TEST OF A DISPERSION SWEEP CORRECTION SYSTEM USING A 'CENTROID' IN THE DIRAC BEAM LINE

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Abstract

A new proton beam position detector named 'Centroid' is placed in the DIRAC target station and is aligned with respect to the beam. Behind it there is a set of various targets used for the DIRAC experiment. The 'Centroid' itself collects the secondary electrons, which are emitted by the target when hit by the proton beam [1]. This provides an on-line verification of the beam position without obstructing the beam path by a screen, and without perturbing the experiment. A computer application then calculates the corrections needed to centre the beam in both planes as a function of time. This paper will explain how this is done.

1 INTRODUCTION

The DIRAC (Dimeson Relativistic Atom Complex) experiment takes place in the East Area of the CERN PS. The beam, with an intensity of about 10^{11} protons, is slowly extracted from the PS machine over 400 ms and has an average momentum of 24 GeV/c.

Due to the resonant extraction, the particles in the head of the extracted beam spill have a higher momentum than the particles in the tail. Adding the dispersion of the transfer lines to this makes the beam sweep horizontally over the target of the experiment. Therefore two correction dipoles, one horizontal and one vertical, which are independently controlled by a function generator were installed prior to the commissioning of the experiment.

Until now the horizontal and vertical beam position were manually verified, putting scintillator screens in and correcting the beam position by adjusting the function generators. The 'Centroid' can now be used to fulfil this task in an automatic, non-invasive and more precise way.

2 THE CENTROID

The 'Centroid' consists of a ceramic disc on which a conductive silver layer is deposited in four separate quadrants. The diameter is Φ80mm with a hole of Φ30mm in its centre, as shown in fig. 1.

The device is polarised, with a bias voltage applied on the target system while the electrodes are virtually grounded through the electronics.

When the proton beam (which passes through the hole in the device and therefore does not interact with it) hits the target, secondary electrons are produced with a secondary emission efficiency of approximately 5%. If the polarisation is sufficient, the electrodes capture these electrons, which results in a current measured by the electronics. This current is directly proportional to the number of electrons collected on the electrode, which then depends on the position of the proton beam with respect to the centre of the target and thus the 'Centroid'.

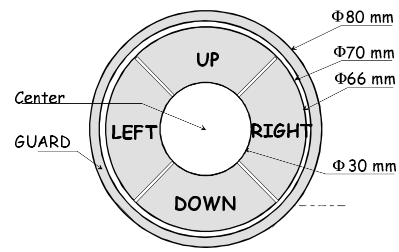

Figure 1: Layout of the 'Centroid' detector.

If the proton beam is centred on the target, the currents in all four electrodes are equal. However, if the centre of gravity of the beam is moved towards the right, the current in the right electrode will become larger than the current in the left electrode, and vice versa. This principle, once calibrated, allows us to calculate the beam position 'x' on the target. Equation (1) shows this for the horizontal plane, but the same equation applies for the vertical plane,

$$x \propto \frac{I_{right} - I_{left}}{I_{right} + I_{left}} = \frac{\Delta_{hor}}{\Sigma_{hor}} . \quad (1)$$

3 FEEDBACK SYSTEM

A fully electronic system calculates the beam position instantaneously, and this can be used in a feedback loop in combination with a horizontal and vertical dipole to maintain the beam centred on the target during the beam spill, as shown in fig. 2.

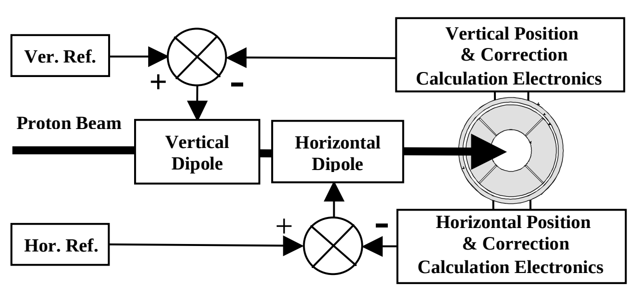

Figure 2: Block schematic of the feedback system.

The electronics connected to the plates calculates the beam position error and the difference in current that needs to be applied to the dipoles in order to centre the beam in both planes. The signals from the plates are very small and therefore very sensitive to noise. This means that the signals need to be filtered and the electronics used should introduce very low noise levels, otherwise the error in the position calculation becomes too important and corrections cannot be made.

The overall bandwidth of the feedback loop is expected to be at least 100 Hz, which is above the dipole bandwidth. This system is still under test and dedicated beam time is needed to validate the system.

