Results and Consequences of Magnet Test and Cosmic Challenge of the CMS Barrel Muon Alignment System

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Abstract

In the last year - as part of the first test of the CMS experiment at CERN [1] called Magnet Test and Cosmic Challenge (MTCC) - about 25% of the barrel muon position monitoring system was built and operated. The configuration enabled us to test all the elements of the system and its function in real conditions. The correct operation of the system has been demonstrated. About 500 full measurement cycles have been recorded. In the paper the setup –including the read-out and control - is described and the first preliminary results are presented.

I. SYSTEM OVERVIEW

As it follows from the construction and parameters of the CMS experiment, the positions of the 250 barrel muon chambers have to be known (measured) with 150-350 micrometer accuracy depending on their radial distance from the interaction point in order to be able to determine the muon momentum with 5-20% accuracy depending on the muon energy. The barrel muon chambers have a typical size of 2.5x3x0.3 m^3 embedded in the return yoke of the detector magnet. The size and configuration of the chambers as well as the additional circumstances and requirements - like radiation background, long-term autonomous operation, an acceptable price - have made it necessary to develop new methods to build the position monitoring system. The measurements of the position of the muon chambers are performed by means of about 10000 light sources mounted on the chambers and observed by an opto-mechanical network composed of 36 rigid structures called MABs (Module for Alignment of the Barrel) holding 600 videocameras. The operation and synchronisation of the elements of the system and the datataking and preliminary evaluation of the collected data are executed by 36 PC-modules mounted on the detector and connected to each other and to the main control computer via an Ethernet network.

The System described in more detail in [2] is schematically shown in Fig. 1. The MABs are fixed on the iron yoke of the magnet. Furthermore, there are about 300 LEDs and 100 cameras making direct connections between the MABs (called diagonal connections). Finally there are 6 long carbon-fiber bars (called z-bars) located inside the barrel muon system containing in total 144 LED light sources allowing direct measurement of the Z coordinates of 24 MABs (where Z direction in the experiment corresponds to the direction of the proton beam path).

The system is measuring the positions of the centroids of the LED images provided by the cameras. In order to be able to reconstruct the positions of the muon chambers additional data - in addition to the measured centroids - are required. These are the parameters of the cameras (magnification, and tilt angles of the sensor with respect to the optical axis of the camera, sensitivity and homogeneity of the video-sensors of the cameras) and the positions of the LEDs on their holders. Also, the positions of the cameras and the LED holders in their embedding objects (muon chambers, MABs, Z-bars) are also needed. These additional data were obtained by the calibration of the elements.

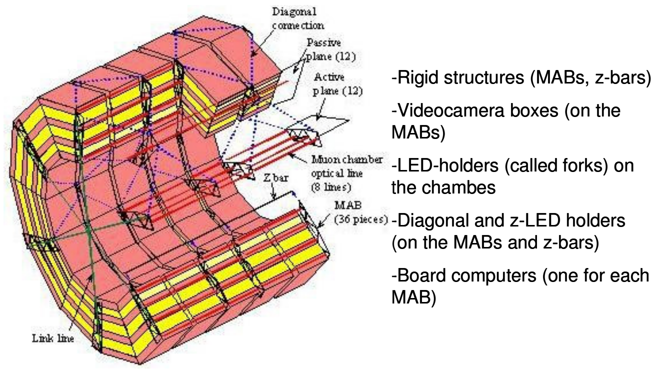

Figure 1: CMS Barrel Muon Alignment scheme

II. THE MTCC SETUP

During the MTCC the bottom part of the Barrel muon position monitoring (or alignment) system was built consisting of 10 MABs and 2 z-bars including 152 video-camera boxes and 1764 LED light sources of which 1680 are mounted on 42 barrel muon chambers included in the system and installed in the sectors 10 and 11 on all the 5 barrel wheels.

The logical scheme of the control and read-out of the system is shown in Fig. 2. The MABs are controlled and the read-out and pre-processing of the video-images is performed by PC-104 form-factor compatible embedded personal computers (one for each MAB) called Board PCs (BPC) [3].

