Dynamic Beam Based Calibration of Orbit Monitors at LEP

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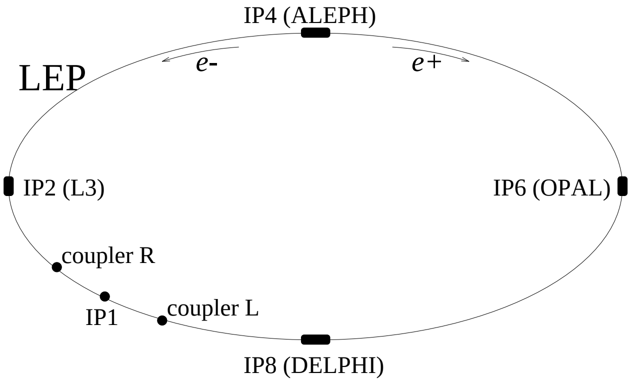
Abstract

The offsets of the beam position monitors (BOM) with respect to the centre of the quadrupoles were determined for 16 wide band electronic and 18 narrow band electronic monitors. The first are located near to the IPs and the latter are in all other parts. The distribution of the wide band monitor offsets at the low beta focusing quadrupole magnets has a mean value of 1000 μm and a width of σ = 600 μm. The offsets are almost identical with the beam position of the orbit which allows to obtain highest luminosity. The distribution of the narrow band monitor offsets has a mean value of 19 μm and a width of σ = 245 μm.

1 INTRODUCTION

At LEP, 504 beam position monitors measure the position of the circulating beam. The k-modulation method [1, 2, 3] is used to measure the relative offsets of these beam position monitors with respect to the magnetic centre of quadrupole magnets.

The centre of the quadrupole is detected by measuring induced closed orbit oscillations for different orbit positions in the magnet. The orbit oscillations are induced by modulating the strength of the magnetic field of a quadrupole. The amplitude of the orbit oscillation depends linearly on the modulation strength and on the beam displacement in the quadrupole magnet. The beam position is changed by orbit bumps or by using slow unavoidable orbit drifts. The modulation of the magnetic field is done by modulating the current of the magnets at fixed frequencies between 0.8 and 15.7 Hz. The relative change of the magnetic field is of the order of 10^{-4}. The resulting oscillation amplitude of the beam is measured by calculating the Fourier spectrum of a coupler signal (Fig. 1).



distance between:	
IP2 and coupler R	2370m
IP8 and coupler L	2370m
coupler R and coupler L	1920m
IP1 and couplers	860m

quadrupols with excitation cuircuits:
IP2, IP4, IP6, IP8 (QS12 left to QS12 right)

installation during shut down 94/95:
QS14 to QD48 at both sides of IP8

Figure 1: Location of couplers and quadrupole magnets with equipment to change the focusing strength.

2 INSTRUMENTATION

The magnetic field of the quadrupoles is changed in two different ways. The quadrupoles near to the IPs have a single power converters each, thus they can be modulated by changing the current in the power converters. All other quadrupoles are powered with one power converter for at least two quadrupoles. These magnets were equipped with additional windings (back legs), which can be powered by a harmonic generator (Fig. 2). A power cable and a multi wire selection cable is connecting the generator and the control unit with the magnets. One magnet with back leg windings can be selected in each part of the ring between the IP and the middle of the next octant. The actual installation allows to modulate 16 magnets by their own power converters (maximum number) and 116 (out of 488 with pick ups) with

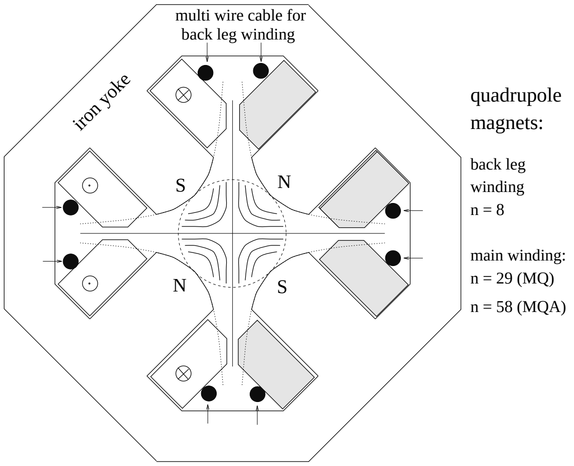


Figure 2: Cross section of a LEP quadrupole magnet. The additional windings (multi wire cable) are mounted on top of the main windings.

