Restoring contaminated wires, removing gas contaminants, and aging studies of drift tube chambers

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Abstract

The original muon detection system of the Fermilab D0 colliding beam experiment contained 12,000 drift cells 10 cm by 5 cm in cross section and up to 580 cm in length. The gas mixture used was Ar/CF_4/CO_2 (90:6:4). There was one recycling gas system for all the chambers. During the first year of operation, it was discovered that inefficient cells, all in regions of high radiation, had a contaminating shell of crud coating their wires. The source of the contaminant was outgassing of the cathode pads, which were made from a laminate of fiberglass and epoxy/polyester resin, with a copper cladding on one surface. The vapor formed a brittle sheath on the wires, but only in regions of high current discharge due to radiation from the accelerator and colliding beams. A method for cleaning wires in place was devised. By heating the wire quickly to a temperature close to the melting temperature of gold, the sheath was ripped to shreds and blown away. The procedure for "zapping" wires and for removing the contaminating vapor is presented. The upgraded D0 experiment now uses Iarocci-type mini-drift tubes for the forward muon system. The results of aging tests for these chambers are also presented.

Keywords: Aging effects; contamination; drift chambers; gaseous detectors

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1. The Gaseous Muon Detectors

The Fermilab D0 experiment is a large, general-purpose collider detector. The D0 detector is described in detail in Ref. [1]. It consists of three systems: tracking, calorimetry and muon detection. The central muon detection system (WAMUS) is made of a set of proportional drift tube (PDT) chambers which surround large magnetized iron toroids. All of the WAMUS PDT chambers are made of the same 10 cm by 5 cm aluminum tubes, but vary from 330 cm to 580 cm in length. Each drift cell has top and bottom cathode pads, which are made of either G-10 (25%) or Glasteel (polyester and epoxy based plastic sheets with a glass fiber mat) (75%). Only the cathode surface has copper cladding. The aluminum tube is grounded while the potentials of the sense wire and pads are kept at +4.6 and +2.3 kV, respectively. The gas mixture was Argon/CF_4/CO_2 (90:6:4) during the first run, but was changed to Argon/CF_4/CH_4 (84:8:8) for the upgraded detector in Run 2, because a faster drift velocity was required. The gas gain for the PDT's is $2 \cdot 10^4$. All PDT's share a recycling gas system. The Run 1 Forward muon-tracking detector (FAMUS) consisted of 3 cm diameter stainless steel tubes with a 50 micron W-Au anode wire in the center. Because of the higher occupancy rates expected in Run 2, the upgraded FAMUS detector now consists of three layers of Iarocci-type mini-drift tubes (MDT's) covering large toroid magnets. Each tube has eight 1 cm by 1 cm cells up to 583 cm in length, with a 50 micron W-Au anode wire in the center. The tubes are made from aluminum extrusion combs with stainless steel cover foil and inserted into plastic (PVC) sleeves. The anode wire is grounded at the amplifier while the cathode potential is –2.3 kV. The fast gas mixture is CF_4/CH_4 (90:10), unchanged from the first run. The

gas gain for the MDT's is $2 \cdot 10^5$. The MDT's also have their own recycling system.

2. The Contamination

Although most of the hadrons and electrons are filtered out by the calorimeters before they reach the muon system, at small forward angles the background particle flux is rather high. Another large source of radiation during the first run was from the main ring accelerator, which passed, with very little shielding, right through the detector. During the first year of running we realized that the WAMUS drift cells in regions of high level radiation were becoming very inefficient. We extracted and replaced several wires that were in these regions. The bad news was that the exposed wires were covered with a thick brittle sheath of crud. The good news was that the walls and pads of the drift cells were not damaged.

3. Contamination Properties

We performed some tests and discovered a number of crud facts and attributes:

- The crud scraped off easily, and dissolved in ammonia and in water.

