Mu2e ELECTROSTATIC SEPTA VOLUMETRIC EXCHANGE OF Fc-40 DIELECTRIC IN HIGH RADIATION ENVIRONMENTS*

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Abstract

Two electrostatic septa (ESS) are being designed for the slow extraction of 8 GeV proton beam for the Mu2e experiment at Fermilab. Special attention is given to the high voltage feedthrough (HVF), which energizes the cathode creating the bending field. The FC-40 dielectric fluid, surrounding the HV cable breaks down from radiation exposure, which reduces its insulating capabilities. The new HVF design focuses on effective replacement of the exposed fluid and eliminating the stagnant areas of low exchange rate. A preliminary test using a fully transparent prototype HVF and water was conducted to understand the volumetric exchange rate of the high radiation region. Here we discuss the results of these tests and further studies using the FC-40.

INTRODUCTION

Mu2e experiment requires 8 GeV proton beam to study rare neutrinoless decays of a muon to an electron. The delivery of 8 spills every 1.4 seconds with 1E12 protons per spill is provided by means of resonant slow extraction. Two ESS will be designed to facilitate the slow extraction. Each septum will have a cathode that is energized to a nominal voltage of 100 kV with a gap of 12 mm to achieve a 2 mrad total kick [1]. It is critical to provide stable voltage at 100 kV. Any drops in the voltage due to dielectric breakdown can affect the beam quality to the experiment. Dedicated studies show that FC-40 dielectric properties degrade in high radiation environments [2] [3] [4]. FC-40 is a branched, linear and cyclic perfluorinated hydrocarbons having carbon numbers in the range of C5-C18. 3M lists the hazardous decomposition byproducts such as hydrogen fluoride and Perfluoroisobutlylene (PFIB) both of which are very toxic gases [5]. These byproducts need to be flushed out and run through chemical filters to safely remove them from the system. It is imperative that the breakdown of the FC-40 in the HVF be mitigated by ensuring sufficient mixing within the volume.

ABSORBED DOSAGE OF THE HVF

A simplified version of the septum was used in a MARS simulation to understand the radiation exposure of the HVF at various locations across the septum [6]. It was determined that the peak dose is in the range of 1E7 Gy/yr near the leading part of septum. The dosage decreases towards the end of the septum as seen in Fig 1. Using JPARCs study on fluorine ion production via radiation exposure [4], 1E7 Gy/yr corresponds to approximately 5ppm/hr of potentially toxic gases forming in the HVF. Overtime, this gas can potentially displace the FC-40 and cause discharges in the HVF. Thereby creating more toxic byproducts. The hazardous level, according to the National Research Council (US) Subcommittee on Acute Exposure Guidelines Level, is 3 ppm of HF in air [7]. It becomes important to minimize this number as much as possible. Therefore, utilizing the MARS simulation data, the placement of the HVF was defined and placed downstream (132 cm) of the leading flange of the septum totaling 182 cm. Furthermore, the peak dose from the simulation is used to determine the necessary volumetric exchange of the FC-40 within the HVF.
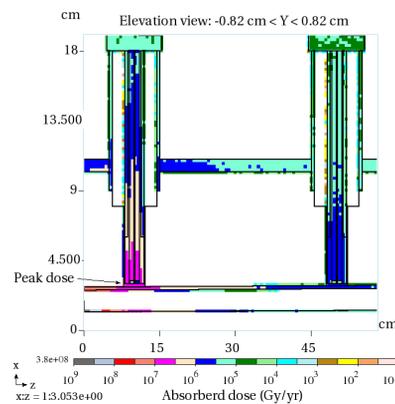
Figure 1: Radiation Absorbed Dose for the HVF.

HIGH VOLTAGE FEEDTHROUGH DESIGN
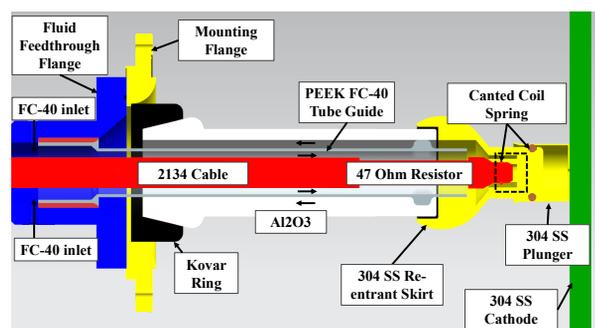
Figure 2: High Voltage Feedthrough Mechanical Details.

