The Tracker–Muon Hardware Alignment System of CMS

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The CMS detector has been instrumented with an optical and mechanical system that allows to perform a link between the central Tracker of the detector with the outer Barrel and Endcap muon chambers in order to relate the local alignments of these subsystems in a common reference frame.In this paper the system will be described in detail and preliminary resuls of its operation under different magnetic conditions during the MTCC done in 2006 will be reported

1. Introduction

The CMS Magnet Test and Cosmic Challenge -MTCC- took place in two different phases during Summer and Autumn 2006 in SX5 at CERN. Several components of the muon system were tested, amongst them a fraction of the hardware alignment system.

This document describes the basic setup of the Alignment Hardware installed during the MTCC followed by the reconstruction methods used for the analysis. Finally some prelimary results obtained from the Link subsystem both from direct observation of analog data and offline reconstruction of data coming from digital sensors are presented.

2. General description of the Muon Alignment system

The Muon Hardware Alignment system consists of three different subsystems, which are described below.

The Barrel Alignment system [1] measures the positions of the barrel muon chambers with respect to each other and the whole barrel muon spectrometer. Each barrel muon chamber is equipped with light sources (LEDs, more than 9000 in total). The LEDs are observed by small video-cameras (600 in total) mounted on rigid carbon-fiber structures called MABs (Module for the Alignment of the Barrel). There are direct observations between the MABs called diagonal connections. The system is completed with long carbon bars called z-bars fixed to the vacuum-tank of the magnet.The z-bars (12 in total, 6/side) are also equipped with LED light sources and observed by video-cameras mounted on the MABs. The MABs (36 altogether) are fixed to the return yoke in the gaps between the barrel wheels (6 per gap) and on both ends of the barrel (6 per side). The MABs on the two ends, containing Link and Endcap elements are used to connect the three alignment subsystems to each other. During the MTCC the two bottom sectors of the full barrel were equipped (10 MABs, 4 z-bars).

The Endcap Alignment system [1] is designed to monitor the relative positions of the CSC chambers. The system consists of different components: the axial transfer lines, consisting of laser lines connecting end-cap to the external MAB's using DCOPS (Digital CCD optical position sensor); a straight-line monitoring measuring the relative position of chambers in the same disk; Z and R-monitoring sensors. The muon end-cap ME+ on the positive z-side of the CMS detector was fully instrumented with alignment sensors for the MTCC.

The purpose of the link alignment system is to measure the relative positions of the muon spectrometer and the tracker in a common CMS coordinate system. It is designed to work in a challenging environment of very high radiation and magnetic fields, meet tight space constrains, and provide high precision measurements over long distances. A distributed network of opto-electronic position sensors placed around the muon spectrometer and tracker volumes are connected by laser lines. The ASPD 2D sensors (Amorphous Silicon Position Detector) consist of two groups of 64 silicon micro-strips with a pitch of 430 microns oriented perpendicularly.

The entire system is divided into three ϕ-planes 60° apart. Each plane consists of four independent quadrants, resulting in 12 laser paths, or lines: 6 on each side (positive or negative z) of the CMS detector, matching the 12-fold segmentation of the barrel muon spectrometer. Rigid carbon fiber annular structures are placed at both ends of the tracker (Alignment Rings) and at the YE+1 and YE-1 wheels of the end-cap muon spectrometer (Link Disks). Rigid structures called MABs are also attached to the barrel yokes. These are the reference structures for the alignment of the muon spectrometer. The ME1/1 and ME1/2 disks of the end-cap muon spectrometer are also linked to the corresponding MAB via an opto-mechanical transfer plate. The link measurement network is complemented by electrolytic tiltmeters, proximity sensors (optical and mechanical), magnetic probes and temperature sensors.

One can see in figure 1 a sketch of the position of the analogical proximity sensors –indicated by broad arrows– (left) and the direction followed by the three laser paths active during the MTCC (right).

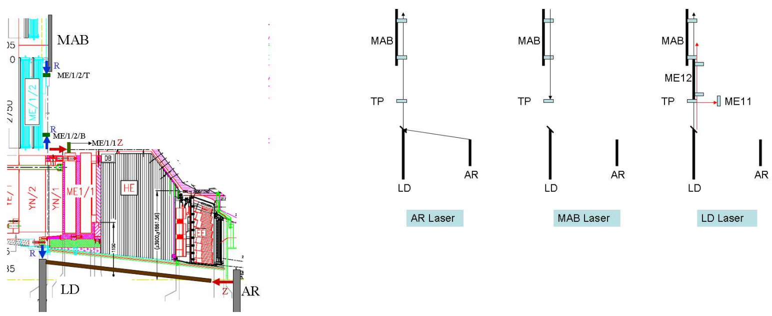

Fig. 1. Sketch of the position of the analogical proximity sensors of the Link System (left) and of the three laser paths of the Link System (right).

