CLAM, a Continuous Line Alignment and Monitoring method for RICH mirrors.

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Abstract

A method is proposed for the angular alignment of RICH mirrors and for its monitoring, in particular for the COMPASS RICH-1 mirror system. Observing (by means of four cameras) apparent discontinuities in the images of continuous linear objects reflected by the mirrors surface, a relative misalignment of adjacent mirrors can be deduced and then corrected. The method can attain a sensitivity of at least 0.1 mrad, and can also be applied on-line to keep under control the stability of the mirrors during data taking.

Key words: mirrors alignment, RICH
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1 Introduction

Particle identification (PID) is a fundamental requirement of many high energy physics experiments and it is often satisfied by employing RICH detectors. A common characteristic of RICH detectors with gas radiator is to obtain image focalisation by large reflecting (spherical) surfaces made up of many mirror segments of smaller size, which must be very accurately aligned so to form a single smooth mirroring surface. The reconstruction of the Cherenkov angle for each photon from a particle track assumes an accurate knowledge of the actual orientation of the mirrors and the alignment stability.

To be specific, let us refer to the RICH-1 [1] of the COMPASS experiment [2] at the CERN SPS. The mirror system of this detector [3] is composed by 116 spherical VUV reflecting units supported by a lightweight mechanical structure so to form two spherical surfaces (R = 6600 mm), with centres 1600 mm above and below the beam axis (Fig. 1).

Fig. 1. The mirror wall of COMPASS RICH-1.

As the centres of these spherical surfaces lie well outside the vessel volume and are not accessible to align the mirrors (standard Foucault procedure), a different procedure (Theodolite in autoreflection) was adopted [3], allowing absolute mirror alignments with at least 0.1 mrad accuracy with a typical residual misalignment angle of 0.06 mrad.
It consists in placing a theodolite supported by a special structure, in front of each mirror, and measuring the co-ordinates of theodolite centre and its orientation in the surveyor reference frame. In this frame, the co-ordinates of the centre of the design sphere are also known. These two points determine a reference line on which the theodolite telescope is aligned toward the mirror and the mirror is rotated until its normal and the reference line coincide (a cross hair on the theodolite objective and its image from the mirror are seen superimposed).

As this procedure is very time consuming and an access in the vessel is needed, we propose a simpler method for relative alignment of the the mirrors, largely reducing the number of absolute alignments that must be performed. This method is complementary to the theodolite in autoreflection one: the absolute alignment of a small subset of mirrors is required; then this subset can be taken as reference for the relative alignment of the other mirrors.

2 The method

The basis of the proposal is the observation that linear objects appear broken when imaged by adjacent mirrors which are not coherently aligned. Therefore, looking at the image of a grid of continuous lines, relative misalignment of adjacent mirrors can be detected by a discontinuity, i.e. a shift in the lines imaged by the two mirrors. This displacement increases with the angle α between the two normals to the surfaces of the mirrors (Fig. 2).

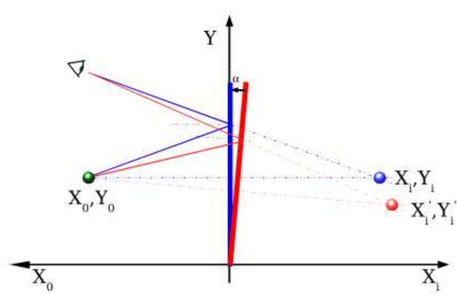

Fig. 2. Image point displacement due to a mirror rotation.

A first estimate of the sensitivity in determining α can be simply obtained, for small rotations and in planar mirror approximation, by evaluating the displacement $(X'_i - X_i \, ; \, Y'_i - Y_i)$ of the image of a point $(X_o \; Y_o$ in the object space) when the mirror is rotated by an angle α.

One has

$$\begin{aligned} X'_i &\simeq X_o + 2\alpha Y_o \\ Y'_i &\simeq Y_o - 2\alpha X_o \end{aligned} \qquad (1)$$

And therefore, for a camera with pixel size p and focal length f_c,

$$|\alpha_{min}| \simeq |(Y'_i - Y_i)/2X_o| \approx \frac{p}{f_c}$$

Assuming to employ a camera with 5 microns wide pixels and with a focal length f_c of 50 mm, the smallest observable value for the α angle is $\alpha_{min} \sim 0.1$ mrad. This estimate of sensitivity can be improved by line fitting and redundancy of broken lines.

3 Simulation and analysis

The method just described has been simulated for the COMPASS RICH-1 by using the *POV-Ray* [1] tracer, a free software package for creating three-dimensional photo realistic pictures. *Ray-tracing* is a rendering technique that calculates an image of a scene by simulating the way in which rays of light travel in the real world.

