Accuracy of the LEP Spectrometer Beam Orbit Monitors

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Abstract

At the LEP e+/e- collider, a spectrometer is used to determine the beam energy with a target accuracy of 10^{-4}. The spectrometer measures the lattice dipole bending angle of the beam using six beam position monitors (BPMs). The required calibration error imposes a BPM accuracy of 1 μm corresponding to a relative electrical signal variation of $2 \cdot 10^{-5}$. The operating parameters have been compared with beam simulator results and non-linear BPM response simulations. The relative beam current variations between 0.02 and 0.03 and position changes of 0.1 mm during the fills of last year lead to uncertainties in the orbit measurements of well below 1 μm. For accuracy tests absolute beam currents were varied by a factor of three. The environment magnetical field is introduced to correct orbit readings. The BPM linearity and calibration was checked using moveable supports and wire position sensors. The BPM triplet quantity is used to determine the orbit position monitors accuracy. The BPM triplet changed during the fills between 1 and 2 μm RMS, which indicates a single BPM orbit determination accuracy between 1 and 1.5 μm.

1 INTRODUCTION

The LEP energy calibration requires the determination of the beam energy ratio between 50 GeV and 93 GeV. The beam energy at 50 GeV is accurately calibrated using the spin polarization of the circulating electrons. Therefore only changes of the relevant quantities which occur during the calibration procedure have to be taken into account. The spectrometer measures the change in bending angle in a well-characterised dipole magnet as LEP is ramped [1, 2]. The beam trajectory is obtained using three beam position monitors (BPMs) on each side of the magnet. The BPMs used consist of an aluminium block with an elliptical aperture and four capacitive button pickup electrodes placed at the corners of a square with a length of 62 mm. The button signals are fed to customised electronics supplied by Bergoz Instrumentation. The electronics use time multiplexing of individual button signals through a single processing chain to optimise for long-term stability. The position of the BPM block is surveiled with wire position sensors [6]. Two independent wires are used to monitor the relative horizontal and vertical movements. The environmental magnetic field in the drift space is monitored with fluxgates.

The required BPM accuracy of 1 μm means that a orbit position determination at time t_1 and a second at t_2 should not differ more then 1 μm for the same beam position. In between of t_1 and t_2 the beam energy has to be changed from 50 to 93 GeV and several other parameters will change accordingly (for example: radiated synchrotron power, transverse and longitudinal beam size). A unobserved BPM support movement of 1 μm in between of t_1 and t_2 for the same beam position would be not acceptable.

An estimate of the influence of changing measurement conditions on the orbit determination accuracy is given in section 2 and 3. The absolute calibration of the BPMs with wire position sensors is explained in section 4. The orbit determination accuracy is estimated by using a beam position independent quantity (BPM triplet) and by calculating the difference of measurements taken at t_1 and t_2 (see section 5).

2 BEAM CURRENT AND BEAM ORBIT

During the operation, differences in the beam current in a fill were observed with a mean value of 55 μA and a RMS of 44.4 μA. The average beam current in a fill was 2050 μA. Estimating the position changes due to current variations, using the beam simulator results [3], an upper limit of position changes of 0.3 μm is calculated. The difference and the absolute value of the beam current during a fill as function of the fill number are shown in figure 1. The absolute beam currents in fill 7833, 8223 and 8443 were on purpose reduced.

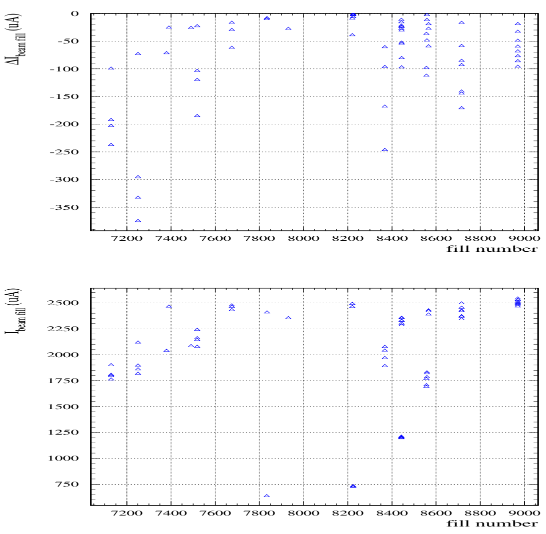

Figure 1: The beam current changes (top) and the absolute beam current (bottom) during a fill throughout the year.

