An optical sensor for the ATLAS Muon Spectrometer: The reference alignment system

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Abstract

The muon spectrometer of the ATLAS detector at the LHC has been designed to provide a precise track momentum measurement for muons up to 1 TeV. It is composed of several hundred monitored drift tube chambers. Their positions must be known with an accuracy of 20 µm in translation and 200 µrad in rotation. For this purpose, a precise alignment system is required. This system is based on several subsystems using optical sensors measuring the deformations, and the relative and absolute positions of muon chambers. In this article we will focus on one of them: the reference system

Keywords: ATLAS Muon spectrometer; Alignment; optical sensor;

1. Introduction

The ATLAS detector [1][2], today in the installation phase at the future LHC proton-proton collider, contains a muon spectrometer based on a toroidal magnetic field with an average bending power of about 2.5 Tm in the barrel and 3-7 Tm in the end-cap. The track momentum measurement is performed by over 1100 high precision monitored drift tube chambers (called hereafter MDT) mounted cylindrically in three layers around the interaction point (see Fig 1.) in order to reduce as much as possible the geometrical acceptance losses. Outgoing muons will experience a bending, which can immediately be translated into a momentum. The corresponding sagitta will be measured by a subset of 3 MDT chambers, mounted at 2.5 m radial distance from each other. Typically, 1 TeV muon tracks will have sagittas varying between 400 and 700 µm, depending on the detector region. One of the goals of the ATLAS muon spectrometer [3] is to achieve a 10% resolution for these high energy muons, which leads to the constraint that the sagitta has to be measured with a 50µm precision in the high energy regime where multiple scattering is negligible. To achieve this goal, the knowledge of the MDT chambers relative position is needed with an accuracy better than 30µm. As this accuracy cannot be obtained by mechanical means only, a network of optical survey monitors (commonly called alignment) has been designed. It consists of over 7,000 optical sensors (for the barrel part), giving real time information on the MDT positions or deformations during the data tacking runs. The barrel alignment system of ATLAS is made of six different alignment types.

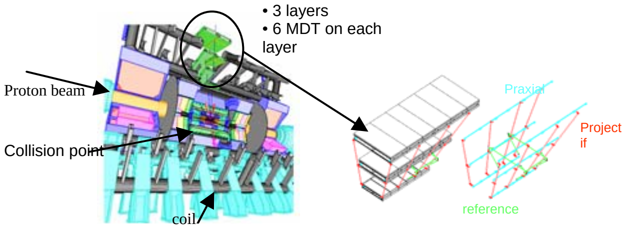

Fig. 1. Atlas muon spectrometer

- The IN-PLANE alignment which measures chamber deformation.
- The PRAXIAL system composed of two parts:
  - A PROXIMITY part which gives the position of one chamber with respect to the neighbouring one.
  - An AXIAL part which controls the saloon door effect of chambers within a chamber layer.
- The PROJECTIVE system which gives the chamber position within a tower.
- The CCC system which connects large chambers to small chambers since the latter are not connected through PROJECTIVE sensors.
- The REFERENCE system which will be developed in this article.

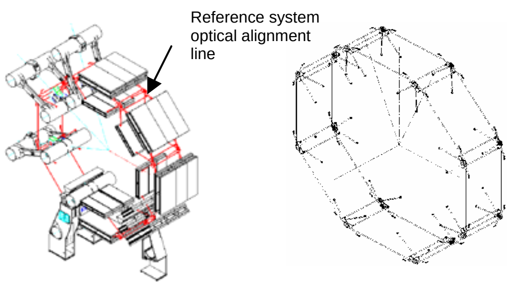

Fig. 2. Reference system optical alignment line

2. The reference system

The reference alignment is used to link a sector of chambers to its neighbor sectors and to the coil (see Fig 2.). It can also allow PROJECTIVE system angle correction.

