

EXPERIMENTS ON A HIGH-VACUUM, HIGH-ELECTRIC FIELD STRESS PULSED POWER INTERFACE

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Abstract

Improving the materials used in a vacuum interface between a pulsed power system and the vacuum region has been a goal for many years. The interface problem is difficult because of the electrical, mechanical and vacuum issues that must be satisfied simultaneously. Traditionally the pulsed power community has made use of acrylics for the interface, and has found applying a light coating of oil is needed for reliable operation. However, the oil coating typically limits use for tens to hundreds of pulses and must be re-applied periodically. The acrylic material limits the base vacuum obtainable; the vapor pressure of acrylic is in the low 10^{-7} Torr vacuum. The opposite end of interface spectrum is conventional vacuum tube industry that uses ceramics to obtain ultra-high vacuums. The goal has been to obtain the base vacuums obtainable by ceramic interfaces without the associated high cost relative to acrylic interfaces. Several years earlier, a pulsed power system (500 kV, 100 Ω , 1 μ sec, 1 pulse/sec) was assembled using a high-density polyethylene vacuum interface. The base vacuum was observed to reach the low 10^{-9} Torr level. We present results on experiments comparing the performance of an acrylic and high-density polyethylene interface. We also discuss a ceramic interface that was designed and built.

I. INTRODUCTION

The vacuum interface between a high voltage generator and the vacuum diode is an area of interest in the continuing development of pulsed

power systems, for both repetitively operated and compact. Applications of pulsed power continue to develop and evolve, and most have requirements to make them more compact and to operate repetitively. These application requirements require great care in the material choice and design choices in implementing the interface. These requirements also increase the electric field stress on all component surfaces, and increase the number of pulses or the lifetime of the components.

We recently completed an upgrade to the ETDL pulser [1] that is intended to power arbitrary impedance vacuum diodes for High Power Microwave (HPM) source research. The ETDL pulser has been previously described [2] and the various PFN impedances and pulse lengths listed. Even though ETDL is not a compact pulsed power system, the vacuum interface is relatively compact and is common among several types of HPM sources being studied at AFRL. In conjunction with the pulsed power upgrades to ETDL we elected to carryout a modest research effort to test alternatives for the vacuum interface. The present ETDL pulser is shown in Figure 1,

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14. ABSTRACT

Improving the materials used in a vacuum interface between a pulsed power system and the vacuum region has been a goal for many years. The interface problem is difficult because of the electrical, mechanical and vacuum issues that must be satisfied simultaneously. Traditionally the pulsed power community has made use of acrylics for the interface, and has found applying a light coating of oil is needed for reliable operation. However, the oil coating typically limits use for tens to hundreds of pulses and must be re-applied periodically. The acrylic material limits the base vacuum obtainable; the vapor pressure of acrylic is in the low 10^{-7} Torr vacuum. The opposite end of interface spectrum is conventional vacuum tube industry that uses ceramics to obtain ultra-high vacuums. The goal has been to obtain the base vacuums obtainable by ceramic interfaces without the associated high cost relative to acrylic interfaces. Several years earlier, a pulsed power system (500 kV, 100 μ s, 1 pulse/sec) was assembled using a high-density polyethylene vacuum interface. The base vacuum was observed to reach the low 10^{-9} Torr level. We present results on experiments comparing the performance of an acrylic and high-density polyethylene interface. We also discuss a ceramic interface that was designed and built.

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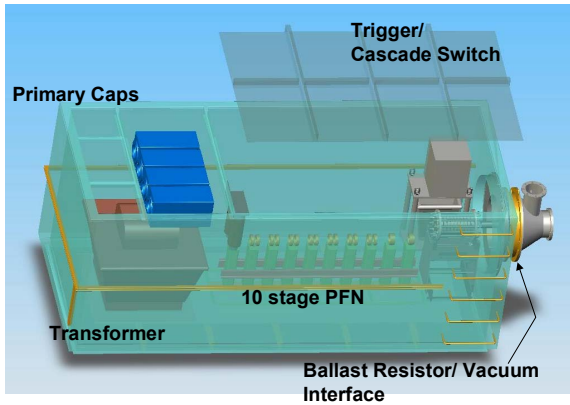


Figure 1 Drawing of the ETDL pulser.

and Figure 2 shows the detail of the radial ballast resistor [3] and the interface plate which must mechanically withstand one atmosphere pressure difference, the electric field stress resulting from the high voltage pulse transitioning from the oil tank to the vacuum region, and must do this reliably for many thousands of pulses.

