A Laser Alignment System for Low Beta Quadrupoles

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Abstract

The positions of the low beta quadrupoles in the BØ area of the Fermilab Tevatron were monitored using a laser based system. Two identical systems were used on either side of the collision point. The essential components of each system included a 2 mWatt helium neon laser, a set of lenses which could be remotely flipped into the laser beam, and a four quadrant silicon photocell detector. A computer system took the data remotely and stored the data in files for chronological comparisons. Mainly due to drifts in the laser the accuracy of the system was .5mm, but this was sufficient to check for long-term settling of the area around the collision pit.

I. Introduction

The low beta quadrupole system in the Tevatron was installed before the central detector of CDF was rolled in. Portions of the system were installed on a girder that extended out from the side of the collision hall and the girder was supported by invar rods. In addition, part of the girder was encapsulated by the muon toroids and the forward calorimeters of CDF.

There were various concerns associated with this situation: motion due to the roll in of the central detector, stability of the girder (members of CDF used the horizontal invar rods to stand on while servicing the toroids), motion associated with turning on the toroids, etc. Also checking the positions of the quadrupoles using conventional alignment techniques was a time consuming process due partly to the inaccessibility of the magnets and partly due to the time necessary to bring vertical control into the collision hall through various radiation shielding walls

Hence there was a desire to have a system that would enable the horizontal and vertical positions of the quadrupoles to be monitored remotely while beam was running. The absolute accuracy was not so important as the ability to check for a gross movement of a quadrupole without spending several days of beam time. There are very elegant techniques[1] for monitoring the vertical motions of elements, however these techniques do not work for the horizontal motion. We therefore deleveloped a laser based system that would remotely monitor the horizontal and vertical motions of beamline elements .

II. Overview

Two identical systems were used on either side of the collision point. A schematic of one side is shown in figure 1.

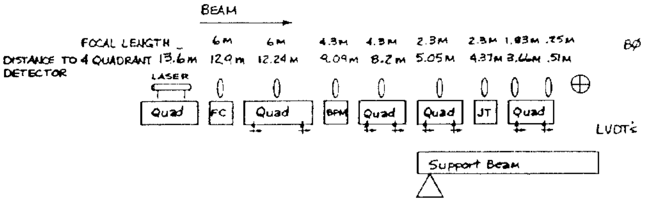

Figure 1 System Overview

The laser was a 2mWatt helium neon laser and the detector was a four quadrant silicon photocell detector. The lenses could be flipped remotely into the laser beam, figure 2 shows the flipping mechanism along with the associated stepping motor.

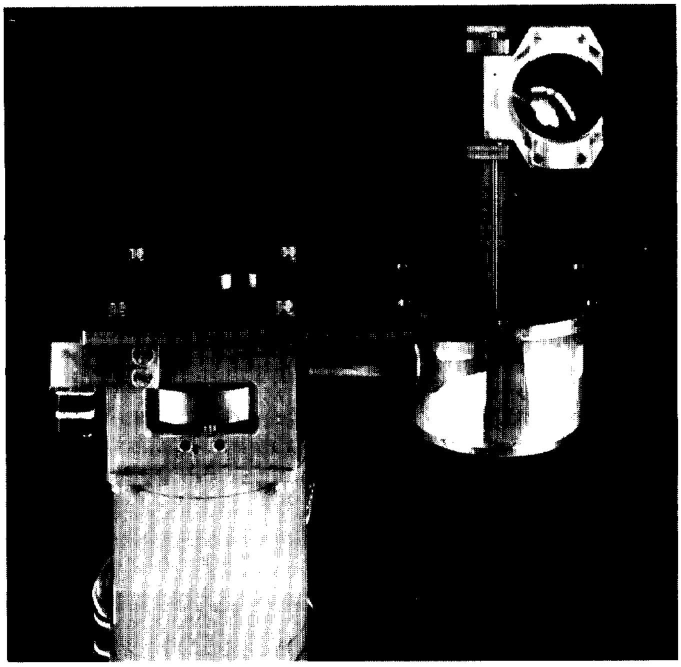

Figure 2 Lens Flipper

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A data taking run involved a calibration lamp reading, a reading with all lenses out, and a reading as the lenses were flipped in one by one. A reading simply implies that each of the four quadrants of the detector were recorded.