back leg windings. The equipped magnets are located in the straight sections to both sides of the four even IPs of LEP where the experiments are located (Fig. 3). The oscillation of the beam is detected by two couplers installed at locations with different betatron phases (Fig. 1). This arrangement allows measurements of beam oscillations induced by any quadrupole around the ring.

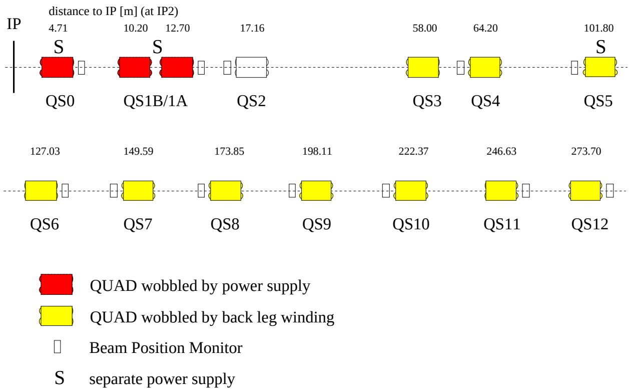


Figure 3: Location of quadrupole magnets and beam position monitors on the right side of IP2. This arrangement is symmetrical around all even LEP IPs.

A data acquisition system measures the position at every bunch passage using the signals from the couplers: The beam position is sampled with a sampling frequency given by : $f_{rev} \times N_{bunches}/N_{av}$ ($N_{av} = 400$, number of single passages averaged), resulting in a sampling frequency of 112.46 Hz. Each coupler gives values for both planes and in each plane signals from electrons and positrons are digitized at the same time.

The excitation and measurement are synchronized by using the LEP timing system (MTG). Measurements show the expected phase change of π for beams passing on different sides in the quadrupole.

3 DETERMINATION OF THE BOM OFFSETS

For each of the eight superconducting quadrupole magnets (QS0s) and the adjacent normal conducting quadrupole magnets (QS1s) the modulation frequency can be selected in a range between 10 Hz and 15.6 Hz. A spacing of 0.8 Hz between two frequencies was used. For the quadrupoles excited by back leg winding the frequencies can be selected between 0.8 and 2.0 Hz with a spacing of 0.4 Hz.

This low limit is given by the closed loop break frequency of the quadrupole power converters. The current change in the back leg winding induces a voltage in the main winding of the magnet. This voltage has to be counterbalanced by the regulation of the main power converters to avoid current changes in this circuit. The coupling between two magnets powered by the same power converter was found to be smaller than 0.1 ($f_{mod} < 2$ Hz) by modulating one magnet and measuring the field changes in both of them.

If the beam is centered in the quadrupole, the peak height is at a minimum. If the beam is off centre, the peak height rises linearly with the displacement. The plot of measured Fourier spectrum peak height versus the orbit measurement is shown in figure 4. The fit parameter P1 determines the BOM offset. The parameter P2 denotes the absolute value of the slopes to both sides of the minimum and P3 expresses the modulation amplitude at the minimum of the curve. In quadrupole magnets with large beta functions (QS0, QS1) the natural orbit drifts are large enough to determine the excitation minimum and thus the BOM offset (Fig. 4 top). For the other magnets closed orbit bumps are used to displace the beam (Fig. 4 bottom).