The HVF nominal voltage is 100 kV. Figure 2 shows the mechanical design of the HVF, which is composed of 304

stainless steel (yellow), kovar (black), PEEK (grey) and alumina Al203 (99.5 %) ceramic (white). A Dielectric Science 2134 cable (red) is used along with a 47 ohm resistor (red) to energize the cathode and dampen the effects of a spark. The purpose of this HVF is to bring HV to the cathode, while providing a vacuum seal and electrical isolation using FC-40. Electrostatic simulations have been done to minimize the chances of discharges within the dielectric to prevent generating toxic byproducts [8].

The FC-40 is injected into the fluid feedthrough flange (blue) at two inlets spaced 180 ° apart. It is guided using the peek FC-40 tube guide (grey) towards the cathode. The idea of channeling fluid to the forward area was suggested at CERN [2]. In our case it is very important to effectively continue this channeling of the fluid into the bottom of the 47 ohm resistor tip, sitting in the very narrow cup. This region, highlighted with a black rectangle in Fig. 2, will see the highest radiation exposure and the lowest flow rate. The 304 SS re-entrant skirt (yellow) has a cylindrical slotted design to allow for enhanced mixing just below the cable tip. It also provides sufficient electrical contact using a canted coil spring. The two fluid inlets to the HVF and the two outlets are placed in different planes, orthogonal to each other. The end of the peek tube channel is closed in the plane of outlets, thus creating the azimuthal pressure distribution favorable for effective mixing of the fluid into the resistor cup. The FC-40 then returns on the outside between the ceramic tube (white) and the PEEK tube and exits normal to the inlets on the fluid feedthrough flange (blue). It also allows for the passage of FC-40 on the return path. Finally, a comparable fully transparent prototype of the HVF was built and we performed preliminary tests using water as the working fluid.

EXPERIMENTAL SETUP

Water was initially chosen as the working fluid due to the availability of water soluble dyes. A transparent prototype (TP) was 3D printed (Fig. 3b) with the exact internal geometry of Fig. 2, which is represented by a simplified schematic in Fig. 3a. The inlet and outlet are mechanically normal and out of plane of each other, which is not shown in Fig. 3a. The source and collector of the StellarNet portable BLACK-Comet-SR spectrometer (190 nm-850 nm)is placed near the mechanical location of the cable tip [9]. This region is near the end of the 47 ohm resistor within the pocket of the 304 SS re-entrant skirt as seen in Fig. 2. The positioning of the spectrometer collector and source on the TP is best seen in Fig. 3b.

Figure 3a shows valves that are used to fill the system with water and the water soluble dye [10]. Before the measurements are taken, the system is first filled with water and the the fluid is recirculated using a pump. After recirculating the water at 1.9 LPM for 1 to 2 hrs, the dye is added to the reservoir and it is recirculated through the system. Once the solution is homogeneous, the necessary valves are open and closed to allow the reservoir to drain. After all the dye is

removed from the reservoir, the spectrometer and the pump are turned on. A 10Hz sample rate is specified in the software and the spectral intensity of light from the collector is measured within the range of 350 nm-846 nm.
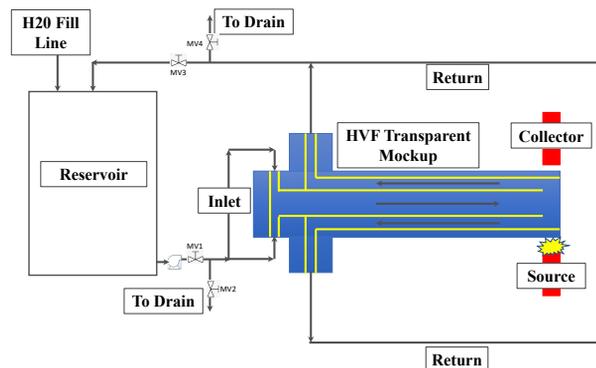
(a) Simplified Schematic of the HVF H20 Volume Exchange Test.
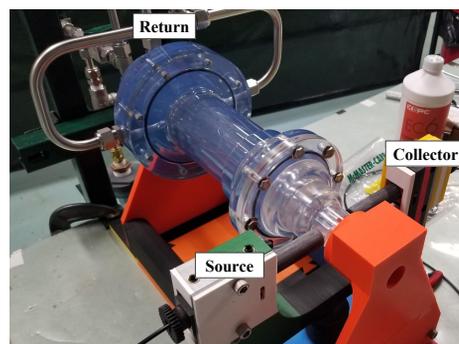
(b) Transparent Prototype.

Figure 3: Transparent Prototype Test Setup.

