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Resistive Plate Chambers for the RE4 upgrade of the CMS endcap system

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ABSTRACT: It is proposed to install the fourth endcap (RE4) consisting of Resistive Plate Chambers (RPCs) for the Compact Muon Solenoid (CMS) muon endcap system, in order to improve its Level-1 trigger efficiency and thereby completing the full implementation of the Technical Design Report (TDR). This station will be installed in the first long shutdown of the Large Hadron Collider (LHC) during 2013-2014. With lessons learnt from the earlier installation of the RPCs, several modifications in the new construction and test procedures have been recommended for this upgrade. The prototypes for the upgrade were assembled in 2011, thereby giving the green signal for mass production for bakelite and gas gaps. This paper also discusses the standardisation of leak and spacer tests for the bakelite gas-gaps, the new design for the Cu cooling system, the data base and the preparedness at the three assembly sites at CERN, Mumbai and Ghent.

KEYWORDS: Gaseous detectors; Large detector systems for particle and astroparticle physics

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[1] On behalf of the CMS collaboration.

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1 Introduction

The Technical Design Reoprt (TDR) for the muon trigger for the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) facility envisages to have four layers of Resistive Plate Chambers (RPCs) in the forward region ($1.2 < \eta < 1.6$) [1]. The present CMS experiment has three layers of RPCs in the end-caps. The end-caps consist of three trapezoidal bakelite gas-gaps configured as a double gap RPC [2–4], with each RPC having a segmented readout strip along η, called as η partitions. The present RPC trigger logic, from the end cap, requires hits in at least three layers, which causes the observed drop in efficiency for the endcaps with only three stations, being close to 80%. Adding the 4th layer in the endcaps, enabling a 3-out-of-4 trigger logic in those regions, will bring the RPC endcap performance to a similar level as in the barrel region, to 95%. In order to increase the Level-1 trigger efficiency, it is proposed to install the fourth end-cap layer during the long shutdown (2013–2014), after which LHC will run with its full designed luminosity.

The construction procedures of RPCs, with the experience gained during the operation of RPCs in the present set-up, has been improved, keeping backward compatibility with the presently installed RPCs. As in the past, the fourth layer will consist of 2 rings denominated as RE4/2 and RE4/3, each having 36 chambers. Both end-caps will be instrumented for a total of 144 chambers with another 56 chambers as spares, adding to 200 chambers for the RPC upgrade project, which then fully restores the TDR version of CMS with RE4 RPCs.

2 Prototype assembly of RE4

A pre-production run, prior to the actual mass production of gas-gaps for the RPC upgrade was planned in March/April 2011 and about 18 gas-gaps for the two rings (RE4/2 and RE4/3) were sent to CERN for their evaluation. The prototype assembly for RE4 was thus launched with the arrival of fresh set of gas-gaps from Korean DEtector Lab (KODEL), South Korea, mechanics from

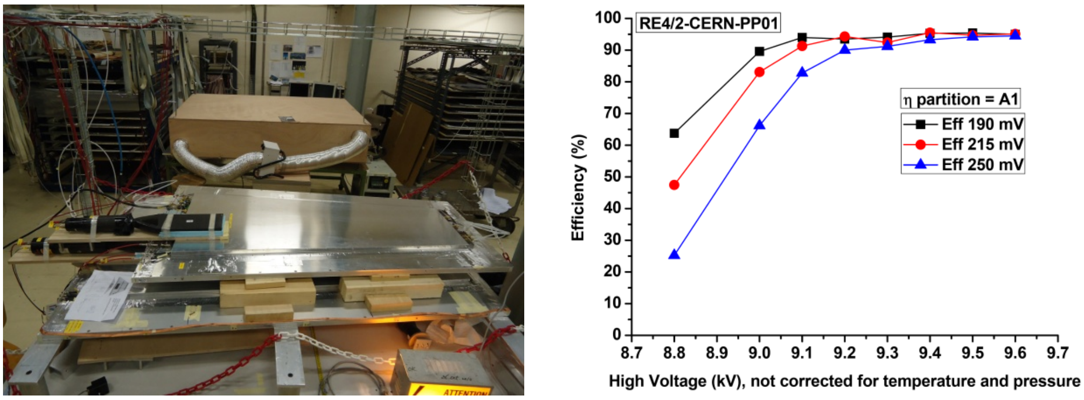

Figure 1. RE4/2 prototype under tests (left) with efficiency plot (right) for different threshold settings.

