Completion of the Muon Barrel Alignment System and its integration into the CMS detector environment

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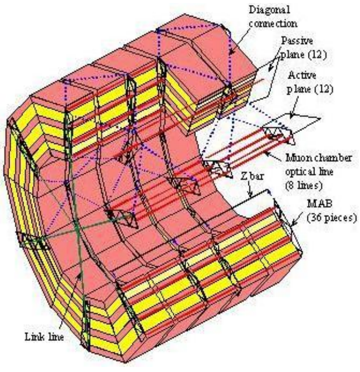
Abstract

During the past years our group has built, calibrated, and finally installed all the components of the Muon Barrel Alignment System for the CMS experiment. This paper covers the results of the hardware commissioning, the full system setup and the connection to the CMS Detector Control System (DCS). The step-by-step operation of the system is discussed: from collecting the analog video signals and preprocessing the observed LED images, through controlling the front-end PCs, to forming the measurement results for the CMS DCS. The first measurement results and the initial experiences of the communication with the DCS are also discussed.

I. SYSTEM OVERVIEW

In order to provide reliable muon track parameters and therefore good muon momentum resolution of the CMS experiment, the positions of all 250 Barrel Muon chambers (DT) have to be measured with an accuracy of 150-350 micrometer (depending on their radial distance from the interaction point). Due to the size of the CMS barrel region and the fact that the muon chambers are embedded into the magnet yoke a novel system had to be developed that can cope with both the high magnetic field and the radiation background at a tolerable price.

The CMS Muon Barrel Alignment System, described in more detail in [2], is schematically shown in Fig.1.



- -Rigid structures (MABs, z-bars)
- -Videocamera boxes (on the MABs)
- -LED-holders (called forks) on the chambes
- -Diagonal and z-LED holders (on the MABs and z-bars)
- -Board computers (one for each MAB)

Figure 1: CMS Barrel Muon Alignment scheme

According to the concept, about 10000 LED sources are mounted on the 250 DTs. Centroids of these LEDs are then measured by about 600 cameras installed on 36 rigid structures called MABs (Module for Alignment of the Barrel). Furthermore, several MABs hold so called diagonal LEDs and therefore can be observed by the others, while other MABs can observe LEDs mounted directly on the outer shell of the CMS solenoid magnet. This kind of connection between the LEDs, cameras and the MABs therefore forms an opto-mechanical network. The positions of their elements can be reconstructed from the measured data and the calibration constants that have been determined before the full system installation.

II. OPERATION OF THE SYSTEM

Each MAB is equipped with its own intelligent module, that is capable of processing the analog signals of the cameras and is able to control the LEDs mounted on the MAB. The module is also responsible for reading the temperature and relative humidity (RH) sensors of the MAB. This module consists of a PC-104 type PC and a FrameLocker type video image grabber card.

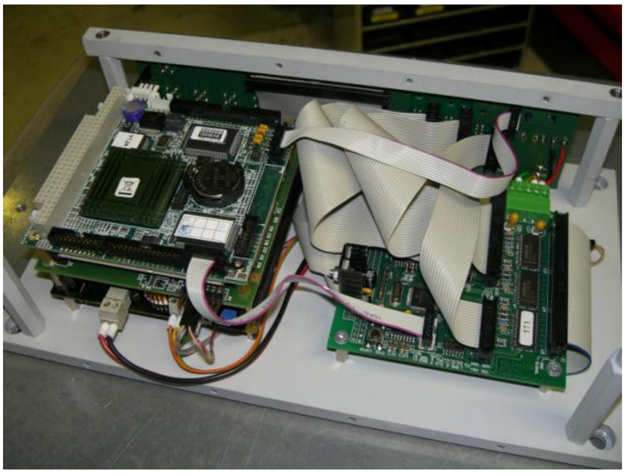


Figure 2: BoardPC

The module is also equipped with a custom designed board (CustomBoard) that is able to multiplex analog video signals, to control LEDs and to read out the temperature/RH sensors. Altogether this module is referred to as BoardPC (Fig.2). The BoardPCs run a customized Linux, which is stored on a central server. On bootup this Linux system is loaded via network using DHCP, TFTP and NFS.

