IMPACT OF BEAM BASED ALIGNMENT ON POLARISATION AT LEP

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Abstract

The degree of spin polarization at LEP is strongly dependent on the knowledge of the vertical orbit. Quadrupole magnet alignment and beam position monitor (BPM) offsets are the main source of the orbit uncertainty. The error of the orbit monitor readings can be largely reduced by calibrating the monitor relative to the adjacent quadrupole. At LEP, 16 BPM offsets can be determined in parallel during 40 minutes. The error of the measured offset is about 30 μm. During the LEP run 1997, more than 500 measurements were made and used for the optimisation of polarization. The method of dynamic beam based calibration will be explained and the results will be shown.

1 VERTICAL ORBIT UNCERTAINTIES

The uncertainties of the vertical beam positions $y_i$ are shown in Fig. 1. They are divided in three types:

1. The quadrupole misalignment with respect to the LEP reference plane.
2. The geometric BPM offset relative to the magnetic centre of the adjacent quadrupole.
3. The electronic offset in the BPM signal processing chain.

The BPM offsets 2 and 3 are determined at LEP by a beam based alignment technique known as $k$-modulation [1, 2].

$$\Delta k = \frac{\Delta k_0 \cdot L \cdot y_Q}{2 \sin(\pi Q_y)} \sqrt{\beta_Q \beta(s)}$$

where $\beta_Q$ and $\beta(s)$ are the beta functions in the modulated quadrupole and at the longitudinal position $s$, and $Q_y$ is the betatron tune. The oscillation amplitude $\Delta y_0$ depends on the beam position $y_Q$ in the modulated quadrupole which can be changed with local orbit bumps. A relative change in the quadrupole strength $\Delta k/k \leq 10^{-3}$ is sufficient to detect the oscillations with the required accuracy. The modulation frequency $f_k$ is in the range of 0.7–3.3 Hz. The oscillation $\Delta y(t)$ is detected with two precise beam position monitors (couplers) with a betatron phase advance of $(2n + 1)\pi/2$ to guarantee that the orbit oscillation can be seen by at least one of the couplers. In order to modulate several quadrupoles at the same time, a windowing harmonic analysis is used to record the orbit oscillations. The windowing allows a minimum modulation frequency separation of 0.1–0.15 Hz. The beam position in the quadrupole is varied over five positions with orbit bumps. The measurements are fitted with the three parameter function

$$\Delta y = f(y_Q) = a + b \cdot y_{BPM} - y_{off}.$$

Figure 1: Beam position monitor misalignment with respect to the reference plane.

2 CALIBRATION PRINCIPLE

A particle passing at a distance $y_Q$ from the centre of a quadrupole with strength $k$ receives a deflection $y'$

$$y' = k \cdot L \cdot y_Q$$

where $L$ is the length of the quadrupole. When the beam position $y_Q$ is fixed, a change of the quadrupole strength $\Delta k$ leads to a change of the deflection

$$\Delta y' = \Delta k \cdot L \cdot y_Q.$$
k-modulation windings. Motivated by the impacts of the BPM offsets on the achievable polarization level [2], every arc and dispersion suppressor quadrupole with a nearby BPM was provided with additional (so called back leg) windings which can be powered separately (see Fig. 3). The whole installation (quadrupole selection, power supply settings like modulation frequency and amplitude, data acquisition, etc.) is driven from the LEP control room.

16 quadrupoles (one per half octant) can be powered independently and simultaneously with different frequencies. This number is limited by the available quadrupole power supplies.

**3 DATA COLLECTION**

The k-modulation in the arcs and dispersion suppressors is possible while the beams are in collision. Four independent measurements (two coupler readings for electrons and positrons) are available to determine the BPM offsets. The simultaneous calibration of 16 offsets takes 40 minutes. Four corrector bumps are used to steer the beam. The vertical dispersion created by each of these bumps is reduced by a second bump π away in phase. In addition, the phase advance between two modulated quadrupoles of the same octant is chosen to be a multiple of π. This leads to a luminosity reduction of up to 15% with the largest bump amplitude. Normally k-modulation measurements are only performed in the last part of the fills.

