STATUS OF THE ALIGNMENT SENSOR CALIBRATIONS IN THE ATLAS-MUON EXPERIMENT

J.-C Barriere, O.Cloue, B. Duboue, V. Gautard[1], C. Guyot,
P.Perrin, P.Ponsot, Y. Reinert, J.-PSchuller, P. Schune
DAPNIA
CEA-Saclay
F-91191 GIF-SUR-YVETTE

Abstract

ATLAS is a particle detector which will be built at CERN in Geneva on the LHC accelerator. The barrel is made up of three layers of 600 chambers of few square meters, amongst other things. The relative position of a chamber within a triplet must be known with a spatial resolution of 30µm. To fulfil these requirements, different alignment systems have been designed. The PRAXIAL and the REFERENCE sensors, developed at Saclay participate in two of them. In order to reach the required precision, each sensor must be individually calibrated.

After a short introduction on the alignment of the experiment, the second part of this paper is devoted to the PROXIMITY system (one part of the PRAXIAL sensors) calibration. In a third part, we will introduce the AXIAL (the other part of the PRAXIAL sensors) and the REFERENCE alignment systems. The last part is related to the user interface that manages all alignment types.

1 THE ALIGNMENT IN ATLAS MUON DETECTOR

1.1 The Muon detector

The ATLAS experiment, see Fig. 1, is a detector that will be installed on the LHC accelerator [1, 2, 3] at CERN [4]. The LHC will provide proton-proton interactions with a centre of mass energy of 14.10^{12} eV. One of the physics goals of the experiment is to detect the Higgs particle. Despite the fact that its existence is crucial for the particle physics Standard Model, it has not yet been observed.

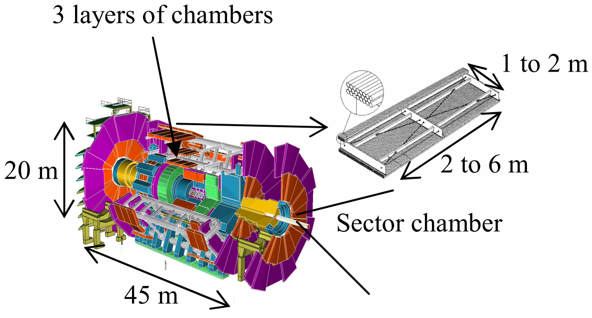

Figure 1: The ATLAS detector and a muon chamber

The Higgs particle may break up in through two Z^0 particles each into two leptons: e.g. muons or electrons. Thus the muon track is of particular importance. The momentum measurement in the ATLAS muon spectrometer aims an accuracy in the order of 10% for muons of momentum 1 TeV. It proceeds from a sagitta measurement using triplets of precision drift chambers with a mean inter chamber distance of 5 meters. The target degree of accuracy for the precision chamber alignment is such that the alignment contribution to the final sagitta measurement error stays below the intrinsic chamber measurement error which contributes at a level of 50 µm.

To fulfil this global precision, several alignment sensors have been designed.

1.2 The Alignment system

The alignment system is composed mainly of five different alignment types:

1. The first one is the IN PLANE alignment. It measures the deformation of the chamber. The responsibility belongs to the NIKEF institute of Amsterdam [5].
2. The second one is the PROJECTIVE system which gives the position between the 3 layers of chambers.
3. The next one is the PRAXIAL system. Two types of alignment are in one mechanical system :
   - 3.1. The PROXIMITY system gives the position of one chamber with respect to the neighbouring one.
   - 3.2. The AXIAL system measures the sagitta of a layer of chambers.

   We will discuss mainly these two alignments.
4. Lastly, the fifth one is the REFERENCE system. It used to link the sector of neighbouring chambers with the toroidal magnet.

For each of these alignment systems, we have several sensors of different type. These systems are redundant to fulfil the accuracy requirement.

The PROJECTIVE and the PRAXIAL (as well as the PROXIMITY and the AXIAL) use the RASNIK optical system. We will detail it now.

1.3 The Rasnik sensor

This sensor has been developed by the NIKHEF institute in Amsterdam [5,6]. It is called RASNIK for

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[1] Corresponding author, Gautard@cea.fr, (33)-1-69-08-45-96

Relative Alignment System from NIKHEF. It measures the relative position between three elements: a coded mask lightened by a set of infrared LED, seen by a camera through a lens (see Fig. 2).

