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Dynamic Beam Based Alignment

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Abstract

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Slow unavoidable orbit drifts lead to changing beam positions. The beam position is detected by modulating the strength of the magnetic field of a quadrupole and measuring the amplitude of the induced closed orbit oscillation. The amplitude of the orbit oscillation depends linearly on the modulation strength and on the beam offset in the quadrupole magnet.

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INTRODUCTION

The method of beam based alignment is already used in some accelerators and storage rings (1-3). Using a modulation of the quadrupole strength was first used in LEP in 1992 and presented on the Third Workshop on LEP Performance (4).

The measurements are carried out during normal luminosity runs. The modulation of the magnetic field is done by modulating the current of the magnets at fixed frequencies between 0.8 and 17 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 directional coupler signal (Fig. 1).

This allows simultaneous excitation and amplitude measurements of several magnets with different frequencies (Fig. 3). These measurements are recorded for several hours, and the offset is extracted by evaluating the minimum response and comparing it to the nearby position monitor.

INSTRUMENTATION

The magnetic field of the quadrupoles is changed in two different ways. The quadrupoles near to the IPs have their own power supply thus they can be modulated by changing the current in the power supply. All other quadrupoles are powered with one power supply for at least two quadrupoles. These magnets were equipped with additional windings (back legs) which can be powered by a separate generator.

In LEP 16 magnets are modulated by their own power supply and 88 are modulated with 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. 2).

For the quadrupole magnets with back leg windings the magnetic field can be modulated at a frequency of up to 1.6 Hz. This limit is given by the closed loop break frequency of the quadrupole power supply. 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 supply to avoid current changes in this circuit. The coupling between two magnets powered by the same power supply was found to be smaller than 0.1 by modulating one magnet and measuring the field changes in both of them.

The oscillation of the beam is detected by two directional couplers installed at locations with different betatron phases. This arrangement allows measurements of beam oscillations induced by any quadrupole around the ring.

A data acquisition system collects the signals from the couplers: the pulse from one bunch passage is integrated in a gate of about 500 ns and digitized using a 12 bit ADC. The ADC is read out with a Digital Signal Processor which adds the values of 200 or 400 bunch passages and writes up to 17000 sum values into memory. LEP operates with a revolution frequency $f_{rev} = 11.246$ kHz and eight bunches per beam. Due to the electronics only every second bunch can be measured. The sampling frequency is given by : $f_{rev} \times N_{bunches}/200(400)$, this results in a sampling frequency of 224.92 Hz or 112.46 Hz. Each coupler gives values for both planes and in each plane signals from electrons and positrons which are all digitized at the same time.

CALIBRATION OF THE BEAM POSITION MONITORS

For each of the eight superconducting quadrupole magnets (QS0s) the modulation frequency can be selected in a range between 12 Hz and 15 Hz. A spacing of 1 Hz between two frequencies was used. Four quadrupoles were modulated at the same time. Figure 3 shows a FFT spectrum with the modulation of four quadrupoles switched on.

The amplitude of the peaks shown in Fig. 3 are stored together with the orbit measured with the orbit monitors at approximately the same time. If the beam is centered in the quadrupole, the peak height is at a minimum. If the beam is off center the peak height rises linearly with the displacement. We now plot the measured peak height versus the orbit measured with the orbit monitors. Results for some quadrupoles around an interaction point are shown in Fig. 4.

From these plots it is possible to get the offsets for the different pickups. The offsets can be different for different particles and also for different gains in the electronics of the orbit monitors. Preliminary results for the offsets using the recently installed orbit monitor electronics are given in Table 1. If the offset is calculated by doing a fit, the error on the offset is between 30 and 50 μm . The reason for the - quite large - errors at the moment is, that the new electronics have just been installed and a more accurate analysis is not finished yet.

Table 1. Preliminary results for determination of the absolute offset of pick-ups located close to the superconducting quadrupoles (QS0s). All values are estimated from the plots and given in mm. Large errors occur, if the beam was always on the same side of the quadrupole and never went through the center.

QS0		electrons		positrons	
		gain 0dB	gain 10dB	gain 0dB	gain 10dB
IP 2	left		$.1 \pm .2$		$.2 \pm .2$
	right		$-.8 \pm .2$		$-.8 \pm .1$
IP 4	left	$-1.4 \pm .3$	$-1.75 \pm .1$	$-1.55 \pm .1$	$-1.75 \pm .1$
	right	$-1.3 \pm .3$	$-1.4 \pm .1$	$-1.3 \pm .1$	$-1.3 \pm .1$
IP 6	left		$-1.7 \pm .1$		$-1.75 \pm .1$
	right		$-1.2 \pm .1$		$-1.5 \pm .1$
IP 8	left		$-.2 \pm .2$		$-.7 \pm .1$
	right		$-.25 \pm .1$		$-.5 \pm .1$

CONCLUSION

It is possible to measure the offsets of beam orbit monitors using the modulation of the quadrupole strength. The measurement can be done during luminosity runs and has no influence on the quality of the beam. The accuracy of about 0.1 mm is achieved if the beam approached the magnetic center from both sides. If it was just on one side, it is more difficult to determine the minimum (Fig. 4). Fitting a V-shaped function to the data gives errors between 30 and 50 μm .

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Figure. 1. Principle of dynamic beam based alignment

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Figure. 2. Location of quadrupole magnets and beam position monitors on the right side of IP2. This arrangement is symmetrical around all even LEP IPs.

K-Modulation FFT spectrum 10-52 06 Sep 1994

Figure. 3. Spectrum of the beam oscillations. The sampling frequency is 112.46 Hz and the peaks correspond to a quadrupole magnet excitation frequencies of 12, 13, 14 and 15 Hz.

Figure. 4. Modulation amplitudes of four magnets symmetrically located around LEP interaction point 4 as a function of the orbit measured with the orbit monitors. The minimum indicates the center of the magnet. The offsets are -.5 mm, -1.7 mm, -1.4 mm and -1.4 mm. P1 gives the offset with errors from fitting.