The BPCs are connected to the Main workstation via local Ethernet network. The LED light sources mounted on the muon chambers were controlled via two different control paths. As part of the MTCC the barrel muon chambers of sectors 10 and 11 of the YB+2 wheel and sector 10 of the

YB+1 wheel (14 chambers altogether) were operated and took data generated by cosmic rays. On these chambers the LEDs were operated according to the final CMS-scheme using the minicrates of the chambers. These minicrates are mounted directly on the DT-chambers performing - among other functions - the connection of the chambers to the Detector Control System. As for the other 28 chambers the standard way of control could not be used as the minicrates of the chambers were not operational. For these chambers a special unit, a PIConNET based I2C control unit has been

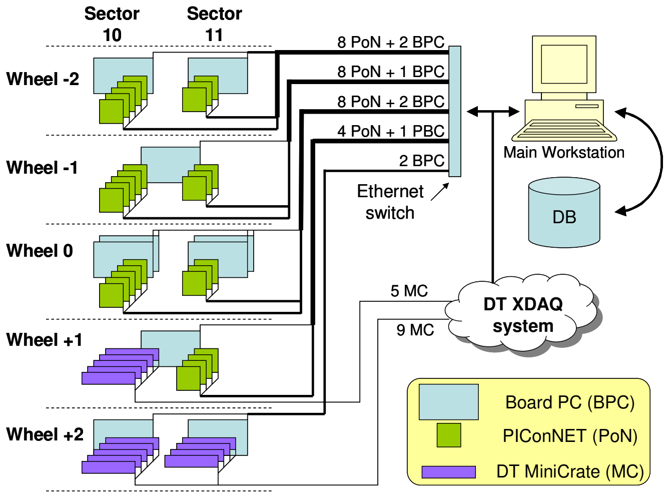

Figure 2: Logical scheme of the MTCC setup

developed [4]. During the MTCC the switch unit shown in Fig. 2 was at about 25m from the CMS barrel. At this distance the field even at full magnet current is below 50 Gauss. In the final configuration, however, the switch units must be closer to the barrel where the nominal field is above 600 Gauss. A separate test channel has been installed during the MTCC to check the operation of commercial Ethernet switch units in magnetic field. This test was successful, the model selected for final deployment worked correctly.

III. THE MEASUREMENT CYCLE

The measurement cycle of the system consists of the measurement of the images of all the LED light sources by the corresponding video-cameras, the calculation of the centroids of the light spots in the images and the storing of all the output information. To perform a measurement cycle first all the possible (allowed) 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 those connections where the image quality is not satisfactory (e.g. the light is blocked, distorted or too weak) have to be excluded. This operation to create the initial set of allowed connections is part of the system commissioning procedure and not repeated later unless necessary. After this operation the system is ready to take data. Of course during the regular operation the conditions might 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 (it equals to the number of LED light sources) and there are several constraints to measure a given connection at a certain moment. These constraints are as follows:

- The BPCs are independent of each other and can work in parallel
- Only one camera can work on the same MAB at a time (a limit imposed by the multiplexing of the video-signals)
- LEDs observed by the same camera are measured separately (true for the MTCC and can be relaxed later)
- Only few LEDs can be switched on at a time on a chamber (due to current limit)

Only those measurements are possible that do not contradict to these conditions at the given moment.

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. If 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 if the measurement is possible. If yes the step 2. is executed for the given connection. This allows the parallel operation of all the available MABs and their BPCs.
4. If the connection list is over it is restarted until all the measurements are done which is the end of the measurement cycle.

This procedure called “dynamic measurement control” 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/MAB can work at a time and it is observing one LED at a time. For this elementary measurement a timeout limit has been preset in order to avoid system hanging. As the measurement time of one optical connection (grabbing 20 images, calculate the centroids, communication between the given BPC and the main workstation) takes about 20 sec and the maximum number of connections that has to be measured by a MAB on YB +/-1 is 344, the theoretical value of the duration of the measurement of one full cycle is about 2 hours except in those cases when several timeouts occur. During the MTCC operation the duration of the measurement cycle was very close to this limit which is the direct proof of the advantage of the principle of the dynamic measurement control.

IV. THE DATA-FLOW SCHEME

The communication and the data flow as well as the distribution of the work among the different levels are schematically shown in Fig. 3. The full muon barrel alignment is part of the general Detector Control System (DCS). The DCS is written in PVSS [5] implementing the Finite State Machine (FSM) model over a custom-made TCP protocol (DIM). In this framework the muon barrel alignment has its own PVSS script which allows the system to accept commands from higher level nodes and at the same time makes the system status able to be propagated upwards in the DCS hierarchy.

During the MTCC both the configuration data and measurement output were stored in a local MySQL database which was connected to the main measurement control program written in JAVA via JDBC protocol.

