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Remote alignment of large mirror array for RICH detectors

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ABSTRACT

Image focusing in large RICH detectors is obtained by composite systems of mirror elements. Monitoring and adjusting the alignment of the mirror elements during data taking are important handles to improve the detector resolution.

Mirror adjustment via piezoelectric actuators can combine unprecedented accuracy and match some fundamental requirements: the detector material budget can be kept low and the high purity of the gas radiator can be preserved, a prerequisite when UV photons are detected.

A system based on this principle, well suited for COMPASS RICH-1 mirrors, is proposed.

1. Introduction

In RICH detectors with extended gas radiators, image focusing is obtained by large reflecting surfaces formed by mirror segments of smaller size (see, for instance, Refs. [1–3]).

The extended mirror walls are included in the gas vessel and they are sitting in the acceptance region of the experimental setup. These architectural aspects dictate specific requirements for all the components of the mirror systems. They must be compatible with the required purity of the radiator gas, as pollutants can reduce the radiator transparency, particularly for UV photons. The amount of material must be minimised. Moreover, the mirror sets are not accessible during detector operation.

The mirror elements must be very accurately aligned so as to form a single smooth reflecting surface. In fact, their misalignments result in poorly focused images, directly affecting the detector resolution. The most critical parameter is the relative angular alignment. It is often not possible to recover for the resolution degradation even if the misalignments themselves are precisely determined. In fact, offline corrections are only partially effective. The Cherenkov photons hit the reflecting surface in a pseudo-circular region and the reflection point of each individual photon is not known because the photon emission point is randomly distributed along the particle path in the radiator. If the disk is entirely included in a single mirror element, the correction is fully effective. If the disk is shared among several adjacent mirror elements, the correction can be applied only on a statistical base: it can result in a limited or null improvement. The fraction of images that can be effectively corrected depends on the ratio between the mirror element surface and the disk surface and it increases for larger values of this ratio. On the other hand, the size of the mirror elements is limited because of the total amount of material tolerable, the optical quality requirements and economic considerations.

Relative mirror misalignments can be determined from the collected data (see, for instance, Ref. [4]), from surveying procedures with direct access to the mirror setup performed when the detector is not in operation (see, for instance, Ref. [5]) or via optical monitoring [6–8]. This last approach offers several advantages: the information can be obtained during the detector operation almost in real time and no integration over long time intervals is needed, making possible a true monitoring of the alignment evolution.

The obvious complement of the online monitoring of the mirror alignment is a system making possible quasi-online adjustment of the alignment: this adjustment, to be performed during detector operation periods, requires remote control. Systems for remotely control adjustment of large mirror arrays have already been implemented, for instance in large Cherenkov telescope for the cosmic gamma-ray spectroscopy. In the MAGIC experiment, an Active Mirror Control (AMC) system [9] provides fast correction of the global mirror shape: each of the 241 mirror panels is controlled by laser spot monitoring and is adjustable through a pair of mechanical actuators moved by stepping motors.

The implementation of an adjustment system in a gaseous RICH counter must satisfy the requirements concerning material budget and gas pollution. We propose and discuss a system matching these requirements, well suited for the COMPASS RICH-1 mirror system.

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2. The mirror system of COMPASS RICH-1

The COMPASS experiment [10] at the CERN SPS makes use of a large scale Ring Imaging Cherenkov detector, RICH-1 [1], to identify hadrons in a wide momentum range. The radiator gas is C_4F_{10}. The photon detectors are MAPMTs in the central region, detecting visible and near UV photons and MWPCs equipped with CsI segmented photocathodes in the peripheral area, sensitive only to VUV photons, with wavelength below 200 nm. COMPASS RICH-1 has large angular acceptance, resulting in extended transverse size; in particular, the surface of the mirror system is about 21 m^2. We recall here those features of this huge mirror wall [5], which are relevant for the adjustment system we propose.

The mirror system is formed by 116 spherical VUV reflecting units, about 3 kg each, supported by a lightweight mechanical structure so as to form two spherical surfaces ($R = 6600$ mm). The image dispersion due to the mirror optical imperfections results in a contribution to the error on the measured Cherenkov angle of 0.1 mrad; the error contribution caused by the misalignment adds in quadrature. It is therefore reasonable to require angular misalignments of the same order of magnitude at most.

The centres of the two spherical surfaces lie well outside the vessel volume and are not accessible to align the mirrors by standard Foucault procedure; a different procedure based on the use of the theodolite in auto-reflection mode was adopted, able to provide the absolute mirror alignment with 0.1 mrad accuracy. The mirror orientation can then be corrected acting manually on the individual mechanical actuators on the mirror element rear face (Fig. 1). The adjustment is obtained rotating around two orthogonal axes: the translational push (or pull) of a micrometric screw (pitch 0.5 mm) against one end of a rigid bar (200 mm long) is converted into a rotation at the other end of the bar constrained to a pivot anchor; the angular resolution is 2.5 mrad/turn with very good linearity, practically no hysteresis and a negligible (0.01 mrad) cross-talk.

In practice, the minimum correction that can be applied is about 0.1 mrad. The unit weight of these support and adjustment elements is 112 g.

Fig. 1. Mirror wall rear face, detailed view: the mechanical arrangement for the angular adjustment of an individual mirror element is visible.

The mirror rear faces are reachable removing a large panel ($3 \times 4\,m^2$) closing the vessel volume. The procedure is time consuming; moreover, it requires both accessing the vessel and removing part of the vessel walls: it must be performed outside data taking periods. In year 2001, the whole mirror wall was aligned and the measured residual misalignments showed a standard deviation of 0.06 mrad. Later, the mirror alignment was measured several times between the experiment data taking periods, typically once or twice per year, and misalignments with a random distribution in the range 0–1 mrad have been observed, with a few elements exhibiting misalignments up to 1.5 mrad. The source of the misalignments developed after the initial alignment procedure is not known. Some information about the mirror alignment during detector operation is obtained from the collected data and it provides information averaged over long time intervals. An optical system to monitor online the relative mirror alignment has been recently built and put in operation [7].

