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A novel solution for various monitoring applications at CERN

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Abstract. *The construction of the LHC, world's largest particle accelerator, includes the high-precision positioning of large structures. To achieve the needed accuracy, the development and implementation of new monitoring methods is required.*

Keywords: BCAM monitoring system, Corner cube prism,

1. Introduction

Situated on the outskirts of Geneva, CERN is the leading centre for particle physics in the world. The Large Hadron Collider (LHC) with its 27 km ring - shaped accelerator, which is currently under construction and will be operational in 2007, will begin a new era in high energy physics by revealing the basic constituents of the universe. The LHC is going to collide proton beams configured in bunches of 10^{11} protons separated by 25 ns, giving a centre of mass energy of 14 TeV. It will collide ion - beams as well. The collisions will take place at four experimental sites on the accelerator ring.

One of the experiments is ALICE, short for "A Large Ion - Colliding - Experiment", a detector consisting of multiple layers of subdetectors around the collision point to detect different types and properties of particles created in the collisions. Those particles are identified via their energy, momentum, track and decay products, therefor it is important to align the various subdetectors very precisely to each other and monitor their position. The monitoring - systems have to function for a very long time under extreme conditions (e.g. high radiation) and must not absorb too many of the particles created in the collisions. In the following chapters a system developed for that purpose is presented with some of its applications at ALICE.

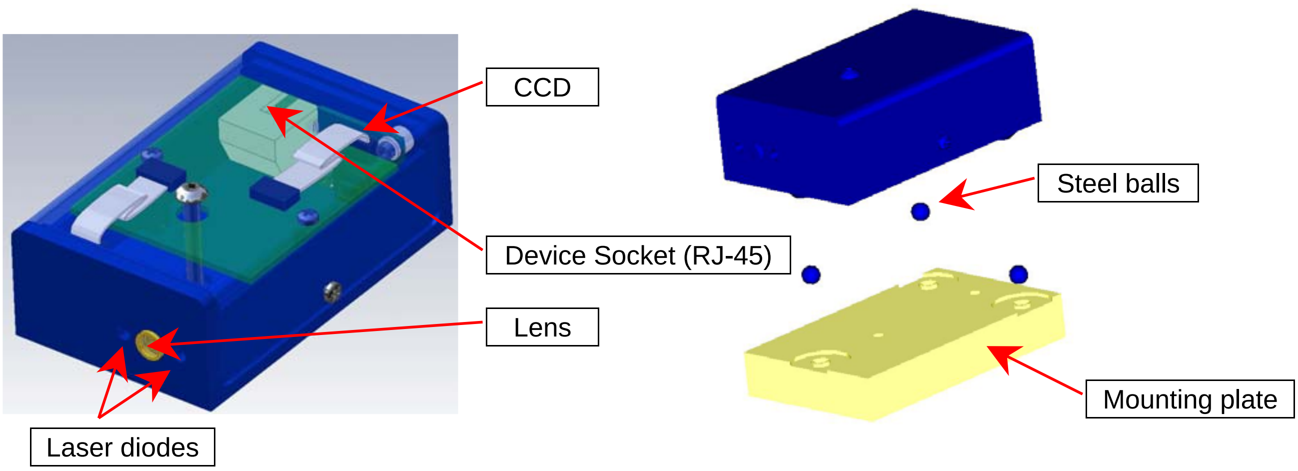

Figure 1: left: BCAM (91 x 55 x 30 mm); right: mounting principle

2. The BCAM-System

The BCAM (Brandeis CCD Angel Monitor) (Figure 1) [1] is a simple optical device which has been developed by Brandeis University for one of the LHC experiments. It consists of an electronic camera and a pair of light sources, all integrated into a single enclosure kinematically mounted on three steel balls.
The camera contains a CCD (Charge Coupled Device) image sensor and a lens with a focal length of 72 mm. Its field of view is 40 mrad horizontally and 30 mrad vertically to its mounting plane. The CCD provides an array of 344 by 244 pixels, serving as a two - dimensional coordinate system. A pixel measures 10 μm square. The light sources of the BCAM are red laser diodes, treated as being point - like. Each laser transmits at 650 nm in a rectangular cone that measures 75 mm by 25 mm on a screen at a distance of 100 mm from the BCAM. Lasers and CCDs can be controlled via an RJ - 45 socket.

