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Assembly and Quality Certification for the First Station of CMS Endcap RPCs (RE1)

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The production of Resistive Plate Chambers (RPCs) for the first Endcap station (RE1) of CMS experiment at Large Hadron Collider (LHC) has started at CERN since June 2004. For good performance of CMS muon and trigger systems these chambers have been assembled in accordance with strict QC (quality control) and QA (quality assurance) procedures during various assembly steps. Up to October 2005, more than 140 chambers have been constructed and more than 100 of them have been tested with cosmic rays. The chambers are assembled with the sensitive volumes (namely gas gaps) which were manufactured in Korea and all relevant mechanical parts were made in China. The procedure of chamber construction and the experience we have accumulated during the assembly will be described.

1. Introduction

The CMS detector being constructed at CERN for the Large Hadron Collider (LHC) will be operational in the middle of 2007. Muons can provide clean signatures for many physics processes. Therefore, CMS puts a great emphasis on its muon system, and even embeds the muon in its name. The muon system has to identify muons and to precisely measure their momenta. In addition, the muon system can provide a fast triggering service for the whole detector. In CMS, the Resistive Plate Chamber (RPC) operated in the avalanche mode performs as the muon trigger device [1,2].

The first station of the CMS Endcap RPC system (RE1) and its early stage of the construction have been documented in details in the year

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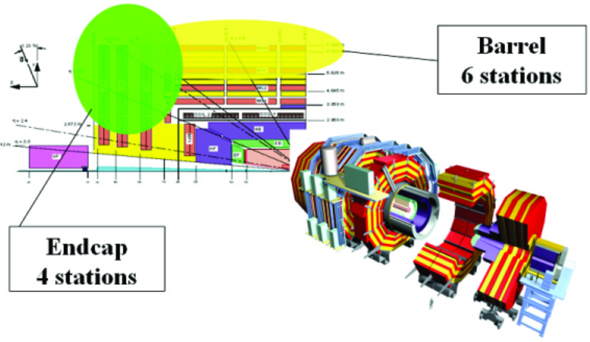

Figure 1. CMS detector and its muon system.

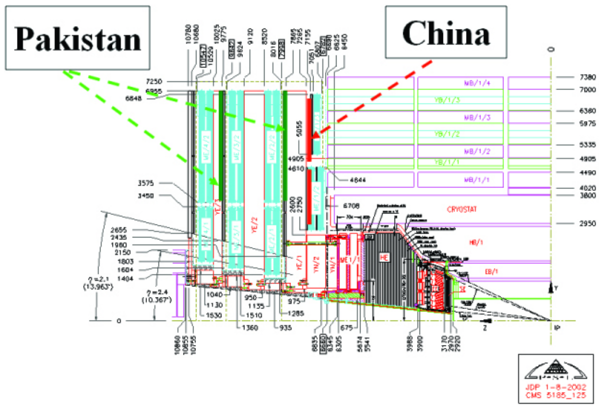

Figure 2. Assembly responsibilities in the staged RE system.

2004 [3]. Since then, up to the beginning of October 2005, more than 140 chambers have been constructed and more than 100 of them have been tested with cosmic rays under the strict quality control (QC) and quality assurance (QA) procedures. In this paper, the CMS muon and RE systems are briefly reviewed in Section 2; the RE1 construction process is outlined in Section 3; the QC and QA at various stages of construction are described in Section 4; then the last Section is to conclude with the status of RE1 construction and its installation on CMS overall detector. The muon system in CMS experiment is shown in Fig. 1.

2. CMS Endcap RPC system

The original design of the RE system has 4 (four) stations (with the label '1' as the innermost station) and each station has 3 rings (with the label '1' for the ring at the smallest radial position). Due to technical and budgetary reasons, the RE system is staged to the first 3 stations and to lower pseudo-rapidity (η) regions (i.e. the 2nd and 3rd rings) for the initial CMS detector when LHC will start to operate in 2007.

Though Fig. 2 shows that China is mainly responsible to the assembly of two rings on the first station (RE1/2 and RE1/3) in the staged endcap RPC system and Pakistan is for RE2 and RE3, this project is a truly international collaboration among several partners: all gas gaps are produced in Korea, all Front-end Electronics Boards (FEB) are provided by Pakistan, all read-out strips and major mechanical components (e.g. honeycomb panels cases, etc.) are procured from China; while CERN team plays the roles of coordination and of setting up the RPC assembly and test laboratory at CERN.

Each low η RE chamber consists of 3 gas gaps with trapezoidal shape as shown in the left part of Fig. 3. The dimension of RE1/2 is about 1.89 m long and 1 m at the wider end of trapezoid, while RE1/3 is about 1.76 $\times$ 1.4 m^2. There should be 36 RE1/2 and 36 RE1/3 chambers to be installed on each of two (i.e. positive and negative endcaps with respect to the collision point) CMS endcap iron yokes. The layout of the RE1 on each endcap is shown in the right part of Fig. 3. After including 10 % of spare chambers, a total of 160 chambers must be constructed for RE1/2 and 1/3.

