DYNAMIC BEAM BASED CALIBRATION OF ORBIT MONITORS AT LEP

I. Barnett, A. Beuret, B. Dehning, P. Galbraith, K. Henrichsen, M. Jonker, G. Morpurgo. M. Placidi, R. Schmidt, L. Vos, J. Wenninger
CERN, CH-1211 Genève, Switzerland

I. Reichel, F. Tecker
III. Physikalisches Institut, RWTH Aachen, Germany

1 Introduction

The properties of an electron positron storage ring are mainly determined by the quadrupole magnets. Highest luminosity and best performance are obtained when the beam is well centered in the quadrupole magnets.

The quadrupole magnets are accurately aligned to form a reference system. Beam position monitors (BPM) are installed with tight mechanical tolerances with respect to to the magnets to measure the closed orbit relative to this reference.

Despite careful alignment and electrical calibration of the monitors, there can still be a residual offset between the monitor and the magnetic centre of the quadrupole. The system described measures this offset by a beam-based method [1, 2, 3].

2 Principle of k-modulation

When the strength k of a single quadrupole magnet of length l at the location s_0 is changed, the beam gets an additional local kick. The kick $\Delta y'$ is proportional to the change in quadrupole strength Δk and the displacement y of the beam in the quadrupole:

$$\Delta y'(s_0) = \Delta k \cdot l \cdot \ y(s_0) \tag{1}$$

This additional kick changes the closed orbit at any location s by $\Delta\, y(s)$ according to

$$\Delta y(s) = \frac{\sqrt{\beta(s_0)\cdot\beta(s)}\ \cos(|\mu(s)-\mu(s_0)|-\pi Q)}{2\ \sin(\pi Q)} \cdot \ \Delta y'(s_0) \tag{2}$$

where ,b, m and Q are the betatron function, phase advance and tune in the plane of motion under consideration, respectively. Obviously, this change is proportional to the closed orbit position in the quadrupole magnet where the strength is changed.

Since the kick changes the whole closed orbit, it is sufficient to measure the beam position at a location where the cosine term is non-zero. To assure this for all quadrupoles, it is favourable to have two sensitive beam position monitors (couplers) with a betatron phase advance of a multiple of $\pi/2$ between them.

The difference to other methods [4, 5, 6] is that the change of the quadrupole strength is done in a dynamical way by an harmonic modulation at a fixed frequency w well below the synchrotron and betatron frequencies:

$$\Delta k = \Delta k_o \cdot \sin(\omega t) \tag{3}$$

The beam position is measured for a certain number of consecutive turns. An harmonic analysis gives the amplitude of the beam oscillation at the modulation frequency. This allows to detect changes of the closed orbit smaller than 1 μm in the presence of other sources which change the closed orbit and permits measurements at very small values of the relative strength perturbation $\Delta k_o/k$. The offsets for several magnets can be determined at the same time by using different excitation frequencies.

3 Implementation at LEP

Out of 808 quadrupole magnets at LEP, 504 are equipped with a BPM. Only 16 quadrupole magnets can be modulated by their individual power converters. These are the two closest quadrupoles on each side of the physics experiments. The closest one (QS 0) is a superconducting magnet. The frequency of the modulation was chosen in the range between 10 and 15.6 Hz where beam oscillations caused by other sources are small. A relative change in the quadrupole strength of $\Delta k/k < 10^{-3}$ is sufficient to detect the oscillations.

The other magnets in the straight sections are fed in pairs symmetrically around the interaction points (IP) by a single power converter. All focusing quadrupoles in the arcs are connected in series and so are the defocusing quadrupoles, as well. The strength of these quadrupoles can therefore not be modulated separately.

For this reason, magnets have been equipped with additional (back leg) windings. A power cable and a multi wire selection cable connects them to an harmonic generator. Presently, 88 magnets in the straight sections around the physics experiments and 36 magnets with a BPM in the arc around IP 8 have a back leg winding (see Fig. 1). One magnet on each side of the IP can be selected at the same time.

