A FULLY DEMOUNTABLE 550 kV ELECTRON GUN FOR LOW EMITTANCE BEAM EXPERIMENTS WITH A 17 GHz LINAC*

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Abstract

The design details and fabrication features of a 550 kV electron source for operation with a 17 GHz chopper-prebuncher linac injector are described, and initial test results using the M.I.T. Plasma Fusion Center HV pulse modulator are presented. The electron gun was designed to satisfy the stringent injection specifications required for the linac to demonstrate a 20 MeV beam with a bunch current of 100 A and a normalized emittance of 5 mm-mradian. Fine mesh simulations of the electron gun optics revealed that, to minimize geometric contributions to the source emittance, a very tight tolerance (±25 μm) was required for the edge spacing between the cathode and focus electrode. Means of accurately locating the gun electrodes are discussed; and the vacuum demountable features that enable convenient field replacement of the anode, focus electrode and cathode/heater are described.

1 INTRODUCTION

The 17 GHz linac system [1] comprises a chopper-prebuncher injector and a 94 cavity, $2\pi/3$ mode, quasi-constant gradient structure having an RF filling time of 58ns. The injection system is designed to operate with a 550 kV, 1 A, low emittance electron source to produce fully gated bunches of < 20° at injection into the linac with a bunch current of 6 A and a pulse current of 280mA. The accelerator structure is designed to provide subsequent bunch compression to 1° and a steady-state beam loaded energy of 20 MeV. A new style, racetrack shaped, dual feed input coupler has been developed [2] and incorporated into the linac structure to avoid beam emittance contributions due to field asymmetry.

2 DEMOUNTABLE GUN ASSEMBLY

Based on a ceramic to copper, dry hydrogen furnace brazing technique (previously established during the development of a family of low beam emittance, 250 to 550 kV dc electron guns [3]), a thick wall, large diameter, tapered ceramic shell terminated with brazed copper/stainless steel subassemblies was the design of choice for this pulsed HV application. This concept enabled standard vacuum flanges to be attached to the ceramic insulator (13-1/4″ ϕ at the HV end and 16-1/2″ ϕ at the ground end) and provided a variety of electron gun assembly options. For example, in the Figure 1 layout of the demountable assembly, the low emittance gun configuration for the 17 GHz linac is shown as (A) below the centerline; and means for retrofitting a higher perveance, larger diameter cathode and focus electrode assembly is shown as (B) above the centerline.

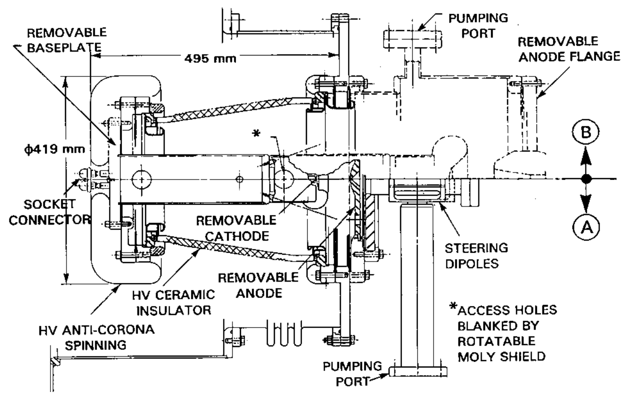

Figure 1: Demountable Electron Gun Concept Showing Alternate Retrofit Configurations (A) for the 17 GHz Linac Low Emittance Injector and (B) for High Power Microwave Tube Research.

The POISSON code equipotential plots and electric field gradients for the 17 GHz linac electron gun (mounted in the HV modulator oil tank) are shown in Figure 2. At a pulse voltage of 550 kV, the maximum gradients on the surface of the focus electrode and anode are 195 and 151 kV/cm, respectively. Iterative design adjustments of the HV seal braze joints and shields were performed in order to achieve the indicated low gradients (20 and 11 kV/cm) at the critical ceramic/metal interfaces, so that the possibility of achieving satisfactory HV operation, without baking-out the system and without TiN coating of the ceramic, could be investigated.