3. Process for RE production

As mentioned in the previous section, several countries are involved in the RE production from the bakelite procurement to the gas gap manufacture to the chamber assembly. Many materials have to be transported back and forth over 20,000 km across the continents (Fig. 4). For example, (1) bakelite sheets were procured from an Italian company (Frati Laminati), then were cut

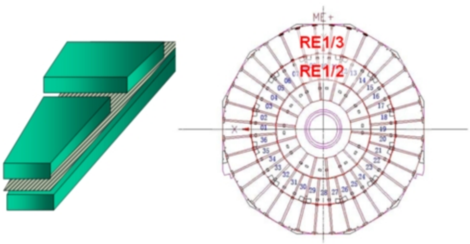

Figure 3. Three gas gaps in a low η RE chamber (left) and the view of the first station in RE system (right).

to trapezoidal shapes at another Italian company (Riva), then were shipped to a 3rd Italian company (General Tecnica) near Rome to clean the surfaces of bakelite sheet before being transported to Seoul (South Korea), crossing more than 10,000 km;
(2) gas gaps were built in Korea, then were partially shipped to CERN in Geneva for the RE1 assembly, and partially to Pakistan for the RE2 and RE3 assembly;
(3) mechanical parts and read-out strips, etc. were procured in China, then partially shipped to CERN for the RE1 assembly, and partially to Pakistan for the RE2 and RE3 assembly;
(4) FEBs (as well as the adapter boards and distribution boards) were ordered by Pakistan and procured from Italy, then shipped to Pakistan from Italy before re-shipping a part of total to CERN (from Pakistan) for RE1 assembly with nearly a round trip of over 20,000 km;
(5) finally, RE1 chambers were assembled at CERN by a Chinese+CERN team while RE2 and RE3 are being assembled at Pakistan before being shipped to CERN.

For the RE1 assembly at CERN, some special tools (e.g. handling bars, a scissor table, storage and transport rigs, and a jib crane, etc.) were developed. The assembly procedures were described in [3]. With great effort from all partners and people involved, the massive assembly rate at CERN reached 5~7 chambers per week.

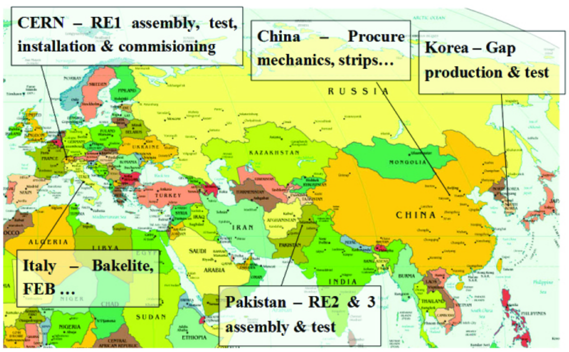

Figure 4. Logistical movement of materials and job sharing in the RE assembly.

4. QC and QA at various stages

Because of the large and long-distance logistical processes in the RE project as described above,

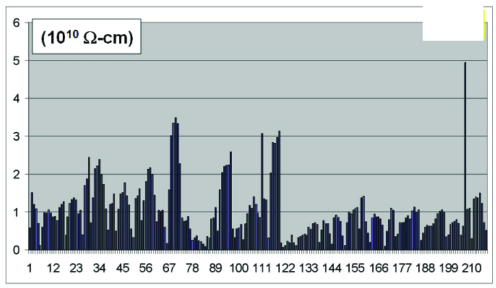

Figure 5. Volume resistivity (unit of 10^{10} Ω-cm) measurement on 220 bakelite sheets.

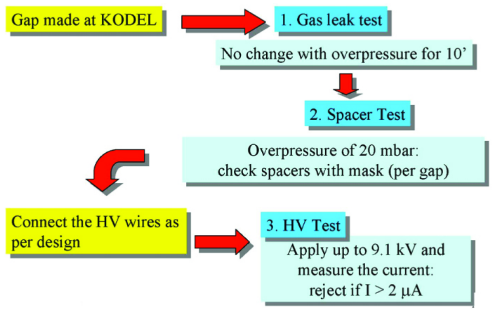

Figure 6. Gap QC in Korea, which is repeated at CERN.

the strict QC and QA procedures have been applied at every stage of RE construction in order to guarantee the quality of final RPC system. Here QC is to define the specifications and QA is for every means to meet those specifications. The main stages of QC+QA in the RE assembly include

(1) bakelite sheet selection,
(2) gap production in Korea and test at CERN,
(3) RPC assembly,
(4) QC data in a comprehensive database.

The details of items (3) and (4) were presented in a separate report [4] by W. Whitaker at this workshop, so here only the items (1) and (2) are described.

For the bakelite sheet, two major controls were performed: one is the volume resistivity of each sheet which must be in the range of $1 \sim 6 \times 10^{10}$ Ω-cm at 20°C; another is the surface quality of sheet, which must be 'brilliant' without any blemish or deformation, and the roughness of surface must be less than 0.1 mm. The QC at this stage was under the supervision of our team. Fig. 5 shows the resistivity uniformity QC for about 220 bakelite sheets at the beginning of selection, and it can be seen that only a small fraction of sheets passed the control; in the later stage, the fraction of good sheets was improved.

