Analysis of the MDC-II Feedthroughs

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Abstract

The poor performance of the BES MDC II has been traced to the feedthroughs. While every effort was made to produce high-quality parts by constant inspection and testing, the change of a mold parameter by the injection molding company produced an unseen fault in the feedthroughs. This fault did not manifest itself until after the feedthroughs had been installed and the chamber operated for several months.

1. Introduction

The problems in the MDC-II have been traced to the feedthroughs. Investigations have concentrated on the magnitude of the problem, what is causing it, and possible fixes. Other talks at this meeting discuss the first and third of these; this talk will concentrate on what is causing the problem.

The root cause is that the Delrin^{TM} that the feedthroughs were molded from was not handled properly during the injection molding process. Material choice for the MDC-II feedthroughs was driven by cost, ease of production, ability to hold the required mechanical tolerances, and electrical characteristics. Delrin^{TM} fulfilled all these requirements, as evidenced by its successful application in previous experiments (Mark III, HRS, and BES-I for example). After consultation with IHEP about candidate materials, injection molded Delrin^{TM} was chosen since that would allow the feedthroughs to be produced most economically. Delrin^{TM} is produced in its raw, pelletized form by DuPont. The grade of Delrin^{TM} chosen was 500P, a moderate viscosity thermoplastic with good injection molding characteristics. However, in an effort to produce feedthroughs within specified mechanical tolerances, the mold temperature was reduced below DuPont's recommendation. At the time the feedthroughs were molded, it was not known that this would cause problems later. Initially, the feedthroughs were mechanically and electrically satisfactory. The low molding temperature produced a hidden fault that did not manifest itself until many months after they were produced. Furthermore, this problem doesn't show up until after the feedthroughs have been on high voltage for a period of several weeks.

2. Production of the feedthroughs

The feedthroughs were produced in Ft. Collins during summer 1994. They were made by a local molding company that had been recommended by physicists at the University of

Colorado. Their recommendation was based on successful parts the company produced for prototype SSC intermediate tracking chambers. Several dozen prototype feedthroughs were produced and sent to IHEP for inspection and testing. Only after approval was received from IHEP did production of feedthroughs for MDC-II begin.

The feedthroughs were delivered to CSU where they were cleaned in an unheated ultrasound bath using ethanol and dried in room temperature air. Samples from the beginning and end of each molding run were examined for dimensional stability (about 4% of the feedthroughs were examined). Because of the well-known problem of voids in molded Delrin, the feedthroughs were visually inspected very carefully Many of them were cut open to look for voids, which were not found. A machined Delrin$^{\mathrm{TM}}$ insert was placed in each feedthrough to position the wire. The inserts were cleaned using the same procedure as the feedthroughs. Excess plastic was removed during inspection, and each insert was required to have a clean hole of the appropriate diameter. Concentricity measurements of the insert inner diameter to the feedthrough outer diameter were made for the 4% of the feedthroughs we inspected. A small sample of the feedthroughs was placed on high voltage for several days and no current draw was seen. The feedthroughs were bagged and shipped to IHEP in September 1994.

3. High Voltage Tests

A few months after MDC-II was commissioned, the outer layers began drawing high amounts of dark current and the chamber became exceptionally noisy in specific areas of the detector. The high voltage distribution system was suspected as a cause of the former problem, and shower counter crates as a cause of the latter. Both were worked on, and the situation improved initially. However, the performance of MDC-II continued to degrade, and the feedthroughs were now considered suspect. BES collaborators at IHEP placed about 100 unused feedthroughs in an MDC-II prototype with solder pins and applied -4 kV to the pins. The current in the prototype began to rise after 21 days, reaching 80 microamps 16 days after that. Several of the feedthroughs sparked through the Delrin$^{\mathrm{TM}}$ wall.

After CSU learned of the potential problem with the feedthroughs from IHEP, another test was immediately set up using overproduction feedthroughs that never left CSU. These feedthroughs had been cleaned and handled in the same manner as those sent to IHEP, and had been stored in a sealed plastic bag. The results were qualitatively the same as from the IHEP test, but the maximum current was only about 10 microamp total. One of the feedthroughs sparked through the Delrin wall. The current in the CSU test seems to depend strongly on humidity (Figure). The differences in the amount of current drawn at IHEP and CSU is probably due to environmental factors, such as temperature and humidity.

