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INITIAL TESTING OF THE MARK-0 X-BAND RF GUN AT SLAC

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Abstract

A new X-band RF gun (Mark-0) has been assembled, tuned and was tested in the ASTA facility at SLAC. This gun has been improved from an earlier gun used in Compton-scattering experiments at SLAC by the introduction of a racetrack dual-input coupler to reduce quadrupole fields. Waveguide-to-coupler irises were also redesigned to reduce surface magnetic fields and therefore peak pulse surface heating. Tests of this photocathode gun will allow us to gain early operational experience for beam tests of a new gun with further improvements (Mark-1) being prepared for SLAC's X-Band Test Area (XTA) program and the LLNL MEGa-ray program. Results of current testing up to ≈ 200 MV/m peak surface Electric fields are presented.

INTRODUCTION

As part of a joint effort, X-band RF gun test facilities are being set up at LLNL (MEGa-ray) and SLAC (XTA). A new rf gun design (Mark-1) has been completed and parts are currently being fabricated and assembled. To jump start this effort, an improved version of a 5.5 cell gun from an earlier SLAC and -U. C. Davis Compton program [1] has been assembled and initial RF tests have been performed. The goal for this study is to investigate the RF conditioning characteristics expected with the new design, i.e., the level of dark current generated as a function of peak surface gradients and pulse width; temperature regulation requirements due to RF heating; radiation generation, as well as establish a protocol for the initial component handling and assembly leading to the completed device. The complete gun assembly is shown in Fig. 1. It consists of the gun mounted in a solenoid; a short beamline terminating in a Faraday Cup; an isolating vacuum valve; three vac-ion pumps; and an input waveguide assembly consisting of an rf window and splitter.

The gun is a 5.5 cell resonant structure with a copper cathode. Results from HFSS [2] simulations and cold test measurements both indicate a coupling factor (beta) of ≈1.7 for the operating (π) mode and a mode separation to the next lower mode of 10 MHz. The RF filling time (2Q/ω) is 65-70 ns. The dual-input coupler cell is a racetrack structure designed to remove dipole and reduce quadrupole rf fields.

The solenoid consists of two identical coils operated with oppositely directed polarities. The cathode is positioned in the central null of the coils.

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The Faraday cup consists of an electrically isolated right angle prism with a CE-YAG scintillator mounted on the front face. The scintillator is positioned on the prism so that it is can be viewed with a camera thru a viewport mounted on one side of a 6-way cross. This arrangement permits a simultaneous viewing of the generated dark current while the cup measured the collected charge. Two 8 liter/s vacuum ion pumps maintain the gun vacuum while a 20 liter/s pump was used for the beamline. A vacuum valve is positioned between the gun and Faraday cup permitting modification or removal of the Faraday cup while maintaining the vacuum integrity of the gun. During operation these pumps maintained the pressure to ≤1nTorr.

Figure 1: RF gun test assembly

The high power RF tests were conducted in the ASTA facility at SLAC. XL4 klystrons were used to supply RF power of up to 21 MW (at the gun input). The temperature at the gun was stabilized using a temperature controlled (±0.1 C) heater/chiller. Two thermocouples, mounted at the cathode and coupler cell measured the actual gun body temperature and verified the temperature stability.

PREPARATION

After brazing the coupler cell to the other, diffusion bonded cells, the input waveguide and splitter assembly along with tuning posts and cooling channels were brazed onto the assembly. The completed gun then underwent bead-drop measurements and tuning. Initial measurements indicated that the coupler cell had a significantly higher

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frequency than the other cells, requiring significant tuning. Final tuning established a flat field distribution in all cells, but because of the degree of tuning required, the gun overall resonant frequency could not be lowered to the desired 11.424 GHz but rather to 11.426 GHz at the usual 45°C operating temperature. (See Figs. 2 and 3).

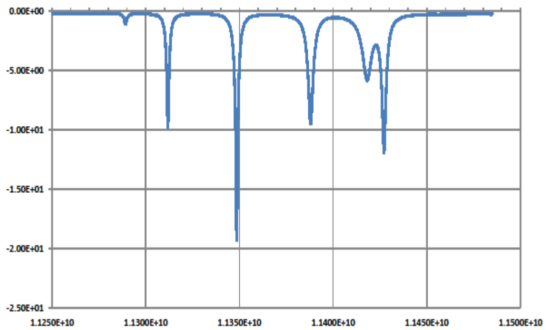

Figure 2: Complete RF spectrum.

This was not a significant problem for these tests since either the klystron frequency could be adjusted or the gun could be operated at a higher temperature (53°C). Both schemes were, in fact, used.

