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Aging tests of full scale CMS muon cathode strip chambers

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Abstract

Two CMS production Cathode Strip Chambers were tested for aging effects in the high radiation environment at the Gamma Irradiation Facility at CERN. The chambers were irradiated over a large area: in total, about 2.1 m^2 or 700 m of wire in each chamber. The 40%Ar+50%CO_2+10%CF_4 gas mixture was provided by an open-loop gas system for one of the chambers and by closed-loop recirculating gas system for the other. After accumulating 0.3-0.4 C per centimeter of a wire, which is equivalent to operation during about 30-50 years at the peak LHC luminosity, no significant changes in gas gain, chamber efficiency, and wire signal noise were observed for either of the two chambers. The only consistent signs of aging were a small increase in dark current from ~2 nA to ~10 nA per plane of 600 wires and a decrease of strip-to-strip resistance from 1000 GΩ to 10-100 GΩ. Disassembly of the chambers revealed deposits on the cathode planes, while the anode wires remained fairly clean.

Keywords: aging, cathode strip chamber, radiation, CMS

Introduction

The CMS Endcap Muon system [1] consists of 540 six-plane cathode strip chambers of trapezoidal shape, the largest being about 3.4 m × 1.5 m in size. In total, there are about 2.5 millions wires and the overall area covered by the planes is around 6000 m^2. Strips, milled on the cathode panels, run radially in the endcap geometry and thus provide a precise measurement of the φ-coordinate. Wires are stretched across strips and define the radial coordinate of muon hits.

Chambers have to operate at high hit rates[1], reaching up to 400 Hz/cm^2 at the area closest to the beam line. In these conditions, they are to provide about 150 μm spatial resolution as well as correct bunch crossing identification with a probability of 92% or better in 25 ns time window between LHC bunch collisions.

Here we describe the results of aging tests with two CMS production chambers carried out at the Gamma Irradiation Facility [2] at CERN.

1. CMS Cathode Strip Chamber design

The chamber design is shown schematically in Fig.1 (see Ref. [1] for the detailed description). Since the choice of chamber materials exposed to the inner volume often define chamber susceptibility to aging in high rate environment, here we give exact references to vendors and materials used.

Seven trapezoidal panels form a CSC chamber with wire planes sandwiched between panels. The panels are made[2] of two 1.6 mm copper clad FR-4 (fire-retardant fiberglass epoxy) skins[3] glued onto a 12.7 mm polycarbonate core. The panels are the basis of the chamber mechanical structure. Strips and all other on-panel artwork are milled directly on the panels. The gap between strips is about 0.5 mm wide and about 0.2 mm deep.

Gap bars, made[4] of FR-4 material, are placed along panel perimeter and define the 9.5 mm cathode-cathode gaps. Each bar is bonded to its corresponding panel with 3M double-sided scotch tape and then a continuous epoxy glue[5] bead is applied along both the inner and outer seams. In addition, spacer bars[6] are installed (fastened with polycarbonate screws through a panel) every 60 cm along the chamber centerline to allow for an extra support for panels. This relaxes tolerances on panel flatness and helps prevent panel bulging due to gas over-pressure.

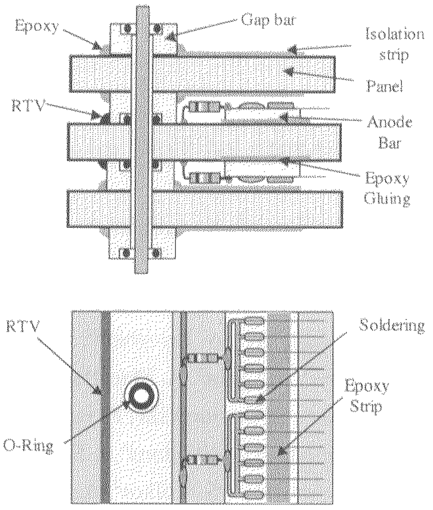

Fig. 1. CMS cathode strip chamber design

When the chamber is assembled and the bolts along its perimeter are tightened, a continuous bead of two-component RTV[7] is applied from the outside of the chamber along the newly formed seams between panels and gap bars, which provides gas-tight seal.