Harmonic excitation of the back leg windings at LEP has a drawback caused by the low cut off frequency of the main winding current regulation circuit. The back leg winding current induces a frequency dependent voltage on the main winding. The resulting current change in the main loop affects the quadrupole strength of any other magnet in this circuit. For this reason, the modulation has to be done at frequencies below 2 Hz where the regulation loop of the power converter keeps the variations in the main current small. The current coupling for a two magnet circuit was measured to be below 10%.

To detect the induced orbit oscillations, two sensitive couplers with a resolution of less than 1 μm are installed at locations with different betatron phases. The signals from the couplers are digitized and averaged over a number of bunch passages by a Digital Signal Processor. Averaging over N_{av} = 400 passages gives a sampling frequency of $f_{revolution} \cdot N_{bunches}/N_{av}$ = 112.46 Hz. The data sample is multiplied by a windowing function to get a better frequency resolution in the following harmonic analysis,

The excitation of the magnets and the measurement are synchronized by the LEP timing system to be able to determine the phase of the orbit oscillation.

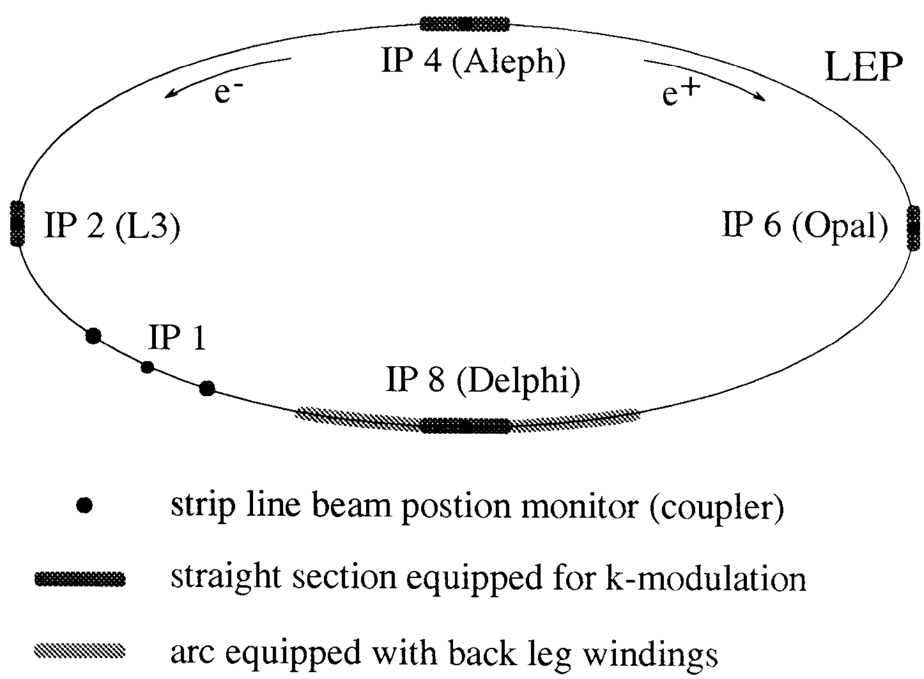

Figure 1: Locations of the couplers and the quadrupole magnets having the possibility to change their focusing strength.

4 Determination of monitor offsets

The measured Fourier amplitude is plotted versus the reading of the BPM at the quadrupole (Fig. 2). This amplitude has its minimum for a beam passing through the centre of the magnet and rises linearly with the distance from it. A three parameter fit $y = p2 \cdot |x - p1| + p3$ gives the offset $p1$ of the magnet. The measured phase of the oscillation gives an additional information since it differs by π for orbits on different sidcs of the magnetic centre. It shows a big scatter when the beam is passing centered in the magnet since it is dctermincd by random oscillations of the beam.