Together with the operating system, two custom built applications are also downloaded. They provide services that are available through TCP/IP protocol. One of them is responsible for centroid calculation from the camera images, while the other handles the Custom Board services.

Figure 3: Barrel Fork. Each of these elements contain 10 LEDs. Four of these forks are mounted on each of the 250 DTs.

As was described before, the LEDs of the System are mechanically connected to the DT chambers. However, they are not directly mounted on these chambers but rather on an opto-mechanical reference body called a Fork (Fig.3). The Forks have been precalibrated and, therefore, the position of every LED is known in the frame of the Fork. During a second calibration phase these Forks were mounted on the chambers and their positions were reconstructed and therefore can be used as a calibration parameter. This object-like approach of the system's components results in a better overall performance of the alignment system as has been proven by simulations at an early stage of the development. Furthermore, Forks act as driver units for the LEDs since they contain a microcontroller-based intelligent circuit that can be reached via I^2C bus. I^2C master devices are embedded into each DT chamber's control and data taking unit, called a MiniCrate. MiniCrates, and hence the Forks, can be reached via a custom protocol through their server machines. If a need for switching on a LED arises, our system sends a command to one of the five MiniCrate servers, where it is then translated to an I^2C message that is then sent out to the destination Fork. This scheme prevents the Alignment System from requiring a separate power and data network in parallel to the existing DT readout and power network.

There is a 37th PC called the Measurement Control Machine (MCM). This is a standard rack-mount PC situated in the electronics cavern of the CMS experiment. This machine is equipped with two NICs and therefore acts as an interface machine between the CMS network and the Alignment's intranet containing all the BoardPCs. Besides acting as a boot server the MCM controls all aspects of the measurement. The measurement control abilities are realised in a Java-based control software: it sends out commands for switching the LEDs on and off and also instructs BoardPCs to measure centroids. The MCM then collects the measured data and, by using predetermined reference values, it eliminates false results due to reflections of the LED's light (cf. paragraph V).

III. THE MEASUREMENT CYCLE

The measurement cycle of the system is as follows: capture of images from all the LED light sources by the corresponding video-cameras, calculation of the centroids of the light spots in the images and storage of all the output information. To perform a measurement cycle first all the possible and enabled optical connections have to be recorded in the construction database. To do this all the light sources have to be checked by the corresponding video-cameras and the connections with inadequate image quality (e.g. the light is blocked, distorted or too weak) have to be excluded. This operation of creating the initial set of possible connections was part of the system commissioning procedure and it is not repeated later, unless necessary. After this operation the system is ready to take data. During regular operation the conditions might, of course, change and different quality-check and time-out procedures assure that only good quality images are accepted.

The number of optical connections is very high (equal to the number of LED light sources) and there are several conditions to measure a given connection at a certain moment. These conditions are as follows:

- The BoardPCs are independent of each other and can work in parallel
- Only one camera can work on the same MAB at a time (limit of the multiplexing of the video-signal)
- LEDs observed by the same camera are measured one by one
- Only a few LEDs can be on at a time on a chamber (current limit)

Only those measurements that do not contravene these conditions at the given moment, can be processed.

The measurement cycle consists of the following steps:

1. The list of connections to be measured is obtained from the construction database.
2. The possibility to execute the measurement of the next connection on the list is checked according to the rules above. If "yes" then the execution command is given and the rule-parameters are set in order to prevent the execution of any interfering measurement. When the measurement is finished then the given connection is marked as "done" and the condition parameters are released.
3. Without waiting for the result of any measurement the next connection not yet measured is checked to ascertain whether the measurement is possible. If "yes" the measurement is executed for the given connection, as in step 2, above. If "no", the connection is skipped. This allows the parallel operation of all the available MABs and their BoardPCs.
4. Upon reaching the end of the connection list, it is repeated until all the measurements are done, which is the end of the measurement cycle.

