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Radiation hardness studies of cooling fluids epoxies and capacitors for CMS pixel system

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Abstract

Radiation hardness studies of C_6F_{14} Fluorinert (FC72) fluid, some epoxies and tantalum capacitors were studied for the Compact Muon Solenoidal (CMS) experiment at the Large Hadron Collider (LHC) of CERN. For a successful operation of Forward Silicon Pixel Tracker of the CMS, the cooling fluid, epoxies to be used and the filter capacitors of bias voltage supplies need to be radiation hard. It was also necessary to find out whether the cooling fluid would dissociate under the expected fluence and damage beryllium cooling channels of the Forward Silicon Pixel Discs. This paper is a report of our findings from the performed tests.

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1. Introduction

The Silicon Vertex Tracker of the CMS Detector [1] is going to play an important role in determining impact parameters of the b and c quark decays and for pattern recognition, especially for identifying high p_t electron and muon tracks within jets. A perspective view of the pixel vertex tracker is shown in Fig. 1. It shows two layers of barrel pixels and two forward pixel discs. We are planning to have three layers of barrel pixel system and three pixel discs on each side. This is necessary for decay vertex determinations and pattern recognition to sufficient efficiency. Three-point determination of tracks can be considered a minimal requirement.

The pixel size of the pixel tracking system is chosen to be $150 \times 150\,\mu m^2$ size, with a total number of about 18 million pixels on the forward discs. Each and every pixel will be flip-chip bump bonded to the same size of readout electronics. There may be 106 transistors in each matching circuitry; therefore requiring a very efficient cooling system. The total power dissipation is estimated to be about 1.4 kW, together with the peripheral electronic circuitry. We plan to run the tracker at a temperature of $-12°C$. A beryllium cooling tube and beryllium panel structure were chosen for their mechanical strength and for

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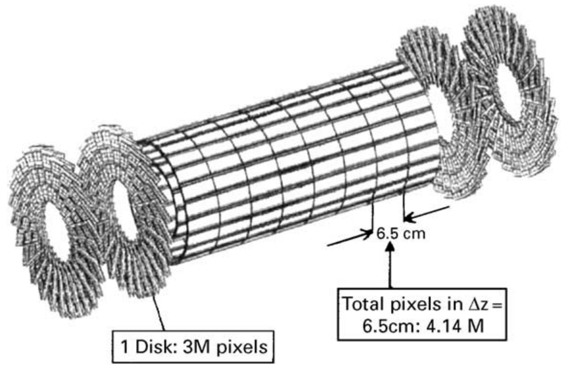


Fig. 1. A perspective figure of the pixel tracker of the CMS. It shows two layers of barrel pixels and two forward discs. We plan to have three barrel layers and three forward discs in the final configuration.

minimizing the amount of radiation length of materials in the way of charge particle tracks. We plan to circulate C_6F_{14} (FC72) fluorocarbon liquid as coolant due to its good heat capacity. Our radiation test results showed that this would be a good choice. Coolants containing water would be corrosive to beryllium (Be) and aluminum (Al); therefore such coolants should be avoided. We were concerned about FC72 dissociating and interacting with Be and therefore we carried out the following tests.

2. Radiation damage tests

A 3 cm diameter, 9 g Be-disc was placed into a glass jar containing the FC72 cooling fluid. The cap of the jar had polyethylene lining. The weight of the Be-disc was taken using a high precision scale before and after exposing to 20 Mrad of Co^{60} per cm^2 irradiation in a facility at Purdue University. The level of irradiation is sufficient for 5–10 year LHC running time, due to the reason that only small fraction of the coolant will be

