Software management for the alignment system of the ATLAS Muon Spectrometer

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Abstract

ATLAS is a particle detector which will be built at CERN (Geneva) at the Large Hadron Collider (LHC) accelerator. The ATLAS barrel muon spectrometer is made up of 600 chambers positioned in three layers embedded in a toroidal magnetic field. Thus each muon track is detected by three muon chambers within a projective tower performing a sagitta measurement. In order not to deteriorate the sagitta measurement, the muon chamber position must be known within a tower with a spatial resolution of 30µm.

A short introduction on the alignment of the experiment is given in the first section, the second and third sections are respectively devoted to the PRAXIAL and REFERENCE alignment systems. In the fourth section, ASAP, the software package written to reconstruct the spatial position of the chamber in the muon spectrometer will be described.

1 THE ALIGNMENT OF THE ATLAS MUON SPECTROMETER

1.1 The Muon Spectrometer

The ATLAS experiment (see Fig. 1), is a detector being built on the LHC collider [1] at CERN [2]. The LHC will provide proton-proton interactions with a centre of mass energy of 14.10^{12} eV. One of the physics goals is to detect the hypothetic Higgs boson. Despite the fact that its existence is crucial for the particle physics Standard Model, it has not yet been observed. The Higgs particle may decay through two Z^0 particles each decaying into two leptons: e.g. muons or electrons. Thus the ATLAS spectrometer is particularly important.

The muon momentum measurement in the ATLAS muon spectrometer aims at an accuracy of the muon sagitta with the order of 10% for 1 TeV muon. At this energy the resolution is dominated by chamber sagitta resolution which is about 40µm. Thus the sagitta resolution coming from (mis)alignment should not exceed 30µm. To fulfil this precision, several alignment sensors have been designed.

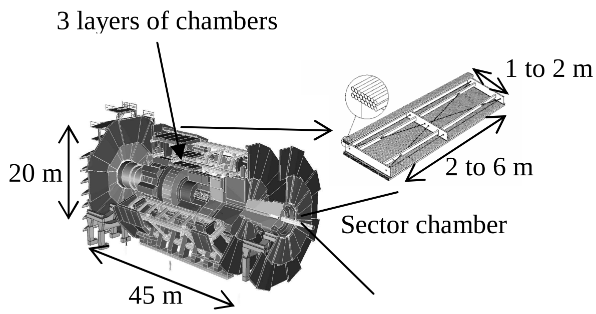

Figure 1: The ATLAS detector (left) and a muon chamber (right).

1.2 The Barrel Alignment System

The ATLAS barrel spectrometer alignment system is made of six different alignment types:

1. The IN-PLANE alignment which measures chamber internal deformation.
2. The PROJECTIVE system which gives the chamber position within a tower.
3. The PRAXIAL system composed of two parts:
   3.1. The PROXIMITY part which gives the position of one chamber with respect to the neighbouring one.
   3.2. The AXIAL part controls the saloon door effect of chambers relative position within a layer.
4. The REFERENCE system used to link a sector of chambers to the neighbouring sector and to the coil.
5. The CCC system which connects large chambers to small chambers since the lasts are not individually aligned with the PROJECTIVE and REFERENCE systems.
6. The BIR-BIM system used on the feet region of the experiment due to special muon chambers layout.

To fulfil this alignment, 7500 sensors were elaborated. A kind of sensor is developed according to each alignment system. And for each kind of sensor, we have a lot of different types.

All these alignment systems may be divided in two categories of individual optical sensor: the Rasnik system and the Sacam and Sacled system which are described in next sections.

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1.3 The Rasnik Sensor

The Rasnik sensor (Red Alignment System of NIKHEF) has been developed by the NIKHEF institute in Amsterdam [3, 4]. It measures the relative position between three elements: a modified chessboard pattern mask lightened by infrared LEDs, seen by a camera through a lens (see Fig. 2).

