioned that a beam dumping system is presently under consideration in the SL/BT group (in collaboration with TIS).

Although this study is still in a preliminary stage, it is possible to outline the main features of this system:

• A single kicker (for the two beams) will be installed near QL8 (G. Schröder).
• Two absorbers will be located near QL6 and QL10 respectively (S. Peraire, G. Stevenson).
• Two spoilers are foreseen about 12 m before the absorbers (S. Peraire, G. Stevenson).

61.8.3 Preliminary schedule for the modifications

It is obvious that a large effort in coordination is required to schedule the modifications and minimise the number of major interventions on the layout of the machine.

Independently of this programme, the timetable for the modifications follows directly from the RF power available. To our present knowledge, the schedule for the installation of the SC cavities in LEP can be summarised as follows:
<table>
<thead>
<tr>
<th>Year</th>
<th>N0. SC cavities</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>12 in IP2</td>
<td>$\leq$ 62 GeV</td>
</tr>
<tr>
<td>1992</td>
<td>32 in IP2</td>
<td>$\leq$ 65 GeV</td>
</tr>
<tr>
<td>1993</td>
<td>32 in IP2, 32 in IP6</td>
<td>$\approx$ 75 GeV</td>
</tr>
<tr>
<td>1994</td>
<td>32 in IP2, 32 in IP6, 64 in IP4, 64 in IP8</td>
<td>$\approx$ 90 GeV</td>
</tr>
</tbody>
</table>

According to this schedule, it follows that:
- QS6 in IP2 and IP6 should be displaced by the end of 1991.
- The high-$\beta$ insertions should be modified for the run in 1993.
- Depending on the performance of the SC units and the availability of the new QSCC magnets, the latter could be installed either in 1993 or in 1994. At the same time, the QS3 magnets in IP2 and IP6 will be moved by about 1.8 m towards the IP.
- The layout modifications for the low-$\beta$ in IP4 and IP8 should be completed for the run in 1994.

61.8.4 General remarks on the LEP 2 insertions

As demonstrated above, the energy upgrade of the LEP machine implies several basic modifications of the present layout. It should be stressed that such a study is not only to provide space for the SC units by displacing some quadrupoles, but also implies, at a deeper level, reconsidering the positions of many elements such as collimators, separators, beam stoppers, skew quadrupoles and so on.

A so-called Version 1 of the LEP 2 machine accounting for all these modifications is presently available in the LEP Database and it is hoped that this first iteration will be a valuable tool for future implementations.

References

Figure 61.1: Layout for new superconducting RF units
Figure 61.2: Transition of low beta insertions in points 4 and 8 from LEP1 to LEP2
Fig. 3

**NEW PROPOSAL**: HIBL FOR LEP 2.

**LEP 1**:

\[
\mu_x = 0.877 \\
\mu_y = 0.823
\]

- **MODIFIED HIBL**
- **PILAT-LIKE**