CLOSED ORBIT FEED-BACK FROM LOW-BETA QUADRUPOLE MOVEMENTS AT LEP

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Abstract

Left and right of each of the four LEP interaction points superconducting low-beta quadrupole magnets are installed to squeeze the vertical beam size at the interaction points. These magnets are the dominant source of vertical closed orbit drifts at LEP because of their strength, the large vertical beta function and their support. Hydrostatic Levelling Systems and resistor-based position sensors were installed to measure the vertical movements of these magnets continuously. The correlation between the mechanical movements and closed orbit variations has been studied. The analysis has shown that the orbit can be kept stable by acting on one correction dipole per low-beta quadrupole pair. This has led to a feed-back system which uses the mechanical measurements to correct the closed orbit and to prevent large orbit variations.

1 INTRODUCTION

Since the beginning of LEP operation the vertical closed orbit has been found to be drifting with time. This required frequent orbit corrections by the operation crew. The distribution of corrector magnets used for the corrections showed that the correctors near the low-beta quadrupoles (QS0) or with a phase advance of $n\pi$ nearby were used for the majority of corrections.

The superconducting low-beta quadrupoles are vertically focusing and have a quadrupole strength ($k = -0.16\,\mathrm{m}^{-2}$) 10 times larger than other magnets in LEP to obtain the small beam size at the interaction point. Their strength and the large vertical beta function at this location make the closed orbit very sensitive to any vertical mechanical displacement of these magnets. In addition, the mounting of the magnets makes it likely that they can actually move.

Hydrostatic levelling systems (HLS) and potentiometer-based position sensors were installed to measure the movements of the magnets continuously. A first analysis of the observed movements and their correlation to orbit drifts can be found in [1]. This analysis was extended and led to a feed-back system for the vertical orbit.

2 MECHANICAL INSTALLATIONS

The schematic layout of one of the four experimental interaction point (IP) is shown in Fig. 1.

The low-beta quadrupoles are mounted on a cantilever support structure which extends into the experimental detectors. Since it is not supported on the inner side, it is possible that the magnets move with the support. Hydrostatic Levelling Systems [2, 3] are installed to monitor the movements. They consist of vessels with capacitance-based hydrostatic sensors and temperature sensors connected by communicating tubes. These vessels are placed at different locations on the magnets and supports. One system with horizontal tubes is installed on each support for the QS0 and the next closest magnets (QS1). Since the tubes are horizontal, local temperature differences do not introduce a measurement error and the precision is better than 1 μm. A different system of communicating vessels is connecting the supports and the ground on both sides of a detector. It was not possible to install the tubes in a horizontal plane and the precision is limited to $\mathcal{O}(10)$ μm. The HLS at one interaction point (IP 8) which was installed as a pilot system has also non-horizontal tubes and hence a lower precision.

In addition potentiometer-based systems measure the position of the magnets with respect to reference points in the experimental detectors with precision of a few μm.

3 OBSERVED MOVEMENTS

Fig. 2 shows a typical vertical movement of a low-beta quadrupole measured by the hydrostatic levelling system.

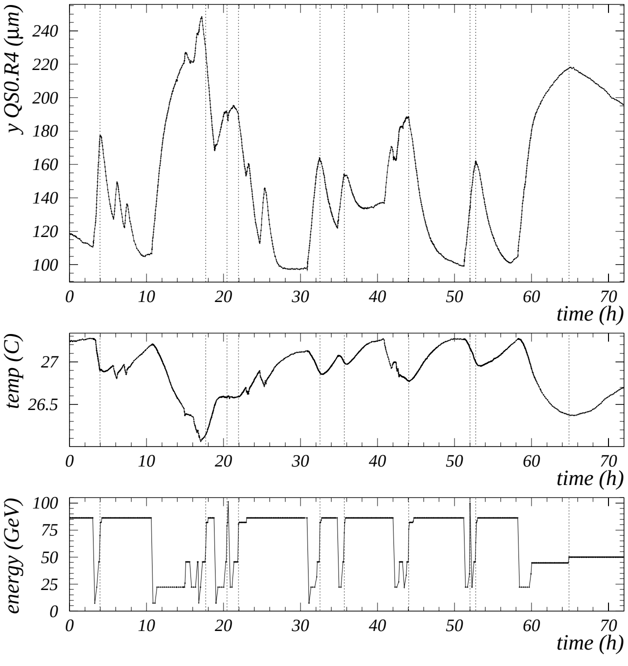

Figure 2: Movement of a low-beta quadrupole (QS0.R4) for a period of three days (top), the temperature measured at the support of this magnet (middle) and LEP beam energy (bottom). The vertical dashed lines indicate the end of the ramp to collision energy.