Anode bars[8], having a thickness of half of the cathode-cathode gap bar, are glued to the panels with the same epoxy used for gap bars. Gold plated tungsten wires of 50 μm in diameter[9] are first glued with another epoxy[10] and then soldered[11] to the anode bars. Wire spacing is about 3.2 mm. Each wire plane is split by the above mentioned spacer bars into 3 to 5 segments. A few wires are pulled out between segments and 200 μm gold plated Cu-Be guard wires[12] are placed to make the first and the last wire of each segment. This allows one to apply independent high voltages on each of the segments. Positive high voltage is brought to wire groups via

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[1] Mostly induced by background of 0.1-10 MeV gammas.

[2] PLASCORE INC., 615 N Fairview St., Zeeland, MI 49464

[3] GE ELECTROMATERIALS, 1350 S 2nd St. Coshocton, OH 43812. Copper clad FR-4 sheets of 1.5m x 3.6m.

[4] EPTAM, 25-T Waterford Place, Gilford, NH 03244

[5] 3M ADHESIVE DIVISION, 3M Center, Building 220-7E-05, St. Paul, MN 55144. Epoxy type 2216 A/B (two part room temperature curing epoxy with high peel and sheer strengths).

[6] Also made of FR4 material by EPTAM.

[7] GE SILICONES, Waterford, NY, 12188. Sealant type RTV41/RTV9811 (two part silicone rubber adhesive sealant)

[8] ADVANCE ELECTRONICS INC., 721 Winston St., West Chicago, IL 60185. Copper clad FR4 material with artwork etched using standard PC board technology.

[9] LUMA METAL USA, 672 Greenscape Ln Colorado Springs, CO 80916. Wire type 821/60

[10] WESTERN FIBERGLASS INC., 1555 Copperglass PKWY Santa Rosa, CA 95403. Epoxy type 5313 A/B (two part room temperature epoxy adhesive).

[11] SEIKA MACHINERY INC., 3528 Torance Boulevard, Ste. 100, Torrance, CA 90503. ALMIT KR-19 SH RMA flux cored wire solder (new product developed for soldering with no subsequent cleaning required).

[12] LITTLE FALLS ALLOYS INC., 189 Caldwell Av Paterson, NJ 07501. Wire type C17200/17300.

½ W 1.0 and 4.7 MΩ carbon-composition resistors[13], while the signals are read out from the other side via 1 nF 7.5 kV ceramic capacitors[14].

Long and thin (0.5 mm) FR-4 isolation strips are glued[15] to the panels to protect resistors, capacitors and wire soldering joints from being exposed to the ground (metal surface).

A stainless steel inlet tube is inserted in the top gap bar while a similar outlet tube is placed symmetrically in the bottom bar. Gas flows through all six gaps in series in a zigzag manner through special holes made in the panels.

2. Experimental setup

The aging tests were carried out using the 740 GBq radioactive ^{137}Cs source (0.662 MeV gammas) at the Gamma Irradiation Facility [2] at CERN. The source can irradiate large area detectors with uniform flux rate. The hit rate observed in our chambers during irradiation was about 20 kHz/cm^2, i.e. about 50 times larger than that expected at LHC. Two production ME1/2-type chambers of 0.8 m × 1.8 m in size and gas volume of about 75 liters were used in these studies.

Each chamber was irradiated for about 5 months, the first one in 2000 and the second one in 2001. The major difference between the two rounds of tests was in the arrangement of gas flow. The 2000 tests were done with gas mixture flushing through the chamber and directly to the exhaust, while the 2001 studies were done with a prototype of a closed-loop gas system, where 95% of the gas coming out of the chamber gas outlet was mixed with 5% of fresh gas and diverted back to the chamber inlet. The gas mixture[16] used in both tests was 40%Ar + 50%CO_2 + 10%CF_4. The purity of the primary gas components in the tests of 2000 was as follows: Ar (99.998%), CO_2 (99.998), CF_4 (99.995). In 2001, about 2/3 of all irradiation was done with the same gas quality to see whether recycling of the gas would have a dramatic impact on the chamber aging susceptibility. During the remaining 1/3 the quality of Ar and CO_2 was degraded to 99.996 and 99.990 correspondingly to check whether this change would make a difference. The gas flows were 1 chamber volume per day in 2000 and 4 chamber volumes per day in 2001 (4 V_0/day is nominal for these chambers at CMS).