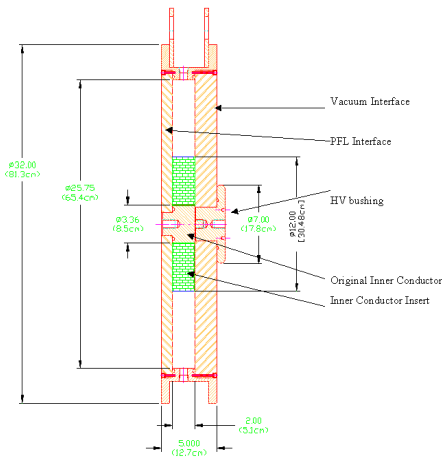


Figure 2 Drawing of the Radial Ballast resistor.

This ballast resistor is a parallel load with the vacuum diode, and is used to match the parallel impedances of the ballast resistor and the vacuum diode to the PFN impedance. The ballast resistor is intended to not significantly increase the series inductance between the pulser and vacuum diode because the phase relationship between the applied voltage and the resulting current pulse may be critical to the HPM vacuum diode. This

requirement for low inductance restricts the techniques one may use to mitigate the high tangential electric field stresses and to enable large numbers of pulses between maintenance.

This paper discusses the different interfaces we have investigated as we transition from single pulse systems to repetitive pulse systems. The materials considered for the vacuum interface included traditional pulsed power materials and those used by conventional microwave tube manufacturers. We start the discussion by considering the electrostatic field distribution applied to the vacuum interface. We then present data on how the interface responded to single pulse operation.

II. INTERFACE MATERIALS

The interface materials we focused most of our attention are: 1) acrylic ($\epsilon_r=2.55$), 2) ceramic ($\epsilon_r=9.7$), and 3) high-density polyethylene ($\epsilon_r=2.2$). The interface plate in Figure 2 is 69.85 cm (27.5 inches) outer diameter. We verified that all the materials studied could maintain a one atmosphere pressure difference without risk of implosion. This requirement set the 5.08 cm (2 inch) thickness of the plate.

We used acrylic as the traditional pulsed power interface material, with the operating requirement that the interface periodically have a layer of vacuum pump oil applied to the vacuum side of the interface. The re-application of the oil is one of the primary issues in why acrylic is not of interest for repetitive operation. Also, the base vacuum of acrylic is observed to be in the low 10^{-7} Torr range, which is not sufficient for many sealed microwave tube systems. One very nice positive feature is the low cost and ease of fabrication of the acrylic plate.

We also looked into a standard alumina ceramic plate. These interfaces are typically brazed, but the mass of the ceramic made that impossible.

Instead we employed mechanical fixtures to compress gaskets on the ceramic. This caused the ceramic interface to be prohibitively expensive to reproduce. Also, handling the ceramic interface is difficult since manufacturers don't recommend physically touching the surface to avoid any contaminants. The best feature of the ceramic interface is the base vacuum $\leq 10^{-9}$ Torr.

The final material selected was High-Density Polyethylene (HPDE), which was originally used in the AFRL pulser Cathode-Test-Bed [4] (CTB). This interface material was kept during the upgrade to the present Repetitive Test Pulser (RTP). We had to verify this exact material by the specific gravity. During operation on RTP the HPDE interface has been used for several million pulses (up to 500 kV, 1 μ sec) without degradation, and has been observed to obtain base vacuums in the 10^{-9} Torr range. This seems to indicate that HPDE has the best features of both acrylic and ceramic

III. INTERFACE ELECTROSTATICS

The operational feature not discussed above dealt with the interfaces ability to hold-off surface tracking due to the large tangential electric fields. Results from two electrostatic calculations are shown in Figure 3 and Figure 4, for acrylic and HPDE respectively.