In general, the pattern of the movement in time is the

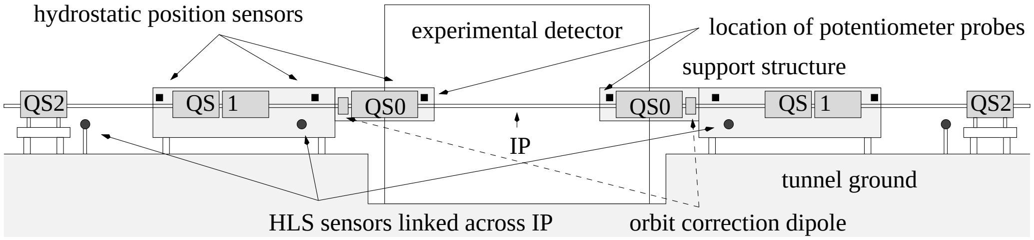

Figure 1: Schematic view of the low-beta insertion around an experimental detector. The QS0 are the superconducting low-beta quadrupole magnets. The layout of one IP is slightly more complicated since the inner magnets (QS0,QS1) and the inner parts of the detector are mounted in a support tube (not shown).

same for all QS0 magnets. The movement is correlated with temperature changes of the support. When the temperature rises, the magnets start moving downwards. The temperature changes are mainly caused by the operation cycle of LEP. The temperature starts rising after LEP has been ramped to higher energy. This can be understood by the higher current heating up the current feed-throughs which traverse the support. The time constant of the thermally driven movements is of the order of a few hours and a short refilling time keeps the amplitude of the movements smaller.

4 ORBIT ANALYSIS

The vertical orbit drifts were studied in detail to determine the contribution from the movements of the low-beta QS0 magnets. A movement Δy_Q of a quadrupole at location s_0 creates an angular kick $\Delta y'(s_0) = kl\Delta y_Q$ which changes the closed orbit at any location s by $\Delta y(s)$ according to

$$\Delta y(s) = \frac{\sqrt{\beta(s)\beta(s_0)}\cos(|\mu(s)-\mu(s_0)| - \pi Q)}{2\ \sin(\pi Q)} \cdot \Delta y'(s_0). \tag{1}$$

β, μ and Q are the betatron function, phase advance and tune, respectively. Since both k and $\beta(s_0)$ are large for the QS0, the movement Δy_Q of a single QS0 generates a RMS change of the vertical closed orbit $\sigma_{\Delta y}$ 40 times larger than the mechanical movement. This factor is only 2 for a regular lattice quadrupole.

The beta function is symmetric around the interaction point and the vertical betatron phase advance between the two magnets is nearly π. Eq. 1 shows that the effect on the orbit nearly cancels if both magnets move by the same amount in the same direction. A common movement of $\Delta y_Q = 10\mu$m for both QS0s results in a RMS orbit change of only $\sigma_{\Delta y} = 7\mu$m.

Fortunately, the pairs of QS0s at the different interaction points tend to move in a similar way. Eq. 1 also implies that the differential movement of the QS0 pair can be corrected with only one orbit correction dipole (see Fig. 1) at each IP.

The differential movement can be seen in the closed orbit. Orbits logged during physics data taking were used to calculate the *'bare orbit'*[1] from the measured orbit y_{meas}

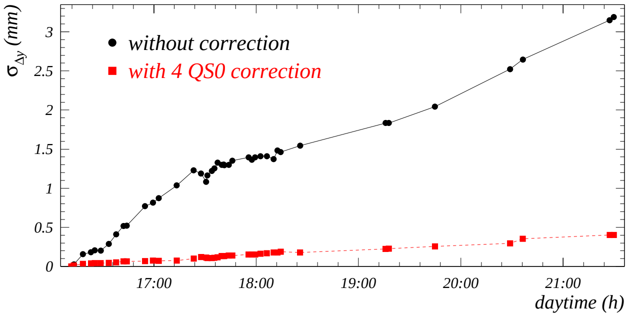

Figure 3: RMS of the difference of bare orbits during a physics fill relative to the first physics orbit before and after orbit correction with only 4 QS0 correctors. A typical vertical orbit has a residual RMS of about 500μm.

by

$$y_{bare} = y_{meas} - \frac{\sqrt{\beta_{bpm}}}{2\sin(\pi Q)} \sum_{cor} \sqrt{\beta_{cor}} \cos\left(|\mu_{cor} - \mu_{bpm}| - \pi Q\right) \cdot \theta_{cor} \tag{2}$$

where the sum is taken over all vertical correctors. θ_{cor} is the kick angle for the corrector, β_{cor} and μ_{cor} are beta function and phase at the corrector, β_{bpm} and μ_{bpm} at the beam position monitors, respectively. This procedure removes the effects of all corrector magnets. The difference of two bare orbits shows the orbit changes from other sources than corrector magnets and can be used to localise the source of the changes.

The bare orbit of the first orbit acquired after the physics experiments start taking data is used as a reference for each fill. For all subsequent orbits the bare orbit is calculated and the RMS of the difference from the reference $\sigma_{\Delta y}$ is evaluated. This represents the movements of the orbit if no orbit corrections had been made.

An example of the movements during a fill is given in Fig. 3.