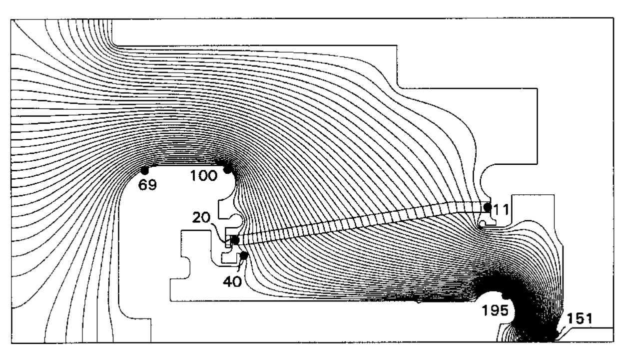

Figure 2: 550 kV Electron Gun Assembly POISSON Equipotential Plots and Electric Field Gradients (kV/cm).

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3 EMITTANCE SENSITIVITY

Fine mesh simulations were performed with EGUN to study the effects of small changes in gun geometry, and in particular, the sensitivity of beam emittance to the radial clearance and axial separation between the cathode and focus electrode edges. The dashed curves in Figure 3 show the sensitive dependence of emittance on this axial distance for two slightly different focus electrode designs, without the cathode temperature related transverse velocity contributions of the emitted electrons being taken into account. The Figure 3 solid curve shows the results of EGUN simulations that take into account thermal effects associated with a 1350°K, 2.5 mm radius cathode. This data indicated that, with a carefully constructed system, a 1 A beam having a normalized emittance of between 2π and 3π mm-mradian should be attainable.

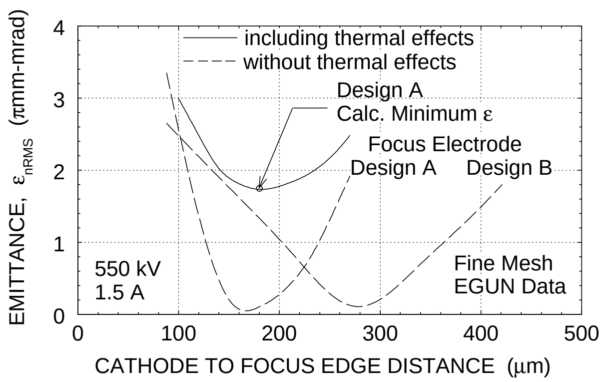


Figure 3: Normalized Emittance Dependence on Distance Between the Cathode and Focus Electrode Edges.

4 FABRICATION FEATURES

To accurately determine the small but critical movement of components caused by the cathode/heater dissipation (including radiation and reflection effects), prior to final machining of the focus electrode, the electron gun was fully assembled, fitted with an array of ceramic insulated thermocouples (refer to Figure 4), and operated in high vacuum with the cathode heater at full power. This temperature survey also enabled the thermal dynamics of the system to be evaluated, in particular, the delay in reaching equilibrium due to the high thermal isolation of the rigid stainless steel cantilevered support. For example, the Figure 5 curves reveal that a cathode preheating period of between 6 and 8 hours is required before achieving the steady-state condition. Reduction of the temperature survey data enabled the room temperature dimensions of the focus electrode to be accurately established, the contour machining finalized and the gun assembly completed. Views of the HV ceramic assembly and internal components of the gun are shown in Figure 6. Self centering and sealing of the ceramic and copper components during the brazing process was accomplished, without the need for peripheral grinding of the large ceramic, by using novel graphite fixtures; and the copper sealing technique ensured the complete absence of magnetic materials (e.g., Kovar or other Ni-Fe alloys).

