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Nuclear Physics B (Proc. Suppl.) 158 (2006) 16–20
NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS
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Production and the quality control for the CMS endcap RPCs

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The production for the endcap RPCs in the CMS experiment has entered a mature stage of the production stream. In this paper, the production facilities and the selection procedures of the qualified RPC gaps are presented. The mass production and the quality control tests for the endcap RPCs have reached the maximum productivity. The yield to produce the qualified gaps is now above 80 % of the qualified bakelite sheets provided by Italy. We also report an intensive aging study for the endcap RPCs performed by using a 200 mCi ^{137}Cs gamma-ray source. A few diagnostic methods to observe aging phenomena are discussed. The test result is equivalent to approximately 12 years of Compact Muon Solenoid (CMS) RPC operation.

0920-5632/$ – see front matter
doi:10.1016/j.nuclphysbps.2006.07.001

1. Introduction

The Resistive Plate Chambers (RPCs) for the muon trigger in the endcap region of the Compact Muon Solenoid detector (CMS) covers a pseudo-rapidity ranging from 0.92 to 2.1, as shown in Fig. 1 for a quadrant of the CMS detector [1].

A total of 432 RPCs for three inner RPC endcap stations (RE1, RE2, and RE3) is being produced, tested, and installed for the muon trigger of the endcap CMS detector [2]. The contruction of the whole RE system, which was initially proposed in the CMS Technical Design Report [1], was planned to be completed by series of upgrades after the first operation period of the LHC experiments. Therefore, the current goal of the production of gas gaps is to establish a qualified muon trigger system consisting of the 3 RPC endcap and 6 RPC barrel stations. The production of gas gaps also includes the preparation of complementary detectors for the RE stations.

Important parameters to determine the geometrical layout and the mechanical details for the gas gaps, which are the core components of RPCs, must be chosen by the considerations of the geometrical coverage of the trigger, spurious noise rates, the electric and long-term stability against aging which could be arose by the intensive beam-induced background particles [3,4]. The choices of materials, consisting of the gas gaps, were also decided by the same considerations. In addition, an intensive aging test was carefully carried out to simulate effects equivalent to those caused by 10 years of the RPC operation in the environment of the endcap region of the CMS detector.

In this paper, we briefly report the production and the quality controls of gas gaps for the endcap RPCs in Section 2. The test result for a gamma irradiation of 150 days by using 200 mCi ^{137}Cs source is presented in Section 3. The conclusions for the detector production and for the aging test are discussed in Section 4.

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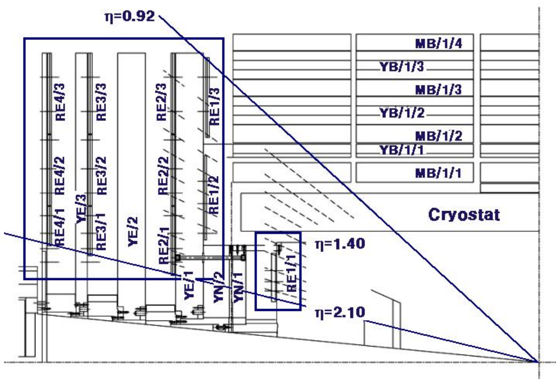

Figure 1. Schematic view of a quadrant of the CMS detector. The endcap RPCs trigger muons in the psudorapidity η ranging from 0.92 and 2.1.

2. Production of gas gaps

The important factors to be considered for the production facilities are the mechanical uniformity and the electrical stability of the gas gaps, which should be preserved for more than 10 years of the CMS operation.

Before the assembly of gas gaps, a thin carbon layer and an insulator sheet are coated on the bakelite sheet. Linseed-oil coating is performed after the gas gaps are assembled. The final stage of the production consists in the tests for the quality control. The production procedures for the gas gaps are briefly enumerated as the follows:

(1) visual inspection and selection of bakelites,
(2) coating of thin carbon layers,
(3) coating of insulation (PET) films,
(4) assembly of gas gaps,
(5) linseed-oil coating,
(6) sealing of peripheries of the gas gaps,
(7) wire connections for high-voltage tests.

The details for the facility and the procedure on each step were described in the previous publication [2]. The operation table and the accessories of the silk screen are shown in the left panel of Fig. 2. The right panel of Fig. 2 shows the extrusion facility and the control device of the PET film coating. The facility for the assembly of the gas gaps, consisting three sets of metric tables and rubber chambers is shown in Fig. 3. The oil coating facility, as shown in Fig. 4, consists of oil tanks and a lifting device to hydrostatically inject the oil, an air compressor to control the pressure of the system, and a press device which vertically holds the gas gaps both during the oil coating and the air drying.

Figure 2. Silk screen table and the accessories for the graphite coating (left), and the PET film coating facility for the protection of the carbon layers (right).