If the QS0 magnets are the source of the drifts then it should be possible to correct most of the effect with only one orbit corrector magnet per IP. This was done with the COCU package [4] using the MICADO algorithm [5]. The result showed that this correction is very effective, taking away about 70–90% of the orbit movements (Fig. 3). This

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[1] The closed orbit if all correction magnets were switched off.

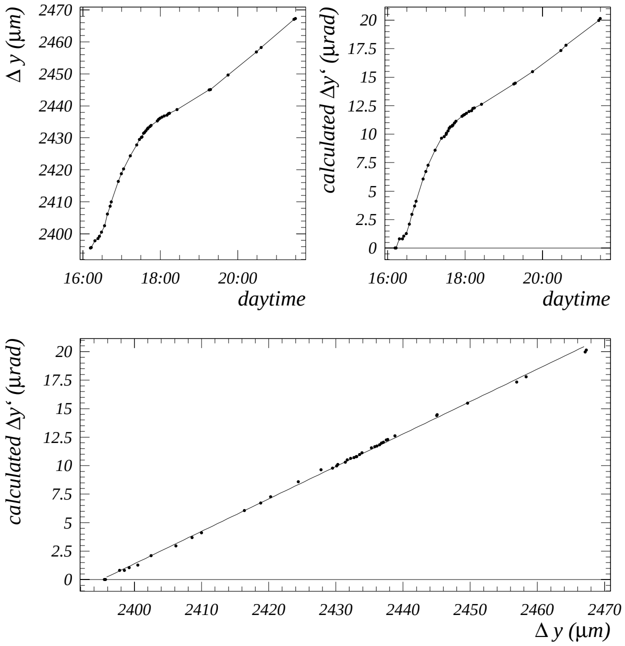

Figure 4: Example of the mechanical movement (top left), the calculated orbit correction kick (top right) and their correlation (bottom) at one IP during a fill with large quadrupole movements.

proves that the superconducting low-beta magnets are indeed the major source of the drifts.

5 CORRELATION AND FEED-BACK

The calculated orbit correction kick $\Delta y'$ should be proportional to the differential movements of a QS0 pair. This was examined for the different interaction points. Only the HLS with horizontal connecting tubes on the supports are used for the analysis. Due to the lower precision, including the HLS system connecting the supports on both sides of the IP does not improve the correlation. An example is shown in Fig. 4.

A proportionality constant between the correction kick and the differential movement was derived for each QS0 pair from this correlation. A software feed-back was developed which reads the mechanical position of the magnets and calculates the necessary correction kick from the differential movement. Whenever the correction kick exceeds a certain threshold, it is sent to the orbit corrector. The HLS is used except for IP 8 where the potentiometers are more precise than the pilot HLS.

The feed-back has been running very successfully at the end of the 1996 operation period of LEP. Fig. 5 shows an example.

The feed-back was compensating well for the movements of the orbit. The potentiometer system used at IP 8 is less precise than the HLS but still capable of tracking the movements. The feed-back significantly reduced the number of orbit corrections that had to be made by the operator.

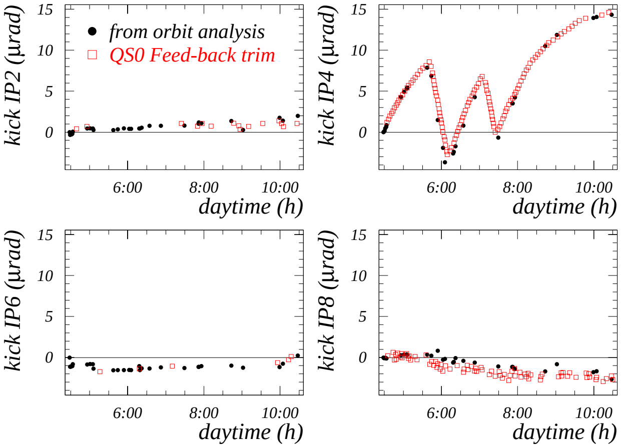

Figure 5: Example of the feed-back during one fill. The correction kicks sent by the feed-back are compared to the corrections calculated from the off-line orbit analysis.

Another application of the QS0 measurements is the reload of a previously stored set of corrector excitations of an orbit which gave high luminosity and good background conditions. The positions of the QS0 magnets of storage and reload time are compared and the necessary correction is incorporated. An experiment was performed and it demonstrated that the orbit with the incorporated correction had a significantly lower RMS excursion. This reduces the risk of accidental beam loss when an old set of corrector settings is reloaded.

6 CONCLUSIONS

The superconducting low-beta quadrupoles are the major source of vertical orbit drifts at LEP. Hydrostatic Levelling Systems with horizontal connecting tubes measure the vertical movements of these magnets very precisely. A feed-back system based on the measurements has been implemented and prevents large orbit variations during the physics data taking. The HLS at IP 8 will be upgraded this year and the more precise HLS measurements will be used for the feed-back at all IPs.

7 REFERENCES

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