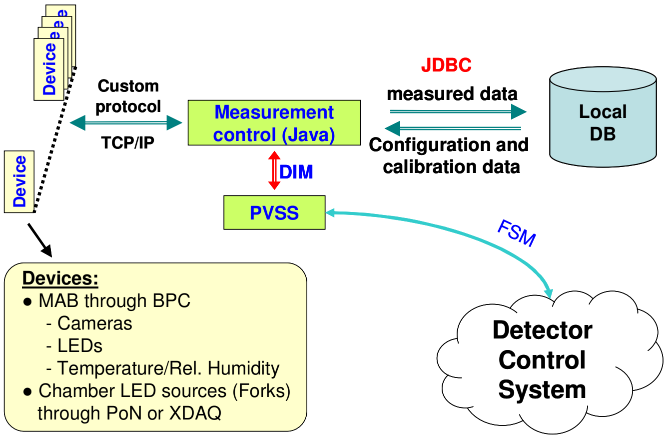

Figure 3: The data-flow scheme

V. Results of the Measurements

The MTCC was split into two periods called "phase 1" in July-August 2006 and "phase 2" in October 2006. During these periods about 500 full measurement cycles were taken and recorded by the barrel muon position monitoring system. As the detailed evaluation of the data is still in progress, here we can present only some results of common interest that could be achieved already at the present level of analysis.

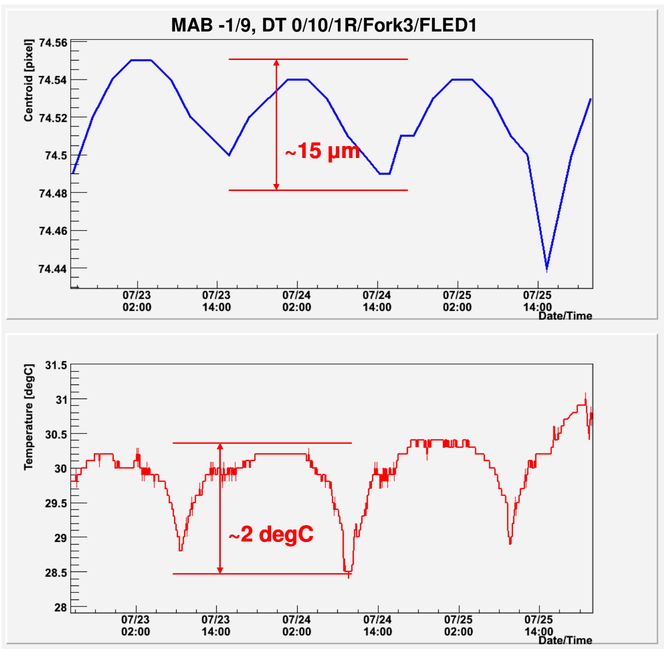

Figure 4: Daily thermal effects

Fig. 4 shows the response of the CMS barrel to thermal changes. The relative movement of the video-sensor mounted on the MAB and the LED mounted on the chamber is about 15 micrometer which is well below any value relevant for CMS physics but shows the sensitivity and the resolution of the position monitoring system. The temperature value is measured on the MAB close to the observed object but in the air.

