THE CONSTRUCTION AND INITIAL HIGH POWER TEST
OF AN X-BAND RF GUN

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Abstract

The collaboration between the UC Davis Department of Applied Science (DAS), and the Synchrotron Radiation Research Center (SRRC) has reached high power test stage. An X-Band (8.5 GHz) high power rf cavity and a pair of solenoids were constructed at SRRC and installed at UC Davis at LLNL. The initial high power test results are presented.

1 INTRODUCTION

The requirements of high brightness and high intensity for relativistic electron beams for Free Electron Laser (FEL) and laser scattering and acceleration experiments have made the photoinjector an attractive source.

A collaborative research effort for the rapid development of the X-Band photoinjector system has been formed between UC Davis DAS, and SRRC. The high power, ultra-high vacuum, brazed structure was constructed at SRRC. The gun was installed and characterized at LLNL by the UC Davis DAS personnel and the SRRC staff.

2 DESIGN AND CONSTRUCTION

Extensive simulation runs using the codes SUPERFISH and PARMELA predict an energy of 4.3 MeV with a peak gradient of 150 MV/m, corresponding to a drive power of 9 MW [1]. With a microbunch charge of 0.1 nC, the predicted transverse, rms, invariant emittance is less than 1 p mm-mrad at the gun exit. The energy spread for this case is 0.31 %. A prototype X-Band rf accelerator cavity has been fabricated at SRRC, and has been characterized and optimized at UC Davis DAS [2].

The 3-D drawing of the high power cavity constructed is shown in Fig. 1.

A 22.5 cm long, 200 turn, 3.400 kG solenoid is installed at the exit of the rf gun for focusing the diverging beam. An identical bucking solenoid is located at an equal distance behind the cathode plane, providing zero field on the cathode surface where the electron beam is photoemitted.

The measured field profile at the maximum drive current of 256 amps is found to be in excellent agreement with the simulation.
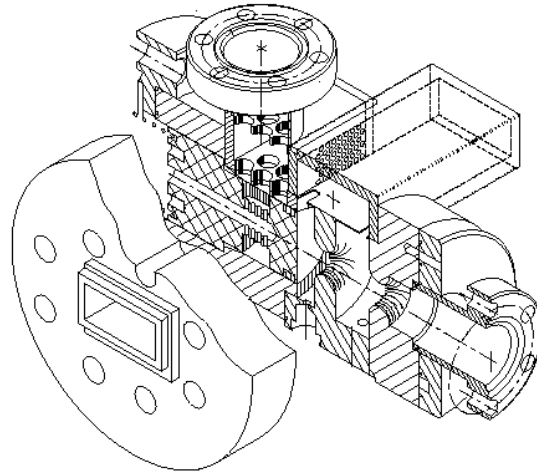

Figure 1: High power cavity 3-D drawing.

The first brazed RF accelerator cavity that was produced had a few problems. The brazing joints between the various cavity components failed between the water cooling channel and the inner surface of the RF cavity. All cavity leaks were sealed with vacuum epoxy. External cooling was applied in the form of heat sink and copper tubing wound around the body of the accelerator cavity.

3 HIGH POWER TEST RESULTS

Final cold test adjustments of the high power cavity were performed to achieve critical coupling, regardless of field balance. As verified by measurements with the Klystron presented later in this section, the cavity resonances were separated by a few MHz. Fortunately, critical coupling of the Klystron signal corresponded to half cell coupling. Critical coupling allowed the accelerator to be safely used as a resonant load for the Klystron despite this non-optimized condition. In addition, since the half cell was energized, high energy photoelectron production is still possible. Acceleration of field emission electrons is presented later in this section.