Thermally driven vertical displacements of the QS 0 quadrupoles lead to orbit drifts in the vertical plane during a physics run. This changes the beam position in the quadrupole and allows to determine the offset. If the orbit in a magnet does not vary enough, the orbit can be displaced by a local closed orbit bump. This can also be used to speed up the measurement. The accuracy achieved by the method is of the order of' 30 μm.

The modulation depth is so small that it does not affect the important parameters of the beam like luminosity and background for the physics experiments. The tune change is of the order of 0.001.

Two different electronic systems are used for the Beam Orbit Measurement (BOM) system of LEP. a narrow band and a wide band type. Only four BPM's on each side of an IP are equipped with the wide band system. These have different gain settings depending on the beam current. All others are of the narrow band type. The distribution of the offsets measured for the wide band type is shown in Fig. 3. There is a systematic difference for the QS 0 and QS 1 quadrupole magnets. The offsets of the superconducting QS 0's have a mean value of about 1 mm while it is only 0.3 mm for the QS 1. The width of the distribution is only slightly higher

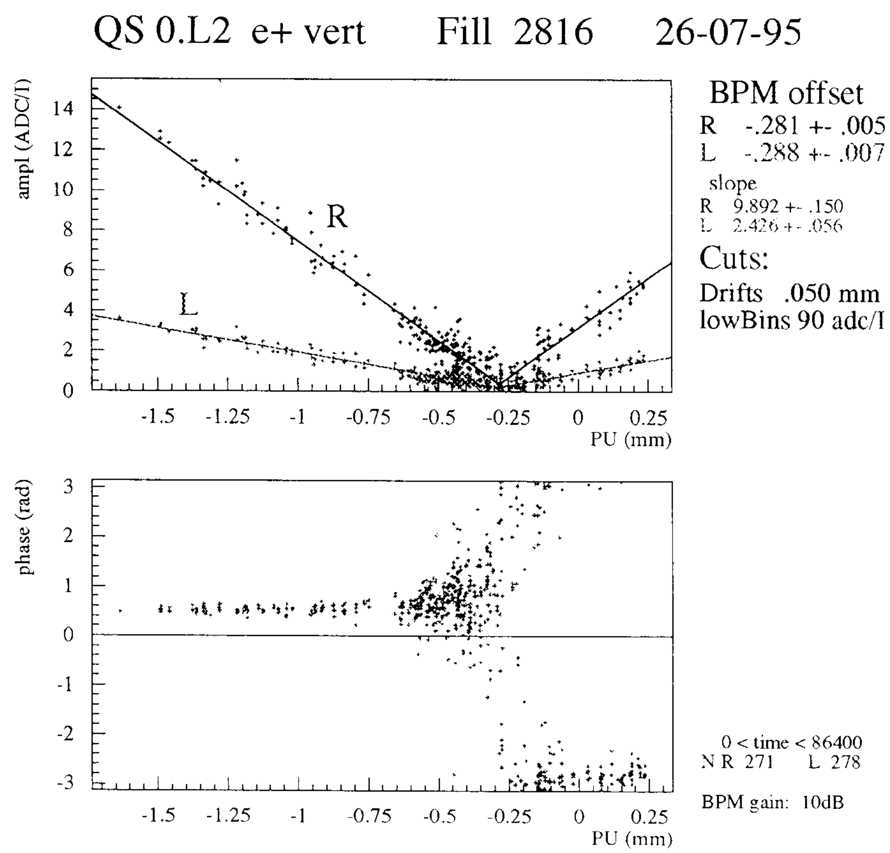

Figure 2: Determination of an offset using natural orbit drifts during a physics fill. The picture shows the results for both couplers (R and L).