4. Analysis by DuPont

Several feedthroughs were sent to DuPont, who agreed to examine them. Two used feedthroughs from IHEP, two unused feedthroughs from IHEP, and two unused feedthroughs from CSU were sent. DuPont made thin sections ($\approx 15 - 20\mu$m thick) and examined them under a polarized-light microscope, which allowed the crystal structure of the Delrin was examined. What they observed was poor development of Delrin$^{\mathrm{TM}}$ crystals (spherulites) in the interior of the feedthrough walls, and a thick ($\approx 100 - 200\mu$m) skin layer (Figure 2). According to their analysis, either the mold temperature was too cold, or the temperature

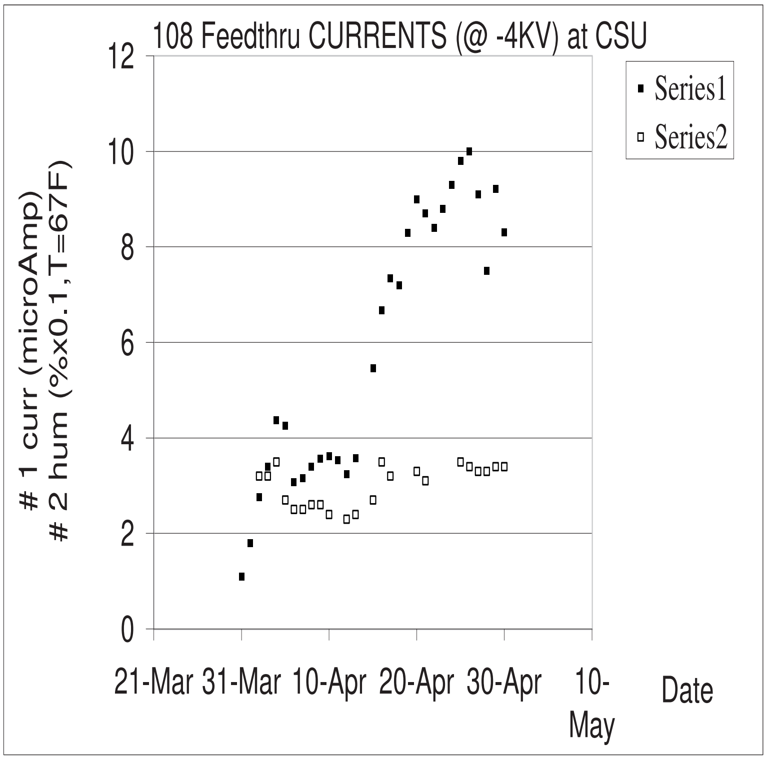

Figure 1: Total current draw from 108 unused MDC-II feedthroughs measured at CSU (filled squares). Also plotted is the relative humidity (open squares). Changes in current draw track fairly well with changes in humidity.

of the molten Delrin^{TM} was too low when the feedthroughs were made. CSU has since developed the capability to reproduce DuPont's analysis, and confirmed their findings.

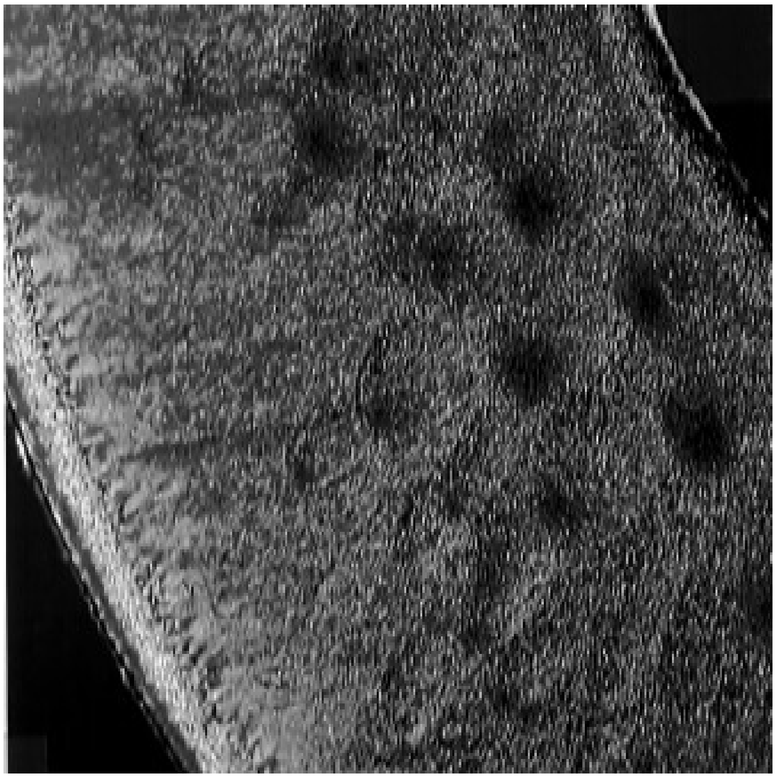

Figure 2: Thin section micrograph of an MDC-II feedthrough taken by DuPont. The inner wall of the feedthrough is in the upper right-hand corner of the picture and the outer wall is in the lower left-hand corner. The thick skin and poorly developed spherulites are indicative of a mold temperature that was below recommended.