The centres of the steel balls on which the BCAM is mounted define a local BCAM - coordinate system. All relevant BCAM - parameters, like e.g. the centre of the lens or CCD rotation, can be related to this local coordinate system by a calibration procedure. Thus one only needs to know the position of the centres of the steel balls in a global coordinate - system to know position and orientation of the BCAM - coordinate system.

The standard setup for a BCAM measurement contains two BCAMS, BCAM A looking at BCAM B. Flashing the light sources of BCAM A yields two light spots on the CCD of BCAM B. When A moves, the light spots on the CCD move as well. Knowing the spot movement on the CCD and the focal length of the BCAM, one can calculate the angular movement of A. If the distance between the light sources of A is known, the distance between the two BCAMs can be calculated as well.

The BCAM is connected to a driver board with a TCP/IP interface that can be connected either directly to a PC or to the internet via a network plug. The BCAMs can be connected to the driver either directly or via a multiplexer that connects up to ten BCAMs. With the driver supplying all the connected devices with power, the BCAM system is a stand alone data acquisition system connected to the rest of the world through the driver's Ethernet socket [2].

The angular resolution of a BCAM is 5 μrad. The resolution when measuring a small angular separation, this including two consecutive angle - measurements, is therefor 7 μrad. This limit is given by the errors of the calibration. In addition to the measurement of the relative angle of two BCAMs, the relative distance of two cameras is given by the separation of the light spots on the CCD. The accuracy of this measurement depends on the distance D between the light spots and the camera according to dx.

$$dx = \frac{5 \cdot 10^{-6} \cdot D^2}{16}$$

As an example, at a distance of 1 m the accuracy is 0.3125 mm.

3. Applications

ALICE - Spaceframe. The subdetectors of the ALICE - Detector are held in place by a structure called 'Spaceframe' (Figure 2). It has a cylindrical 18 - sided geometry with a length and diameter of 8 m. The weight of all the subdetectors, about 80 tons on the whole, will deform the Spaceframe. For obvious reasons these deformations have to be monitored.

Simulations have shown that deformations will only happen in a plane perpendicular to the axis of the Spaceframe. The 18 corners of the Spaceframe will show up to 5 mm relative movements according to the simulations. The Spaceframe Monitoring System has to determine all the positions of the corners to an accuracy of better than 500 µm. The BCAM system is implemented by fixing a mounting plate with two BCAMs on each corner. By measuring the relative angles of all BCAMs the 18 internal angles of the Spaceframe are monitored.