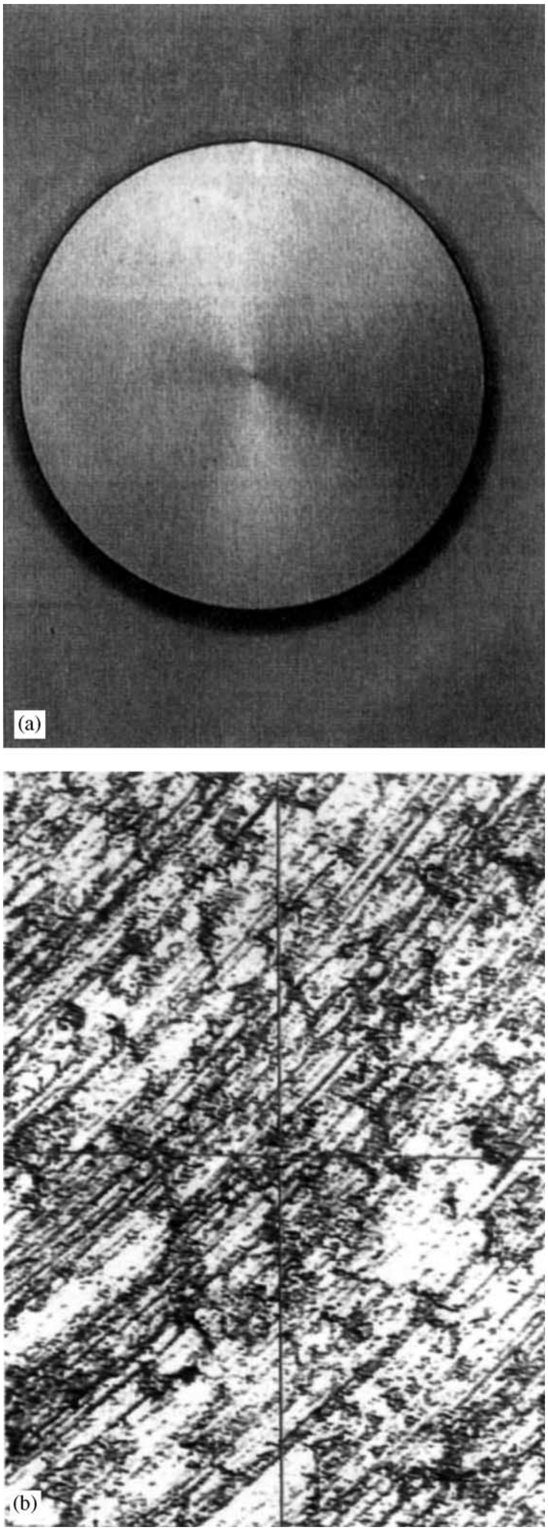
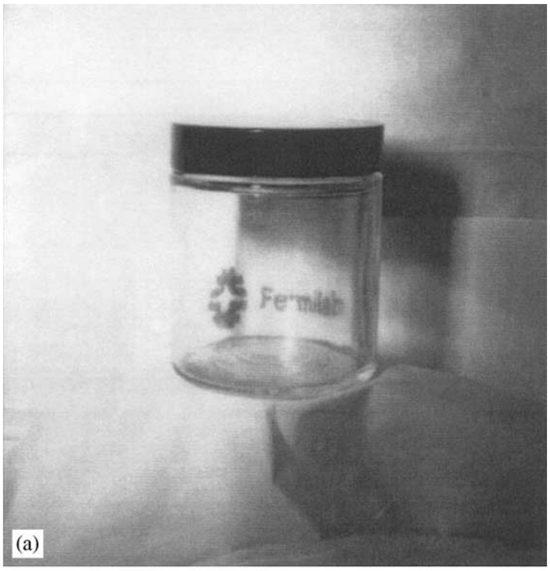


Fig. 2. Surface pictures of the beryllium disc after irradiation: (a) full disc surface and (b) the magnified portion of the surface. Magnified view shows that machined grooves were not covered with any residue.



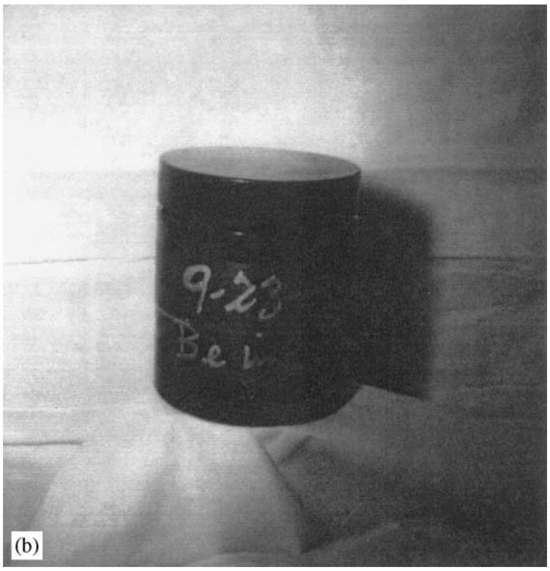


Fig. 3. Photos of the glass jar: (a) before and (b) after irradiation. It shows how dark in color the glass jar became after the irradiation.

exposed to irradiation. There will be a coolant reservoir away from the CMS detector. The precision of the scale was better than 0.01 mg. The disc was left in the liquid for 3 weeks before scaling its weight after the irradiation. There was no measurable change in the weight of the disc after this period. An optical picture of the Be-disc