The prototype of the closed-loop gas system contained the same materials as those to be used in the final gas system being built for the CMS cathode strip chambers. Two copper pipes[17] (10 and 14 mm inner diameter, each being 50 m in length) connected the gas system with the chamber inlet and outlet. These pipes were cleaned according to the standard CERN procedure[18] to be used during construction of the CMS gas system. The piping of the gas system rack itself was made of stainless steel tubes. The prototype also included a purifier cartridge[19] filled with activated nickel, nickel oxide, and aluminum oxide to remove water vapor and oxygen. The bubblers filled with vacuum oil were used at the exhaust line and other various points for overpressure protection.

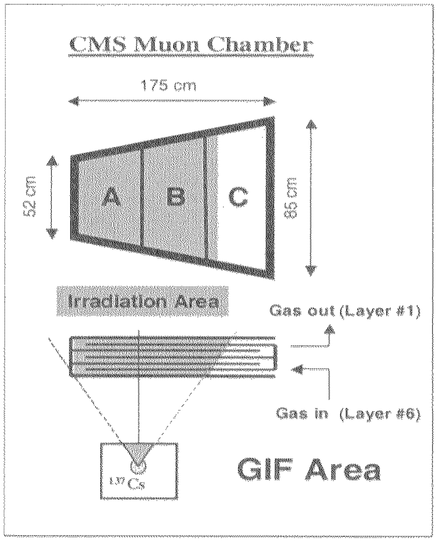

Fig. 2. Schematic diagram of the experimental setup for the aging tests. Two thirds of a chamber were irradiated using the 740 GBq ^{137}Cs source of the Gamma Irradiation Facility at CERN.

The chambers were placed at a short distance from the source (Fig. 2) so that about two thirds of the chamber area were irradiated during the tests. Four chamber planes (2, 3, 4, 5) were under sustained photon beam irradiation. In total, about 2.1 m^2 of area, or 700 m of wire length were irradiated. The two outer planes (1 and 6) served as a reference: during irradiation, high voltage for these planes was turned off. The anode wire planes of the ME1/2-type chambers are divided into three independent HV segments (A, B, and C).

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[13] NEWARK ELECTRONICS, 4801 N. Ravenswood, Chicago, IL 60640. Type: RC1/2G105JT, RC1/2G475JT,

[14] MURATA ELECTRONICS NORTH AMERICA, 2200-T Lake Park Dr., Smyrna, GA 30080. Type: DHR15Y5P102M 7.5KV

[15] Same glue as used for gap bars and anode fixation bars.

[16] Gas mixture was prepared by CARBOGAS, Switzerland.

[17] Round copper tube. CERN Catalogue # 39.71.05.232.2

[18] Cleaning procedure: rinsing with hydrochloric acid, soap. washing, rinsing with demineralised water and then with alcohol, flushing with dry air and pumping.

[19] LEUNA-WERKE AG, GB Katalyzatoren, O-4220 Leuna, Germany. Type: Leuna-Catalyst 6525

3. Results

While irradiating (usually one-day long runs), the monitored parameters were: 1) anode current and 2) counting rate of anode wire signals.

During the breaks between the irradiation runs the following chamber parameters were measured: 1) dark current from cathode strip planes with a high sensitivity Keithly pico-ammeter, 2) anode wire signal noise, 3) efficiency plateau for cosmic ray muons, and 4) strip-to-strip resistance.

The experimental environment (atmospheric pressure, temperature, and humidity) was recorded as well.

The nominal operational point for CMS chambers is 3.6 kV, which corresponds to 7×10^4 gas gain, or about 1 pC total charge released in an avalanche per minimum ionizing particle. The major source of background hits was Compton electrons. It was shown in earlier tests at GIF that signals due to Compton electrons tend to make signals on average 4 times larger than those produced by minimum ionizing particles. At the full LHC luminosity with the expected hit rates up to 400 Hz/cm^2 (130 Hz/cm), one expects to integrate of the order of 0.08 C/cm of charge per unit of wire length in about 10 LHC years (assuming that average integrated luminosity per year is about one half of the LHC peak luminosity).

Fig.3 shows the accumulated charge per unit of wire length in the tests of 2001. One can see that the four planes that were exposed to irradiation accumulated a total charge of the order of 35-55 LHC years.