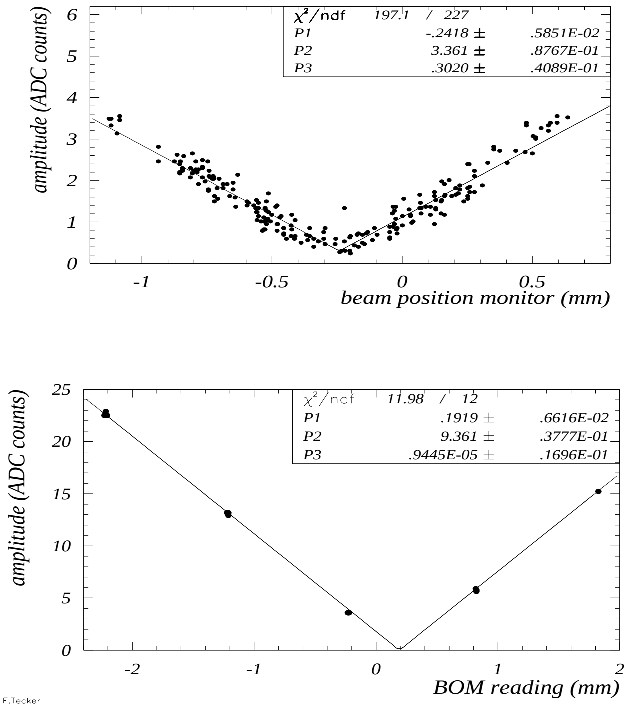


Figure 4: Beam oscillation amplitudes of magnets as a function of the orbit measured by the orbit monitors.
Top: Determination of an offset (-0.24 mm) using natural orbit drifts and orbit corrections during a period of 6 hours. The excitation frequency is 12 Hz.
Bottom: Determination of an offset (0.19 mm) using closed orbit bumps with an excitation frequency of 0.8 Hz.

The measured offsets near to the even IPs are almost equal to the reference orbit ('Golden Orbit': high luminosity orbit). This means that the 'Golden Orbit' is an orbit which goes through the centre of the quadrupole magnet (Fig. 5).

The distribution of measured offsets are systematically different for the QS0 and QS1 quadrupole magnets. For the QS0s the mean value of the offsets is about 1 mm whereas for the QS1 it is about 0.3 mm (Fig. 6). The width of both distributions is not significantly different (QS0: 0.6 mm, QS1: 0.45 mm). For the wide band monitors differences in the offsets were of about 100 μm observed for different gain

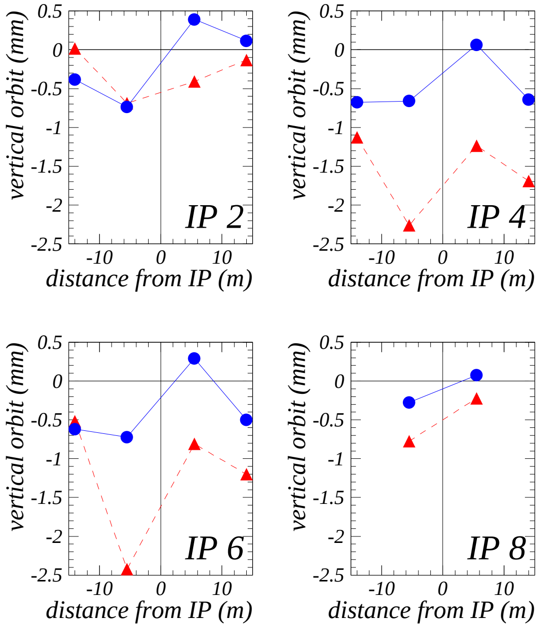


Figure 5: Vertical 'Golden Orbits' around the even interaction points in the superconducting low beta quadrupoles (QS0) and the adjacent normal conducting quadrupoles (QS1). The triangles denote the 'raw' 'Golden Orbit' and the circles the orbit corrected for the measured BOM offsets.

settings of the BOM system and for the two particle types.

4 TESTS OF K-MODULATION METHOD

Tests were done to study systematic errors of the method.