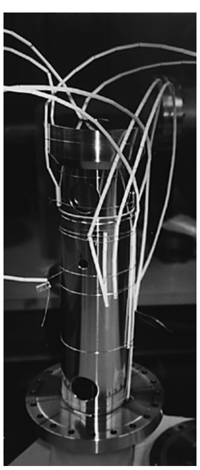


Figure 4: Focus Electrode, Cathode/Heater and Support Subassembly Fitted with Ceramic Insulated Thermocouples.

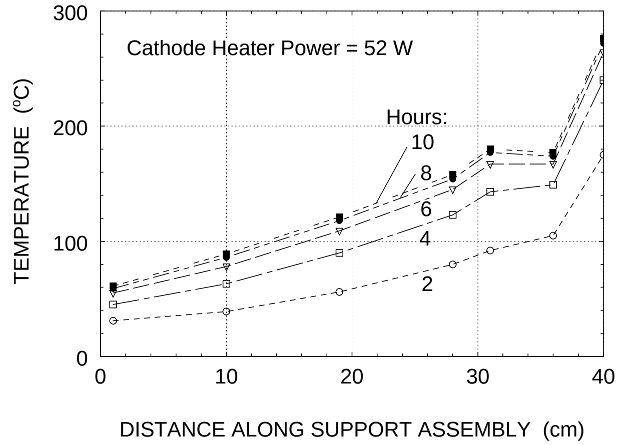


Figure 5: Cantilever Support Temperature-Time Curves.

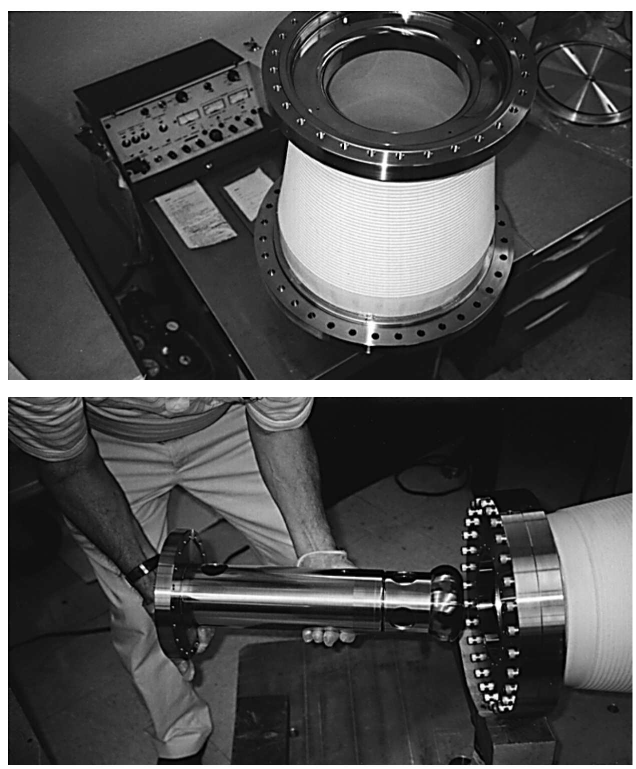
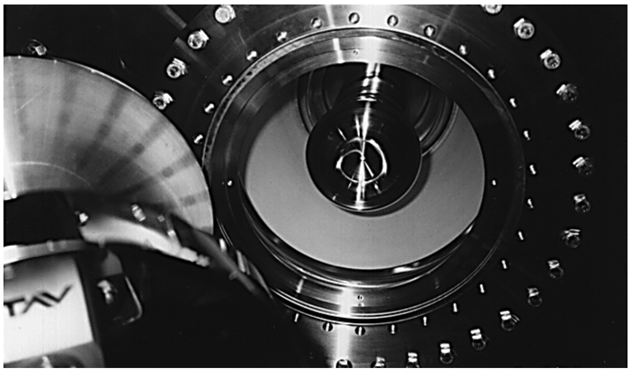


Figure 6: Upper View - HV Ceramic Insulator; Lower View - Installing the Focus Electrode and Cathode/Heater Subassembly.