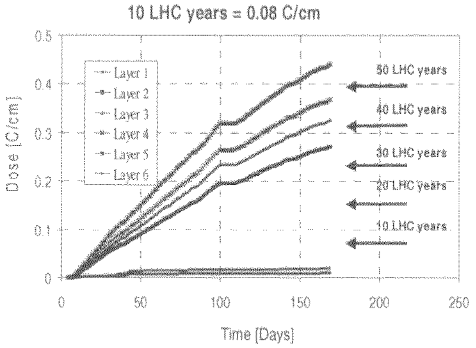

Fig. 3. Accumulation of charge per cm of wire during the half-year test period. Collected charge of 0.08 C/cm is equivalent to 10 LHC years run time. The two outermost layers (#1 and #6) were used as reference layers (they had no HV during radiation runs).

Fig.4 illustrates how current measurements in combination with a high rate source allow one to measure the chamber gas gain. At low high voltage all one sees is a flat ionization current I_0. With the onset of avalanche process, the current I(HV) grows exponentially with high voltage. The gas gain can be easily evaluated at any high voltage point as $G=I(HV)/I_0$. During irradiation, the high voltage on the four inner planes was set at 3.7 kV, which corresponded to $G=10^5$. From fig.4, one can see that, despite of the somewhat increased gas gain and very high irradiation rates, no significant space charge effects were observed.

The gas gain versus high voltage was measured a few times at the same GIF conditions and remained unchanged throughout the test period for both 2000 and 2001 year tests. Fig.5 illustrates this result for the tests done in 2000.

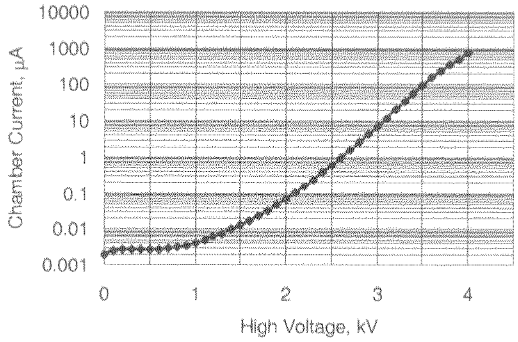

Fig. 4. Chamber current from cathode strips vs. high voltage.

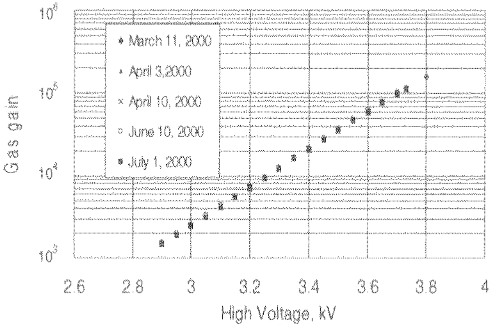

Fig. 5. Gas gain as a function of high voltage at different dates during 6 months of irradiation.

Another more commonly used way of monitoring gas gain changes is to compare gas gain in irradiated planes to that in a reference not irradiated plane. Since we had two reference planes, we defined $I_{ref}=(I_1+I_6)/2$ and plotted I_i/I_{ref} for four irradiated planes—see fig.6 for the chamber aged in 2001. No gas gain deterioration was observed.

Efficiency plateau measurements made with scintillating counters triggered on cosmic ray muons did not show any systematic changes either.

Anode wire count noise for our chambers is dominated by hits due to natural radioactivity of materials used and cosmic rays. At a threshold of ~15% of the average m.i.p. signal, the rate is about 10 Hz per anode wire group (~120 cm^2). Fig.7 shows that this "dark" noise hardly changed after the entire period of irradiation of the 2000 tests. The 2001 year results were practically identical.

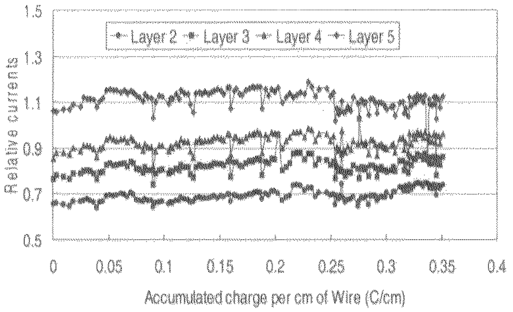

Fig. 6. Relative currents normalized on average of the 1st and 6th non-irradiated planes, [I_1+I_6]/2, vs. accumulated charge.

Dark current is yet another measure of chamber performance stability. Fig.8 shows results obtained in 2000. One can see that dark currents did grow on average from ~2 nA per plane (about 600 wires) to around 10 nA (one of the aged planes did not change its dark current, while the largest increase was about 60 nA). In the 2001 tests the results were very similar, with all currents for six planes scattered between 1 and 10 nA at the end of the tests.