A test was done by changing the excitation frequency and keeping all other parameters constant. The frequency was changed in a range between 10.8 and 15.6 Hz by using the power converter excitation on a QS0 quadrupole magnet. The offsets were constant within the errors, but there is a clear reduction in the excitation amplitude with increasing frequency. This effect is expressed by the slope parameter P2 of the fit.

On one magnet (QS5 left of IP2) it is possible to modulate the focusing strength by the power converter and by the back leg windings. This test allows to show that the measured offset is the same in both cases. The modulation frequency for the power converter was 15 Hz and for the back leg windings 1.96 Hz. The offsets are, within the errors, equal for both methods.

5 CONCLUSION

The k-modulation method was frequently used during the LEP run 1994. Most of the offset determinations were done parasitically during physic operations. 34 offsets were determined and taken into account by the LEP orbit acquisition. Multi frequency excitation (up to 8 frequencies were used simultaneously) is possible and allows to reduce the time for offset determinations. It was discovered that the offset of the BOM system for the wide band monitors is significantly (100 μm) dependent on the particle type and of the chosen gain of the system.

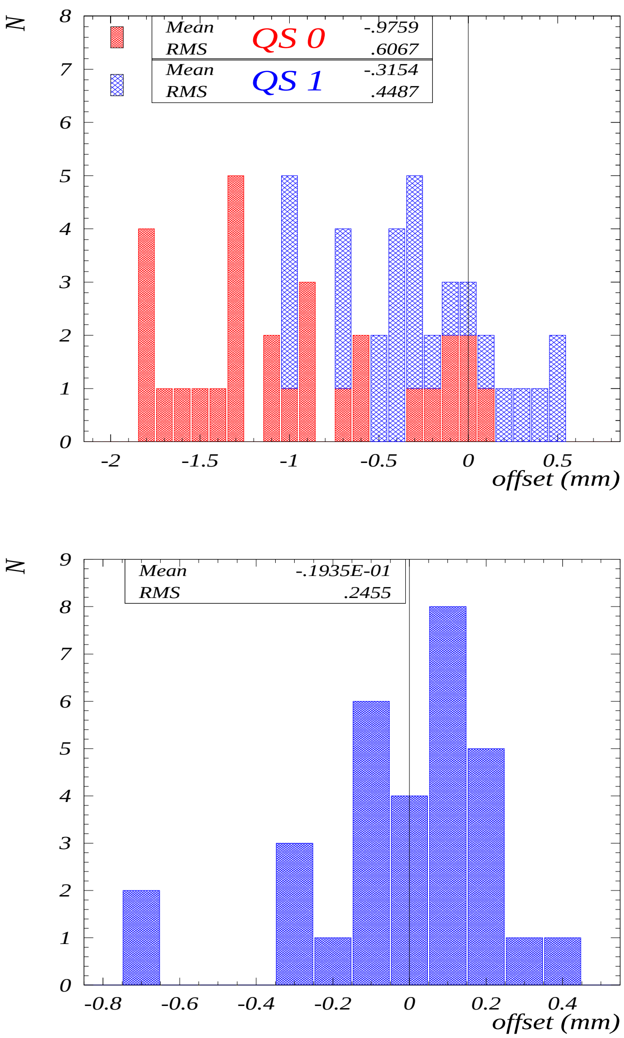


Figure 6: Distribution of measured BOM offsets.
Top: Offsets of the superconducting low beta quadrupoles (QS0) and the adjacent normal conducting QS1 magnets.
Bottom: Offsets of other normal conducting magnets in the straight sections equipped with narrow band BOMs.

6 REFERENCES

[1] D. Rice et al., "Beam Diagnostic Instrumentation at CESR", IEEE Transitions on Nuclear Science **Vol. NS-30, No. 4**, August 1983, pp.2190.

[2] R. Schmidt, "Misalignments from k-modulation", Proceedings of the Third Workshop on LEP Performance, CERN **SL/93-19 (DI)**, 1993, pp.139.

[3] I. Barnett et al, "Dynamic Beam Based Alignment", CERN **SL/94-84 (BI)**.