Following tuning, the gun was vacuum fired to 700°C to remove Hydrogen from the copper surfaces and volume. The vac-ion pumps, beamline valve and input window assembly were first baked at individually at 200°C and then mounted on the gun and pumped out with the gun valve closed.

The Faraday cup and Ce YAG scintillator were also baked to 200°C. After assembly, the complete system was baked out to 200°C and installed/aligned in the solenoid.

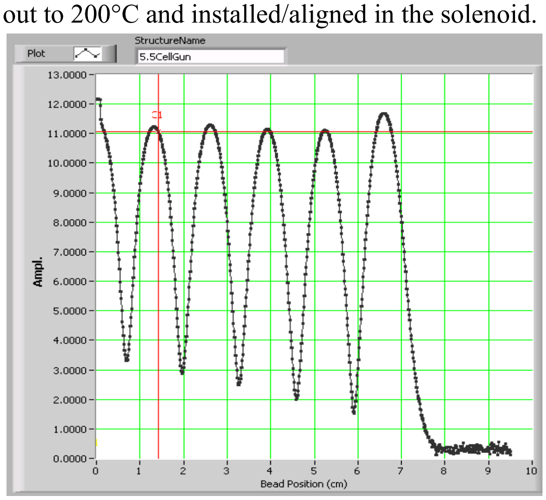

Figure 3: Field balance at 11.4267 GHz.

Tests

Initial tests were performed at 11.427 GHz, with the Gun water temperature at 40°C. The rf pulse width was set to 100 ns to limit possible damage to the gun due to rf breakdown. Gun rf breakdown was monitored by Faraday cup dark current, reflected rf power and vac-ion pump current spikes. Pulse to pulse rf forward and reflected power as well as Faraday cup current were monitored and stored for later analysis. There were almost no RF breakdown events resulting in measurable vacuum activity (≤1/day). RF breakdown events were observed almost exclusively from Faraday cup current spikes. A log of breakdown rate was monitored and stored. Fig. 4 shows the conditioning progress with no-operation time periods removed. In total, ≈ 6200 occurred.

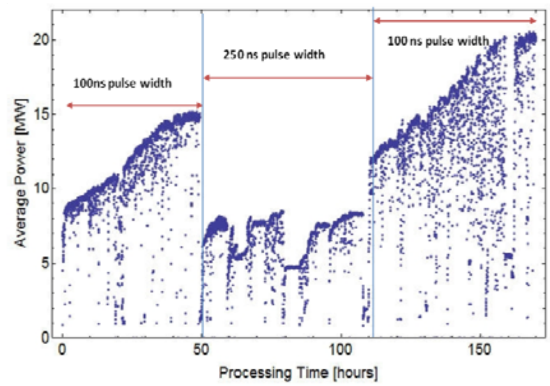

Figure 4: Total processing time.

After reaching surface fields of ≈ 152MV/m, the pulse width was increased from 100ns. to 250 ns and conditioning was continued. This resulted in a higher Faraday cup current and slower processing progress. It was then decided to return to the narrower pulse width and higher power. The gun water temperature was also raised to 53.3°C to permit conditioning at 11.424 GHz. A frequency scan was performed with a 500 ns RF pulse width (≈ 7 filling times) while measuring the equilibrium reflected power. At resonance this should be a minimum. A minimum was found at ≈ 11.424 GHz verifying 53 C as the correct temperature for 11.424 GHz operation. (See Fig. 5).

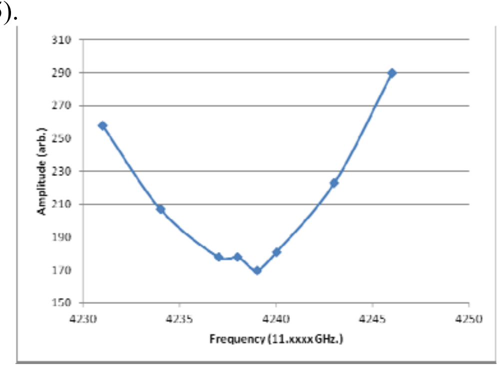

Figure 5: Reflected power vs. frequency in steady- state for a gun Temperature of 53.3 C

The rf pulse width was then reduced to 100 ns and conditioning continued up to a power level of 20-21 MW corresponding to a surface field of 186 MV/m.

Throughout conditioning, the temperature of the gun was monitored at the cathode and coupler cells with thermocouples. Temperature stabilization of the gun was maintained using a heater/chiller capable of ±0.1 C stabilization is shown in Fig. 6. As can be seen, removal of rf power due to breakdown events caused fluctuations in the gun temperature while the stabilized water temperature deviated only slightly. Magnet inlet and exit water temperature are also shown as is ambient temperature.