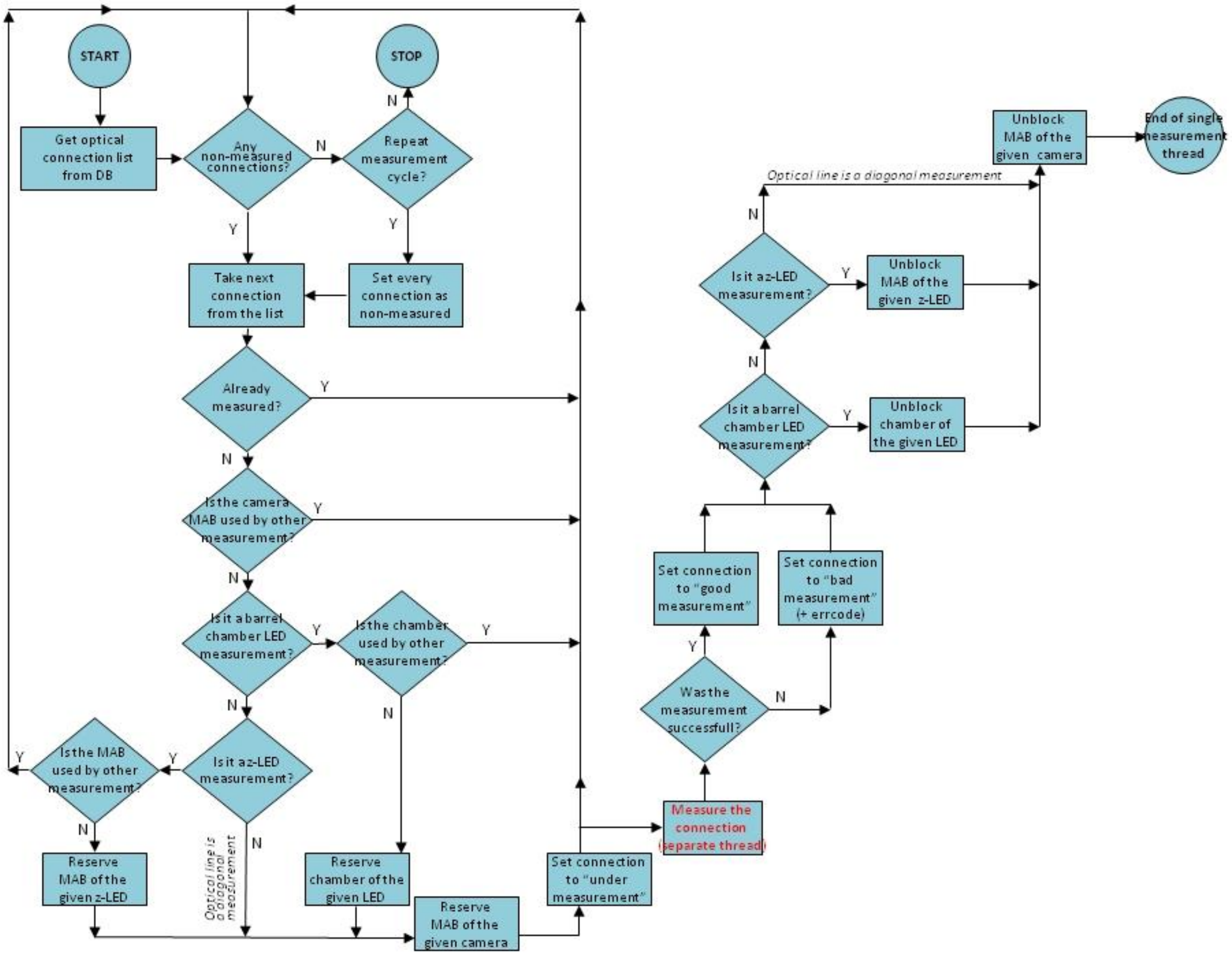


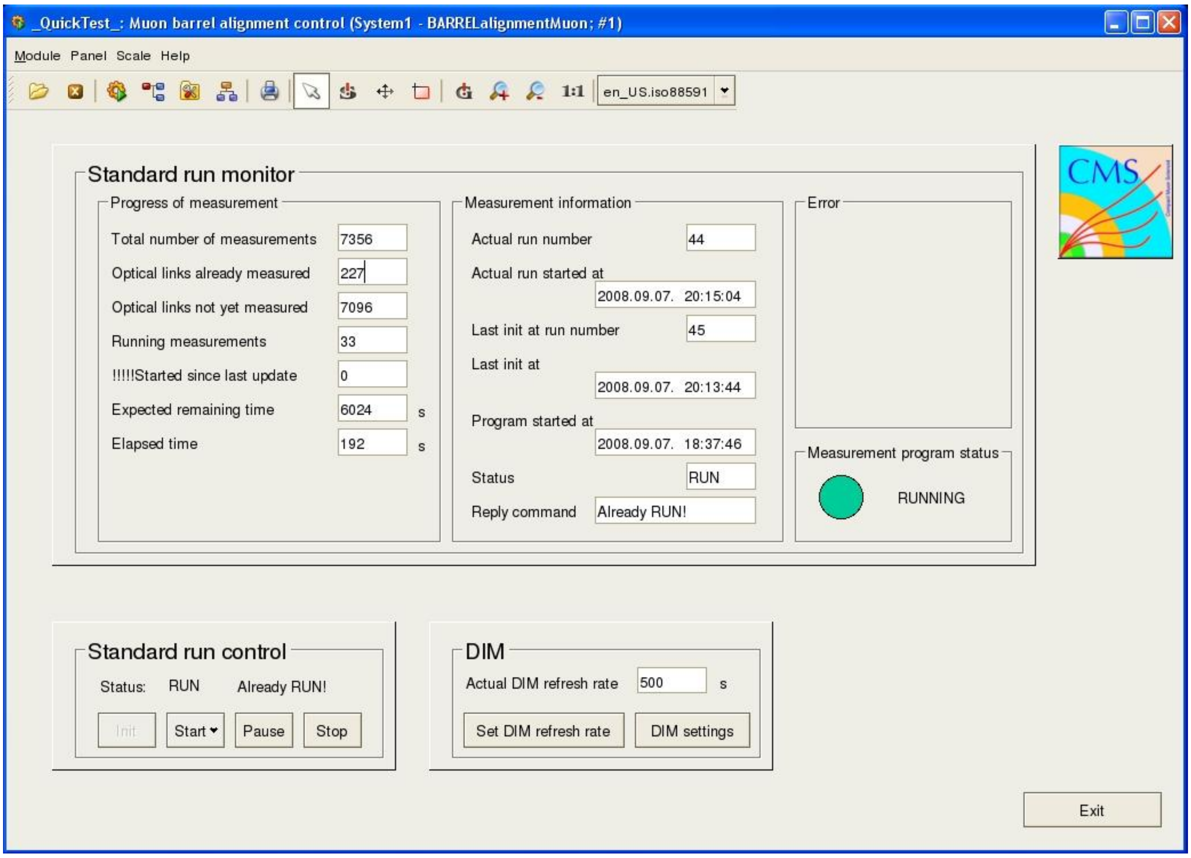
Figure 4: Schematic diagram of the Measurement Control