The conclusion that the mold was too cold has been confirmed by the molder. Because the feedthroughs are long thin parts with straight sides, they would not release from the mold when molded at the proper temperature. In order to get the feedthroughs out of the mold, the molder reduced the temperature of the mold below the DuPont recommended range. This resulted in the Delrin^{TM} failing to crystallize properly at the surface of the feedthroughs. The molder claims no knowledge of ill effects caused by varying temperatures in the molding process. Indeed, adjustment of molding parameters is an industry-wide practice, used to compensate for invariable differences in plastics, injection molding machines, molds, and ambient environmental conditions.

Post-mold shrinkage over a period of hours or days of injection-molded plastics is an unavoidable consequence of this manufacturing process. Mold cavity dimensions are deliberately over-sized to compensate for this. However, as a result of the improper crystallization, the Delrin^{TM} continued to shrink over a long term, possibly months. This continued shrinkage lead to a buildup of stress in the plastic. The small (micron sized) cracks on the surfaces of the feedthroughs are probably a response to this stress.

5. Visual Inspection

Two small groups of MDC-II feedthroughs were sent back to CSU from IHEP. One group was unused, and the other was used in the prototype test. Following a discussion with DuPont where it was learned that injection molding Delrin^{TM} produces a skin on the molded part, we decided to examine the surfaces of the returned feedthroughs. For this examination we used a scanning electron microscope (SEM). Examination of feedthroughs returned from IHEP and feedthroughs that never left CSU show two distinct features: cracks and pits.

Common to all feedthroughs are very small cracks on the inner and outer surfaces. These cracks are in general less than one micron wide, and their distribution is not uniform. There are relatively large areas that show no surface cracking. The used feedthroughs from IHEP have these small cracks, as well as relatively large cracks, 10 microns or more wide. Used feedthroughs from CSU do not show these large cracks, with one exception: there are large cracks near the puncture in the CSU feedthrough that sparked, indicating that the release of energy into the plastic by an electrical discharge of less than 4 kV is sufficient to damage the plastic.

Pits on the inner surface, 10 microns or more in diameter, are common to used feedthroughs from both IHEP and CSU. Pits have not been found on an unused feedthrough.

6. Energy Dispersive Spectroscopy

The Energy Dispersive Spectroscopy (EDS) attachment on the SEM was used to do an elemental analysis on the surfaces of feedthroughs. When the electron beam of the SEM strikes the sample, characteristic x-rays are emitted. Because the non-conductive samples must be covered with a thin coating of gold to be visible in the SEM, gold is present in all x-ray spectra. The SEM raster can be stopped to examine a small ($\approx$ 1000 Å) spot on a sample. Once a spectrum is collected, it is compared to a library stored on computer disk for elemental identification. Because some x-ray lines overlap, elements may be hidden or confused with other elements. Sometimes a decision must be made based on what element is expected to be found.

In a spectrum taken on a crater on a feedthrough from the IHEP prototype, the most prominent peak is silicon, present in the RTV used to seal the feedthrough on the outer surface of the endplate. The silicon probably either diffused along the surface of the feedthrough, or else was scraped off the endplate when the feedthrough was removed. A spectrum taken on a small blob of material found on the same feedthrough shows aluminum or bromine is the most prominent peak. If this is aluminum, it was most likely scraped off the endplate when the feedthrough was installed or removed.

An axial cross-section of a used feedthrough from IHEP was made, exposing a deep crack on the surface. EDS spectra taken on the inside of the crack and on the cut surface of the Delrin^{TM} adjacent to the crack show aluminum or bromine and silicon contamination in the crack near the surface of the feedthrough, with the aluminum or bromine persisting deep into the crack. No contamination was found adjacent to the crack. These findings imply that the contaminating molecules were probably ionized by the micro- discharging and driven into the crack by the electric field. the impact of these ions may have accelerated the degradation of the plastic.

7. Conclusion

The BES MDC-II feedthroughs are failing and drawing current. These effects continue to get worse under longer exposure to high electric fields. CSU is continuing to investigate the mechanism for the feedthrough failure using a variety of techniques (SEM, polarized light microscopy, cryofracturing, surface chemical analysis) to avoid these problems in the future.