SUCCESSFUL LABORATORY-INDUSTRIAL PARTNERSHIPS: THE CORNELL-FRIATEC SEGMENTED INSULATOR FOR HIGH VOLTAGE DC PHOTOCATHODE GUNS

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Abstract

High voltage DC photocathode guns currently offer the most reliable path to electron beams with high current and brightness. The performance of a photocathode gun is directly dependent on its vacuum and high voltage capabilities, determined in large part by the ceramic insulators. The insulator must meet XHV standards, bear the load of pressurized SF_6 on its exterior, support the massive electrode structures as well as holding off DC voltages up to 750 kV. The Cornell-Friatec insulator was designed collaboratively between the industrial and laboratory teams and has now been produced in quantity for projects at Cornell University and elsewhere. Stray electron tracking has guided the design of internal collector rings to ameliorate punch-through failures that have plagued earlier guns.

INTRODUCTION

Many future linac and ERL based accelerator facilities require sources of high current and brightness electrons. Over the past 15 years the Cornell ERL injector project has led to advancements in the performance and reliability of DC gun technology enabling these new accelerators [1]. These guns have proven themselves by setting world records for high-average current from a high brightness photoinjector [2]. These guns are now being used as the electron source for two new projects: LEReC, an electron cooler at RHIC [3], and for the Cornell-Brookhaven Electron-Recovery-Linac Test Accelerator (CBETA). Cornell and Brookhaven National Lab have begun collaboration on the design, construction and commissioning of a four-pass 150 MeV electron accelerator based on a superconducting, six-cavity linac with energy recovery, using 106 fixed-field alternating gradient (FFAG) cells as the return loop [4, 5]. This accelerator will be based on the existing Cornell ERL Injector with an upgraded DC gun as shown in Fig. 1.

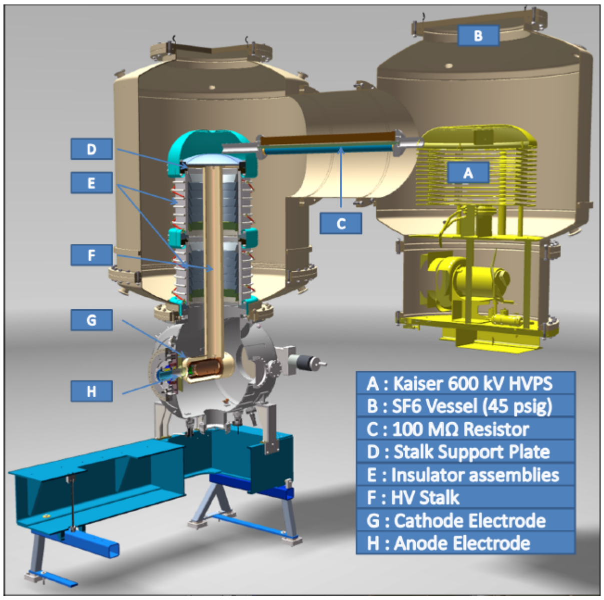

Figure 1: DC gun utilizing the Friatec segmented insulator (E) is shown on the left, inside an SF6 pressure vessel. The HVPS (A) is on the right, inside a common SF6 vessel.

DESIGN

DC guns suffer from the problem of controlling field emitted electrons from the high voltage surfaces. These electrons can land on the insulator, and if the charge builds up, punch-through can occur, causing a vacuum leak to the high pressure SF_6 space. In past guns we have used monolithic cylindrical insulators with an internal resistive coating to bleed off these electrons, but it has only been successful up to 450 kV during processing, above which punch-through failure occurs. In addition, the coating has not adhered well, depositing a layer of particulate on the electrodes, certain demise for reaching higher voltages. Two such insulators were built and tested with similar damage occurring to both. A second batch of insulators were built with a doped alumina material with a known resistance, sufficient to drain electrons without drawing excessive current from the power supply, but unfortunately similar failures occured.

These setbacks have led to the use of more complex segmented insulators with internal shields. These insulators were designed in a partnership between Cornell University and Friatec AG, with Cornell responsible for the high voltage design and Friatec responsible for the vacuum design and fabrication. The new insulator has internal guard rings to block any field emitted electrons ejected off the central support tube from reaching (and potentially damaging) the insulator. The diameter of the insulator is increased in order to reduce the maximum field on the central tube to 10 MV/m at 750 kV. At 500 kV, this will result in a reasonable field level of 6.7 MV/m.