- The source of the crud was from the Glasteel of the cathode pad. The crud can be created quickly by flowing gas through Glasteel ground up into a powder and then into a test cell operating at a current of 0.4 μA per cm of wire. The test cell had the same geometry as the PDT's. Crud formation was not dependent upon the percentage of Freon in the operating gas mixture of $Ar/CF_4/CO_2$. It formed easily in an Ar/CO_2 (80:20) mixture, as well.

- The crud could be removed under the same conditions in which it was formed, by increasing the cell voltage to create currents of 4 μA per cm of wire, but this process took several days and was not a practical way to clean thousands of 500 cm or longer wires.

A sample of the wire and crud was given to Argonne National Laboratory's chemical physics lab. The Argonne lab analysis seemed to confirm our results, identifying the crud as being similar to CASCAMITE 14, a powdered resin glue, which uses styrene in the curing process. We have been able to produce the same contaminant on the wire of our test chamber by replacing the ground up Glasteel with liquid styrene.

4. "Zap" Cleaning

We made several attempts at renewing dirty wires inside drift cells, using water and ammonia in liquid form (not ammonia gas), but only succeeded in forming an insulating layer of aluminum oxide on the cell walls and copper oxide on the pad surfaces.

In our attempt to exploit the high current cleaning effect, however, we discovered that if the wire was heated quickly to a temperature close to the melting point of gold, the sheath of crud would shatter and be blown away! Investigating further, we found some other properties of this "zapping" procedure:

- If the heating was too slow, the crud cooked into a black, insoluble coating that was very hard to remove.

- If the temperature was too high, the gold melted and beaded up (later tests showed that the drift cells still worked if the gold was beaded up, or even completely removed from the tungsten wire).

- At the correct zapping speed and temperature, the gold might change its color (wires from different venders gave different zapped wire color). Green, orange and white tints have been seen.

- The zapping did not appear to harm the wire. One wire in our test chamber has been zapped over 100 times as a test. The signals from that zapped cell did not change, and the wire is still intact after 6 years have passed.

The procedure for zapping is illustrated in Fig. 1. One end of a cell sense wire is grounded to the chamber. A 1.5 microfarad capacitor is charged to between 3500 volts for a 190 cm long chamber and 6300 volts for a 580 cm chamber (this corresponds to a very lethal stored energy of 9.5 to 31 Joules). The zapping probe is then touched to the other end of the grounded sense wire and a switch is closed. The capacitor discharges through the wire in less than 2 milliseconds. The signals from the zapped wires are as good as newly replaced wires. Furthermore, the zapped crud does not return to the vapor phase and does not affect the detector performance. During a two-week shutdown we were able to clean over 5000 wires using this "zapping" procedure.

4. Crud Prevention

Because the muon system uses re-circulated gas, adding a few percent of new gas per cycle to make up for losses, the procedure was concentrating the contaminating vapors. We discovered two ways to trap out the evil vapor. During our first physics run, a cold trap operating slightly above the freezing temperature of CO_2 (Argon and CF_4 have even lower temperatures of liquefaction) was added to the gas re-circulation system, and reduced the aging rate by a factor of ten. For the present run we are simply using a large (300 lb.) activated charcoal filter. It has removed the contaminants without changing the gas mixture ratio.

5. Aging Studies

The FAMUS MDT detectors have replaced the forward WAMUS PDT's, which would not have survived the present run, which will reach an integrated luminosity of two inverse femtobarns. Aging tests of MDT's have been performed at Dubna, where the tubes were built. Several detectors made in the style finally used in the D0 detector were illuminated by a ^{90}Sr source.
A comparison was done between the irradiated MDT and a non-irradiated MDT, using the signals from a ^{55}Fe source. All studies were performed with the CF_4/CH_4 (90:10) mixture. No deterioration in the detector performance was seen with an accumulated charge up to 5 C/cm. The estimated charge accumulated on the anode wires during Run II is about 0.02 C/cm. These studies demonstrate that the MDT's can operate for many years at the expected Tevatron luminosity without aging.

References

[1] D0 Collaboration, S. Abachi et al., Nucl. Instr. Meth. A 338 (1994) 185.