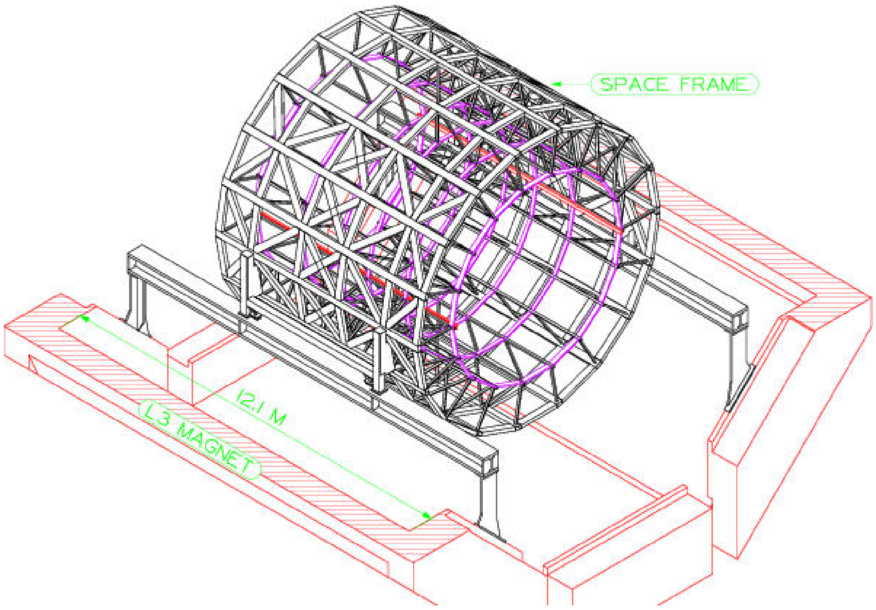

Figure 2: ALICE - Spaceframe

Detector - Monitoring. In particle physics experiments it is necessary to monitor the position of all subdetectors [5] with high accuracy. One way of realising this task is to put one BCAM on the subdetector and one BCAM on an external reference point. Since some detectors are to fragile to carry a BCAM and since space is usually limited, a novel solution is required. The idea is to mount a BCAM on the external reference point and a reflecting mirror on the subdetector. Using a corner cube prism instead of a plane mirror eliminates the sensitivity to rotations of the mirror. Tests results for this application are presented in the next section.

4. Test results for mirror application

The tests were done in a cleanroom with a standard BCAM (one CCD) and one corner cube prism made of BK7.

BCAM - Corner cube test alignment.

- Initial distance corner cube - BCAM: 820 mm
- Adjusting plate movement precision: 1 µm
- Measured distance: 20 mm
- 10 measurements for each 0.5 mm = 410 values/test
- Corner cube diameter: 15 mm

The following diagrams present two of several results about the correlation between corner cube prism movements with respect to the BCAM. Figure 3 shows the averaged distance between the two spots on the CCD during a longitudinal corner cube prism movement with respect to the BCAM. This function shows linar behavior. The residuals of the linear fit have a standard deviation of σ = 0.204389 µm resulting in a measurement accuracy dx = 250 µm. The LWDAQ software settings [1] for this test were the same as for the standard two BCAM alignment.

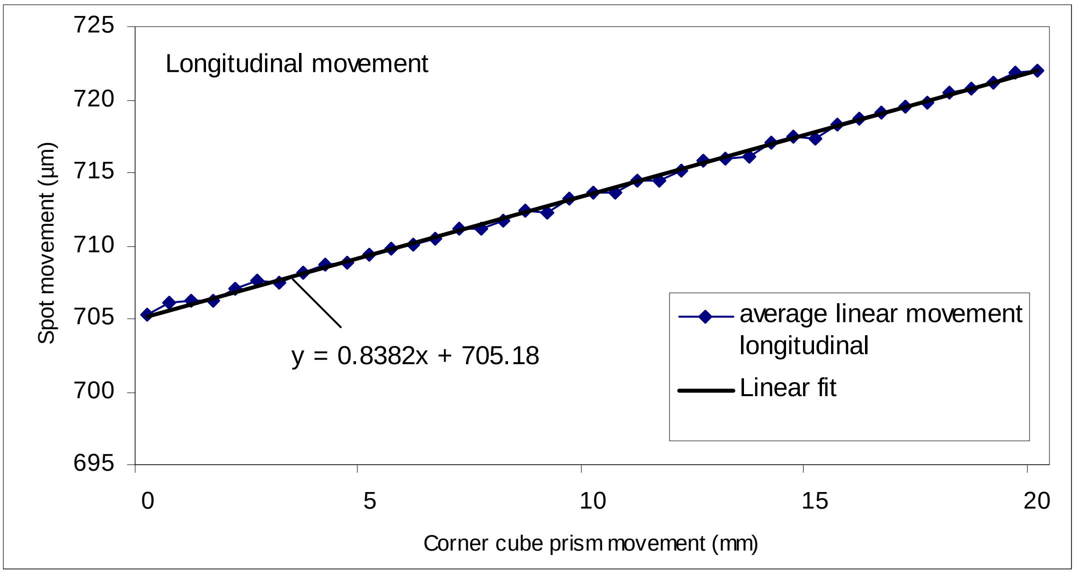

Figure 3: Longitudinal corner cube prism movement

Figure 3 shows the averaged x and y spot positions on the CCD after a transverse corner cube prism movement with respect to the BCAM. The spot properties are almost constant and the output function represents a linear correlation. For the measured distance the spot intensity is satisfactory. The residuals of the left spot have a standard deviation of σ_1 = 0.318111 µm giving an accuracy of dx_1 = 4.379548 µm. The residuals of the right spot have a standard deviation of σ_2 = 0.28528 µm giving an accuracy of dx_2 = 3.9218 µm.