3. Remotely controlled positioning actuator

Piezo micrometric actuators can be chosen to adjust the individual mirror inclination: they can be remotely controlled, are compatible with the radiator gas purity and are light-weighted devices: they can be locally mounted, as they do not represent an important increase of the material budget of the mirror system.

A major problem for standard piezoelectric actuators is their lifetime when high voltage is applied to keep the desired position: keeping the mirror correctly aligned, in our application. Typical values range around 100 days, fully incompatible with the life of an experiment like COMPASS: COMPASS data taking period extends over typically five–six months per year over about a decade. Short lifetime is due to metal diffusion from the electrodes used to apply the supply voltage to the ceramic insulator: eventually this results in a high leakage current and finally into the reduced capability or impossibility of actuator movements. Moreover, if the mirrors are kept aligned by the voltage supply, an accidental power cut will result in the loss of the whole mirror wall alignment.

The new principle applied in the NexLine® miniature High-Load piezo nanopositioning devices by PI[1] is based on the combination of the feed forward and the clamping cycles to provide push/pull forces: it looks the natural answer to the difficulty previously discussed.

A piezo actuator NexLine® N110 is shown in Fig. 2. The device keeps the full holding force available when no voltage is supplied, even during a movement cycle: the application of long-term offset voltages, which limit the lifetime, is avoided. The main characteristics of this device are summarised in Table 1. The travel range is wide enough to guarantee a reasonable range for mirror angular adjustment: for example, if coupled to the present mechanical arrangement of the COMPASS RICH-1 mirror wall, the angular adjustment range would be about 15 mrad. The forces that can be applied are also adequate for this application.

The zero voltage stand-by condition offers further advantages. A single power supply and a single control unit are required even for an extended system: both high voltage and control signal can be provided via a multiplexer device, thus reducing the costs, the cable layout and the maintenance requirements.

The feasibility of the application proposed has been tested in a laboratory exercise. A RICH mirror element is mounted on a holder identical to the RICH-1 ones. The mirror rotations are measured by

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Fig. 2. Piezo actuator NexLine® N-110.

Fig. 3. Laboratory setup, the mirror rear side: the piezo actuator replaces one of the micrometric screws.

Table 1
Summary of the main characteristics of the piezo actuator NexLine® N110

Characteristic	Value	Unit
Travel range	3	mm
Max. step size	1.5	μm
Max. freq.	100	Hz
Max. speed	0.15	mm/s
Resolution	<0.1	nm
Holding forces (passive)	>50	N
Push/pull forces (active)	30	N
Stiffness	15	N/μm
Max. operating voltage	250	V
$L \times W \times H$	$46.6 \times 28 \times 35.5$	mm^3
Mass	131.0	g

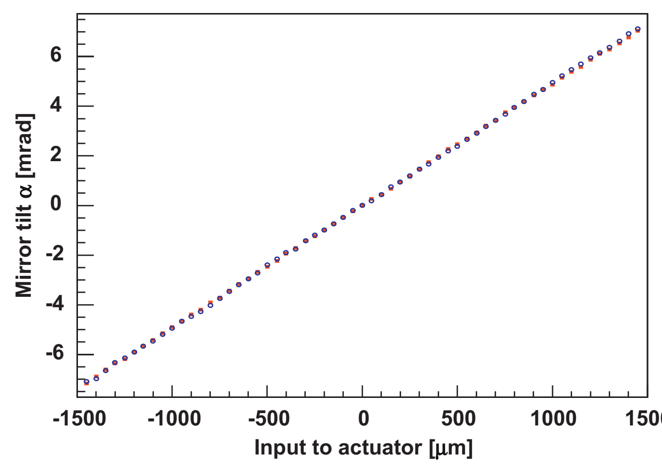

Fig. 4. Mirror rotation versus the input value to the NexLine® N110 actuator, full actuator travel range. Two sets of points are plotted (open circles and solid squares), obtained moving the actuator in the two opposite directions: the results of the two sets are superimposed.

a laser beam spot reflected by the mirror and collected at 12.45 m distance, resulting in a resolution of 40 μrad. The angular adjustment is performed replacing one of the two micrometric screws with a piezo actuator NexLine® N110 (Fig. 3). The result of the test is presented in Fig. 4. The adjustment resolution is improved at least by 2 orders of magnitude respect to what obtained with the micrometric screws. Within the measurement resolution, no hysteresis or non-linearity has been observed exploring the whole 3 mm long travel range.

4. Conclusions

Complementing the online measurement of the relative mirror misalignments with a system for the online adjustment of their position via remotely controlled piezoelectric actuators can enhance COMPASS RICH-1 performances by increasing the resolution of the measured Cherenkov angle: the residual mirror misalignments can be made totally negligible.

The possibility to adjust the mirror alignments without accessing the radiator vessel has other remarkable advantages: the vessel can remain always closed, so that the mirrors can be constantly kept in a dry, clean atmosphere, thus preventing the degradation of the reflecting surface by moisture and dust.

The technological aspects of the proposed system have been reviewed and its technical feasibility has been discussed and checked. The open question is the cost of the system itself, related to the cost of the actuators; the total number of actuators required for RICH-1 is $232 = 116 \times 2$ (the number of the mirror elements $\times$the number of the angular degrees of freedom per element). The technology considered is pretty young; fast technological development can result in a reduction of the costs. Actuators with less pushed resolution can be considered. Both these elements could make the implementation of this system economically affordable in the next future.

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