This procedure, called "dynamic measurement control" (Fig.4), turned out to be very efficient and was able to guarantee parallel work of all the MABs. Of course, the sequence of the measurements may vary from cycle to cycle. The most critical limiting factor that determines the duration of the measurement cycle is that only one camera per MAB can work at a time and it is observing one LED at a time. The measurement time for one optical connection (grabbing 20 images, calculating the centroids, and communication between the given BoardPC and the main workstation) is about 20 seconds. As the maximum number of connections which has to be measured by the MABs is 400 (on Wheels +/-1), the theoretical minimum duration of the full measurement cycle is about 2 hours. This expected duration is verified during the full setup. However, if there is a hardware failure or bad communication to any parts of the system this time can be considerably larger due to the timeout settings. In order to keep the measurement duration low (and therefore maintain the daily measurement frequency at an acceptable level), all the faulty hardware has to be excluded from the measurement.

IV. THE DATA-FLOW – INTEGRATION INTO THE CMS

The Measurement Control collects data from the BoardPCs via a custom protocol over TCP/IP. These data are then collected and archived on the CMS online Oracle-based database system (called omds), to which our Measurement Control software connects via the JDBC mechanism. Since omds cannot be reached from outside of the experiment due to safety reasons we had to organise the transport of the measured data to the offline CERN Analysis Facility (CAF). Data from the Alignment System are regarded as an 'event' and therefore are transported according to the events' transport rule. In order to be able to be read by the reconstruction code all measured data have to be written into a ROOT file. This task is performed by a custom ROOT script. Besides reading and saving centroid data of the given run number, it reads and saves data of the temperature/RH sensors as well as the configuration of the measurement itself. As soon as these data are encapsulated into a ROOT file its transfer to the CAF is initiated by a Perl script. During the start-up phase of the experiment the ROOT file generation and the transfer are started manually. During the physics runs, however, this feature will be implemented into the Measurement Control.

Further processing and quality checks are planned on the data delivered to the CAF before they are finally fed into the main reconstruction process. It is also possible, however, to write these data back to an offline database thus allowing statistical analysis of the data from multiple runs. These processes are not yet settled.



Standard run monitor

Progress of measurement

Total number of measurements 7356

Optical links already measured 227

Optical links not yet measured 7096

Running measurements 33

!!!!!Started since last update 0

Expected remaining time 6024 s

Elapsed time 192 s

Measurement information

Actual run number 44

Actual run started at 2008.09.07. 20:15:04

Last init at run number 45

Last init at 2008.09.07. 20:13:44

Program started at 2008.09.07. 18:37:46

Status RUN

Reply command Already RUN!

Error

Measurement program status ● RUNNING

Standard run control

Status: RUN Already RUN!

DIM

Actual DIM refresh rate 500 s

Figure 5: Graphical User Interface of the PVSS control script

In order to deliver online status information, our Measurement Control is connected into the CMS Detector Control System (DCS) which is a standardized approach of the slow control of the detector. It is written in the PVSS industrial process visualising and management software/framework and implements the Finite State Machine (FSM) model.

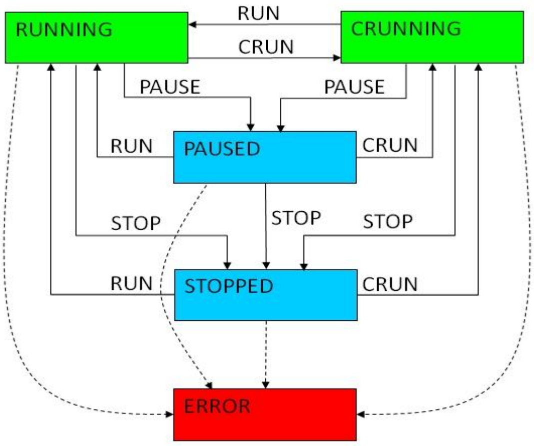


Figure 6: FSM states of the Barrel Alignment System

According to the FSM model our Measurement Control reports its states and receives commands from the upper level in the control hierarchy. Due to the requirements of the DCS and to provide a graphical user interface of the Measurement Control we had to write a control script in PVSS (Fig.5). Connection between this script and the Measurement Control is based on a custom TCP/IP protocol called DIM developed by CERN.