Calibration

We were unsure about radiation damage effects on the four quadrant detector . For this reason and to correct for other systematic effects, we always took a reading with a lamp that gave a uniform illumination of all four quadrants. The raw data readings were scaled by the corresponding calibration readings(the actual number used was the calibration reading divided by the average of the calibration readings, this was done so that the raw readings were divided by a number close to one .

Data Analysis

The four quadrant detector is depicted in figure 3,

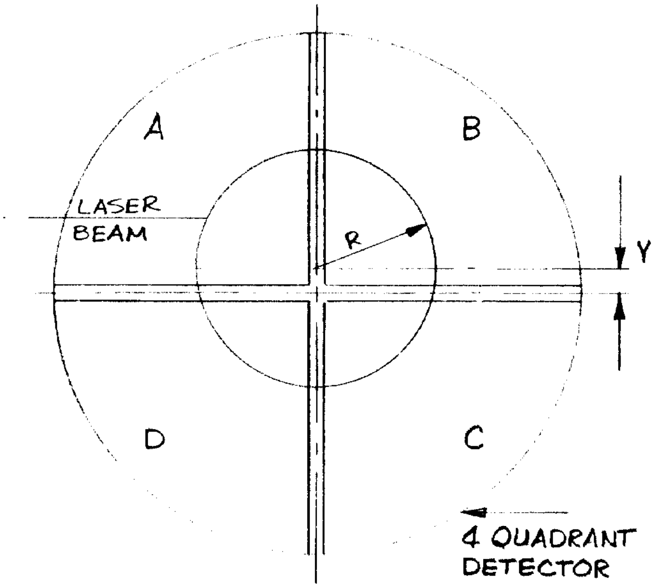


Figure 3. Four Quadrant Detector

and an analysis of how one extracts a centroid displacement from the readings of the four quadrants is as follows. The amount of light transferred from the lower half of the fourth quadrant to its upper half is 2 Ry leaving the following amounts of light on each half:

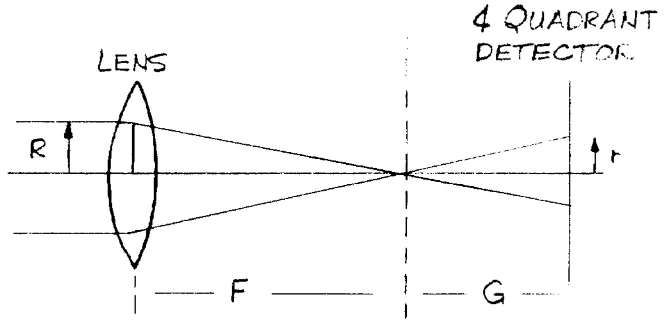
$$\text{Upper half} = \pi R^2/2 + y \times 2R \qquad (1)$$
$$\text{Lower half} = \pi R^2/2 - y \times 2R$$

They signal (normalized to total light response) is:

$$Y = \frac{A + B - C - D}{A + B + C + D} = \frac{4yR}{\pi R^2} = \frac{4}{\pi}\frac{y}{R} \qquad (2)$$

and for small displacements is linearly proportional to the displacement.

From figure 1, one observes that the distance from a lens to the four quadrant detector is not always twice the focal length. This is due to buying the lenses commercially and the constraints of exactly where we could locate the lens flipping mechanism. Figure 4 indicates that the size of the laser beam at the detector is a function of the distance and the x,y values were corrected for this effect.



$$\frac{r}{G} = \frac{R}{F} \Rightarrow r = \frac{G}{F} R$$

Figure 4. Spot size at the 4 quadrant detector

The heart of the data analysis lies in the observation that for a particular lens,the magnitude of the difference between the lens in x(y) value and the all lens out x(y) value is approximately twice the distance in x(y) between the laser beam and the center of the lens. Figure 5 schematically indicates this : and the calcualtion of d is

$$|x - x_0| = d + d \times G/F = d(1 + G/F) \sim 2d \text{ or} \qquad (3)$$
$$d = -(x - x_0)/(1 + G/F)$$