This optical system measures four parameters: the 2D transverse position with an accuracy of ~2µm ; the optical magnification on the camera with an accuracy below 10^{-4} and finally the relative angle along the optical axis between the mask line and the camera pixels line with an accuracy of the order of 150µrad.

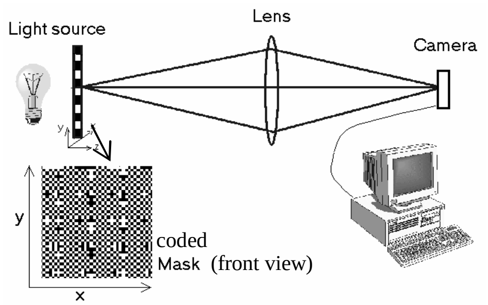

Figure 2: The RASNIK Sensor.

An online software called ICARAS drives the infrared LEDs and the camera, through a RS232 device. The image of the coded mask seen by the camera is then digitised through a frame-grabber card and the four coordinates of the system are computed.

1.4 The Sacam and Sacled Sensor

The Sacam and Sacled sensor consists of a camera embedded together with a lens in a mechanical box (called Sacam) looking to a set of four illuminated holes (called Sacled) (see fig 3). For some optical lines the illuminated holes can surround the lens of the embedded camera resulting to a situation where two cameras are facing to each other.

The measured quantities by the Sacam and Sacled sensors are the two transverse positions with respect to the optical axis. Two other parameters are measured: the rotation angle of the illuminated holes with respect to the optical axis and the magnification of the reconstructed holes on the camera. So the Sacam and Sacled sensors measure the same quantities as the Rasnik sensor.

We developed an analysis module which determines these 4 parameters (see in section 3).

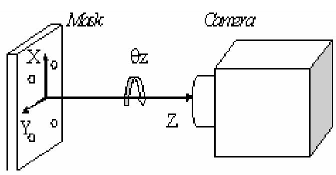

Figure 3: Two points system: The camera, called Sacam is embedded together with a lens in a mechanical box and is facing with four illuminated holes, called Sacled

2. THE PRAXIAL

The PRAXIAL system is composed by two different parts: the PROXIMITY and the AXIAL part (see section 1.2 and Fig.4). We will focuse on the proximity part, see [5] for the axial part.

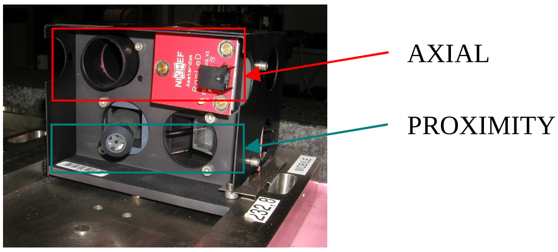

Figure 4: PRAXIAL sensor: PROXIMITY part (bottom) and the AXIAL part (top). For the PROXIMITY part the same components are positioned on the neighbouring chamber.

Remember the PROXIMITY gives the position of one chamber with respect to the neighbouring one. Developed at Saclay [6], it is composed of two crossed RASNIK. The optical components are mounted on two mechanical supports each positioned on two neighbouring chambers (see Fig. 5).

Both RASNIK gives four measurements permitting to calculate the six degrees of freedom describing the relative position of one element with respect to the other one. The wanted resolution is ~10µm for translations and ~100µrad for rotations in a range of ±5mm and ±5mrad.

As it is impossible to mount the optical components with this accuracy, we have to perform a calibration of the PROXIMITY part.

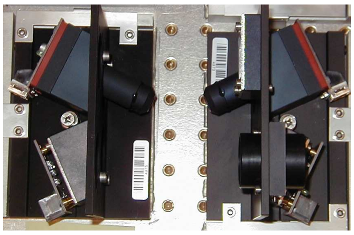

Figure 5: top view of the PROXIMITY part. The two crossed RASNIK components are clearly seen. In real life each mechanical support seats on two neighbouring chambers.