China and the improved Cu cooling system from India. Two prototypes, one for each ring were assembled. Figure 1, shows a fully assembled RPC for the RE4/2 ring under test in a dedicated laboratory at CERN and its corresponding efficiency plot for one of the η partitions (A1), at different threshold settings.

The above quality test validated the entire construction chain and the compatibility of various components used to build the chamber, like the bakelite in terms of surface smoothness and its bulk resistivity. It also validated the gas-gap fabrication procedures in terms of its mechanical and electrical properties, gluing of gas-gaps, bonding of spacers. Finally the measured cosmic efficiencies did certify the behaviour of gas-gaps coupled to the front end electronics, matching the specifications set by CMS. During the pre-production run all the necessary mechanical components were revalidated and the technical specifications and quality assurance and quality control, QA/QC protocols were formalized. For the RPC upgrade project, 660 gas-gaps will be produced at KODEL, with a production rate of 3 gaps/day, thereby needing 11 months for the entire gap production.

3 Mechanical tests for the gas-gaps

Since the gas-gaps are transported through a large distance via air freight and then handled at airports before delivery to the respective assembly sites, their mechanical properties are evaluated through leak and spacer tests before they are assembled. The trapezoidal gas-gaps have nozzles in the four corners for gas flow. The 2 mm gap uniformity is maintained through a grid (10 cm × 10 cm) of button spacers (of height uniformity within 20 μm) between the bakelite sheets. The 20 μm precision ensure that the gap remains uniform over the entire area of the gas-gap providing a uniform electric field. These spacers could also get popped up because of insufficient bonding of the glue at the fabrication site, though sufficient care is taken to keep the spacers pressed, guaranteed by water column, for 14 hours during curing. The spacers can also get popped up because of mishandling of the gas-gap crates at the time of delivery. A gas-gap, even with a single popped spacer cannot be used and is to be rejected.

In order to certify these gas-gaps, a new system has been designed where the gas-gaps on arrival from KODEL, undergo a leak and spacer test. The gas-gaps are pressurised at 20 mbar above atmospheric pressure with Argon gas and the pressure is recorded digitally through a transducer

Table 1.

gas-gap type →	RE4/3 Top Narrow	RE4/3 Top Wide	RE4/3 Bottom	RE4/2 Top Narrow	RE4/2 Top Wide	RE4/2 Bottom
$[dp/dt]_{max}$ (mbar/600 s) →	0.3 mbar	0.1 mbar	0.4 mbar	0.1 mbar	0.1 mbar	2.2 mbar

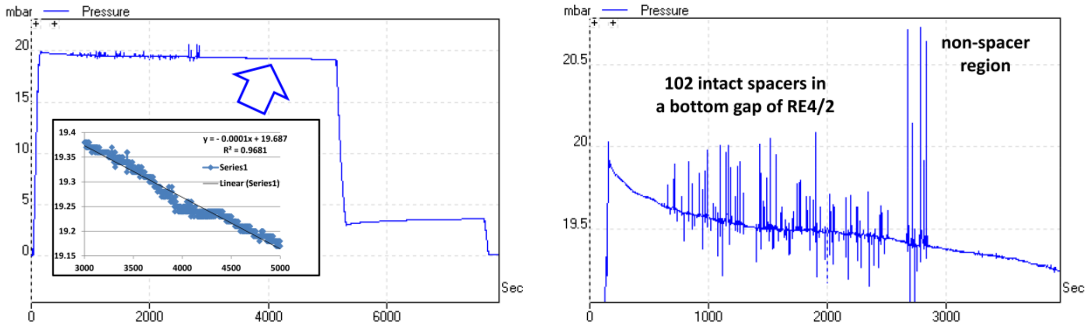

Figure 2. Gas-gaps pressurised to 20 mbar and 3 mbar of overpressure to calculate the leak rate (left side) and spacer test for gas-gaps showing acceptable pressure fluctuations (±0.5 mbar) for intact spacers (right side).