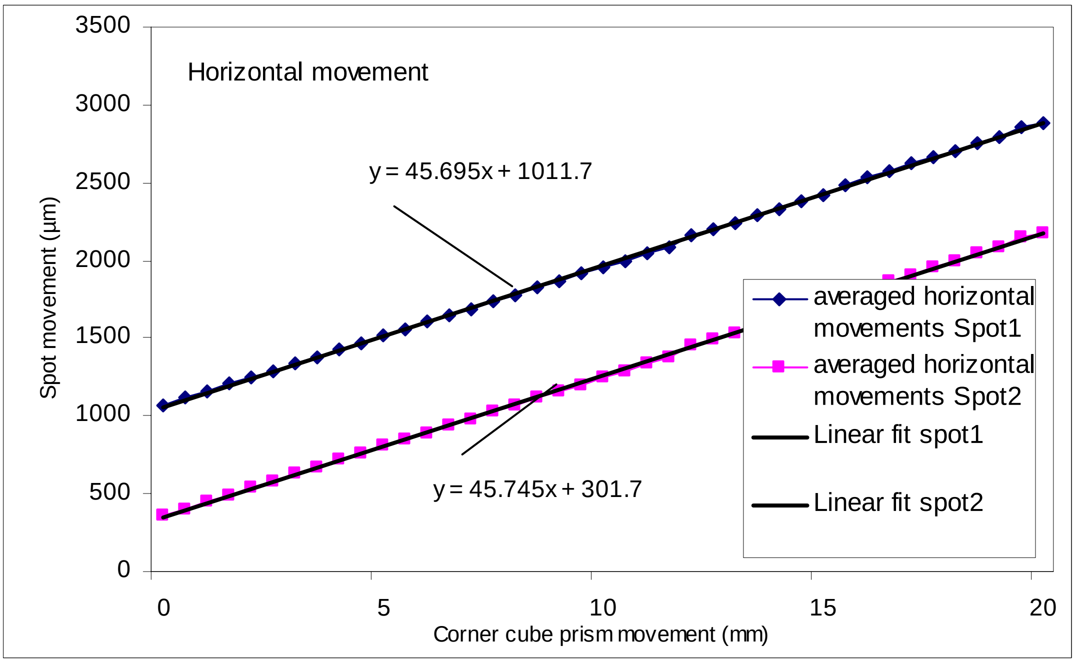

Figure 4: horizontal corner cube prism movement

We conclude that a corner cube prism at a distance of 810 mm from the BCAM can be tracked with an accuracy of around 5 μm transverse to the BCAM axes and 250 μm in the longitudinal direction. For larger distances we expect a linear decrease of the accuracy for the transverse direction and a quadratic decrease for the longitudinal direction.
Minimizing the material absorbtion by using coated mirrors is not necessary for distances up to 10 m. For distances greater than 10 m the intensity can be optimized by using coated corner cube prisms. It has to be mentioned, that the corner cubes physical basic principle is the rationale of a mirror.

5. Summary

The BCAM offers a very simple solution for position monitoring of large structures. A BCAM follows the movement of light sources with 5 μrad or better accuracy all across its field of view. A BCAM at a distance of 20 m can be tracked with accuracy better than 100 μm. A further development consists of a BCAM together with a corner cube prism. Tests with a prism in a distance of 800 mm from a BCAM show a measurement accuracy of 5 μm in the transverse direction and 250 μm in the longitudinal direction. As the accuracy and the spot properties are the same as with two BCAMS, the system can also be used where there is not enough space for a two BCAM solution.

References:

[1] K. Hashemi, "BCAM User Manual (Version 11)", Brandeis University, Boston (October 2004), Open Source Instruments, www.opensourceinstruments.com. BCAM drawings, reports, circuit diagrams and manuals are distributed for free under the GNU Public License, copyright Kevan Hashemi.

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