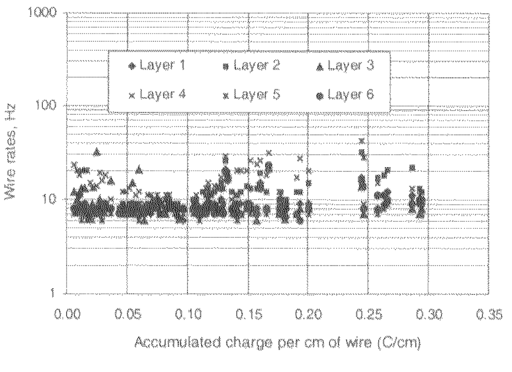

Fig. 7. The variation of the average wire noise count per wire group (120 cm^2) vs. accumulated charge

The last monitored parameter was the resistance between strips: it was evaluated by measuring current between strips at difference potentials of 9 V. Fig. 9 shows an obvious systematic drop in resistance over the course of irradiation from ~1000 GΩ to as low as 10-100 GΩ for the worst planes. Still, this level of resistance is far too large to affect the strip readout. In fact, the strips are normally grounded via 1 MΩ resistors so that they are not left floating when the strip electronics is not connected (these 1 MΩ resistors had to be removed on these two chambers to allow for the strip-to-strip resistance measurements).

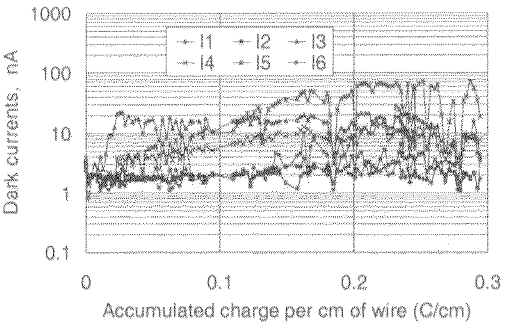

Fig. 8. The dark current vs. accumulated charge

The facts that gas gain remained unchanged and strip-to-strip resistance decreased hinted that the polymerization deposits must have been formed on the cathode surface and not on the anode wires.

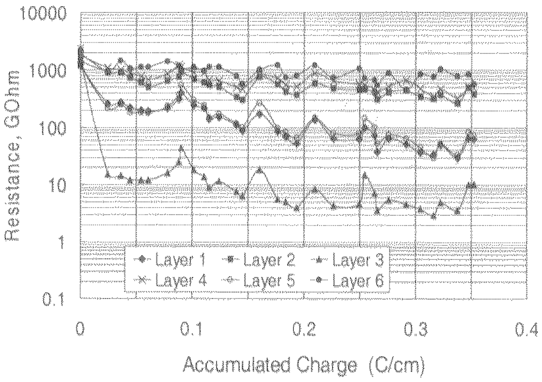

Fig. 9. Resistance between cathode strips vs. accumulated charge

Comparison of the results from 2000 (open-loop gas system) and 2001 (closed-loop gas system) showed no changes in the aging pattern. Also, as was mentioned section 2, the last third of the 2001 run was conducted with a gas of less strict specifications on purity. Again, we did not observe any significant changes that could be attributed to the switch of the gas.

4. Gas analysis

During the tests with the closed-loop gas system, we attempted to measure the possible accumulation of impurities. The gas chromatographic analysis with ~200 ppm sensitivity showed no signs of any contamination. Dedicated high sensitivity O_2 and H_2O sensors showed that oxygen was present at the level of 140 ppm and water at the level of about 10 ppm. Note that the closed-loop gas system had a Ni-based purifier column designed to remove oxygen and water. These measurements were done at the point upstream from the purifier (i.e., for gas as it comes out from a chamber).