The goal of the calibration is to determine a transfer matrix P used to compute the position between two neighbouring chambers. P is a 6×8 matrix: 6 from the 6 degrees of freedom and 8 from the 2×4 RASNIK sensor data. The calibration process is described in [6].

As we have different distances between the chambers in the ATLAS experiment, we have sensors of different types. Indeed, for short distances (~20mm between neighbouring chambers) the two crossed RASNIK make an angle of 25 degrees, while for large distances (up to 370mm between neighbouring chambers) the opening angle is only 14 degrees. As the two crossed RASNIK are more and more parallel, the resolution on some translation is degraded. Also the RASNIK magnification variation in the last configuration deteriorates the final sensor resolution.

Up to now, we have calibrated all PROXIMITY pairs. The PROXIMITY sensor resolution varies with the distance between two neighbouring chambers. We have a resolution better than 10 µm on translations (see fig. 6) and 100 µrad on rotations for the sensors on chambers close to each other. For the sensors on chambers with large distance in-between (up to 370mm) the resolution along this axis is deteriorated and is only ~60µm.

We studied the stability by calibrating successively the same PRAXIAL sensor. We found that the stability is below 3%. We also tested the reproducibility by calibrating the same PRAXIAL sensor at different times. We found that the reproducibility is below 6%.

We conclude that these calibrations fulfil ATLAS requirements.

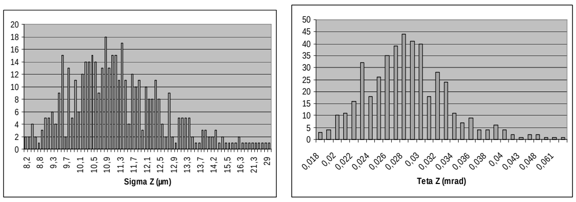

Figure 6: Resolution of 500 PROXIMITY sensors along z axis (left, in µm) and on θz (right, in mrad). In the ATLAS detector, Z is the distance between two neighbouring chamber

3 THE REFERENCE SYSTEM

The reference alignment is used to link a sector of chambers to its neighbor sectors and to the coil. It can also allow PROJECTIVE system angle correction. Whereas most of the alignment system uses a three point system, the reference system is based on a two point system.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 7 and Fig 3).

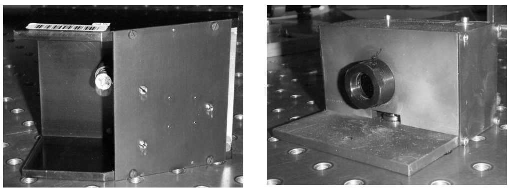

Fig. 7: Photograph of a Sacam (left) and a Sacled (right)

The image given by the camera is composed by 4 main spots and some noisy spots (see fig 8). A dynamic library has been developed under Visual C++, 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. Due to the complexity of the optical sensors immediate environment in the ATLAS experiment, noisy spots often appear on SACLED images.

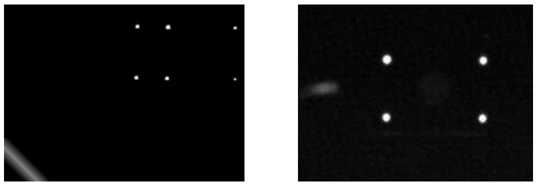

Fig. 8 Two SACAM images of a SACLED

To wipe out parasitic spots, the image analysis is divided into two parts: bad spots filtering and good spots location. To differentiate good spots from noisy spots we proposed a method based on angle recognition. Angles are invariant by translation, rotation or homothetic, 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. A spot is in fact a few pixels large, to determine precisely the spot centre location we considered that a luminous spot obtained by the scattering of a back illuminated hole has approximately a two dimensional Gaussian shape. 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.

