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HIGH VOLTAGE DESIGN FOR THE ELECTROSTATIC SEPTUM FOR THE Mu2e BEAM RESONANT EXTRACTION*

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Abstract

Two electrostatic septa (ESS) are being designed for the slow extraction of 8GeV proton beam for the Mu2e experiment at Fermilab. Special attention is given to the high voltage components that affect the performance of the septa. The components under consideration are the high voltage (HV) feedthrough, cathode standoff (CS), and clearing electrode ceramic standoffs (CECS). Previous experience with similar HV systems at Fermilab was used to define the evaluation criteria of the design of the high voltage components. Using electric field simulation software, high E-field intensities on the components and integrated field strength along the surface of the dielectric material were minimized. Here we discuss the limitations found and improvements made based on those studies.

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 electrostatic septa (ESS) will be designed to facilitate the slow extraction. Each septum will have a cathode that is energized to a nominal voltage of 100kV with a gap of 12mm to achieve a 2mrad kick [1]. It is critical to provide stable voltage at 100kV. Any fluctuations in the voltage due to field emission and dielectric breakdown can affect the beam quality to the experiment. In order to mitigate these problems, electric field simulations were performed on critical high voltage components. The components that are being evaluated are the HV feedthrough (HVF), CS, and the CECS.

HIGH VOLTAGE COMPONENT DESIGNS

High Voltage Feedthrough

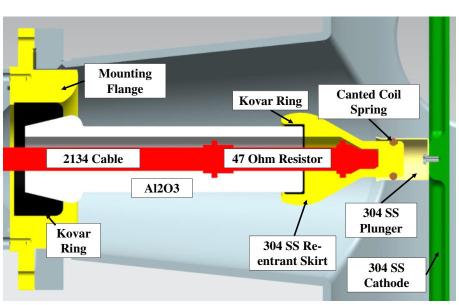

Figure 1: High Voltage Feedthrough Mechanical Details.

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The HVF nominal voltage is 100kV. Figure 1 shows the mechanical design of the HVF, which is composed of 304 stainless steel (yellow), kovar (black), and alumina A1203 (94%) 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.

Cathode Standoff

The CS in Fig. 2 is meant to suspend the weight of the 304 stainless steel cathode (green), which is 7.3kg. A total of three CSs are used in the downstream septum. 28.5mm diameter by 150mm long alumina ceramic (white) rods are used to isolate the cathode from ground and support it. Like the HVF the CS must withstand voltages at 100kV.

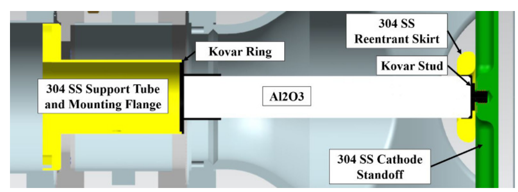

Figure 2: Cathode Standoff Mechanical Details.

Clearing Electrode Standoff

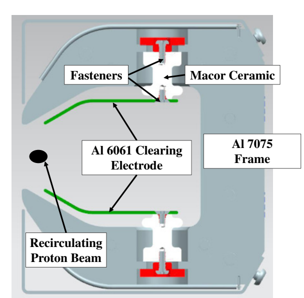

Figure 3: Clearing Electrode Mechanical Details.

The CECSs in Fig. 3 are meant to anchor the clearing electrodes (green) to the frame (silver). The maximum voltage of the clearing electrode (CE) is 20kV. The nominal voltages in service will be 8kV and 3kV for each of the CEs [2]. The dielectric material chosen for this is Macor ceramic, which is a machinable type of ceramic with a dielectric strength of 129kV/mm.

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ELECTROSTATIC SIMULATIONS

Simulation Setup

Poisson Superfish 7.19 is used for understanding the locations of the high field intensities. The top and bottom boundaries of Figs. 4 and 6 are zero potential and axisymmetric boundary conditions. The left and right of these figures are zero potential or ground surfaces. The nominal cathode voltage for both HVF and CS is 100kV. Figure 8 left and right boundary conditions represent 0kV and 20kV. Lastly, the bottom and top of the CECS simulation are axisymmetric. The spacing between the anode and cathode for the HVF and CS was set to 10mm for the simulations below, which is the smallest achievable gap. Finally, each high voltage component is evaluated using two criteria, which are based on current high voltage feedthrough testing done a Fermilab.