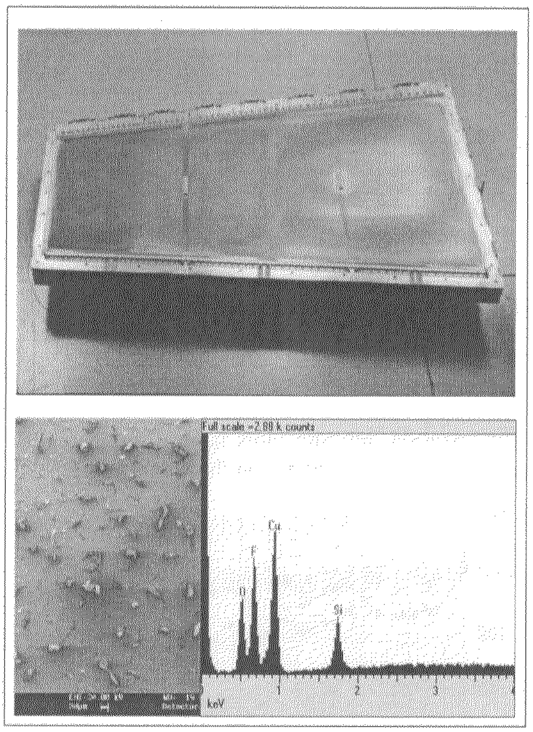

Fig. 10. Top: deposits on a cathode plane. Bottom left: magnified view of deposits as seen with the help of an electron-scanning microscope. Bottom right: element composition of cathode plane residue.

5. Deposits

Disassembling the chamber confirmed these expectations. Indeed, whitish[20] deposits were found on the cathode surfaces spreading far beyond the irradiated area (fig.10). The last plane along the gas flow stream (remember that this plane had HV turned off during irradiation) also had some of the residue. Analysis of deposits revealed presence of O, F, and Si. Analysis of wires showed that they stayed fairly clean with only sporadic blots of polymers of similar composition (fig.11).

6. Summary

Two chambers operating at a gas gain of 10^5 with an $Ar/CO_2/CF_4$=40/50/10 gas mixture were irradiated over an extended time of a few months and over a large area (~2.1 m^2 or 700 m of anode wire per chamber) with the total accumulated charge per unit of wire length of about 0.3-0.4 C/cm. This dose should correspond to 40-50 LHC years for the CMS endcap muon system, the system these chambers are intended for. One chamber operated with an open-loop gas system (gas flushed through the chamber and directly to the exhaust). The other one operated with a prototype of the closed-loop gas system providing, in each cycle of full chamber gas volume exchange, only about 5% of fresh gas. Both experiments, with and without recirculation, did not show any significant chamber performance deterioration. The closely monitored parameters were gas gain, anode wire noise count, dark current, and resistance between cathode strips. The gas gain remained constant within ±10% accuracy. The anode wire signal noise hardly changed from its original rate of ~0.1 Hz/cm^2. The dark current increased from ~2 nA to typically less than ~10 nA per wire plane of 600 wires. The strip-to-strip resistance changed from 1000 GΩ to around 10-100 GΩ.

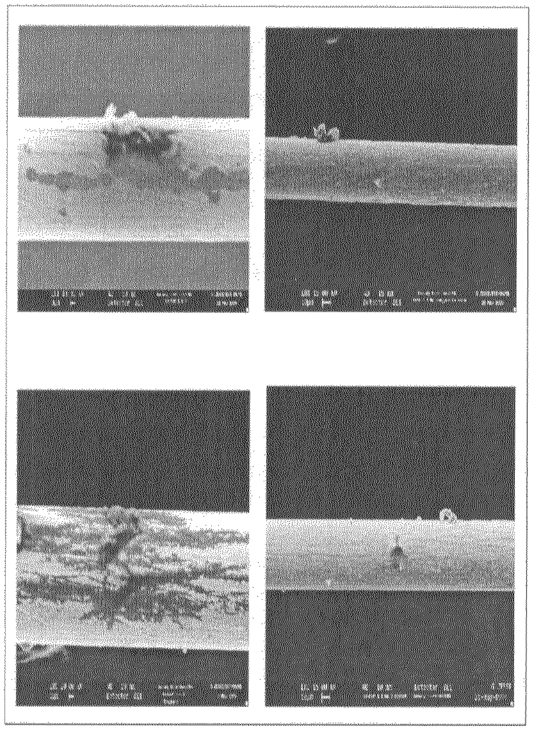

Fig. 11. Anode wires as seen with the help of an electron-scanning microscope

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[20] It is interesting to note that, after a few days of being exposed to air, the residue became very dark.

Summarizing, the performed tests indicate that the CMS endcap muon cathode strip chambers should be able to operate in the LHC environment without appreciable aging effects.

References

[1] The CMS Collaboration, CMS Muon Technical Design Report, CERN/LHC 97-32, 15 December 1997

[2] S.Agosteo et al., Nucl. Instr. and Meth. A 452 (2000) 94