RESULTS AND DISCUSSION

The data was collected using the StellarNet spectrometer using the software provided [9]. The source emits lights in the visible spectrum 380 nm to 700 nm. The program was started at the same instant the pump was turned on. Figure 4a shows the the spectral intensity in the range of 350 nm-846 nm every 0.1 s for 15 s (10 Hz). The overall trend depicted in the measurement shows that most of the emitted light from the source is absorbed in the area of interest (Fig. 4a) by mostly the dye. Hence, the very low spectral intensity in the collector in the 380 nm-600 nm range. As time continues, the spectral intensity increases as a result of the red dye concentration decreasing over the 15 s window. The spectral transparency (ST) was calculated by taking the ratio of the collected light to emitted light $\frac{P_o}{P_e}$. Figure 4b illustrates the spectral transparency for all the samples over the 15 s window. This clearly shows that as the transparency nears 1 the dye concentration is decreasing.

The integrated transparency (IT) was calculated and is illustrated in Fig. 5. The spectral intensities were integrated over the full range of collected wavelengths (350 nm-846 nm) for each time period (0.1 s) to acquire the integrated

MC4: Hadron Accelerators

T12 Beam Injection/Extraction and Transport
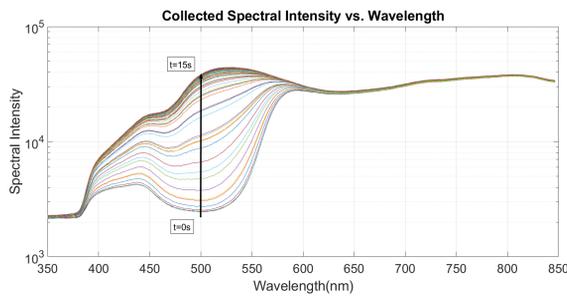
(a) Collected Spectral Intensity vs. Wavelength.
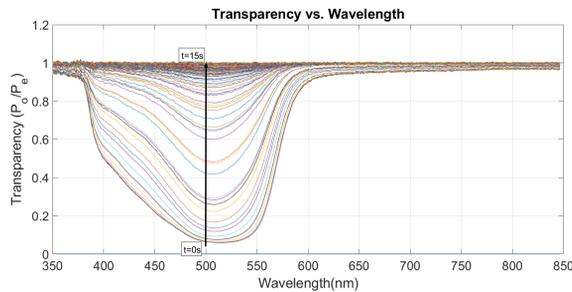
(b) Transparency vs. Wavelength.

Figure 4: Spectral Intensity and Transparency of the Transparent Prototype versus Wavelength (350 nm-846 nm).
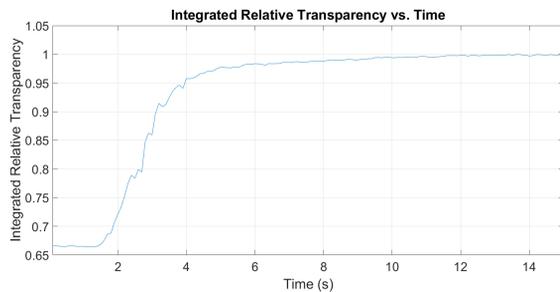
Figure 5: Integrated Transparency vs. Time.

power K_o. The maximum integrated power was determined K_{max} and used to calculate a relative transparency $\frac{K_o}{K_{max}}$. In Fig. 5, the dye concentration decreases, the fluid becomes more transparent and the IT reaches a maximum (99.9 %) after 12 s of pumping at 1.9 LPM. The time delay in the first 1.4 s is the result of the delay in mixing to lower the concentration of the dye as the clear water traverses the system to the affected region. Additionally, between 1.4 s and 6 s, there are subtle fluctuations in the IT. These are likely a result of the swirling of the homogeneous dyed fluid with the clear water which affected the transparency of the region over time. The total time it takes to mix the volume begins at 1.4 s and ends at 12 s for a total time of 10.6 s. An exchange rate of the volume is calculated and is estimated to be 20 $\frac{exchanges}{minute}$. Furthermore, dividing the flow rate of the system by the number of exchanges per minute, yields 10 $\frac{exchanges}{Liter}$ of clear water to dilute the concentration of the dye to zero. This number is indicative to the efficiency at which the dye is flushed out of the volume given an incoming fluid.

CONCLUSION

In general, the measured spectral intensities clearly show the concentration becomes less in the region (Fig. 4a). Furthermore, the region becomes more transparent (Fig. 4b). The overall test to estimate the volume exchanges rate was successful and was determined to be 20 $\frac{exchanges}{minute}$ operation. The region exchange efficiency is 10 volume exchanges per liter of incoming water. The maximum production of fluorine ions int the system is 5 $\frac{ppm(F^-)}{hr}$, which is well below the exchange rate of the region on an hourly basis. The estimated generation of fluorine ions in the FC-40 recirculating system as whole will be further investigated and is potentially higher than estimated. Given the results of the test, the TP will be used with FC-40 as the working fluid. The test setup is underway and measurements of the volume exchange and efficiencies will be measured using the spectrometer in this experiment.

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