4 FEED FORWARD SYSTEM

For historic reasons, each quadrant is connected to an integrator, so that at the end of the beam spill it is easy to determine the average beam position, using a voltmeter. The feed forward is therefore based on these electronics.

4.1 The integrator

The charges collected by the four plates are integrated using very low noise integrators. The output voltage is proportional to the charge at the entrance,

$$V = \frac{Q}{C} = \frac{I \times t}{C} . \quad (2)$$

Using a capacitor of 100 pF the integrator is calibrated at 1 Volt for 6.25x10^8 secondary electrons collected.

4.2 Calibration

Different types of measurement were made in order to calibrate the 'Centroid' in combination with the integrating electronics.

In order to determine the right polarisation voltage, a scan between 0 V and –350 V was made, and the offset was measured without beam, and the total current per plane with beam on the target. A bias voltage of –100 V is chosen as a good working point for the 'Centroid'. During the second measurement, the output voltage of the four plates was calibrated to a beam position on the target in the horizontal and vertical plane. The results of these calibrations are given in fig. 3. From the trend lines it can be concluded that the system is linear for the region in which the device is to be used.

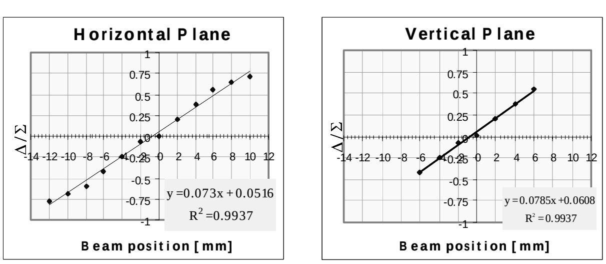

Figure 3: Horizontal and vertical position calibration.

4.3 Theoretical principle

The electron current of the left-right quadrant is integrated by the electronics providing a voltage as a function of time given by,

$$V_{left}(t) = \frac{1}{C}\int_0^t I_{left}(t)dt , \quad (3)$$

$$V_{right}(t) = \frac{1}{C}\int_0^t I_{right}(t)dt . \quad (4)$$

The ratio given in Eq. (5) is proportional to the horizontal beam position in the 'Centroid' as a function of time (using also Eq. (1)),

$$\frac{\Delta_h}{\Sigma_h} = \frac{\frac{d}{dt}(V_{left}(t) - V_{right}(t))}{\frac{d}{dt}(V_{left}(t) + V_{right}(t))} = \frac{I(t)_{left} - I(t)_{right}}{I(t)_{left} + I(t)_{right}} \propto x(t) . \quad (5)$$

This equation is also valid for the vertical plane using the upper and lower quadrants.

4.4 The Dispersion Sweep Compensation system

The DIspersion Sweep COmpensation system, which hereinafter will be referred to as "DISCO" system, is illustrated in fig. 4.

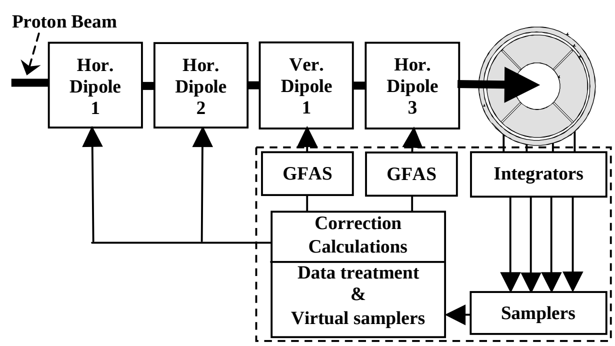

Figure 4: Block schematic of the feed forward system.

It is a feed forward system that is based on the electronics discussed in the previous sections, but completed with a software application in which all the remaining treatments are processed. They result in the beam position versus time in both planes from which one can calculate the necessary corrections to the magnet currents in order to centre the beam during the whole duration of the spill.

The average horizontal beam position is controlled by the dipoles 1 and 2, whereas the dispersion sweep, which is then around the horizontal central position of the target, is corrected by horizontal dipole 3 that is driven by a programmable function generator 'GFAS'. A vertical correction dipole, also connected to a programmable function generator, compensates for any vertical movements as a function of time.

The voltage signals are sampled and stored at a rate of 1kHz using a 16 bit (±15 bit) sampler. Two timings, a start and a stop are associated with the sampler in order to control the window of data validity. The start also acts as a reset of the four integrators. An example of the sampled signals from the four integrators is given in fig. 5.