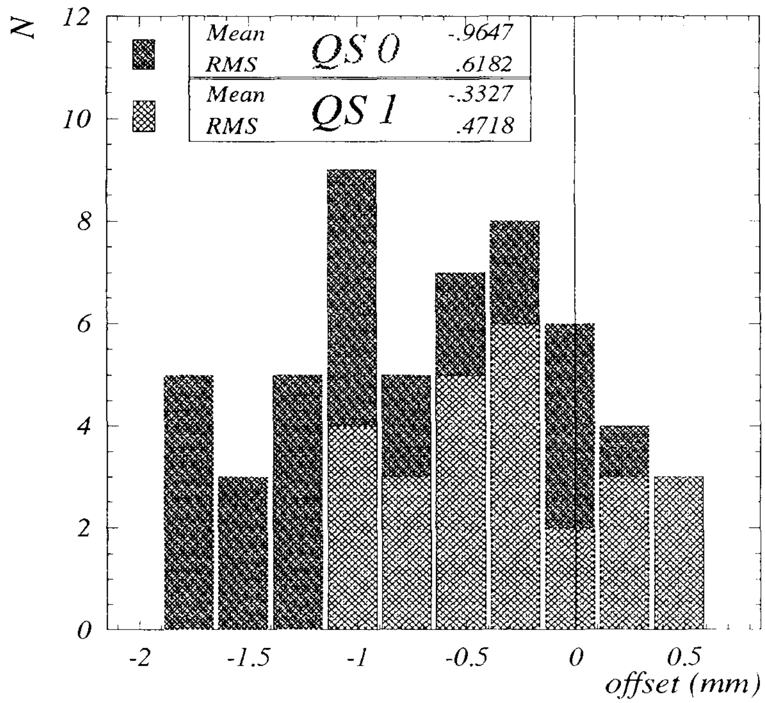

Figure 3: Distribution of the offsets for wide band type BPM

for the QS 0's. Differences of up to 300 μm for the offsets were seen for different gain settings and for the two particle types. Thus, a part of the offset is caused by the BPM processing electronics.

The narrow band type BPM's have another type of electronics. Fig. 4 shows the distribution of the measured offsets. The width of the distributionof 165 μm and the mean offset of -75 μm are significantly smaller than for the wide band type.

5 Effects on transverse spin polarization

In an electron positron storage ring the spin of the particles becomes polarized with time. The degree of transverse spin polarization depends on the quality of the vertical closed orbit. In particular. the distribution of vertical orbit kicks influences strongly the level of polarization. The influence of the offsets in the vertical plane on the level of polarization has been simulated at an energy of 44.7 GeV using MAD [7] and SITF [8]. The polarization level was calculated for different RMS of the BPM offsets and ten different random distributions for each RMS value. A vertical misalignment of 150 μm for the quadrupoles was used. The closed orbit was corrected to a RMS of 400 μm.

The harmonic components in the spin precession frame of the vertical orbit kicks in the arcs arc analyzed. The strongest depolarizing components can be compensated [9] (Harmonic Spin Matching) to increase the polarization level. This method is strongly dependent on the BPM misalignment and the achievable level of polarization is decreasing with increasing BPM offsets (Fig. 5). The determination of the BPM offsets in the arcs is expected to lead to an increase of polarization by 10-15%.

This is important for the precise energy measurement at LEP II since the level of polarization decreases rapidly with energy as $1/(1 + (\alpha E)^2)$ [10]. The precise knowledge of the BPM offsets would decrease the factor α and allow an energy measurement by resonant depolarization at a higher energy.