Whereas most of the alignment system uses a three point system (called RASNIK [4], developed by NIKHEFf institute): a CMOS camera, a lens and a coded target, called Mask, containing a back illuminated chess pattern (see Fig 3), the reference system is based on a two point system.

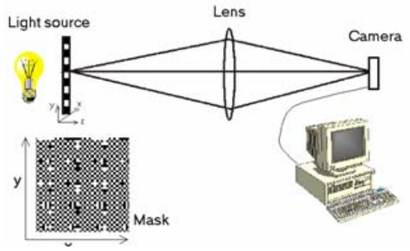

Fig. 3. Rasnik system from Nikhef institute

The reference system has been developed to work with long distance measurements. It is made up by a linked camera and lens (called SACAM) looking at a target consisting of back illuminated holes (called SACLED) (see Fig 4 and Fig5).

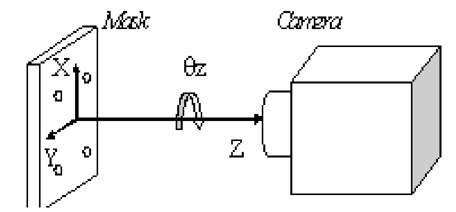

Fig. 4. Schematic of a reference sensor

The image given by the camera is composed by 4 main spots and some noisy spots. A dynamic library has been developed in order to return the position of each main spot in the camera frame, the angle along the optical axis between the camera and the mask and the magnification. It is fully compatible with the software of the RASNIK system.

Fig. 5. Photograph of a SACAM (left) and a SACLED (right)

Thirty-six different models with different spot configuration, lenses, and design have been developed in order to be installed into the complex geometry of the ATLAS spectrometer.

3. Image analysis

From the SACLED images some displacement parameters must be computed such as the translation in the (X,Y) mask plan, the image magnification and the rotation angle along the optical axis. Due to the complexity of the optical sensors immediate environment in the ATLAS experiment, noisy spots often appear on SACLED images (see Fig 6). Then, the image analysis is divided into two parts: bad spots filtering and good spots location.

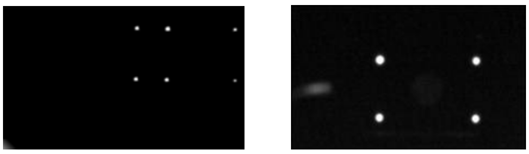

Fig. 6 Two SACAM images of a SACLED

3.1 Parasitic clean up

To wipe out parasitic spots, a first solution consists of proposing two luminosity thresholds: a low one to get rid of surrounding environment luminosity, a high one to determine if the pixel belongs to a spot or not. Nevertheless this method cannot filter reflecting spots. To differentiate good spots from noisy spots we proposed a method based on angle recognition. Angles are invariant by translation, rotation or homothety, so we can compute the angle of each triangle obtained with the mask holes in their well-known nominal positions, and then compare it with those obtained from the studied image. Spots are classified and the four best spots are considered to be the good ones.

3.2 Spots Location

A spot is in fact a few pixels large, to determine precisely the spot centre location two methods have been used:

- A barycentric method which consists in computing the barycentre of the spot pixels. This barycentric location has an accuracy of 1 pixel.
- A luminous spot obtained by the scattering of a back illuminated hole has approximately a two dimensional Gaussian shape (see Fig 7). For computational time saving, we perform two one dimensional Gaussian fit on the spot luminosity respectively projected on the X and Y axis. The Gaussian peak is obtained and considered as the spot centre.

Knowing the spot location it is then easy to compute the displacement parameters.