Figure 3. Facility for the assembly of gas gaps. The facility equipped with 3 sets of flat metric tables and rubber chambers enables three consecutive assembly procedures.

Figure 4. Oil coating facility. The 200 l oil tank and the lifting device are shown in the left figure. Before oiling, the gas gaps are vertically mounted inside a pressing device, as shown in the right picture.

The quality control of the gas gaps consists of two tests: the first one includes checking for gas tightness and failures of spacer bonding. The second step is the measurement of the ohmic currents of the gas gaps at several high voltage settings. For a gas gap to be qualified, the loss of the applied pressure should be less than 0.2 hPa over a 15 minutes period. No failure of a spacer bonding is accepted with the presence of 20 hPa over-pressure.

The measurement of the ohmic currents provides the acceptance criterion for qualified gas gaps at the initial stage of the detector operation. The gas mixture for this high voltage test is 96.5 % tetraflouroethane ($C_2H_2F_4$) and 3.5 % i-C_4H_{10}.

Compared to the previous acceptance criteria applied to the gas gaps produced in 2004 [2], more crucial criteria were applied to the gas gaps produced in 2005. The new current limits of the qualified small cut gaps, large cut gaps, and full gaps at 9.4 kV were 2.0, 4.0, and 5.0 μA, repectively. To be qualified, the ohmic currents of the gas gaps should be also stable both at 8.5 kV for 12 hours and at 9.4 kV for more than 48 hours. The current values of 129 qualified RE1/2 gas gaps at 9.4 kV are shown in Fig. 5. The dark and light circles are the current values measured at the beginning of and the end of the 48-hour tests, respectively.

3. Aging test

The aging study for the endcap resistive plate chambers (RPCs) was performed by using a 200 mCi ^{137}Cs gamma-ray source. For the systematic study, four double-gap RPCs, 40 $\times$ 40 cm^2, were manufactured and tested for cosmic muons and the gamma rays irradiated from the source. During the irradiation, the amount of the induced charge inside the RPC gaps was approximately 1.6 mC/cm^2/gap/day. The typical current induced by the gamma rays in each RPC ranged from 40 to 60 μA.

The integrated avalanche charges per unit area and per gap for 150 days of gamma irradiation induced in the four RPCs are summarized in Table 1. They are equivalent to approximately 12 years of the CMS RPC operation.

The long-term application of a fluoride-rich chamber gas and of the radiation-induced avalanche charge probably cause gradual changes in the chemical and electrical properties of the bakelite plates. The expected effects are degradation of the oiled surfaces, increase of the resistivity of the bakelite, and physical deformations of the gas gaps [5–7]. The first effect accounts for increases in the ohmic currents and the noise rates of the detectors. The degradation of rate capability is arose by the increase of the resistivity. The physical deformations of the gas gaps will deteriorate uniformity of the gap thickness.

Detectors	Integrated avalanche charges
RPC1	205.0 mC/cm^2
RPC2	243.1 mC/cm^2
RPC3	255.2 mC/cm^2
RPC4	233.0 mC/cm^2

Table 1
Integrated avalanche charge per unit area and per gap induced in four test RPCs for 150 days of gamma irradiation.

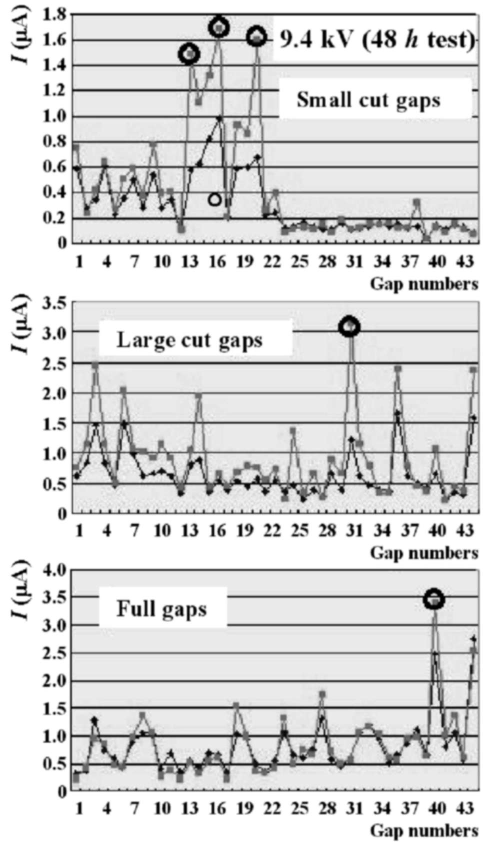

Figure 5. Current values of 129 RE1/2 gas gaps at 9.4 kV. The currents for the small cut gaps, the large cut gaps, and the full gaps are shown in the top, middle, and bottom figures, repectively. The dark and light solid circles are the current values measured at the beginning and the end of the 48 hour test, respectively. The unqualified gaps are marked by the open circles.