In addition, from this control script all the power modules of the Alignment System can be reached and controlled. From the power and the Measurement Control states this PVSS script creates an overall state of the Barrel Alignment that can be reported upwards.

V. RESULTS OF THE COMMISSIONING

The LEDs are situated inside a rectangular tube called the alignment passage on the DT. Therefore, besides the direct image of a LED its reflected images can also be expected. Since our reconstruction needs only the centroid of the direct image, a filtering of the reflections is inevitable. Due to the tube structure the separation of direct images from the reflections can be made on a simple geometrical basis. For example in Fig.7 a real image can be seen that was taken of forks installed on a chamber. Larger dots belong to the closer fork, while the smaller dots are spots of the farther fork.

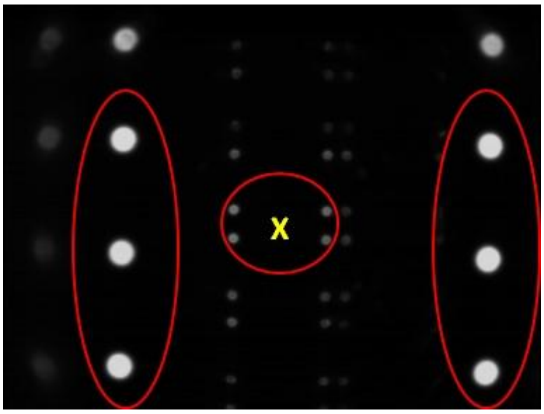


Figure 7: Direct and reflected images taken on two forks installed on a chamber. Larger spots belong to the closer fork while smaller spots are of the farther one. Spots inside the red markers are direct images. If reference is suitably defined on a fork, spots closest to this reference can be regarded as direct spots.

The real spots can be seen inside the red markers. All the other spots are reflections. Therefore on each fork the points closest to a suitably defined reference (marked with yellow cross) can be regarded as direct spots, while others can be classified as reflections that are to be rejected. Unfortunately, this process is not automated and therefore it requires a fairly large human effort to check all 600 cameras after installation.

Figure 8: On this real image not every spot of the closer fork can be seen. Discarding un-observable direct spots helps to minimize errors arising from false spot measurements.

However, as it was experienced during the MTCC, the repositioning of a barrel-wheel is so good that it is expected that there would be no need to repeat such a process unless the MAB is taken out for maintenance.

The commissioning phase had another task, also: to discover all the hardware failures and imperfections and provide inputs for the exclusion procedure. During this process our personnel had to check all the possible optical lines. In order to speed up this process they could use the hardware configuration data stored in the omds. This allowed the verification of these data, too. This process is also time-consuming, but could be performed simultaneously with the reflection rejection procedure. In the future, however, our group plans to automate this process.

During the commissioning phase 1744 individual measurements had to be discarded due to either the imperfect geometry of the CMS barrel or various hardware failures. This represents 19.2% of the total 9072 optical lines. It is in good agreement with the expected failure rate as many LEDs were installed to cover a larger range of visibility in case of imperfect positioning of the barrel wheels or the DTs. Therefore this failure is tolerable in such a redundant system. Furthermore, since the discarded measurements are more or less evenly distributed in the full barrel their impact on the precision that can be achieved by the Muon Barrel Alignment system is small.

VI. SUMMARY

In 2007 and early 2008 our group has completed the installation of all the hardware elements of the Muon Barrel Alignment System of the CMS experiment at CERN. During the following commissioning phase we have checked all the hardware elements and determined all the parameters needed for the reliable operation of the system. During this phase we had to exclude 19.2% of the total 9072 optical lines. This is in good accordance with the exclusion rate and therefore tolerable for the full system which is ready to take data.

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VII. REFERENCES

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