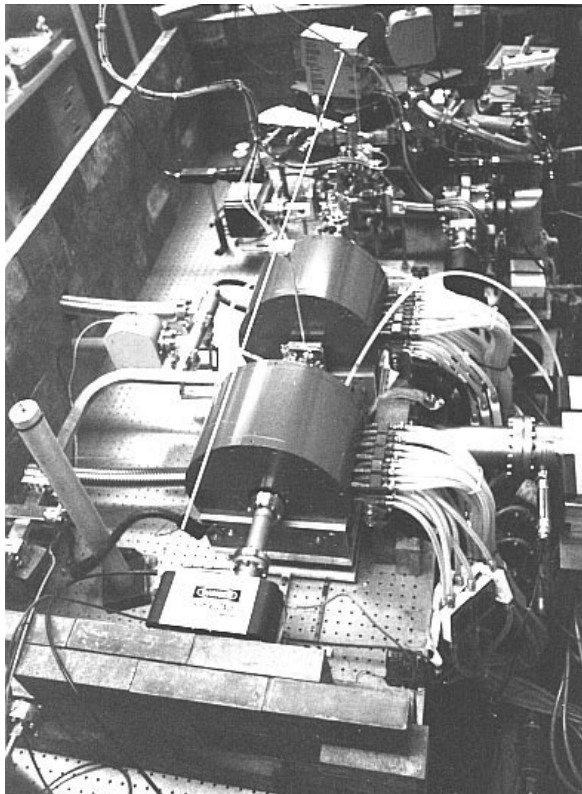| Day	Peak Input Power [kW]	Repetition Rate [Hz]	Conditioning Time [Hours]
1	17	2	2
2	78.5	5	4
3	188	30	4
4	480	30	4
5	1500	20	4
7	1910	20	4

Table 1: Initial RF Conditioning Summary

Figure 2: Complete Photoinjector Beamline

The RF cavity was baked at 125 $^{\circ}$C for four hours prior to final installation in the RF system. The experimental apparatus is shown in Fig. 35. The base pressure obtained after the bake was in the range of 10^{-9} Torr. The waveguide feed and RF cavity vacion pumps were in the low 10^{-9} Torr range when high power RF operation was initiated. An attenuator between the TWTA and Klystron reduced the RF power production of the Klystron in the early stages of RF conditioning. The modulator was operated up to a 30 Hz repetition rate, which greatly reduced the conditioning time required to reach the MW level of drive in the RF cavity. The initial progress of the RF conditioning is summarized in Table 1. Figure 2 shows the whole experimental setup.

For the initial measurements of the dark current signal from the RF gun, a Faraday cup consisting of a ceramic DC break and a blank conflat flange was attached

directly to the output of the accelerator. Resistors were attached across the ceramic break to provide a return path for the electron dark current. A matched load of 50 W was constructed using 20 1 kW Carbon resistors in parallel. This arrangement minimizes inductance and allows measurement of short time scale events. Very large electron current signals were measured when arcing occurred inside the RF cavity. These corresponded to electrons drawn from a plasma in the gun. Vacuum levels as measured by Vacion pumps near the accelerator cavity reached the 10^{-7} Torr range following especially large RF breakdown events.

The peak charging voltage seen by the capacitance of the scope and coaxial cable gives the total charge collected during each RF pulse. Assuming that the RF pulse length remains constant, the collected charge corresponds to the current level during the RF pulse. The electric field scaling inside the RF cavity is found directly by taking the square root of the drive power. These power levels can be scaled to the expected gradient on the photocathode surface given the simulated correspondence between the cathode gradient and drive power (Fig. 3).
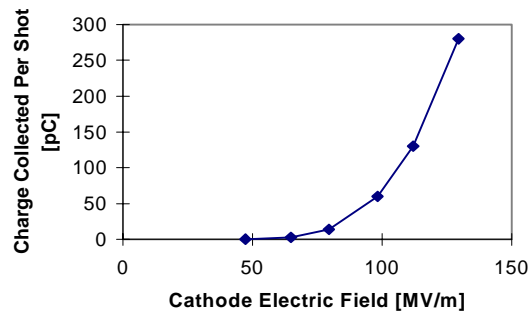

