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].

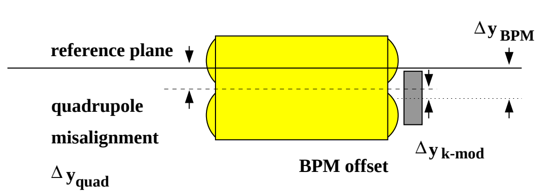

Figure 1: Beam position monitor misalignment with respect to the reference plane.

2 CALIBRATION PRINCIPLE

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

$$y' = k \cdot L \cdot y_Q \tag{1}$$

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

$$\Delta y' = \Delta k \cdot L \cdot y_Q. \tag{2}$$

If a quadrupole field strength k is modulated with a constant amplitude Δk_0 and frequency f_k the residual orbit variation is detectable at any position around the ring where the phase is adequate. The beam position $\Delta y(s,t)$ then oscillates at the frequency f_k. In other words

$$\begin{aligned} \Delta y_0(s, y_Q) &\propto \frac{\Delta k_0 \cdot L \cdot y_Q}{2\sin(\pi Q_y)}\sqrt{\beta_Q \beta(s)} && (3) \\ \Delta y(s,t,y_Q) &= \Delta y_0(s,y_Q)\cos(2\pi f_k t + \psi) && (4) \end{aligned}$$

where β_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 Δy_0 depends on the beam position y_Q in the modulated quadrupole which can be changed with local orbit bumps. The amplitude Δy_0 reaches its minimum (Δy_0^{min}) when the beam is centred in the quadrupole ($y_Q = 0\,\mu$m). The adjacent BPM reading at the modulated quadrupole $y_{BPM} = y_{off}$ gives the BPM offset with respect to the quadrupole.

A relative change in the quadrupole strength of $\Delta k/k \leq 10^{-3}$ 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

$$\Delta y = f(y_Q) = a + b \cdot \mid y_{BPM} - y_{off} \mid . \tag{5}$$

y_{off} is the BPM offset, b is the sensitivity of the oscillation amplitude $\Delta y(t)$ to the beam position y_Q in the modulated quadrupole, whereas a allows a non-zero oscillation amplitude due to noise when the beam is centred. Fig. 2 illustrates the k-modulation principle. A hardware description of the magnet excitation circuit, oscillation detection software and analysis of the data in the straight sections can be found in [3].

Before 1997 only the quadrupole magnets with a BPM in the straight sections and in one arc were equipped with

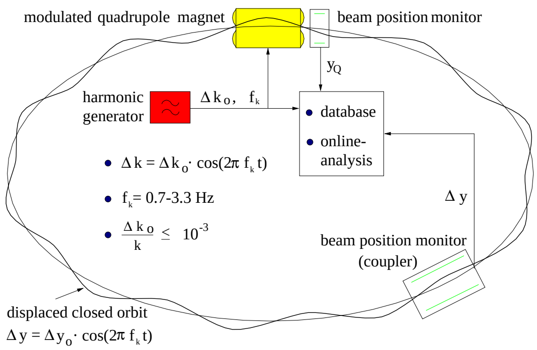

Figure 2: Principle of the k-modulation.

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 sup-

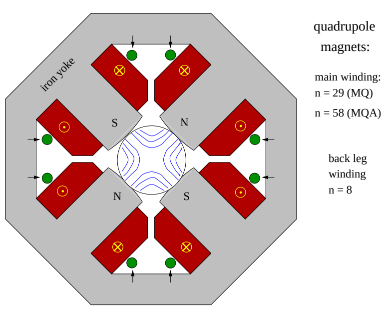

Figure 3: Cross-section of a quadrupole magnet with back leg winding.

ply 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 ($\Delta f_k \geq 0.1$ 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 μm and the e^+ and e^- offsets should not differ by more than 100 μm. 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

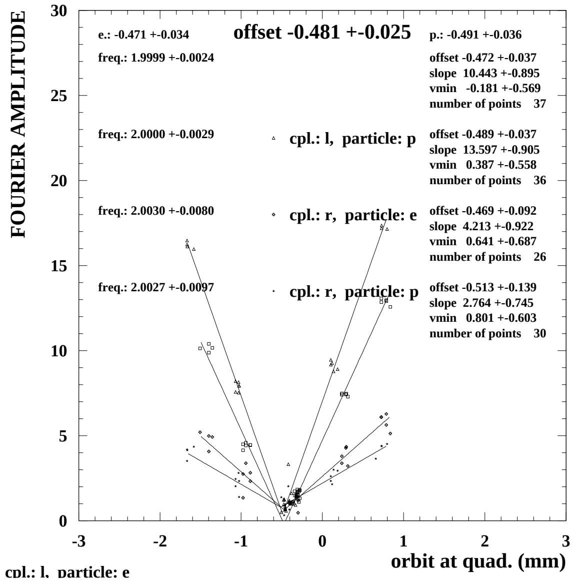

Figure 4: Example of a BPM calibration. The oscillation amplitude Δy is plotted as a function of the beam position in the quadrupole y_Q. The offset is given by the minimum oscillation amplitude. The different marker types indicate the four measurements for electrons and positrons in both detectors. The data of each measurement is fitted according to Eq. 5. The number of data points, results and uncertainties for each fit are also listed in the plot. The average offset is $-481 \pm 25\,\mu$m.

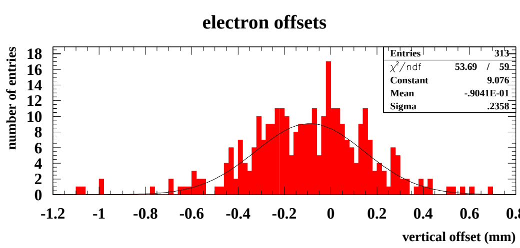

Figure 5: Distribution of BPM offsets for electrons.

for electrons and positrons.

The mean values differ by 50 μm which indicates an electronic offset. The r.m.s. width $\sigma_{total} \approx 270\,\mu$m is almost as large as expected from earlier k-modulation results in the straight sections. The typical precision of the determined offsets is about 30 μm. The determined BPM offsets are used during polarization measurements for beam energy calibration at LEP and are presented in [4]. About 50 beam position monitors were calibrated several times to check the reproducibility of the procedure and gave consistent results.

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.

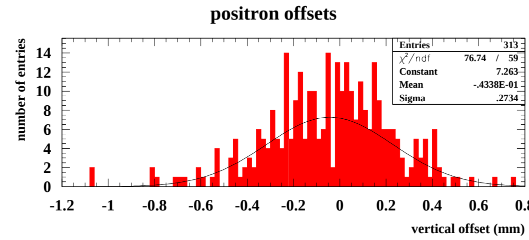

Figure 6: Distribution of BPM offsets for positrons.

Particle	Mean offset [μm]	Offset r.m.s. [μm]	Mean error [μm]	Error r.m.s. [μm]
e^+	-43	273	40	13
e^-	-90	235	45	18
Average	-65	267	30	11

Table 1: Results of the k-modulation.

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

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