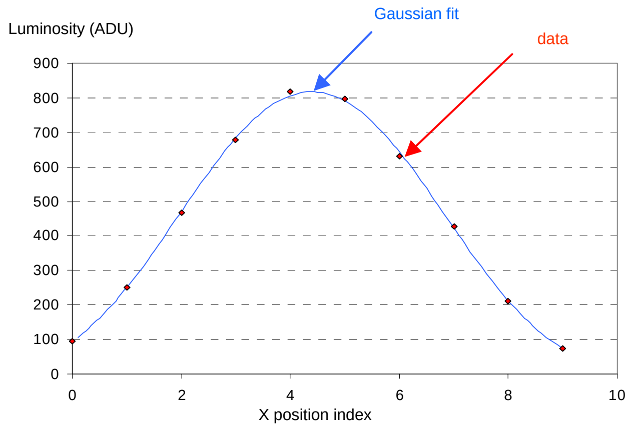

Fig 7 Gaussian Fit of a SACLED spot

4. The calibration bench

From the image analysis, the positions of the SACLED holes are known in the SACAM camera frame. To be used in the experiment it is necessary to know the SACAM and SACLED position on MDT chambers. Mechanical brackets are fixed on chambers on three spheres. Then, the position of the SACLED holes and SACAM camera must be very accurately known in the sphere's frame. Unfortunately, mechanical mounting is not sufficiently precise, and then a calibration procedure must be performed on each SACLED and SACCAM.

Fig 8. The calibration bench

So, a calibration bench has been developed. It is composed of three main parts: a marble table, a SACAM holder and a SACLED holder (see Fig 8). The SACAM or the SACLED to be calibrated are set on the marble in their nominal position. Two calibrations are performed: one with a SACLED in front of a reference SACAM, the other one with a SACAM in front of a reference SACLED. All the calibration procedure is monitored by acquisition software. The SACAM gain is automatically configured in order to obtain non-saturated images with perfectly Gaussian spot. Image analysis results are stored in a data base and the measured movement observed in the SACAM camera frame can be translated in the MDT chamber frame.

5. Results

To test our system accuracy, we have performed

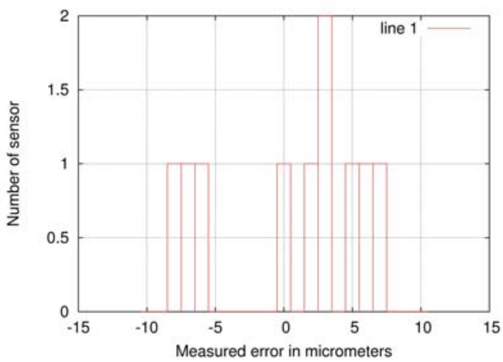

Fig. 9. Histogram of measured error for a translation of 20 µm

several measurements. First, SACAM and SACLED are set on a marble at 1.6m from each other in their nominal position, and then we translated the SACAM by 20µm with a standard spacer (accuracy 1µm). Results have been collected for several sensors and confirmed the fact that the 20µm shift can be detected (see Fig 9). At this distance it means that a displacement in the range of 1/12 pixel can be seen. Such a good result can only be obtained with a Gaussian fit. The rotation angle along the Z axis is 500µrad. Repeated measurements prove that a +/- 10µm accuracy along X or Y axis and a 500µm accuracy along Z axis can be expected. These results are in very good agreement with the ATLAS specifications: 30 µm in translation along X and Y axis and 1mm along Z axis.

In the Year 2002, the ATLAS muon collaboration has installed a large-scale test setup of the muon spectrometer in the H8 test beam at CERN. One of its aims is to test the alignment system before mass production. The validation of the optical system has been undertaken, by moving or rotating physically some of the MDT chambers or by inducing thermal expansion of the support structure. First results [6] show that the goal to control optically the chamber position within 30 µm can be achieved, thus validating the alignment principles, the production chains, the calibration procedures and the final data treatment. Now, all reference sensors have been mounted and calibrated. The installation of the reference alignment system of the ATLAS muon spectrometer is now in progress at CERN.

6. Conclusion

In this article we have presented an original alignment system for the ATLAS muon spectrometer based on optical sensors. This sensor reaches the accuracy needed to know the position of MDT chambers. All sensors have been mounted and calibrated. The installation is in progress at CERN.

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