This optical system is able to measure four coordinates: i) and ii) the 2D transverse position with a resolution of ~2µm, iii) the optical magnification on the camera with a resolution below 10^{-4} and iv) the angle between the mask line and the pixels line of the camera with a resolution of ~150µrad.

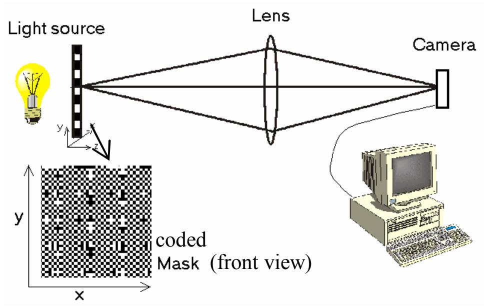

Figure 2: The RASNIK sensor.

NIKHEF has also developed a readout electronic system together with an image analysis software called ICARAS.

ICARAS drives a multiplexer in order to operate the infrared LEDs and the camera, through a RS232 device. An image of the coded mask seen by the camera is digitised through a frame-grabber card. Finally, the four reconstructed coordinates are stored in a file.

The calibration of the PROXIMITY system that uses the RASNIK system will be described in detail.

2. CALIPRAX BENCH

As we have to calibrate 2500 PRAXIAL sensors (PROXIMITY alignment system and AXIAL alignment system), we built two PC controlled calibration benches. They have been installed in an air-conditioned room to avoid thermal variations during the calibration. In this chapter, we will present in a first time the PROXIMITY system, in a second time its calibration principle, in a third time the calibration bench (hardware and software) and lastly, in a fourth time the results we obtained up to now.

2.1 The PROXIMITY system

The PROXIMITY system, developed at Saclay is composed of two crossed RASNIK [7] (see Fig. 3, bottom part, the upper part is devoted to the AXIAL). The optical components are mounted on two mechanical elements each installed on two neighbouring chambers.

The principle of the sensor is to take the four coordinates of each RASNIK in order to calculate the six parameters, three translations and three rotations, describing the relative position of one element with respect to the other one.

As it is impossible to mount all optical components on the PRAXIAL sensors with the required accuracy, we have to perform a calibration of our PRAXIAL sensors and in particular of the PROXIMITY part.

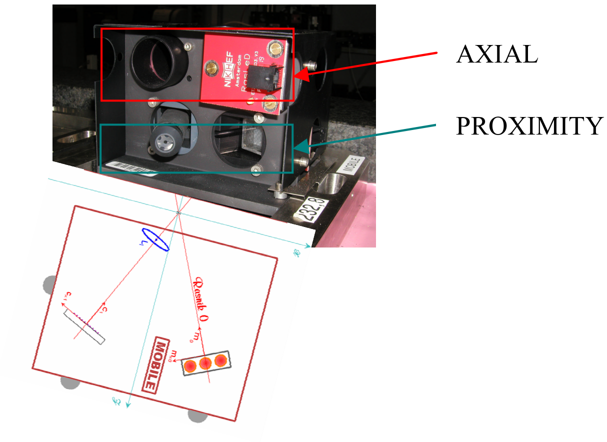

Figure 3: The PRAXIAL sensor: PROXIMITY system (bottom) and the AXIAL system (top).

2.2 The calibration Principle

The objective of the calibration is to determine a transfer matrix which is used to compute the movement between two neighbouring chambers on the ATLAS experiment. This is effected in two parts. The first one determines the transfer matrix P and the second one checks the validity of the determined matrix.

We begin by computing the P transfer matrix. Remember, we have 2x4 RASNIK data for one position and we want to determine a P matrix with a 6x8 dimension. To do that, one of the mechanical elements of the Praxial sensor seats on a static support and the other one on a mobile support. Then, the mobile support is moving about 67 times, in order to scan all the active working space of the sensor (+/- 5mm and +/-5mrad). For each known movement, the RASNIK data are recorded. After this set of movements, an analysis module is used to compute the transfer matrix.

When the transfer matrix is known, another set of 55 random known movements is repeated. So, comparing the computed position and the measured position, the transfer matrix can be validated.