(Sensor Technics – CTE7000) with a 20 bit ADC. The QA/QC "as prescribed by the CMS experiment for the leak test" needs the gap to remain pressurised at 20 mbar for 10 minutes and the dP/dt for each gas-gap is measured. Then, the overpressure is reduced to 3 mbar, which emulates the situation in the CMS cavern, for the next 10 minutes. The dP/dt is measured again at 3 mbar and then the overpressure is released to zero. A plot of the measured dP/dt is shown in the left side of figure 2 for the RE4/2-bottom gas-gap with 102 spacers. The inset in the left side corresponds to the acceptable leak rate (-2.3×10^{-4} mbar×litre/s) from the particular gas-gap. At 3 mbar of overpressure, initially, we do find a positive slope, i.e. rise in pressure with time, but then it stabilizes. Probably we have to allow more time for pressure etc. to stabilize, rather than taking the measurements in quick successions and should also have the environmental pressure outside recorded simultaneously. Table 1 shows the maximum allowed pressure drop for different gas-gaps, normalized to 2 litres of gas volume.

For spacer test, a template with known spacer position is placed over the gap and each spacer position is pressed to record the fluctuations in the pressure. For intact spacers, the fluctuations in the pressure are in the range of ±0.5 mbar, whereas for the same pressure applied in the non-spacer region, resembling a popped up spacer, corresponds to large fluctuations (±1 mbar and beyond), as shown in the right side of figure 2.

4 Electrical tests for the gas-gaps

QA/QCs for electrical tests of the gas-gaps have been formulated to be uploaded on the data base, prior to assembly and dispatch to CERN. Each gas-gaps will be purged with RPC gas mixture (R134a : Iso-butane : SF_6 :: 95.2 : 4.5 : 0.3) with 40 % Relative Humidity (RH) in the gas mixture at a flow rate of 5 litres per hour for 48 hours, with $P_\circ = 1010$ mbar and $T_\circ = 293°K$, before

Table 2.

gas-gap type →	RE4/3 Top Narrow	RE4/3 Top Wide	RE4/3 Bottom	RE4/2 Top Narrow	RE4/2 Top Wide	RE4/2 Bottom
$I_{max}(\mu A)$ →	3.5	2.0	5.1	2.0	2.0	3.5

undergoing the dark current tests. The gas-gaps will be ramped upto 10 kV of applied HV and the maximum acceptable dark currents are shown in table 2.

The gas-gaps are then subjected to stability test for three days at the sites with HV at 9.7 kV. The acceptance criteria for the gas-gaps is that during the stability tests the increase in dark current should be less than 50% and $I < I_{max}$, as mentioned in table 2. Once the gas-gaps pass the acceptable criteria of mechanical and electrical tests, they are ready for assembly into an RPC.

5 Redesigned Cu cooling system for the RE4-RPCs

With the experience gained with the installed RPCs in the existing end-caps, the Cu cooling system for the RPCs was redesigned. In the new design, the area of Cu plates has been increased optimally with water flowing through Cu pipes, in a closed circuit. The earlier installed, 8 mm ϕ brass unions with a single ferrule, have been replaced with SS double ferrules to ensure that there is no water leakage at the coupling junctions. Improvement in the cooling system had to be introduced for RE4, due to its particular position facing the electronics of the other muon system based on Cathode Strip Chambers. The new cooling system is envisaged also for RPC that will replace malfunctioning chambers in the other layers, so the design includes backward compatibility.

A prototype of the Cu cooling system was fabricated in BARC, Mumbai, meeting the required specifications and was dispatched to CERN during the pre-production run. The Cu cooling system was fabricated with Deoxidized High Phosphorus (DHP) semi hard Cu pipes (8 mm OD and 6 mm ID) and Cu sheets with 1 mm thickness. The DHP Copper is a commercially available material of pure copper, which has been deoxidized with phosphorus, leaving relatively high residual phosphorus content. This copper has a lower electrical conductivity and is used where there is need for heat transfer and electrical properties are not important. The Cu cooling system will have chilled water at 19°C running at a pressure of 2 bar, in order to cool the electronics and the body of RPCs through the aluminum honey comb panels on to which it is mounted. A typical Cu cooling system for RE4/3 type RPC is shown in figure 3. The Cu pipes were soldered ($\sim 200^{\circ}$C) to the Cu plates with soldering material having a composition of Sn : Ag : Pb :: 62 : 2 : 36. After complete assembly, the Cu cooling systems are tested for any possible leakage with Argon gas at 20 bar of pressure. Special jigs were made to ensure that the Cu pipes do not bend and maintain their straightness, while soldering them to the Cu plates.