Beam position changes have been minimized during operation (see Fig. 2) to avoid position errors caused by the non-linear response of the monitors [4, 5]. The non-

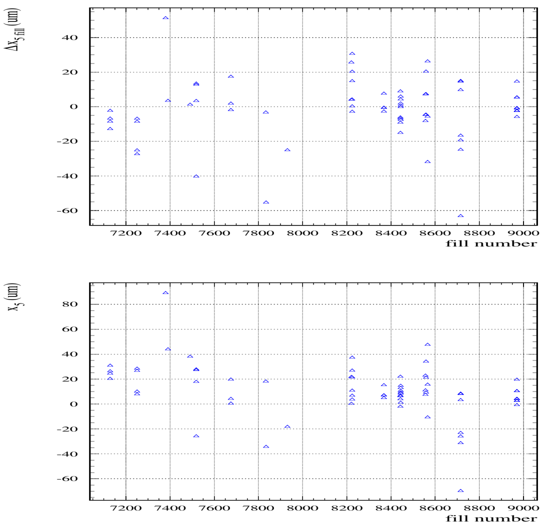

Figure 2: The variation of the horizontal beam position change (top) and the absolute beam position (bottom) during a fill throughout the year.

linear simulations predict systematic position errors below 0.3 μm due to the beam position changes during a fill. For all BPMs the position variations are shown in table 1.

Table 1: Mean and RMS beam position in the horizontal plane for all BPMs in μm

	1x	2x	3x	4x	5x	6x
Mean	0.8	2.79	-3.21	3.03	1.06	4.19
RMS	23.9	33.5	29.5	19.2	32.2	22.1

3 ENVIRONMENTAL MAGNETIC FIELD

The environmental magnetic field requires a significant beam position measurement correction. The environmental field is caused by the earth magnetic field, power cables placed near to the beam line and some vacuum pumps. Fig. 3, top, shows the vertical field component of the environmental field for different operation conditions along the drift space of the spectrometer. The BPMs are placed at $\pm$ 2,6 and 10 m. The large field increases at $\pm$ 3.25 m are due to the permanent magnets of vacuum ion pumps. The horizontal beam orbit at the left and right side of the magnet for two different operating conditions is shown in figure 3, bottom. The relevant orbit correction for the spectrometer is given by the difference between the two curves. The correction is mainly caused by the non zero field and not by the large field changes due to ion pumps. The largest correction of 3 μm has to be applied at the left/right extreme

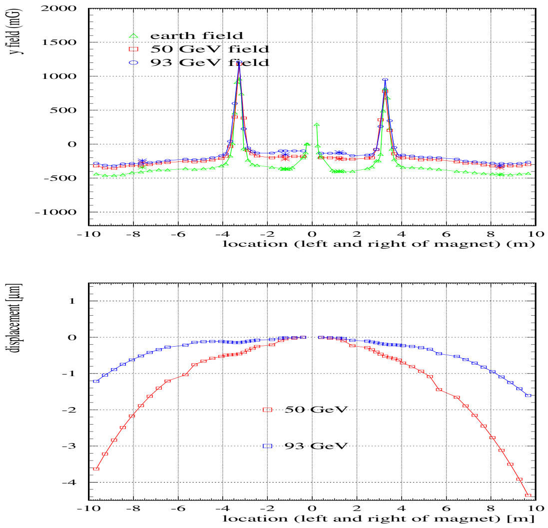

Figure 3: Top: The vertical environmental magnetic field in the region left and right of the spectrometer bending magnet. Different fields are caused by different excitations of the main magnets. Bottom: The calculated horizontal bending of the beam due to the environmental field for two different beam energies.

BPMs.

4 MOVEABLE BPMS AND GAIN CALIBRATION

The absolute gain calibration of the BPM was done by moving the BPM support and measuring the movement with wire position sensors [6]. All 6 BPM supports were mounted on translation stages and driven with stepping motors. The position was measured using the wire position sensors (WPS) installed for surveillance purpose. The BPM position reading is corrected for orbit changes during the 20 min operation by using the BPM triplet (see next section). Fig. 4, top, shows the BPM triplet versus the wire position measurement. The difference between BPM triplet and parametrisation shows no systematic effect (see Fig. 4, bottom) and has a RMS value of 0.8 μm.

5 ORBIT POSITION AND BPM TRIPLET

The monitor orbit reading has to be corrected for possible movements of the BPM support. A system of wire position sensors [6] is used to monitor support position changes (wps_{corr}). The bending effect of the environmental field is another correction applied ($b_{fieldcorr}$). The relative gains ($g_{r\,i}$) of BPMs are determined by orbit bumps before every measuring period [4]. The absolute gains are determined using the wire position sensors ($g_{a\,i}$).