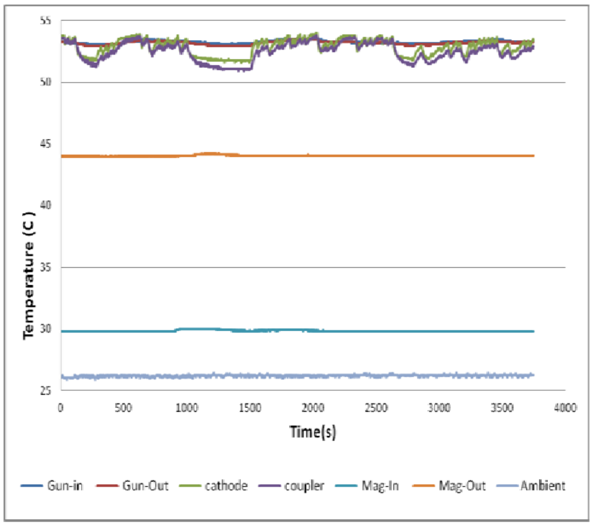

Figure 6: Temperature history of gun and Solenoid

During this particular scan the input RF power was 17.1 MW. The gun temperature response time (10-90%) to rf power drop-out and return is seen to be approximately 2.5 minutes.

A scan of Faraday cup dark current versus rf power was performed at the end of conditioning and is shown in Fig. 7.

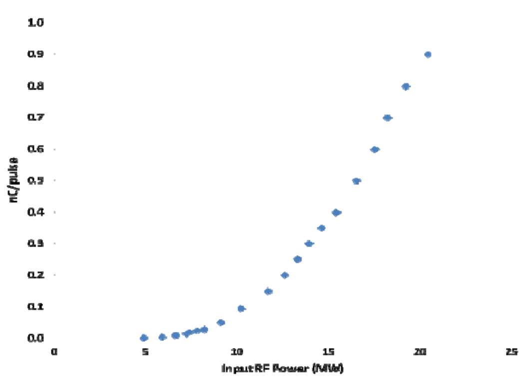

Figure 7: Measure dark Current at the Faraday Cup

A value of 0.9 nC/pulse was measured at 21MW (186 MV/m)

Radiation Measurements

Radiation levels were measured using a survey meter at locations around the solenoid magnet at the conclusion of tests for various solenoid current levels. Figure 7 shows stabilization (under equilibrium conditions). The actual results measured behind the solenoid (upstream) and 132 cm downstream of solenoid (gun exit) at 175 MV/m. (A magnet current of 250 A corresponds to a peak solenoid field of 0.6 T.)

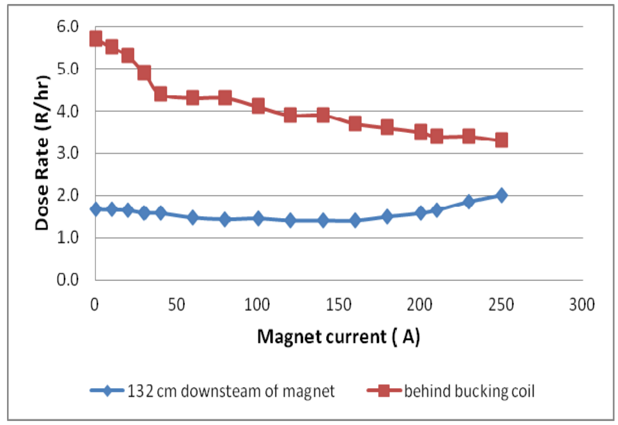

Figure 8. Radiation dose rate vs. solenoid field

Summary

Initial testing of a 5.5 cell X-band RF gun has been completed. The test duration was approximately 175 running hours in which 6200 breakdown events were recorded. Nearly all rf breakdown events occurred without an accompanying change in vacuum which remained at or below 1nTorr.

Significant dark current was measured during testing with 0.9 nC/pulse measured at 186 MV/m. and more than 1 nC/pulse is expected at 200 MV/m.

Radiation measurements were performed around the gun at 18 MW (171 MV/m) . Typical values directly behind the solenoid were 3-6 R/h while downstream of the gun (and Faraday cup) they were 1.5-2 R/h. The highest readings were directly at the Faraday cup which saturated the survey meter at only 8 MW.

The frequency spectrum of the gun before and after testing was virtually identical.

The assembly has now been moved to the XTA facility, awaiting further testing.

References

[1] A. E. Vlieks et al. in *High Energy density and High Power RF 6th Workshop*, AIP CP807, p358 (2003).

[2] HFSS (High Frequency Structure Simulator) is a product of ANSYS Corporation