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A BEAM POSITION STABILIZATION SYSTEM[†]

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Summary

We describe a simple closed loop system for beam position stabilization on an electron storage ring. The system using a differential photoresistive cell for the beam position detector reacts on the beam through appropriate dipole correctors. Typical sensitivity of this cell is 10 mV per micron with less than one mV noise. Results obtained on ACO show that the position of a beam could be stabilized by a few microns and that the efficiency of the system is determined only by the quality of the cell and the mechanical stability of its support. A set of four identical systems will be installed on DCI which operation in space charge compensation implies a good steering of orbits in the common parts of the machine. Preliminary tests on DCI are reported.

Introduction

Systematic studies carried out on ACO had shown that the beam-beam limit was strongly decreased for small beam separation ($\sim \sigma/10$) at one or two crossing points per turn[1,2]. Similar effects were observed on DCI while attempting to achieve space charge compensation in three or four beams configuration.

Dynamic beam separations of this order of magnitude may be induced :

- in a classical e^+e^- ring with separated orbits at some crossing points, by voltage fluctuation on the separating plates, and current fluctuations in the dipoles, or in the quadrupoles in which the orbits are separated.
- in a double ring like DCI, by current fluctuations in the dipoles and quadrupoles[3].

The principle on which DCI is based implies the identity of orbits in the common sections, and their stability versus any drift or fluctuation. A closed loop system was designed for this purpose, and is now under installation. A brief description and first results are presented here.

Brief Description of the System

The orbit adjustement and stabilization in the two common sections of the rings imply a set of four identical loops. The beam position is detected by making use of the synchrotron light emitted in the nearest bending magnet. The light is reflected by a water-cooled mirror and brought out through a sapphire window. An optic bench supports a lens, attenuators, a diaphragm, and a two-axis differential photoresistive cell on which a half-scale image of the beam is formed. The cell position is controlled and adjusted by means of horizontal and vertical translators driven by stepping motors. The loop is completed by two sets of amplifiers, one per direction (fig. 1). A low drift instrumentation amplifier (LDIA) is followed by an active filter and a V to A converter supplying the dipole correctors. This part bringing up no particular problem, we shall pay attention essentially to the position detector, which determines to a large extent the characteristics of the system. Next we shall discuss the necessary LDIA voltage gain as a function of the required position stability and the sensitivity of the different elements.

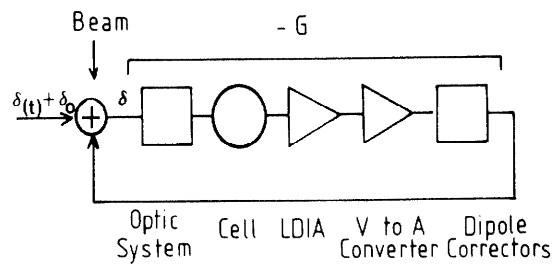

Fig. 1 : Block diagram of the closed-loop system

Position Detector

The detector consists of four photoresistive strips, obtained by vacuum deposition of cadmium sulfide, and eight metallized octants used as connections (fig. 2).

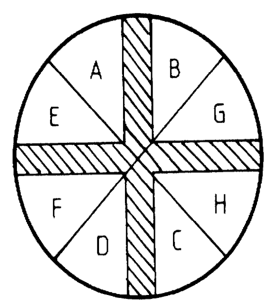

Fig. 2 : Front-view of the cell

The equivalent circuit of the cell (fig. 3) consists of

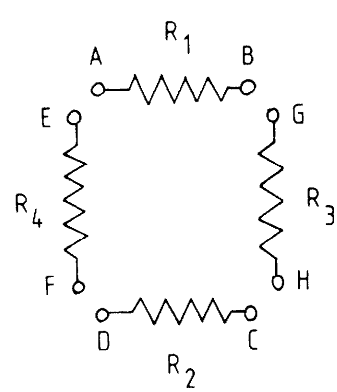

Fig. 3 : Cell equivalent circuit

four resistances which, for given brightness and dimensions, are only function of the image position. The vertical position is determined by R_1 and R_2, the horizontal one by R_3 and R_4. Each pair of resistances forms

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a part of comparison bridge (fig. 4). The potential

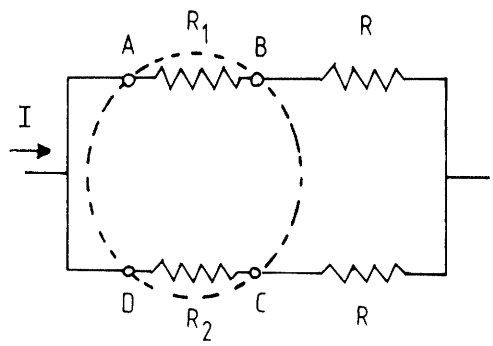

Fig. 4 : Comparison bridge

difference between the points B and C is given by :

$$v = RI \frac{R_2 - R_1}{R_1 + R_2 + 2R}$$

where R_1 and R_2 depend on image and cell characteristics. To first approximation, one obtains for a transverse gaussian-like image :

$$v = \frac{RI}{1 + \frac{R}{2\rho}} \sqrt{\frac{2\pi}{K}} \frac{\delta}{\sigma_i}$$

where ρ is the cell equivalent resistance $[\frac{1}{\rho} = \frac{1}{R_1} + \frac{1}{R_2}]$.

K is a coefficient depending on the photoresistive layer

σ_i is the image standard deviation relative to the considered direction.