It was empirically found that the addition of the water vapor to the chamber gas could retard the resistivity problem and could enable us to control the variation of the resistivity within a range in which the required rate capability of the detectors could be sustained. Figure 6 shows the bulk resistivities of the four RPCs, as measured for the 11 months of the test. The boxes indicate the periods when water vapor was applied to the chamber gas. The global trend of the resistivities was, however, still ascending in spite of the application of the water vapor.

A total of 5 sets of cosmic muon TDC data was measured to observe the degradation in the RPC performance as a result of long-term operation. The efficiencies for muons and the noise rates as functions of high voltage were expected to be sensitive to the degradation in the RPC performance. Compared to the first four cosmic muon data sets measured in 2004, the degradation were observed in the efficiencies for three RPCs in the last data sets measured in April 2005. Figure 7 shows the muon efficiencies and the noise rates as functions of the high voltage, as measured in April 2005. The efficiencies for the degraded RPCs gradually increased from 0.8 to 0.95 as the high voltage was increased from 9.0 to 9.5 kV, which were not observed in the previous four measurements.

However, the degradation of the efficiencies is not attributed to the degradation of the surface quality of the resistive plates, since no significant change has been observed either in the noise rates or in the mean cluster sizes. The degradation of the muon efficiencies was presumably attributed to the deformation of the RPC gaps. It could be avoided if the RPCs are properly operated at room temperature (20 ∼ 25 °C) and if there is a continuous supply of water vapor.

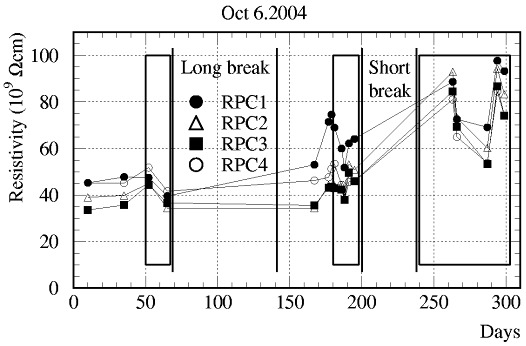

Figure 6. Resistivities of four RPCs, as measured during an 11-month aging test. The rectangular boxes indicate the periods when water vapor was applied to the chamber gas.

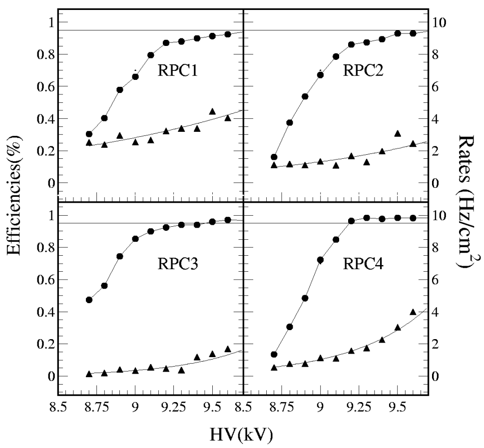

Figure 7. Muon efficiencies (circles, left scale) and noise rates (triangles, right scale) of the RPCs, as functions of the high voltage. The data were obtained in April 2005.

4. Conclusions

The mass productions of the gas gaps and the quality control tests for the endcap RPC system has reached the maximum productivity. The production and transportation of the gas gaps were completed for the RE1 and RE2 stations by October 2005. The further production for the RE3 station is reliably on schedule.

In conclusion of the aging test, proper procedures for the maintenance and the operation of the RE system should be carefully organized to sustain the initial RPC performance for more than 10 years of CMS operation.

REFERENCES

1. 'The Muon Project, Technical Design Report', CERN/LHCC 97-32, Dec. 1997.
2. S. Park *et al.*, Nucl. Instr. and Meth. A **550** (2005) 551.
3. S. Park *et al.*, Nucl. Instr. and Meth. A **533** (2004) 37; *ibid.* **508** (2003) 147; *ibid.* **469** (2001) 323; *ibid.* **465** (2001) 447; *ibid.* **456** (2000) 29; *ibid.* **456** (2000) 23; *ibid.* **451** (2000) 582.
4. S. Park *et al.*, J. Korean Phys. Soc. **47** (2005) 427; *ibid.* **46** (2004) 1325; *ibid.* **46** (2004) 1090; *ibid.* **41** (2002) 667.
5. G. Carboni *et al.*, Nucl. Instr. Meth. A **533** (2004) 107; *ibid.* **518** (2004) 82.
6. G. Aielli *et al.*, Nucl. Instr. Meth. A **533** (2004) 98.
7. J. Va'vra, Nucl. Instr. Meth. A **515** (2003) 354.