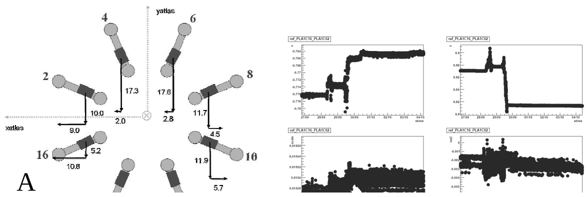

Fig. 9: Optical monitoring of the barrel toroid release

A calibration bench has been developed. It is composed of three main parts: a marble table, a SACAM holder and a SACLED holder. The SACAM or the SACLED to be calibrated are set on the marble table 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 developed under Visual C++. 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 thanks to an ODBC link and the measured movement observed in the SACAM camera frame can be translated in the MDT chamber frame.

Between the 27th and 30th of September 2005 the ATLAS toroid has been mechanically released [7]. This released has been followed-up in real time using 44 reference optical sensors with a frequency of one readout every 30 seconds. The data have been processed in the barrel reconstruction program ASAP (see next section). Computational simulations of the toroid release predicted an 18 mm shift of the top coils after the release. A 17.6 mm shift has been measured with the reference system which is also in good agreement with the geometer survey (see fig 9).

4 ASAP, RECONSTRUCTION SOFTWARE

After each cycle, the image analysis data are written into a database, commonly called Condition Database. The conversion of the image parameters into MDT positions and deformations is done by two alignment programs (Aramys for the endcap and ASAP for the barrel). In the following, we will focus on the ASAP program, keeping in mind that the principles are the same for Aramys.

The main feature of these software packages is their precise description of the optical elements within the detector, taking into account all the individual sensor calibration constants, which have previously been measured in the laboratories. Using this description, ASAP converts the current sensor measurements into MDT chamber positions using standard fitting methods. In other words Asap fits the measurements of the optical sensors mounted with our best knowledge/simulation of the spectrometer. Once done, the corrected positions and distortions of the MDT chambers can be used in the muon tracking software packages, like Moore or MuonBoy.

ASAP is written in C++ using ROOT libraries, such as trigonometric functions, visualisations tools and XML interfaces. Special classes have been developed for our purpose. Among the most important classes, one can find:

- Element class, which permits to describe the detector using tree structures.
- Sensor class, which calculates the response of the sensors using the detector geometry. Sensors can not only be optical modules, but also straight muon tracks detected by the MDTs, or other kind of informations.
- Alignment class, which handles a standard minimisation fitting procedure. This class has been built in such a way that the fitting is reconfigured automatically dependingon how many of the 5800 sensors have been selected, and how many MDT positions have to be reconstructed.

The geometry inputs to the ASAP program are done, via XML decription and some ASCII files, like the AMDB (Atlas Muon DataBase) files. Furthermore a big effort is put today on safe access to various Database, using Java interfaces (Hibernate).

Two reconstruction modes are available:

- Relative mode: This means that we calculate the change of the spectrometer geometry between two times t1 and t2.
- Absolute mode: In this case ASAP has to predict the spectrometer geometry using only one measurement. The absolute mode implies that we have to integrate a large amount of calibration constants.

ASAP has been tested in the muon SPS testbeam setup in H8 (2002-2004). With 6 Barrel and 6 Endcap MDT chambers this setup corresponded to roughly 1% of ATLAS. On different occasions MDT chambers were moved and the ASAP reconstructed geometry was fed to the muon reconstruction software MuonBoy. The residual sagitta had a dispersion around 20~µm in relative mode, well within the specification ($30~µm). For the barrel no absolute alignment has been tempted so far, as today some of the sensors are not fully calibrated.

5 CONCLUSION

In this paper, we have presented a part of the status of the alignment system in the ATLAS muon barrel spectrometer.

In particular, we have been described the PRAXIAL and the REFERENCE systems. A section is devoted to ASAP, the reconstructions software of the spatial position chamber. The first results are now successfully obtained such as the monitoring of the barrel toroid release.

The final integration of ATLAS muon chambers continues and the next step will be the full power in the barrel toroid.

5 REFERENCES

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