Following prior design practice [3], the cathode/heater assembly was mounted directly to the focus electrode, and piloted to an accuracy of 25 μm to maintain a radial clearance of 380 μm. A built-in adjustment system enabled the large diameter focus electrode to be centered and spaced with respect to the anode to a tolerance of 25μm, and then locked in position using an alignment fixture as shown in Figure 7. This technique enabled errors due to small misalignments, and cumulative buildup of fabrication tolerances, to be corrected with a single final adjustment.



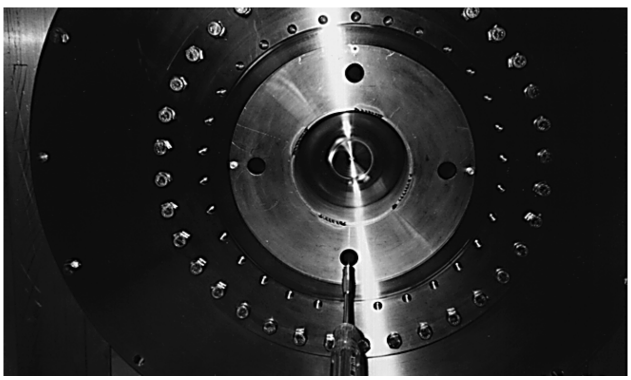


Figure 7: Upper View - Gun Assembly with Anode Removed; Lower View - Final Positioning of the Focus Electrode Using the Alignment Fixture.

5 PRELIMINARY TEST RESULTS AND FUTURE PLANS

The 550 kV electron gun assembly was integrated into the HV modulator, used at MIT [4] for operating the high power TW relativistic klystron for the 17 GHz linac, by attaching an external gun chamber to the side of the modulator tank (refer Figures 1 and 2). Prior to completing the HV processing of the gun, a preliminary simple beam emittance test was performed at 440 kV with a cathode emission current of 1 A. Using a low aberration thin lens, the beam waist from the gun was re-imaged at a 0.8 mm radius collimator, then after drifting 37.5 cm to the location of a 3.4 mm radius collimator, the transmitted beam was collected in a evacuated Faraday cup. Pulse waveforms of the electron gun voltage and the current transmitted through both collimators into the Faraday cup are shown in Figure 8. These preliminary tests were

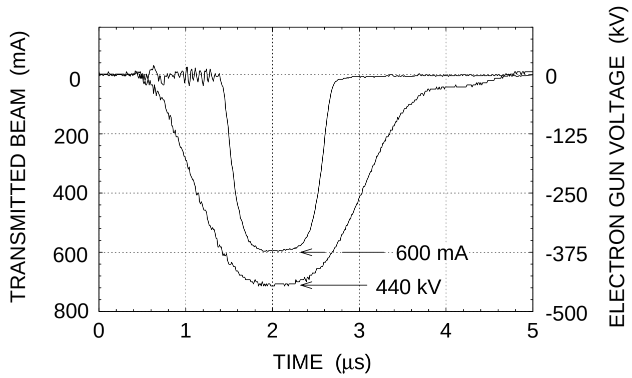


Figure 8: Electron Beam Transmitted into Faraday Cup through 0.8 mm and 3.4 mm Radii Collimators Separated by 375 mm ($\beta\gamma\epsilon = 2.8\ \pi$ mm-mradian).

performed with a space charge limited cathode but without attaining thermal equilibrium of the gun structure (the preheat period was only 2 hours - refer Figure 5). For the given geometric conditions, the results indicate that an rms emittance of approximately 1.8π mm-mradian was achieved at an energy of 440 kV with a transmitted beam of 600 mA and a pulse width of 600 ns.

At this writing, the electron gun has been successfully hi-potted to 550 kV, and is to be processed and beam characterized to a higher level prior to installation of the 17 GHz linear accelerator and spectrometer, and the chopper/prebuncher injector, scheduled for later this year.

6 ACKNOWLEDGEMENTS

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