[1] http://www.povray.org

The user describes a scene by specifying:

- The objects (shape , colour of surfaces, transparencies, ...)
- Lighting and atmospheric conditions
- The eye, i.e. a simulated camera looking into the scene

Hence, for every pixel of the final image, one or more viewing rays are shot from the camera. Rays are then sent backwards to each light source to determine the amount of light coming from that specific source. If the surface is reflective or transparent new rays are set up and traced in order to determine the contribution of the reflected and refracted light to the final surface color.

A POV-Ray simulation dedicated to the COMPASS RICH-1 has been performed taking accurately into account the RICH geometry (Fig. 3) and the optical characteristics of the mirrors. The camera (2/3″ CCD, 5.4 Mpixels, 5 microns pixel size, FOV 55°) has been positioned (see Fig. 3) in the upper right corner of the RICH front wall. Three other identical cameras should actually be added to be able to see the complete reflecting surfaces. A rectangular grid of straight lines has been simulated inside the vessel covering the whole entrance window of the RICH (Fig. 3). In the actual application of CLAM, this grid has to be made with light emitting wires. After testing a number of solutions, we have adopted and realised (Fig. 4) a grid (3.31 x 2.55 m^2) of electrolumines-

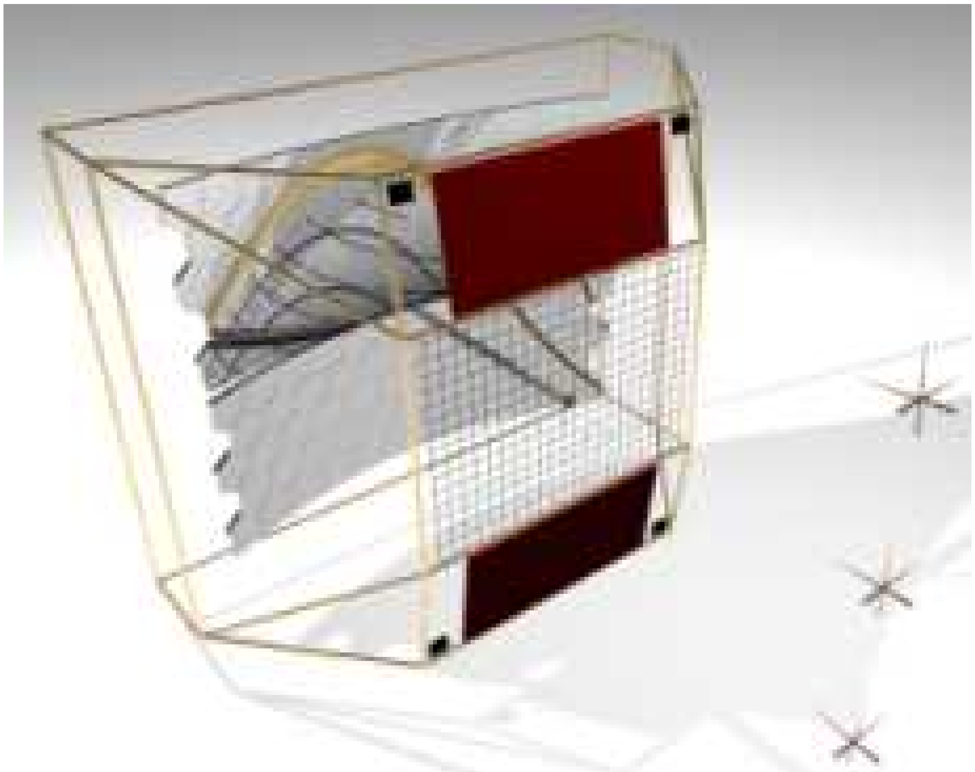

Fig. 3. Essentials of the RICH-1 geometry simulation. The reflecting mirror wall, the two planar photon detectors (large rectangles) and the position of the four cameras (small squares) are shown. Also visible are the grid on the entrance window of the detector, the centres of the two reflecting spherical surfaces and the height of the beam axis.

cent wires [2], diameter 2.5 mm, with a spacing of 100 mm.

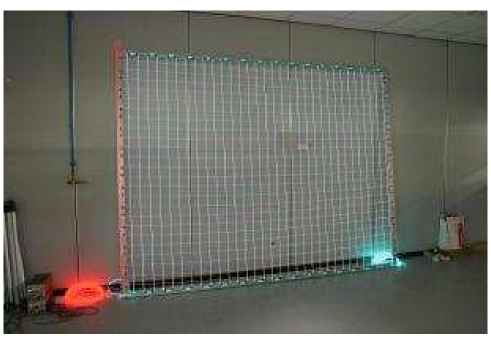

Fig. 4. The grid of electroluminescent wires.