As we have 2500 PRAXIAL sensors, we have built a PC controlled calibration bench, called CALIPRAX. Let us detail it now.

2.3 The calibration bench

First the hardware will be exposed and then the software will be described [8].

2.3.1 The hardware

The calibration bench (see Fig 4) is composed of 5 main components:

1. An independent mechanical piece, called ZEROPRAX is used to define a common mechanical frame for all PRAXIAL sensor. This mechanical piece is built with an accuracy of 5 µm. So we have an absolute calibration.

2. A set of 6 motors (3 for translation and 3 for rotation) are assembled to move the mobile component of the PRAXIAL sensor.
3. Because of the uncertainties of the motors, a set of 9 probes are installed to measure the movement with an accuracy of 1 µm (6 probes are enough but 9 gives redundancy).
4. A set of temperature probes is installed on and around the bench. We must check and record the temperature with the required accuracy (0.2C).
5. The mechanics of the bench is very complex, conceived by expert draftsmen. For example, the sensor seated on studs are adjusted within 100µm.

This bench is controlled by software.

Figure 4: Overview of the calibration bench.

2.2.2 The software

For cost consideration, we decided to use a PC computer. This software requires being adjusted to 6 topics:

1. One friendly interface is made to help the users and to be of sufficient quality, one must just click on the calibration button and all is automatically done.
2. The hardware for the position sensor or motor is controlled by the software. We use RS232 and RS485 devices with data acquisition cards.
3. The task must be sequenced. For example, we can't record the value of the position probe as long as the motor movements are not finished.
4. Some different software work together: the ICARAS soft of NIKHEF (which stores the RASNIK data) is triggered.
5. Some analysis modules are elaborated. The most important is the one which determines the coefficients of the transfer matrix. Another analysis module performs the determination of the movement according to the data of the position probes.
6. The last one is the storage of all the data. They are stored both in text files and in the ATLAS experiment data base. This link with database is an ODBC link.

This bench is used daily. We will now comment the results.

2.4 The results

We will first interest at the number of sensors calibrated up to now, and then at the stability and the reproducibility.

Up to now, we have calibrated 500 pairs of sensors. As we have different distances between the chambers, we have several sensors. For the short distance, we have a s.d. better than 10 µm in translation (see Fig 5) and 100 mrad for rotation for most of the PRAXIAL sensors. For big distances (from 337 mm up to 520mm) the result along the optical axis in translation is deteriorated: about 60µm. There are two explanations: the big lever arm and the small angle between the two RASNIK.

We study the stability. We calibrate many times the same Praxial sensor. We have a stability of 2.8%

Then, we test the reproducibility. We calibrate the same Praxial sensor at different moments. We have a reproducibility of 5.6%.

So the calibrations are satisfying.

Now, let take a look at others alignments systems.

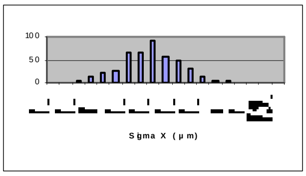

Figure 5: Results in X.

3 OTHERS ALIGNMENT SYSTEMS

In this chapter, we will tackle in a first part the AXIAL alignment system and in a second part the REFERENCE system.

3.1 Axial system

Let's start with the AXIAL system. Remember, this one measure the sagitta along a layer of chambers. The accuracy required is 30µm. So, as the PROXIMITY system, it is impossible to mount all optical components on the PRAXIAL sensors with the required accuracy. So we have to perform a calibration.

Begin with a mechanical and optical description of the sensor. The AXIAL system is based on a RASNIK system. Each component (i.e. mask, lens and camera) seats alone on the top stage of a PRAXIAL sensor (see figure 3). So to have an AXIAL system, you need 3 PRAXIAL sensors. Now let us look at the calibration

The calibration is quite different from the PROXIMITY system. Here, each optical component is calibrated alone with respect to 2 known components. For example, if the mask should be calibrated, a very well known lens and camera are used. So with one RASNIK acquisition, we can calibrate the mask i.e. determine the mask centre and the rotation angle around the optical axis.

This bench is controlled by software and the results are stored in an access data base.

3.2 The reference system

Now, we will be interested by another alignment system: the REFERENCE system. Remember, the ATLAS barrel look like a polygon. If you take one side of a polygon that you link with the polygon centre, you can define a sector as you see on figure 1.