- Limit the total field intensities to 50kV/cm except between the anode-cathode gap.
- Total field intensities greater than 50kV/cm require special processing.
- Dielectric integrated field strength along the surface should be less than 10kV/cm.

The 50kV/cm criteria is specified to limit the effects of field emission from the geometry of the components. The 10kV/cm criteria is specified to limit the effects of secondary electron emission avalanche (SEEA). SEEA is the result of the electrons field emitted from the triple junction (ceramic, metal, and vacuum) that strike the ceramic and causes secondary electrons, which then in turn can ionize monolayers of gas on the surface of the ceramic. This creates the electron avalanche that result in voltage instabilities [3]. The effects of SEEA can be minimized by creating a long path for the avalanche to occur. Various used dielectric constants for fluorinert (FC-40), Polyethylene, Al2O3, and Macor are listed below.

- Al2O3 [6]= 9.3
- FC-40 [4]= 1.9
- Macor [7]= 6
- Polyethylene [5]= 2.2

High Voltage Feedthrough

Within these studies we have made several iterations to the HVF design. Modifications were made near the radius portion of the ceramic near z=25cm and r=5cm in Fig. 4. A 50% reduction in the peak total field intensity (z=27, r=5cm) was achieved when adding a 1.25cm radius (20kV/cm) to the ceramic than without a radius (40kV/cm). Figure 5 shows the total field intensity for z=0-50cm and r=2.6cm. The anode and cathode gap is located in between z=0-1cm and it has a uniform field intensity of 100kV/cm. The field intensity along the ceramic (z-axis) beginning 13cm to 24cm is a maximum of 41kV/cm, which does not require special processing because it is below the 50kV/cm requirement. Finally, the total integrated field strength along the flat and radius portion of the ceramic was calculated and found to be 7kV/cm, which is just below the 10kV/cm threshold. The HVF should provide stable voltages at 100kV given good vacuum pressures, minimal dust particles (i.e. lint, metals, etc.), and good surface finishes.

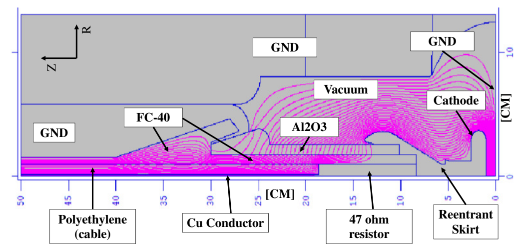

Figure 4: High Voltage Feedthrough Electric Field Simulation.

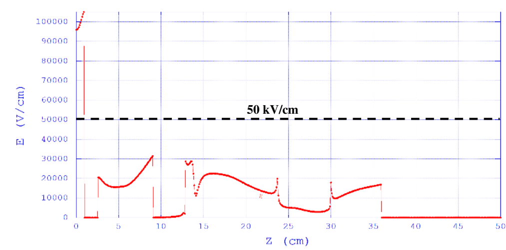

Figure 5: High Voltage Feedthrough Field Intensity Plot for z=0-50cm, r=2.6cm and 100kV Cathode.

Cathode Standoff

The Mu2e CS design was based primarily on the existing CS design that is used in the Main Injector Septum at Fermilab. The highest total field intensity in Fig. 6, other than between the anode and cathode gap, is located at the ceramic and reentrant skirt interface (z=4cm, r=1.5cm). The maximum total field intensity can be seen in Fig. 7, which is 70kV/cm. This peak field intensity is just above the 50kV/cm requirement. Therefore, special care will be taken to minimize this as much as possible during the fabrication process. The kovar stud and reentrant skirt (see Fig. 2), will be polished and rounded to minimize the field intensity at this specific location. Lastly, the total integrated field strength along the ceramic from z=3.8-18.8cm and r=1.46cm is 6.6kV/cm.

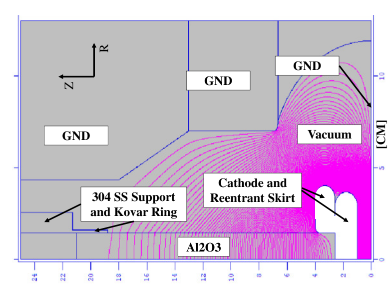

Figure 6: Cathode Standoff Electric Field Simulation.