[2] J. A. LeClaire, Inc. Neon Trim Division, 271 College Street, Ferndale, MI 48220 USA

4 Results of the Simulation

Fig. 5 shows the right portion of the upper sphere of the RICH-1 mirror wall. In this picture all the mirrors are perfectly aligned and the lines of the imaged grid are continuous (the beam tube crossing the vessel and its image are also visible).
By rotating some of the mirrors around a horizontal or vertical axis, discontinuities in the grid lines appear, as it is evidenced by adopting a Differential Image (*DI*) technique, i.e. by subtracting from the aligned mirrors image the corresponding image with rotated mirrors. The shift between the rotated and unrotated

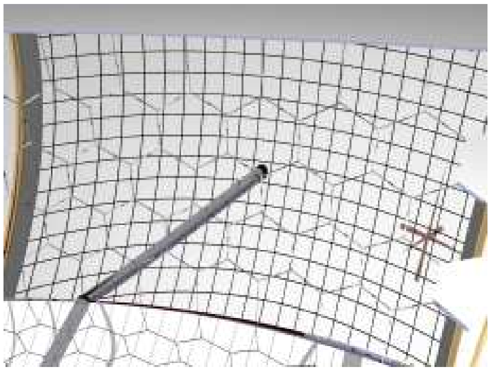

Fig. 5. The simulated view of the grid reflected by aligned mirrors, as seen by the camera in the upper right corner.

segments of the imaged grid wires produces in the *DI* black and white segments (Fig. 6), whose brightness and width depend on the magnitude of the shift **D**, which in turn depends on the rotation angle. In Fig. 7 the differential images for several rotation angles (down to 0.1 mrad) are shown. The shift **D** can be evaluated by a simple pixel counting and its dependence on the vertical or horizontal rotation angle is shown in Fig. 8. The different values of **D** for horizontal or vertical rotation are due to the perspective from the camera position.

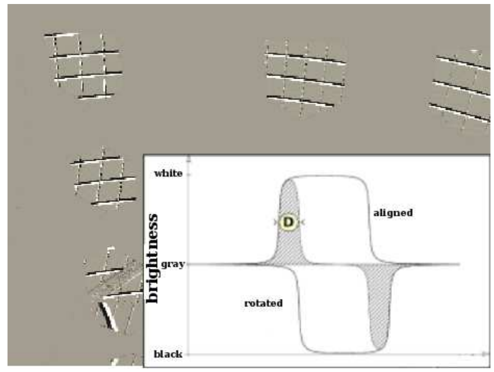

Fig. 6. Differential image between aligned mirrors (Fig. 5) and the same image, but with some mirrors rotated (1.5 mrad). The insert shows how the rotation of the mirror shifts the position of the light emitting wires, leaving in their difference white and black zones of width **D**.

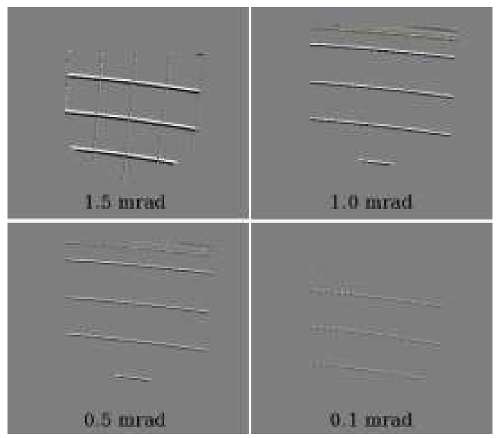

Fig. 7. Differential images of a single aligned/rotated mirror for some rotation angles.

5 Conclusions

The "continuous line" approach looks viable to allow relative alignment of neighbouring mirrors with a precision of at least 10^{-4} rad.
The absolute alignment of a reduced number of mirrors is therefore required.
For application to COMPASS RICH-1, four high resolution wide angle cameras, properly situated, are sufficient to cover the entire mirror wall ($\sim$21 m^2) with enough overlap of the right-left images.
The "differential image" technique provides the possibility to easily control the mirror alignment without opening the vessel, thus allowing the alignment monitoring even during data taking.

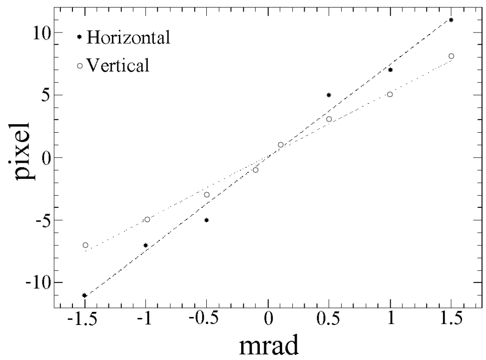

Fig. 8. The shift **D** measured in pixels as a function of the rotation angle of the mirror.

References

[1] E. Albrecht et al., “Status and characterization of COMPASS RICH-1”, these proceedings and references therein.

[2] The COMPASS Collaboration, Proposal, CERN/SPSLC/ 96-14, SPSC/P 297, March 1, 1996 and addendum, CERN/SPSLC/96-30, SPSLC/P 297 Add. 1, May 20, 1996.

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