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The entire insulating structure is composed of two smaller insulator assemblies. Each insulator assembly has 7 segments, or 14 in total installed on the gun. Each segment is a ring of Frialit F99.7 Al_2O_3 with an inner diameter of 435 mm, 50 mm tall, and 20 mm thick. The dielectric strength of the ceramic material is quoted by Friatec to be beyond 30 kV/mm, with a resistivity of 10^{15} ohm-cm at room temperature. The top and bottom kovar segment of each assembly is welded into a 22.125" wire seal flange of 316 stainless steel.

Kovar rings are brazed in at the interface of any two segments. In vacuum, the kovar ring allows the attachment of the aforementioned ceramic-guarding rings. The kovar rings also extend outside the insulator body into the SF_6 environment. In the SF_6, a resistor chain from HV (at the top) to ground (at the bottom) connected to each kovar ring directly defines the voltage on all segment interfaces and inner guard rings. Kovar was chosen as the interface ring material for its similar linear coeficient of thermal expansion to that of the Al_2O_3, so that the braze joints would be minimally stressed during vacuum bake-out.

The insulator column was split into two independant pieces primarily for ease of manufacture. Each braze joint has a finite probability of failure so reductions in the number of braze joints per part led to higher yield rates. Also the weight and size of the piece is reduced allowing for the use of a smaller braze furnace (Fig. 2) and ease of handling, both during manufacture and later during cleanroom assembly. By taking a modular approach, the insulator design can be applied to a variety of gun voltages and can be used by other projects without requiring extensive re-design, for example a single insulator could be used for a 375 kV gun without redesign.

Figure 2: Vacuum braze furnace being loaded with an insulator.

A simplified high voltage model of the insulator, shown in Fig. 3, was generated in the software Opera 2D. Shown is the high voltage support stalk, insulator, and guard rings for the gun operating at 750 kV. This model was used for stray electron tracking to ensure that the guard rings collected all possible stray electrons from the conductor stalk. For simplicity, this HV model is singular, rather than made of two insulator assemblies (as built), and similarly does not show the triple point protection rings. Note the tendency of field emission to come from the stalk at the base of the insulator, and that the field on the lowermost ring to be significantly higher than others. For this reason, the angle of the lowermost rings was increased from the nominal.

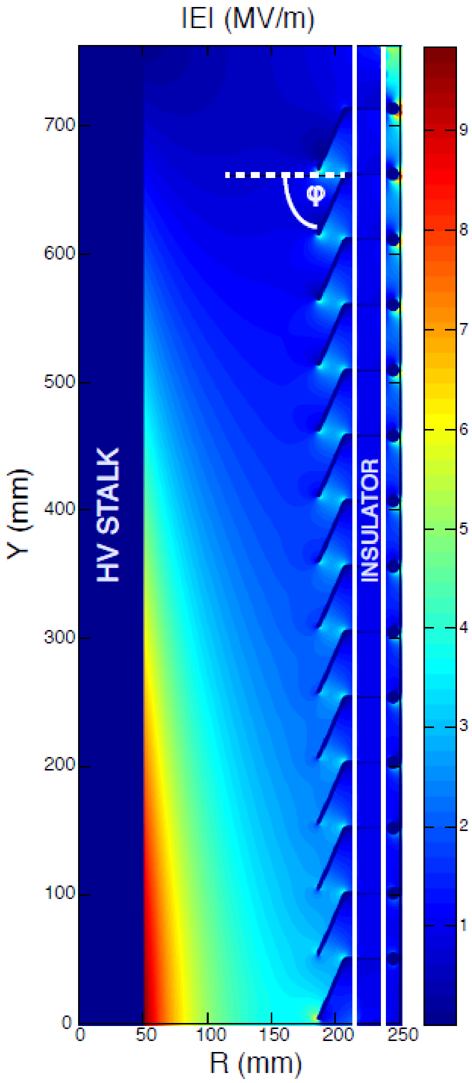

Figure 3: Electron tracking results from Opera 2D simulationl.