Figure 3: Dark Current Charge Collection

Given the form of the dark current, a plot of $\ln\left(\frac{Q}{E^2}\right)$ versus $\frac{1}{E}$ indicates field emission scaling, as shown in Fig. 4. The electric field in this case is determined using the square root of the drive power multiplied by a factor that gives the cathode field for a balanced p-mode. The points fall along a fairly straight line, indicating field emission current, as opposed to emission due to other mechanisms. The linear fit of the data points, and an extrapolation to the expected dark current level corresponding to an acceleration gradient that produces 4.3 MeV electrons is displayed as the top point on the trace. The expected integrated charge at that gradient is ~ 1.6 nC, corresponding to an average current of 0.8 mA, compared to 1 kA of peak current for photoemitted electron bunches with 1 nC of charge emitted in 1 ps.
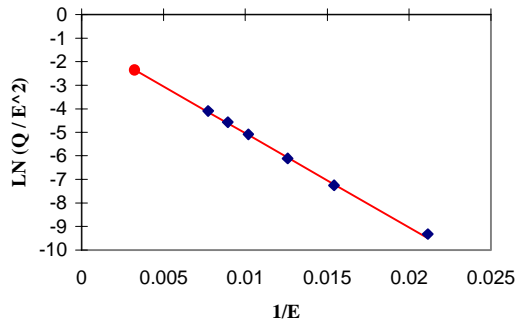
Figure 4: RF Cavity Fowler-Nordheim Field Emission Curve

The horizontal and vertical steering of the crossed dipole electromagnets were used on separate occasions to characterize the energy of the dark current beam. Since the profile did not distort significantly with steering, one can assume that the dark current spot on the phosphor screen was fairly monochromatic, as indicated by the Fowler-Nordheim field emission dependence. Electrons with energy significantly lower than the phosphor spot were likely overfocused by the solenoids and spilled on the walls of the laser feedthrough or gate valve. This may explain why the beam which did propagate the entire 35.85 in from the photocathode plane to the phosphor screen appeared to have a relatively small energy spread. The result of the first dipole scan of electron energy is shown in Fig. 5. The linear fit of the deflection versus drive current indicates electron energy of 321 keV, gained by the electrons in the first cell (5.42 mm).
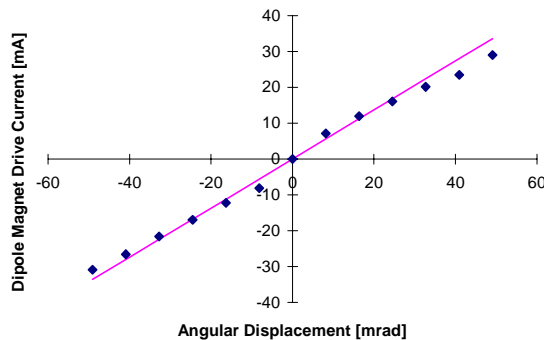

Figure 5: First Energy Scan: 0.321 MeV Electrons

4 SUMMARY

The cavity was conditioned to the multi MW level, with peak surface fields in excess of 150 MV/m. Field emission or "dark" current measurements were performed, and matched to theoretical expectations. Electron energy was also measured. Phase noise and jitter characteristics were measured for the TWTA, Klystron, and resonant accelerator cavity. Phase stabilization measurements were conducted with the high power cavity at the multi MW, >150 MV/m level.

Despite the limitations of the first attempt for the high power cavity and the absence of a functioning pump laser, valuable data and experience were obtainable with the parts that were available. Input power levels in excess of 2 MW were applied to the resonant cavity. Processing of the accelerator from the 200 kW level to the 2 MW level was achieved in less than 1 week. Accelerating gradients (at the photocathode) in excess of 170 MV/m were verified. A beam generated by field emission was transported through the beamline and diagnostics. Beamline focusing and steering elements were utilized, and the field emission electron energy was determined.

With a second attempt at a balanced, leak-free cavity and a stable laser system proceeding, the data presented in this section represents the complete operation of the high power RF system, and the complete characterization of the resonant accelerator cavity.

5 ACKNOWLEDGMENTS

6 REFERENCES

[1] G.P. Le Sage, et al., "A Ghz Repetition Rate X-Band Photoinjector", in AIP Proc. for the 7 th Workshop on Advanced Accelerator Concepts(Oct. 12-18, 1996, Lake Tahoe, California, USA).

[2] C.H. Ho, et al., "The Design and Fabrication of an X-Band RF Gun", in AIP Proc. for the 7 th Workshop on Advanced Accelerator Concepts(Oct. 12-18, 1996, Lake Tahoe, California, USA).