In the dispersion suppressors the irregular phase advance prevents the use of the dispersion compensation scheme. For this reason physics operation can be strongly perturbed, with luminosity reductions of up to 40%.

In the straight sections the bumps cannot be applied because of background problems in the experimental detectors. As the beams are separated in some quadrupoles they cannot be moved to the quadrupole centre.

A complete beam position monitor calibration consists of the following procedure: the quadrupoles which have to be modulated are selected on the operation console. According to this selection, the harmonic generators are powered to modulate the quadrupoles with individual frequencies and amplitudes. A data acquisition program records the harmonic analysis result of the coupler readings. The beam current is also taken into account to normalise the coupler signal. A second program records the beam position in the modulated quadrupole. The oscillation amplitudes and the BPM readings of each quadrupole are displayed online. New BPM data is provided every minute. A higher data taking frequency would affect the ability of the operators to acquire an orbit reading at any moment. The beam position in the modulated quadrupole is moved in steps of 0.5 mm to ±1 mm. For each setting, eight data points are recorded.

The quality of the k-modulation data was checked for signal overlaps between neighbouring frequencies (\( \Delta f_k \geq 0.1 \text{ Hz} \)) as well as for cross-talk between quadrupoles by the induction of the powered back leg windings in the main coils. No significant systematic effect was observed.

**4 MEASUREMENT RESULTS**

An example of a vertical BPM offset calibration is shown in Fig. 4. All four measurements are in agreement and give good fits. The error is given by the weighted average of the single determinations depending on the fit uncertainty of each measurement.

Cuts have been introduced to reject bad measurements: the combined error of the four measurements should be less than 55 \( \mu \text{m} \) and the \( e^+ \) and \( e^- \) offsets should not differ by more than 100 \( \mu \text{m} \). Offsets which have been measured more than once had to be consistent.

More than 550 measurements of vertical beam position monitor offsets have been made. 419 offsets have been determined and analysed in September 1997. After cuts, 313 non-zero offsets were used to correct the BPM readings for each orbit acquisition and could be used during polarization measurements. Unsuccessful offset determinations were repeated in the last two months of the LEP run. 31 monitors out of 353 in the bending area could not be calibrated due to bad BPM readings. This corresponds to 8.8% of the total. Fig. 5 and 6 show the vertical offset distributions of electrons and positrons obtained by k-modulation. Table 1 summarises the k-modulation results.
for electrons and positrons.

The mean values differ by 50 μm which indicates an electronic offset. The r.m.s. width of the electric field is 270 μm which is in the same order as expected from earlier k-modulation results in the straight sections. The typical error on the BPM offset determination is about 30 μm.

Some beam position monitors were measured in previous years. Surprisingly, some of the 1997 measurements resulted in offset changes of more than 100 μm. This time dependence may be due to a change of the signal attenuation in the electronic equipment. Mechanical movement of the BPM relative to the quadrupole cannot be completely excluded. For this reason, at least some of the offsets will be remeasured during the next LEP run. The calibration of the 148 BPMs in the straight sections may also be envisaged for machine optimisation. The 1997 measurements do not indicate any time dependence but they were made on the time scale of a few months.

**Table 1: Results of the k-modulation.**

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mean Offset [μm]</th>
<th>Offset r.m.s. [μm]</th>
<th>Mean Error [μm]</th>
<th>Error r.m.s. [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+$</td>
<td>-43</td>
<td>273</td>
<td>40</td>
<td>13</td>
</tr>
<tr>
<td>$e^-$</td>
<td>-90</td>
<td>235</td>
<td>45</td>
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</tr>
<tr>
<td>Average</td>
<td>-65</td>
<td>267</td>
<td>30</td>
<td>11</td>
</tr>
</tbody>
</table>

**5 SUMMARY**

Every quadrupole with an adjacent BPM in the arcs and dispersion suppressors of LEP was equipped with additional windings to determine the BPM offsets with $k$-modulation in order to use the data specifically for energy calibration. The r.m.s. width is 270 μm which is in the same order as expected from measurements in previous years. The typical error on the BPM offset determination is about 30 μm.

**6 REFERENCES**