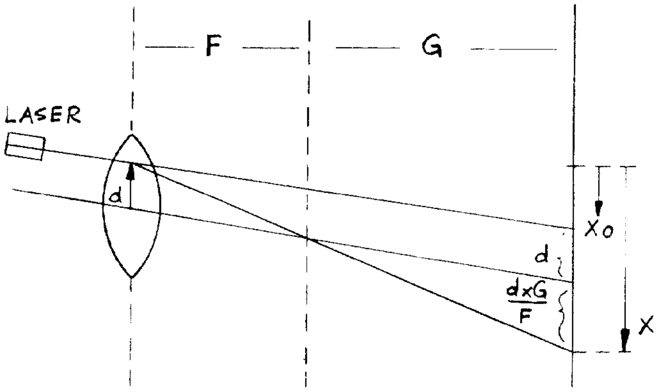


Figure 5. Laser beam traversing lens off center

The situation at this stage of the data analysis is that we have a set of offsets of the lenses' centers from the laser beam. There are several effects that we must address. Since the detector was at the end of the girder; if there were any motion of the girder, the detector would more than likely move the most. Also due to the long lever arm, any small change in laser angle would lead to relatively large effects. The solution that we have adopted is to assume that two of the lenses are fixed (the default choice was the first and third, however the console program had the flexibility to choose any two choices). Since two points determine a straight line we are able to characterize the laser beam with respect to our two monuments. Then since we know the offsets of the rest of the lenses from the laser beam, we are able to calculate the offsets of the rest of the lens from the straight line through the center of our monument lenses.

III. Operational Use

In the beginning, an effort was made to have the centers of the lenses reasonably close to the center of the laser beam. However, in practice we would do a final alignment of the quadrupoles, run the console program, and store the results. Then the console program had the capability to take data and plot the difference between the new data and the reference file since we were interested in relative motion. Up to 99 files could be stored in a wrap around manner, and file differences could be examined between any two files. Figure 6 is an example of the picket line display, a caveat is that the display was in color and not only are the lenses displayed, but LVDT (Linear Variable Differential Transducers, Schaevitz model GCA 121-250) readings. The LVDT readings are for the motion control devices[2] which are indicated on figure 1. The stability of the total system was half a milimeter and quite adequate to monitior for large problems such as an invar rod coming loose from the ceiling. However, the accuracy was not good enough to reset the magnets using the laser system and the motion controllers. We did reset magnets using the motion controllers while checking with conventional optical alignment techniques.

With the knowlege ,gained from experience, that there have not been large motions of the quadrupoles during beam operations, the laser system has been decommissioned to allow the insertion of the larger size low beta quadrupoles. It was however, comforting during the initial commissioning to be able to remotely check the positions of the quadrupoles.

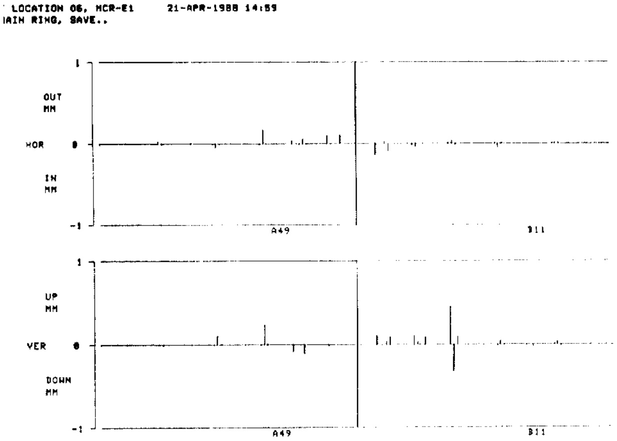


Figure 6 Picket Fence Display

IV. References

(1) D. Roux, "Alignment & Geodesy for the ESRF Project," in Proceeding of the 1st International Workshop on Accelerator Alignment, Stanford, CA., August, 1989, pp. 37

(2) M. Coburn, "Motion Control System for the Fermilab Electrostatic Septa," in Washington: IEEE Press, 1987, pp. 617 and 618.