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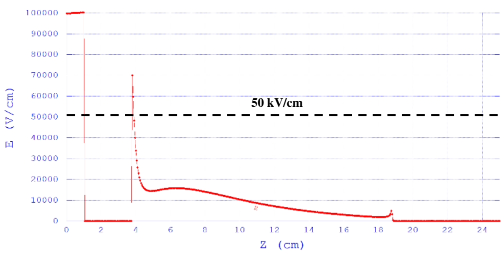

Figure 7: Cathode Standoff Field Intensity Plot z=0-25cm,r=1.46cm and 100kV Cathode.

Clearing Electrode Ceramic Standoff

The CECS total uniform field intensity is 28kV/cm between the GND plane and the clearing electrode in Fig. 8 (z=1.75, r=0-0.75cm). The highest field intensity of 290kV/cm (z=0.625cm, r=0.1cm) is located on the single thread that is modeled for the 20kV fastener. Modification of the threads at the end of the 20kV fastener will be investigated to minimize this high field intensity. Additionally, SEEA is unlikely to occur due to the long path between the HV fastener to the ground plane. The most important aspect of the CECS is the integrated field strength along the surface of the ceramic from z=0-2.6cm. The integrated field strength was calculated for each of the regions seen in Fig. 8 (see Table 1). The total integrated field strength along the surface of the ceramic from the 20kV side to zero potential is 6kV/cm. This is well below the 10kV/cm requirement used for the HVF and CS.

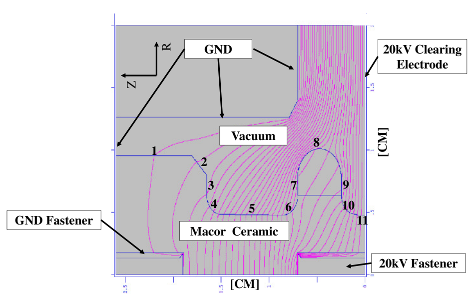

Figure 8: Clearing Electrode Ceramic Standoff Electric Field Simulation (20kV).

CONCLUSION

In general, the simulations demonstrate that the designs of the HVF and CS are sufficient in operating at the nominal voltage of 100kV. The HVF has field intensities that are below the 50kV/cm requirement and does not require special processing. Since the CS design is a near replica of the the CSs used in the Main Injector Septa, it is not too much of a concern that the peak field intensity of 70kV/cm is present. However, special processing (i.e. polishing, radii, etc.) to the kovar stud and reentrant (see Fig. 2) will be done to ensure stable HV. Additionally, the total integrated field

Table 1: Calculated Field Intensities Along the Surface of the CECS

Region	Linear Distance	Field Intensities
1	0.8 cm	1.5 kV/cm
2	0.21 cm	2.6 kV/cm
3	0.16 cm	2.1 kV/cm
4	0.24 cm	9.1 kV/cm
5	0.64 cm	11.5 kV/cm
6	0.24 cm	5.3 kV/cm
7	0.14 cm	2.9 kV/cm
8	0.71 cm	4.9 kV/cm
9	0.14 cm	3.9 kV/cm
10	0.24 cm	12.7 kV/cm
11	0.08 cm	16.2 kV/cm
Total	3.60 cm	6.0 kV/cm

strength along the surface of the HVF and the CS ceramic parts are below 10kV/cm. The only limiting factors that would affect voltage stability at 100kV are vacuum pressure, particles in the vacuum (i.e. dust), and poorly polished surfaces. Furthermore, the total integrated field was lowered to 6.6KV/cm for the CECS by adding a convolution to the geometry. Similarly to HVF and the CS, the CECS can operate stably at 20kV provided good vacuum pressure, minimal dust, and good surface finishes. To ensure HV will not be affected by vacuum pressure, the septa will each have the capacity of pumping up to 900L/s with a design pressure of 1.33E-9mbar (1E-9 torr). The assembly of the Mu2e septa will take place in a ISO class 6 (class 1000) cleanroom. This will minimize particles that may enter the vacuum system that can cause HV problems. Finally, HVF, CS, and CECS will be tested and installed in the Mu2e Septa Prototype, which will be completed near the end of 2018.

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[4] 3M Fluorinert FC-40, `https://www.3m.com`

[5] LDPE, `https://www.professionalplastics.com`

[6] Alumina (94%), `http://accuratus.com/alumox.html`

[7] Macor Ceramic, `https://www.corning.com`