For the gas gap QC, Fig. 6 shows the major control procedures in Korea, which are repeated at CERN after the arrival of gas gaps shipped from Korea. In more details, three major tests were taken for each gas gap: gas leakage test, spacer pop-up test and high voltage test. The parameters checked out in Korea are (a) barcode on bakelite, (b) bakelite status on both sides, (c) electrode resistivity on both sides (100$\sim$150 kΩ/cm^2), (d) gas leakage test result, (e) spacer pop-up test result, (f) environment pressure and temperature, (g) I-V data in the HV test, and (h) status of electrodes, hot melt and PET protection film. The parameters checked out at CERN are the above items (a) and (d)-(h), except the item (a) is modified to 'barcode on gap'. Fig. 7 shows a sample result of the current measurement at HV of 9 kV.

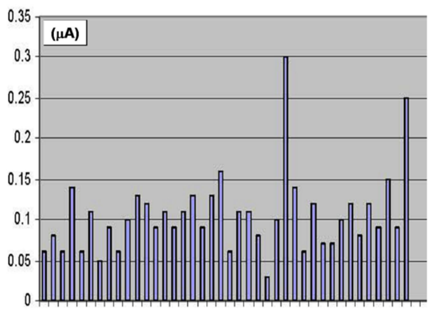

Figure 7. Result of the HV test on 40 good gas gaps (the unit of vertical axis is μA).

Failure (from the criteria outlined in Fig. 6) rate is about 40 from the HV test and 10 from the gas leakage test out of 450 tested gaps. One delicate part on gas gaps is the gas inlets that can be easily knocked off, so must be treated very carefully. The gas gaps were also undertaken the destructive tests by being regularly opened in Korea and twice at CERN. The results of destructive test at CERN show that the spacer bonding and the linseed oil coating found to be fine; the oil surface does not show any reaction to chloroform - polymerization which may deteriote the detector performance.

The QC for the assembled chambers and the QC database are described in a separate article in this proceeding [4]. Some details of QC and QA for RE1 as well as the relevant works were documented in [5].

5. Status of RE1 construction and installation

By the end of October 2005, a total of 160 RE1 chambers has been assembled. The left part of Fig. 8 shows a part of completed chambers that were waiting for being transported to the CMS assembly hall for the installation on the CMS overall detector. Before the installation, a RE1/2 has to be mated to a cathode strip chamber (CSC) as shown in the right part of Fig. 8. Then, the combined CSC+RPC module is installed on the 1st station of CMS endcap iron yoke by using the cherry pickers and the special fixture equipment (with a round shape as shown in the left part of Fig. 9).

The right part of Fig. 9 is an overview af-

Figure 8. Completed RPCs (left) and the mated CSC+RPC (right).

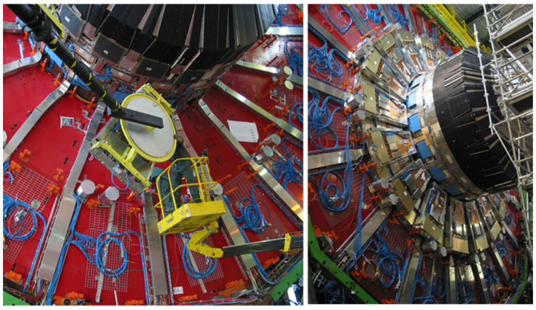

Figure 9. Installation of the very first CSC+RE1/2 module (left); 36 RE1/2s for one endcap have been installed on CMS before December 2005 (right).

ter total 36 RE1/2s are installed completely on one endcap. 18 of the second 36 RE1/2s have also been installed on another endcap in December 2005, and the remaining 18 will be installed in January 2006. The installed RE1/2s have started to be commissioned in December 2005, while RE1/3s will be installed on CMS in the 1st half of 2006.

6. Conclusions

In summary, the CMS initial RE1 system has been tailored to fit the available budget and technology. The assembly of whole reduced RE1 system has been completed. Under the strict QC procedure, the performance of assembled chambers meets the CMS requirement. A total of 54 RE1/2s have been installed on the CMS detector by the end of 2005, and 36 of them have been preliminarily commissioned without any problem. More complete commissioning of installed chambers and the rest of RE1 installation are in full swing and expect to meet the CMS master completion schedule.

Aknoledegment

The RE1 project with multi-national participation and the complicated long logistical movement of materials would be very difficult to be completed if without great helps from many colleagues in all participating groups involved. Here, we would like to particularly thank to the CMS management (spokespersons M. Della Negra and T. Virdee) for their persistent support and encouragement. We are also indebted to many short term colleagues and summer students who have made valuable contributions to the project. We specially appreciate numerous assistances from the INFN group for the CMS barrel RPC; their previous experiences and lessons were great assets for us to speed up our construction. We are also grateful to the CMS CSC team as their help for the RE1/2s installation on CMS detector is a key factor in the final stage of the project.

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