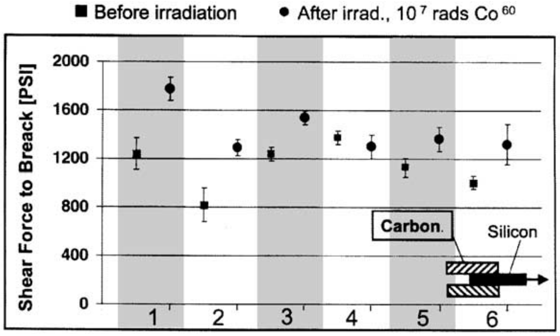


Fig. 4. An average summary of the scatter plot of the shear test results before and after the irradiation of the various epoxies. With the exception of one epoxy, they show some increase in the shear strength. This could be due to more hardening of the epoxies in time: (1) Epon 815–80 EM-308 (the viscosity is 1500 centipoise); (2) Epon 815–13 TETA (the viscosity is 500 centipoise); (3) Epon 815–50 Epon V-40 (the viscosity is 5000 centipoise); (4) Epon 815–70 Epon V-50 (the viscosity is 1500 centipoise); (5) (80 D.E.R. 332 + 20 D.E.R. 732)-13 TETA; (6) (80 D.E.R. 332 + 20 D.E. R. 736)-13 TETA. Epon products are produced by Shell Chemical Co. EM-308 is an epoxy curing agent made by Thiokol Corp.

was taken before and after the irradiation and we did not see any visible change of the surface quality. A photo of the Be-disc together with a magnified view is shown in Fig. 2. The magnified view shows the machine grooves with no visible residue in them. The FC72 fluorocarbon is a very clear transparent liquid. The color of the liquid after the irradiation was as clear as before, but the glass jar became very black as shown in Fig. 3. The irradiated liquid was sent to a commercial company [2] to look for traces of beryllium and fluoride ion. Less than 1 ppm of beryllium (this is the precision of the company's measurement) and 17 ppm of fluoride-ion (F^-) traces were found by the company.

Fermilab has a well-equipped material research facility. Epoxy radiation damage tests were also carried out using the facility. Some selected epoxies with different viscosity were used for the shear tests. Five samples of epoxy joints between silicon wafer and small carbon fiber composite plates were prepared for their shear strength testing before irradiating and after irradiating them using Co^{60} sources to a radiation level of 20 Mrad/cm^2. The results are summarized in

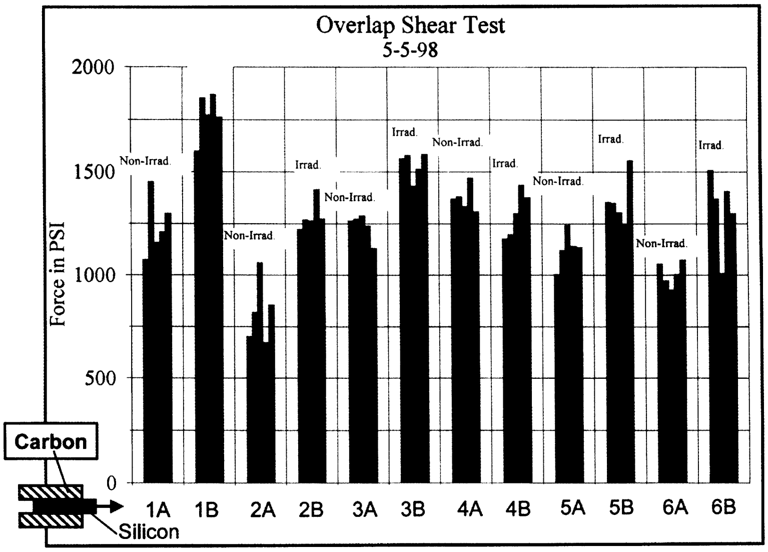


Fig. 5. A histogram plot of the results. It shows that there are small variations in five samples for each epoxy: (1A and 1B) Epon 815–80 EM-308; (2A and 2B) Epon 815–13 TETA; (3A and 3B) Epon 815–50 Epon V-40; (4A and 4B) Epon 815–70 Epon V-50; (5A and 5B) (80 D.E.R. 332 + 20 D.E.R. 732)-13 TETA; (6A and 6B) (80 D.E.R. 332 + 20 D.E.R. 736)-13 TETA. Each Sample A has not been irradiated, but each Sample B has been irradiated.

Figs. 4 and 5. The results indicate that the shear strength is somewhat better after the irradiation. We believe that this is due to more hardening of the epoxies in time. The viscosities of the epoxies just after mixing the two components are given in Fig. 5. We are convinced that these selected epoxies will provide plenty of strength for gluing flip-chip bump bonded pixel chips to the beryllium substrates.

Some tantalum capacitors were exposed to fluence of 2×10^{14} 63 MeV protons at the UC-Davis cyclotron. The value of the capacitors and the breakdown voltages were not measurably altered at this radiation level.

3. Conclusions

We are convinced that the cooling fluid, epoxies and capacitors will survive at the LHC luminosities of the CMS pixel system. We plan doing further test of the pixel-mounted units under realistic conditions.

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[2] Fitzsimmons and Associates Inc., West Chicago, IL.