For the following experimental conditions :

σ(beam)	=	500 μm
σ(image)	=	250 μm
R	=	100 kΩ
ρ	=	50 kΩ
I_{max}	=	0.1 mA
K	=	0.67

the experimental value of the sensitivity is 10 mV/μm for a predicted value of 30 mV/μm, the difference beeing due to a lack of accuracy on ρ, K and σ parameters.

General Characteristics of the Detector

Offset stability

No test was carried out concerning the long-term stability of the photoresistive layers, for want of both light source and mechanical support of a sufficient stability.

A relative variation $\frac{\Delta R}{R}$ of the two resistances R leads to an offset of the cell giving an equivalent displacement :

$$\delta_o = \frac{1}{2} \sigma \frac{\Delta R}{R} \sqrt{\frac{\pi}{2K}}$$

for $|\frac{\Delta R}{R}| < 10^{-4}$ and $\sigma \sim 500$ μm, the displacement is $|\delta_o| < 0.05$ μm.

The thermal stability (10^{-5} per degree) was choosen so that this effect is negligible for ten degrees variations.

Variation of the cell-offset as a function of the beam dimensions

If the conductance of a photoresistive layer is not uniform, the equivalent resistance ρ is a function of the image position. Experimentally a linear variation of the conductance was found, according to :

$$C = C_o (1 - \alpha z)$$

The potential difference between the points B and C is then given by :

$$v = \frac{RI}{1 + \frac{R}{2\rho}} \sqrt{\frac{2\pi}{K}} \left(\frac{\delta - \alpha \sigma^2/K}{\sigma} \right)$$

and the variation of the offset by :

$$\delta_o = \frac{\alpha \sigma^2}{K}$$

Experimentally it was found that the null position of the cell is linearly dependent on the image square dimension. A variation of a factor of 2 for the beam dimensions leads to an offset equivalent to a beam displacement of 20 μm. Of course the variations of beam dimensions compatible with a four beam operation are much smaller.

Influence of the beam intensity and dimensions on the cell sentivity

The equivalent resistance ρ varies like $I_S^{-K} \sigma^{K-1}$. For the choosen parameters the sensitivity is almost inversely proportional to the dimensions, and varies by a factor of 4 for a variation by a factor 200 of the beam intensity (I_S).

Response time

Detectors of this type are intrinsically slow. The cut-off frequency is about 100 Hz for 0.1 mm displacements, and drops to 1 Hz for a few millimeters displacements. Cadmium selenide cells, whose cutt-off frequency is a thousand times higher, were discarded on account of their excessive sensitivity to illumination and temperature variations. Anyway the bandwith of the whole system is defined by the dipole correctors, whose efficiency is inversely proportional to the frequency above 0.5 Hz.

However, the active filters used to prevent possible instability of the loop allow us moreover to obtain, at least for small displacements, a good efficiency up to 100 Hz.

Current supply of the cell

The current supply of the cell was conceived to accomplish the following functions (fig. 5) :

The cell current is maintained constant by a loop through A_3 ensuring a zero mean voltage at the input of the LDIA A_1.

The current level is controlled by means of the potentiometer P_1 and the amplifier A_2. This allows us to change the cell sensitivity in a wide range (100).

The displacement of the beam, independently of the cell position, is realized by off-set control by means of the potentiometer P_2, the amplifier A_4, and the resistances r.

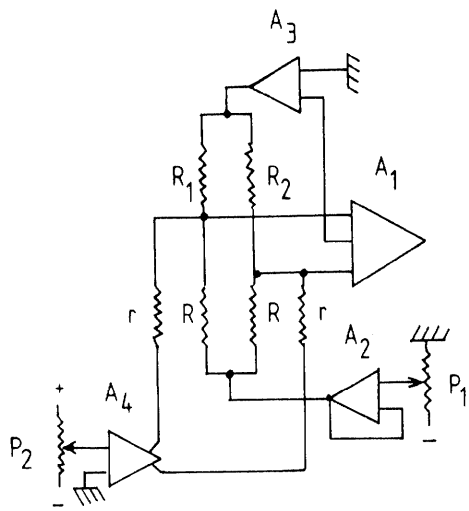

Fig. 5 : Cell current supply circuit

Cell background noise

The cell background noise was not accurately measured for lack of a sufficiently stable light source. Measurements done with a laser led us to an upper limit of 0.1 µm for the equivalent displacement noise of the cell.

Necessary Gain

The static displacements to correct are determined :

- in the horizontal direction, by the reproductibility of the closed orbit, i.e. 0.2 mm.
- in the vertical direction, by the electrostatic separation of the beams, i.e. 2 mm.

The orbit fluctuations due to magnetic fluctuations are of the order of 0.2 mm (peak to peak) for both directions. In order to stabilize beam position in the range of one micrometer, a loop gain of about 300 is required for horizontal and about 2000 for vertical displacements.

The optical magnifying power being 0.5, the conversion gain 2 A/V, the sensitivity of dipole correcting coils 0.2 mm/A for horizontal displacement and 0.6 mm/A for the vertical one, the maximum required gain for the LDIA is 300.

Results

A first set installed on DCI was used to check the sensitivity and frequency response of the different elements.

The measured natural orbit fluctuations have amplitudes smaller than 0.1 mm p.p., and frequencies below 50 Hz. In these conditions the efficiency of the system is only limited by the frequency response of the dipole correctors.

With the closed loop system at maximum sensitivity of the cell, the remaining fluctuations are less than 2 µm p.p. for both directions.

We can conclude that this type of high sensitivity and low noise detector could be of a great interest for electron rings in which a good position stability is required near, and a fortiori inside, a bending magnet.

Acknowledgments

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References

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3 R. Belbéoch, NI/3-75, "Anneaux de Collisions", Laboratoire de l'Accélérateur Linéaire - Orsay.