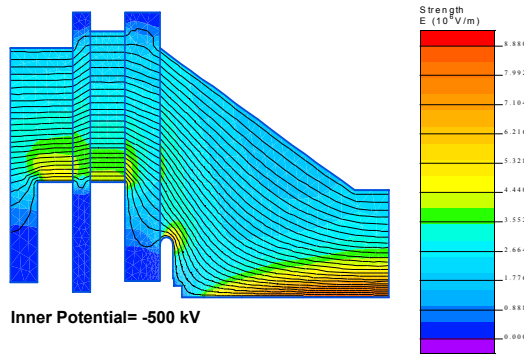


Figure 3 Electrostatics for the acrylic interface.

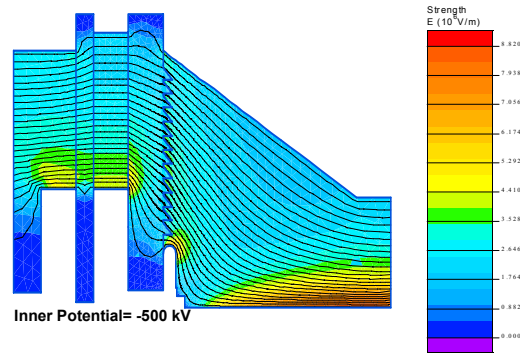


Figure 4 Electrostatics for the HPDE interface.

For both simulations we applied 500 kV between the inner and outer conductors of the geometry. The tangential electric field in both cases peaks ~ 60 kV/cm. The acrylic interface is capable of holding-off this electric field because of the thin layer of oil applied to the acrylic. For the HPDE interface we made use of a “saw-tooth” structure to avoid any arcing at the full machine voltage.

This peak electric field is double the rated tangential electric field stress for ceramic.

IV. INTERFACE CONDITIONING

We used the radial ballast resistor as the load for the ETDL pulser. We adjusted the conductivity of the solution to provide a match to the PFN impedance. Our criteria for obtaining the match were that the output voltage amplitude be one-half the transformer secondary voltage, and that the output voltage monitor remains at zero after the pulse. The data shown in Figure 5 shows these features. These data are for the HPDE interface.

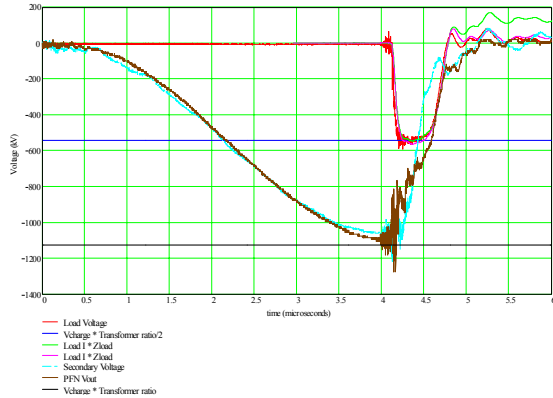


Figure 5 Measured pulsed power following interface conditioning.

During conditioning we did experience a couple of arcs, but these seemed to be due to sharp edges and burrs from the machining being burnt off. We reduced the charge voltage for a couple of pulses following the discharges, and then were able to resume the high voltage conditioning. One other piece of information dealt with using a dry-nitrogen gas during the initial vacuum venting process. By using an inert gas backfill one is able to place a monolayer on the vacuum surfaces and displace any water vapor. This was recommended [4] and found to be helpful in operation on the CTB and RTP pulsers.

V. SUMMARY

We have completed experiments and calculations to identify a good material to fabricate a vacuum interface for future compact repetitive pulsed power systems. We believe a good material is high-density polyethylene. This material has the best features of a standard acrylic interface and a ceramic interface, without the expense and fabrication difficulty associated with a ceramic interface.

VI. REFERENCES

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