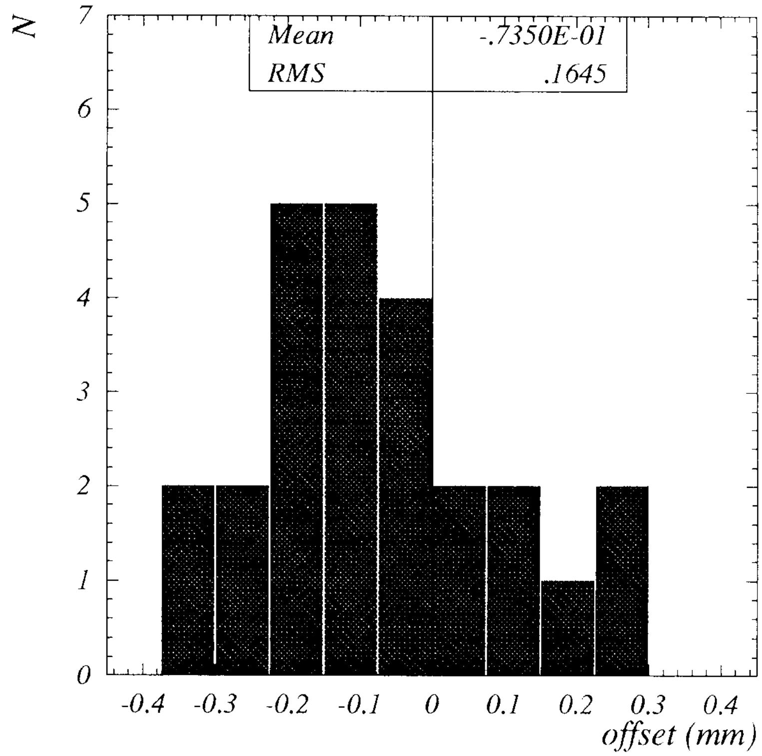

Figure 4: Distribution of the offsets for narrow band type BPM

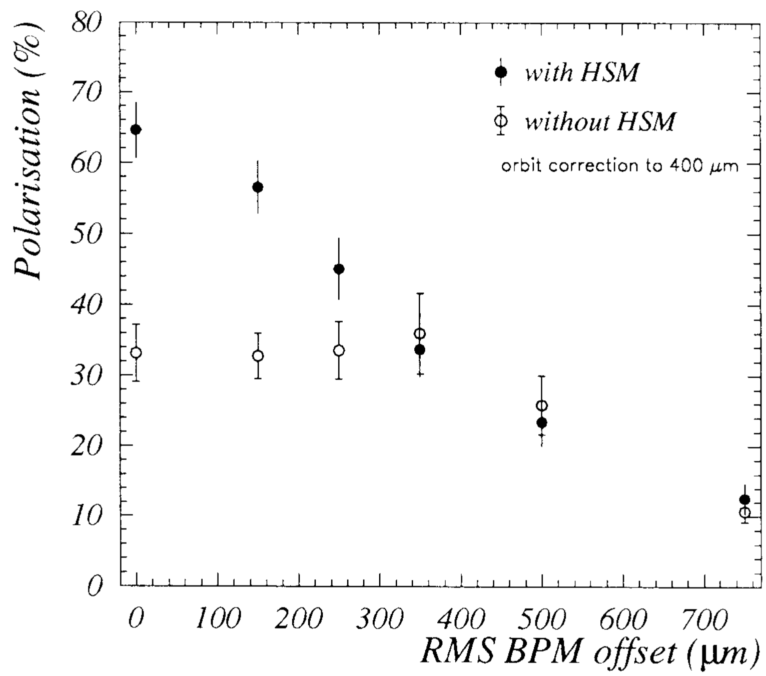

Figure 5: Polarization level with and without Harmonic Spin Matching as a function of the BPM misalignment

6 Conclusions

Modulation of the quadrupole strength of $\Delta k/k < 10^{-3}$ was performed parasiticly during physics operation of LEP without affecting the luminosity. Wide band BPM offsets for the superconducting quadrupoles were found to be as large as 2 mm and systematically larger than for normal conducting magnets. The wide band type BPM show different offsets for electrons and positrons and for different gain settings.

On the other hand, offsets for the wide band BPM system are systematically larger than for the narrow band type. The differences for the two particle types are also smaller for the narrow band type.

The offsets measured so far are taken into account by the LEP orbit acquisition.

Simulation shows that an increase in the polarization level is expected if all BPM offsets in the arcs arc determined.

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