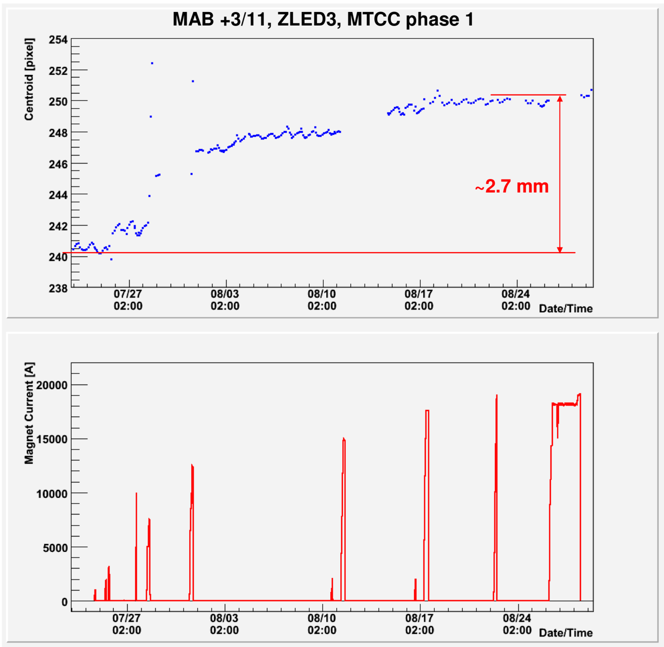

Figure 5: Non-elastic" shrinking of the barrel

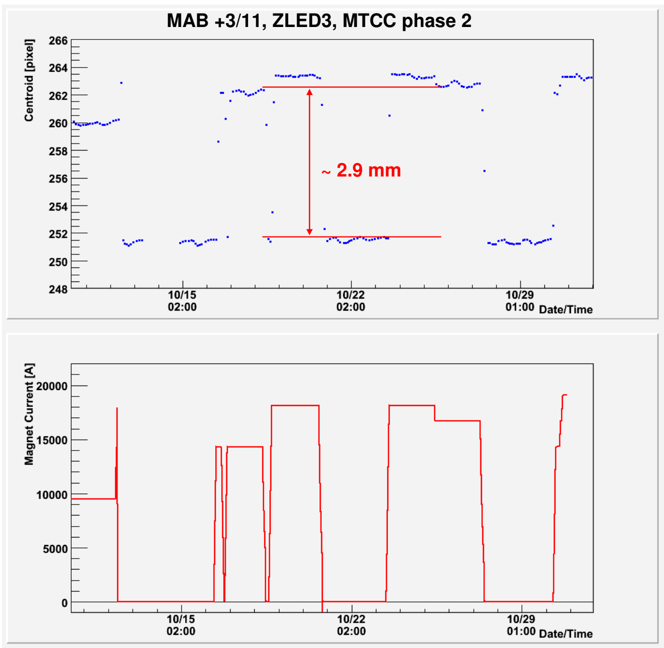

Figure 6: "Elastic" shrinking of the barrel

Fig. 5 shows the period phase 1 when the CMS magnet was switched on for the first time. The magnet was powered for short periods and each time with bigger current until it reached near 20000 A corresponding to ~3.8T field. The bottom part of the picture shows the magnet operation. The upper part shows the position of one of the outer LEDs of the z-bar measured by the corresponding video-sensor on the external MAB fixed to the outer side of the YB+2 wheel. The relative movement is showing the movement of the wheel in the inward direction, in other words the shrinkage of the barrel. This shrinking is not recovering when the magnet is switched off. The measurements were made only during the periods when the magnet was off.

This result can be compared with the result of the measurement during phase 2 and shown in Fig. 6. During this period the magnet was operated for longer periods and the data was taken continuously. As it can be seen a further shrinking of the barrel can be observed, however, this additional shortening recovers when the magnet is off. The values measured for "non-elastic" and "elastic" shrinking are 2.7 mm and 2.9 mm respectively. Both effects and the values have been predicted during the magnet design by finite-element analysis. These results confirm both those calculations and the accuracy of the position monitoring system.

VI. Summary

During the CMS MTCC about 25% of the barrel muon position monitoring system was installed and operated. About 500 full measurement cycles have been taken at different magnetic field conditions.

The main results can be summarized as follows:

- The system worked correctly and provided results that could be interpreted.
- The dynamic control scheme has proved to be very efficient leading to fully parallel operation of the board PCs.
- A full cycle lasted about 140 minutes (when no timeouts occurred). This is already acceptable for future CMS operation, however, speed-up is foreseen.
- Control of the operating muon chambers through the chamber DCS system went smoothly even at the maximum load of the channel.
- A separate test has been made during the MTCC to check the operation of commercial Ethernet switch units in magnetic field. This test was also successful.
- The resolution of the system in the most important phi-direction is ~20 micrometer, well below the specification. This enabled us to detect even thermal deformations due to the daily temperature cycle/variations.
- The irreversible deformation (shrinkage) of the full barrel yoke during the first magnet operation as well as the elastic deformation under field during the changes of the magnetic field have been observed and the result is in good agreement with the preliminary finite-element calculations.

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VII. References

[1] CMS Technical Report. CERN/LHCC 94-38.

[2] CMS – The muon project. Technical Design Report. CERN/LHCC 97-32.

[3] D. Novák, A. Fenyvesi, J. Molnár, G. Székely, J. Végh, N. Béni, A. Kapusi, P. Raics, Zs. Szabó, Z. Szillási, Gy. L. Bencze : Integration study and first test results of the CMS Muon Barrel Alignment system. Proceedings of the 10th Workshop on Electronics for LHC and Future Experiments. Boston, USA, 13-17 Sept., 2004. Geneva, CERN. (CERN-2004-01; CERN/LHCC2004-030; LHCC-G-081) 0 (2004) 264.

[4] Bencze Gy. L., Imrek J., Molnár J., Novák D., Raics P., Szabó Zs., Székely G., Szillási Z.: PIConNET based distributed system dedicated to magnet test of the CMS muon barrel alignment. CERN-LHCC-2005-038, LHCC-G-101 419.

[5] Process Visualisierungs- und Steuerungs-System (PVSS). http://www.etm.at