The guard rings were made of copper due to its high thermal conductivity, thereby minimizing the heating of the ring and nearby braze joints from any stray field emission. A thermal finite element model was used to determine the maximum stray current that could be absorbed by a ring without damage, a consideration due to the relatively poor thermal contact of the copper rings to the insulator itself which is cooled by the SF_6 environment. By utilizing replaceable rings as shown in Fig. 4 we have the ability to rebuild the insulator if the guard rings are damaged, a critical way of controlling costs while extending the service life of the insulator.

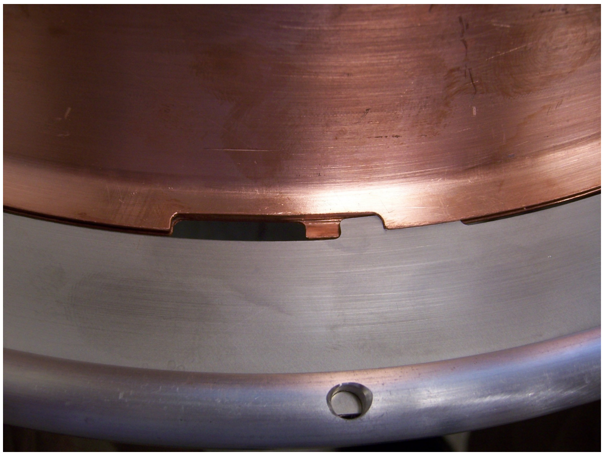

Figure 4: Replaceable Guard Ring Mounted to Kovar Ring.

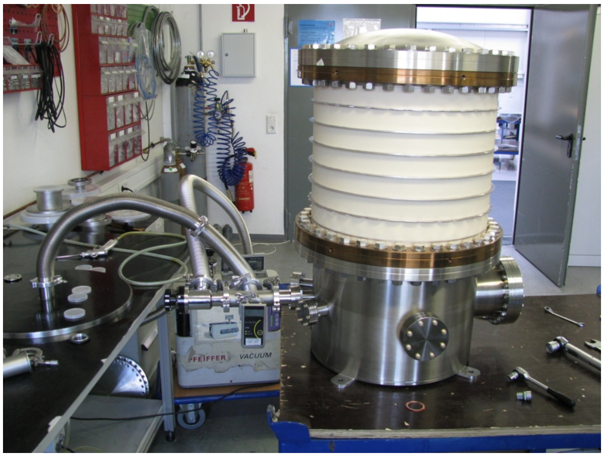

Figure 5: Insulator factory acceptance testing.

FABRICATION

Construction of ultra high vacuum insulators requires a combination of high purity ceramic such as Frialit F99.7 Al_2O_3 and metal components proven to minimize thermal stress between the brazed ceramic rings and metal components. Careful analysis of the joint design ensures that thermal expansions that occur during the long duration high temperature vacuum bakeouts do not cause high peel stresses at the braze joints which could lead to joint failure. Strict quality control of the materials and the machining operations are critical steps in the manufacture of these insulators and a close working relationship between the laboratory and the ceramic manufacturer is essential. Proven technologies and procedures during manufacturing, vacuum testing, and bake out will ensure a finished product that will meet the specification the first time (see Fig. 5). With no ability to repair defective units, manufacturing correctly the first time is the only option.

Critical to high voltage performance is the high pressure rinsing (HPR) of the interior of the insulator prior to installation. The ceramic material is sprayed with oscillating jets of high pressure (100 bar) deionized water for 4 hours in order to remove any residual particulate from the manufacturing process or collected from room air. HPR operations are performed in a clean room where final assembly takes place. Only after UHV conditions are achieved is the gun removed from the cleanroom in a sealed state.

CONCLUSIONS

The segmented insulator with internal guard rings has proven resistant to punch-through failures during routine operation at 400-450 kV and also during processing up to 525 kV. The average current achieved thus far was 65 mA at 5 MeV, the highest ever for a photoemission-based injector. This exceeds the previous record by a group from Boeing. Work is continuing to reach the ultimate goal of 100 mA by reducing beam losses due to halo, improving laser operation, and finding cathodes more resistant to degradation over time. The single biggest lesson learned is the critical importance of close and direct interaction between the engineering staff of both laboratory and industry, the sharing of drawings, models, and resources is essential to a successful product and hence the entire project.

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