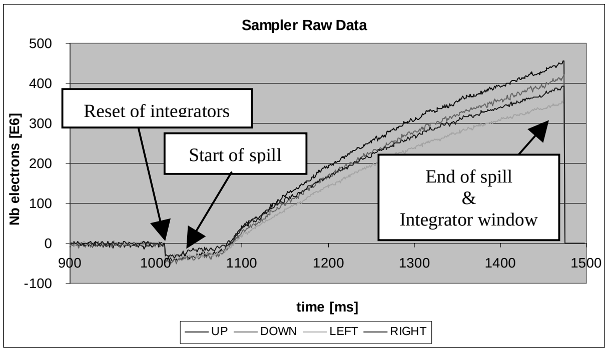

Figure 5: Sampled integrators raw data of four plates

The horizontal position can be calculated from the 'Centroid' using,

$$x = C_h \frac{\Delta_h}{\Sigma_h} + K_h = C_h \frac{\Delta S_{right} - \Delta S_{left}}{\Delta S_{right} + \Delta S_{left}} + K_h , \quad (6)$$

where x is the horizontal beam position, ΔS_{right} and ΔS_{left} are respectively the right and left differentiated sample of the signal, C_h is the horizontal calibration factor and K_h is the offset coefficient for the vertical position.

The same equation is applicable to the vertical plane by replacing left and right by up and down and using different constants for the calibration factor and the offset coefficient.

The use of virtual samplers, where one can re-sample the treated raw data, and a prototype application program made it possible to perform semi-automatic corrections.

The first correction, the average horizontal beam position, is done using the integrated signals of the left and right plate at the end of the spill.

The horizontal and vertical corrections, which are related to a position as a function of time, are made using the differentiated sampler signals. As an intermediate step, the differentiated signals are filtered numerically before using them in the position and correction calculations, using a so-called digital smoothing polynomial filter [2].

The correction function in the GFAS is only updated when the average beam position or the beam sweep goes beyond the predefined tolerance. The rate with which the beam position and sweep are compared to the tolerances is also predefined, depending the number of cycles to be averaged for the measurement. In any case, the correction will only be valid for the cycle that follows the last measurement used for the averaging.

An example of the results that can be obtained with this feed forward is given in fig. 6, where the horizontal and vertical beam position, before and after correction, is given as a function of time [3].

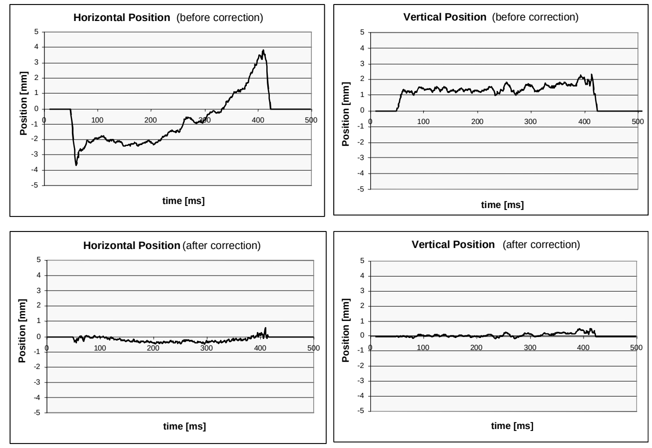

Figure 6: Beam position as function of time before and after correction.

5 CONCLUSION

The 'Centroid' and its electronics based on the integrators, work correctly and the measurements show that the device is linear in a range of ±10 mm. Calibrations have been made and the exact relationship between the number of electrons counted by the different plates and the beam position is established.

The two methods 'feedback' and 'feed forward' can both keep the beam centred. However, both methods have their advantages and disadvantages.

The feedback has the advantage of being a real time system, but when there is an important drift in the central horizontal position it can quickly saturate due to the limitations of the horizontal dipole.

The feed forward does not have this problem since it uses two strong dipoles to compensate the central beam position, while the sweep is compensated with the small dipole. The only inconvenience is that the system is not a real time system, but it is based on the information of the previous cycle(s).

If, in the future, the feed forward does not prove to be sufficient, the two systems can be superimposed. The feedback will then perform the minor final correction.

During the coming months, a test to replace the present integrators by normal amplifiers will be done. Doing this implies that the acquired signal no longer needs to be derived before calculating the beam position.

6 REFERENCES

[1] D.Pereira, O.Sala, U.Schitter, New method for controlling on target beam position, NIM A267 (1988) 41-42.

[2] Numerical recipes in C, the art of scientific computing, 2nd edition.

[3] J. Bosser, G. Molinari, J-M. Nonglaton, V. Prieto, R. Steerenberg, Test of a Dispersion Sweep Correction System by using a Centroid in the DIRAC Beam Line, PS/OP/NOTE 2001-011.