The fabricated Cu assembly was further subjected to leak tests with 20 bar of Argon gas for 70 minutes. As shown in figure 4, the pressure remain stable (closed circles) at 20 bar with surrounding temperature in the lab also remaining constant at 21°C (open squares), thereby ensuring that there were no leaks developed in the system while fabricating the assembly, subjected to high temperatures while soldering the Cu pipes to the Cu plates. The zoomed part (solid squares) shows a pressure drop of -4.74×10^{-3} mbar/s, which translates to an acceptable leak rate of 5.36×10^{-4}

Figure 3. Cu cooling assembly for a typical RE4/3 RPC, under leak test after fabrication.

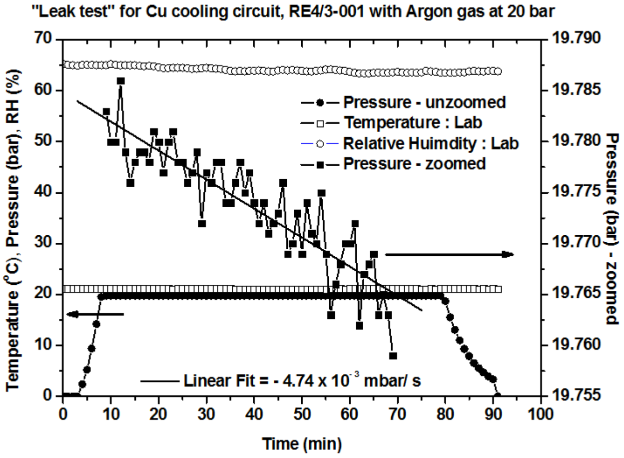

Figure 4. Leak test for Cu cooling assembly with Argon gas at 20 bar of pressure and 21°C.

mbar.litre/s. The Cu cooling systems for all the chambers are being fabricated and tested at BARC, Mumbai and shall be dispatched to the other assembly sites in a phased manner synchronising with the delivery of gas gaps from KODEL.

6 Delivery schedules of chambers from the assembly sites

For the start up it is proposed to build 50 chambers each in India (RE4/2), and University of Ghent, Belgium (RE4/3) and the remaining (50 chambers of RE4/2 and 50 chambers of RE4/3) at

Table 3.

SN	Installation and Commissioning	Proposed schedule
1	36 Super Modules for Endcap 1 ready for P5	end of Mar 2013
2	36 Super Modules for Endcap 2 ready for P5	end of September 2013
3	First endcap (+Z side)	December 2013
4	Second endcap (−Z side)	July 2014

Figure 5. Cosmic hodoscopes at Mumbai (left), CERN (middle) and Ghent (right) assembly sites.

CERN. In India, two institutes are collaborating jointly for the project, namely — Nuclear Physics Division-BARC, Mumbai and Panjab University, Chandigarh. CERN site will coordinate the logistics & setting up protocols for QA/QC. Construction data base has been implemented for QC from chamber components (bakelite, gaps, electronic etc.) to final chamber Super Module assembly. At the time of writing this paper, the relevant mechanics and read out planes have arrived from China at the respective assembly sites for all the 200 chambers and the RPC assembly work is expected to begin soon after the arrival of first batch of gas-gaps at the assembly sites. Gas-gaps will be produced at a rate of approximately 60 gaps per month at KODEL, and will then be dispatched to the three sites. The first set of gas-gaps is expected to be dispatched to the three sites in Sep/Oct 2012. The chamber production rate is foreseen as three RPCs per month in Mumbai, five RPCs per month at Ghent and ten RPCs per month at CERN, given the available logistics and infrastructure in these sites. One RE4/3 chamber coupled to a RE4/2 chamber forms a ten degree Super Module (SM) assembly. It is proposed to have the installation and commissioning of the SM assembly and the endcaps, as shown in the table 3.

Figure 5, shows the three assembly sites respectively at NPD-BARC, Mumbai, CERN-904 and Ghent, with their cosmic hodoscopes. All the assembly sites are ready with their respective hodoscopes, VME based DAQs and QA/QC procedures for the launch of production of the first ten chambers, each, from Oct/Nov 2012 onwards. Instrumentation for monitoring of the environmental pressure, temperature, and relative humidity to run the HV scripts and for ramping of gas-gaps for dark current measurements have been implemented in all the three sites. The development of software tools for offline analysis and characterization of RPCs is ongoing.

Acknowledgments

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