The objective of the REFERENCE system is to measure the relative position of one chamber sector with respect to the neighbouring one. This system is not based on the RASNIK system but on infrared spot.

The reference is made up of a camera, a lens and a mask. The mask with 4 holes (for the redundancy, just 2 are needed) is lightened by infrared LED. The same parameters as the Rasnik are determined: the centre of the mask, the magnification and the rotation around the optical axis.

We developed an analysis module which determines these 4 parameters. In a first time, we calculate the centre of the spot by a barycentre method. To get the accuracy, in a second time, a Gaussian fit of the centre is performed. This method allows determining the spot centre with an accuracy better than 0.1 pixel. In a third time, the parameters are determined by a method based on triangulation.

To resume, we have 5 different alignment systems. For each alignment, we have many configurations. For example the Praxial system, mainly developed in this article, has 2500 sensors. In this set of sensor we have many different types of sensors.

So due to (i) the very high accuracy required, (ii) the number and (iii) the different type of sensors, we have to develop an user interface which we will describe now.

4 THE USER INTERFACE

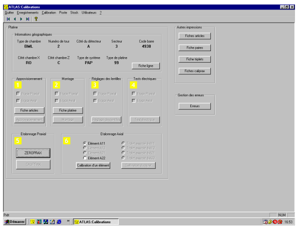

Figure 6: a view of the user interface

The user interface controls all the alignment systems (see Fig 6). It also plays a part in the control command, with data base, and works with several other software.

Let us begin with the control of other hardware. We have a lot of optical sensors of different types, remember: 2500 PRAXIAL sensors. So, all sensors are identified by a bar code. The reading of this one works with an RS 232 device. If you read the bar code, you can know the state of the sensor (built, checked, calibrated or other…)

The user interface is linked with an access data base. Let us take the PROXIMITY example, when a user wants to build a PRAXIAL sensor, he begins by clicking the supply. So the list of what he needs appears. When he checks the goods, these one are subtracted from the database. So, the stock is known very well. This link is an ODBC one.

When an optical sensor is built, it must be calibrated. For example, if you need to calibrate the PROXIMITY system, the user clicks on the calibration button and the Caliprax software is running.

So the user interface is a guide for the users and a quality insurance. You can not do the following step if the previous step is not validated.

5 CONCLUSION

In this paper, we have presented a status of the alignment system in the ATLAS experiment. The user interface which manages this entirely is used daily. It is a user's guide and an insurance .

We have mainly described the PROXIMITY system. This one is mounted, calibrated and checked every day. The results are satisfying, the required accuracy is achieved. The AXIAL calibrations have now begun.

The REFERENCE software analysis is used at CERN, on H8, a part of the ATLAS experiment installed on a muon beam. It works correctly.

The final mounting on the ATLAS chambers has now begun. Some other calibration benches for other alignments systems will appear.

6 REFERENCES

[1] http://lhc.web.cern.ch/lhc

[2] G. Cohen-Tannoudji, « Les enjeux du LHC, le modèle standard » (in French). Scintillations, journal du DAPNIA nº23, may 95 and nº24, june 1995

[3] "ATLAS Technical Proposal", CERN/LHCC/94-43, 15 December 1994;
"ATLAS Muon Spectrometer Technical Design Report", CERN/LHCC/97-22, 31 May 1997;
http://atlasinfo.cern.ch:80/Atlas/Welcome.html

[4] http://public.web.cern.ch/Public/Welcome.html

[5] http://www.nikhef.nl

[6] H. van der Graaf et *al.*, "Rasnik, an alignment system for the ATLAS MDT barrel muon chambers". Technical system description. Publication of NIKHEF institute: ET38110, april 2000. See also: http://www.nikhef.nl

[7] J.-C Barrière, O. Cloué, B. Duboué, V. Gautard, P.Graffin, C. Guyot, P. Perrin, P.Ponsot, Y. Reinert, J.-P. Schuller, P. Schune, An optical sensor for the alignment of the ATLAS muon spectrometer, 3rd Beaune Conference on new developpements in photodetection, Beaune (France), juin 2002

[8] V. Gautard, O. Cloue, PC based Control system of a calibration bench for the ATLAS experiment, 4th Int Workshop on PCaPAC 2002, Frascati (Italie), octobre 2002