3. Link Hardware Alignment MTCC Results

Only three light paths, or lines (out of a total of 12), were instrumented for the MTCC: 75+,255+ and 315+, where the number refers to the ϕ angle and the sign to the z side of the detector. Each light path contains three lasers, one in the Alignment Ring (AR), one in the MAB and one in the Link Disk (LD) (see figure 1 for a sketch). The readout sequence for the link is the following: all lasers from the AR turn on simultaneously and stay on for two minutes –impacting over the TP and MAB sensors–. After this, the AR lasers are turned off and all MAB lasers turn on for two minutes –impacting over the MAB and TP sensors– and finally the MAB lasers are turned off while the LD lasers are turned on for two minutes –impacting over TP, ME11, ME12 and MAB sensors–. This six-minute reading cycle –called an event– is repeated starting again with the AR lasers.

The global reconstruction of the muon alignment events is handled by COCOA [2], which obtains positions and orientation angles of defined reference points or structures from a non linear least-squares fit of the data. In addition to the measurement files described above, the system description has to be provided. This includes the interconnection of elements (which laser points to which sensor, for example) and hierarchy (which elements are attached mechanically to which structure), together with an approximation of the geometry provided with previous measurements (calibrations or photogrammetry). Supplying a good estimation of the geometry is not necessary, but speeds the convergence, ensures the goodness of the result and avoids falling in local minima.

Before attempting a full geometry reconstruction, the data from the different sensors in the system allow to measure the relative displacements and deformations of the yoke structures for the different magnet field values. Two effects were observed. The first is the change in the original positions of the structures (the positions before any magnet operation). The displacements of the structures along the z direction towards the solenoid, of about 3 mm for the barrel iron and about 5 mm for the endcap disks, seem to stabilize after the first 2.5–3 T are reached. This compression is permanent, meaning it is not reversed/recovered in subsequent magnet off states, and it is interpreted as the final closing of the structures due to the magnetic forces acting on the iron. The magnitude of the measured displacement are undestood as specific to the fist CMS closing experience and can not be extrapolated to other scenarios. The second effect is the almost perfectly elastic deformations between magnet-on and magnet-off states. The strong magnetic forces pull the central part of the endcap disks towards the solenoid. At 4 T the nose of YE+1 is pulled approximately 16 mm towards the interaction point. This displacement follows , as expected, a quadratic behaviour with the magnet intensity.

A preliminary study on geometry reconstruction of the Link system data has been performed with COCOA. The full system geometry was coded for the MTCC configuration: including 24 ASPD 2D sensors and the data coming from the analog proximity sensors -15 in total-.

An initial geometry was defined based on the calibrated positions and orientations of all the pieces cited above. In order to get the best possible description of the system an exhaustive use of photogrammetry, laboratory 2D and 3D measurements and calibrations were included in COCOA's description file. The photogrammetry of our system taken at SX5 -see [3] as reference document- allowed to put in place the main mechanical structures which support the ASPD's and other devices.

Fits to data taken in different magnetic field configurations were performed in order to compare the variation of positions and orientations monitored by the system. The result of the reconstruction at B=0T at the end of Phase I was taken as input in the reconstruction program as a better estimation of the geometry.

The comparison of two sets of results monitors the displacements of the different components during the MTCC cycle. Preliminary results show good agreement with the results discussed above and based on the independent analysis of analog sensors response. Table 1 shows the difference in position/orientation for the YE+1, YB+2 and LD disks between the data fit at B=4.0T and the fitted position/orientation at B=0T at the end of Phase I.

Table 1. Preliminary results on the difference in position (in mm) and orientation (in mrad) between the fitted values at B=4.0T and B=0T.

Phase I. B=4.0T	Δ_X	Δ_Y	Δ_Z	Δ_{AngX}	Δ_{AngY}	Δ_{AngZ}
YE+1	-0.13	0.90	-14.66	0.21	0.23	-0.74
YB+2	0.19	3.47	-2.08	-0.07	1.59	-0.89
Link Disk	-0.04	0.43	-0.65	-0.37	-0.12	-0.30

As a first preliminary conclusion from these numbers, the compressed distance between the Link Disk and the Alignment Ring can be directly obtained adding the two Z shifts towards CMS center of the YE+1 disk and the LD disk from table 1: $14.66 + 0.65 = 15.31$mm which can be compared with the analogical values of the three distancemeters placed between these two structures giving a compression of 15.5, 15.1 and 15.6 mm respectively for the distancemeters placed at 195, 315 and 75 degrees.

4. Conclusions

A quarter of the Link Hardware Alignment system was installed and operational during CMS MTCC. A first attemp to reconstruct the 3–D geometry of this system was performed by means of a cross–check of data reconstruction at B=0T against photogrammetry survey of some reference points, resulting in a good undestanding of the system. Furthermore, data taken by this system were analysed at different field conditions to get an estimate of the global movements of different detector structures like Endcap or Barrel disks.

References

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3. J.F.Fuchs, R.Goudard and J.D.Maillefaud, "CMS-YE+1 Photogrammetry of the YE+1", CMS-SG-UR-0058