The evaluated orbit position reads:

$$x_i = g_{r\,i} \cdot < g_a > \cdot bpm_i + offset_i - wps_{corr\,i} - b_{field\,corr\,i} \quad (1)$$

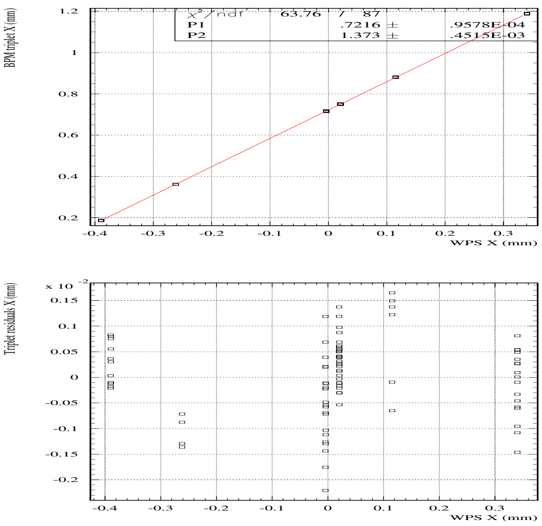

Figure 4: Top: The BPM position measurement as function of the wire position readings over a range of 1 mm. A straight line parametrization is applied to the measurements. The parameter P2 expresses the gain ratio between the two monitors. Bottom: The residuals between data and parametrization as function of wire position readings.

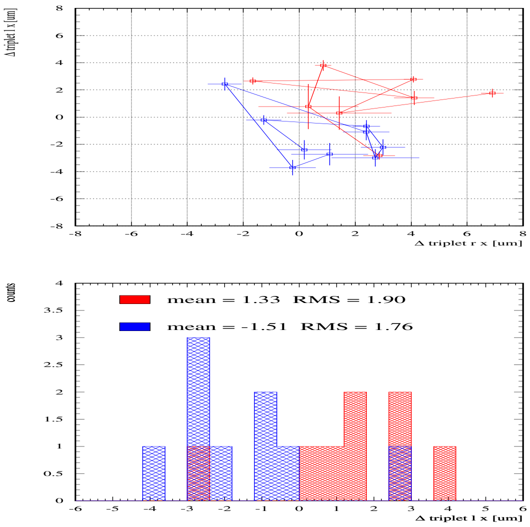

Figure 5: Top: The difference of the left BPM triplet vs the difference of the right BPM triplet for different energies (50 and 93 GeV). The colours (different lines) indicate measurements done using different beam optics. Bottom: The histogram shows the frequency distribution of the left triplet differences with mean and RMS value for the the different optics.

The alignment and electronic offset is summarised in the formula by the term offset.

To study the relative accuracy of the BPM monitors three position signals are combined to the BPM triplet:

$$Triplet = \frac{x_1 + x_3}{2} - x_2 \qquad (2)$$

The BPM triplet response is independent of beam orbit changes. The difference of BPM triplets of different orbit measuements allows to test the relative accuracy of BPMs by changing beam positions. A change of the accuracy of one BPM lead to a non zero BPM triplet difference and a change of the accuracy of 2 or 3 BPMs will likely lead to a difference. The BPM triplet difference is composed of an orbit measurement at a beam energy of 50 GeV and 93 GeV. Figure 5, top, shows the BPM triplet difference of the 3 BPMs on the left side of the magnet versus the 3 BPMs on the right side. Measurement were done using two different optics (different lines and colours) The left BPM triplet (see Fig. 5,bottom) shows significantly different mean values for the two different beam optics (mean: 1.3 and -1.5 μm with a RMS of 1.9 and 1.8 μm, number of measurements: 8 and 9). This systematic difference is not yet explainable. The BPM triplet difference mean value and RMS value result in a single BPM orbit determination accuracy between 1 and 1.5 μm.

6 CONCLUSION

The influence of changing measurement conditions on the orbit determination accuracy (beam current variation, beam position variation) was kept well below 1 μm and is not limiting the accuracy. The orbit position measurements are corrected for BPM block movements and environmental magnetic field influences. A relative BPM calibration procedure using orbit bumps and an absolute procedure using wire position sensors have been applied. The BPM triplet quantity was used to estimate the single BPM orbit determination accuracy.

7 REFERENCES

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