Beam Measurement of Photocathode RF Gun

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Abstract

Test cavities for the photocathode RF gun were built and they have been operated for beam measurement at SPring-8. High power RF tests of up to 18 MW for these cavities were performed. The electric field gradient on the cathode reached 127 MW/m. On February 15th, a laser pulse was irradiated on a copper cathode and the first photo-emitted beam was accelerated up to 2.9 MeV. The effective quantum efficiency of the cathode was obtained by changing laser power and field gradient. The emittance of the beam was also measured and compared with the results of a computer simulation.

1. Introduction

A photocathode RF gun is promising as an optional injector for the SPring-8 linac since the beam emittance is expected to be much lower than that of the present thermionic. This feature can enable such future applications of the linac as a single-pass FEL based on SASE, which requires a normalized emittance of 1πmm mrad.

For the optimization of an RF gun system, an experimental and a simulation study [1] are being conducted in parallel. The purposes of this experiment are to develop a reliable simulation code by comparison with experimental results, confirm the stable operation of the RF cavity in a high gradient field environment, and establish the effectiveness of cavity surface treatment for the reduction of dark current. Furthermore, technical problems concerning the operation of the RF gun system show up clearly. In this paper, the results of the RF gun experiment and simulation in 1999 are described.

2. Experimental Setup

2.1 Gun Cavity

A single-cell RF cavity was designed with a computer code, MAFIA. The field distribution of a single-cell cavity is considered to be simpler than that of multi-cell cavities and is preferable for comparison with the simulation results. The accelerating gap length was determined by TS2 simulation to minimize the emittance, and the dimensions such as coupling hole size and cell radius were obtained by a 3D electromagnetic field solver. A picture and a schematic drawing of the cavity is shown in Fig. 1.

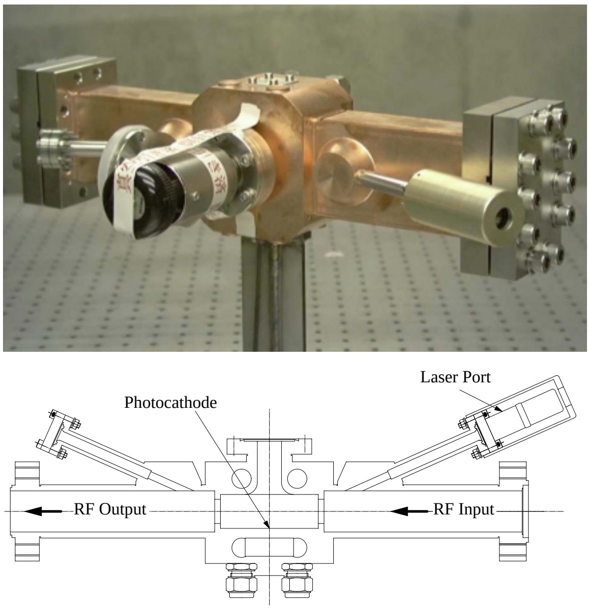

Fig. 1 Test cavity of photocathode RF gun.

A cavity wall made of OFHC copper was used as a photocathode. Two quartz windows for laser injection were located with an angle of 24 degrees from the cathode plane. Two coupling ports were adopted to improve the field symmetry and shorten the filling time. The displacement of the field center from the geometrical center of the cavity was thus 0.13 mm, while it was 0.55 mm for the single coupling port cavity. By connecting a dummy load to the output coupling port, the Q value of the cavity was reduced and the filling time was shortened. A shorter filling time enables a higher field gradient, more stable operation and a reduction of dark currents. A higher field gradient is needed to check the simulation results.

2.2 Laser

The seed laser used in this experiment was a cw mode-locked Nd:YLF laser (Lightwave Model 131) with a repetition rate of 178.5 MHz. A single IR pulse sliced by a Pockels cell was amplified by flash-lamp-pumped regenerative amplifiers at a repetition rate of 10 Hz. Then fourth harmonic photons were generated with two BBO crystals. A UV pulse with a wavelength of 262 nm and a pulse duration of 10 ps was transferred into the radiation-shielded area and focused on the gun cathode. The maximum energy of the laser pulse is about 2mJ at 262nm.

2.3 RF System

A block diagram of the high power RF system is shown in Fig. 2. A 35 MW klystron was installed at the RF gun test area located in the Machine Laboratory Building next to the 1 GeV linac. RF power generated from the klystron is divided into two waveguides, and one is fed into the gun cavity while the other is fed into a dummy load. The RF power divider consists of a Magic Tee, a phase shifter and a 3 dB coupler and is capable of dividing power in an arbitrary ratio. There is an RF window between the waveguide system and the cavity. The vacuum pressure in the cavity is kept lower than 10^{-5} Pa with a 100 l/sec sputter ion pump. The RF power can be monitored through the directional couplers (DC1~5) shown in Fig. 2.

The klystron drive frequency of 2.856 GHz is generated by a 178.5 MHz RF signal from the seed laser.

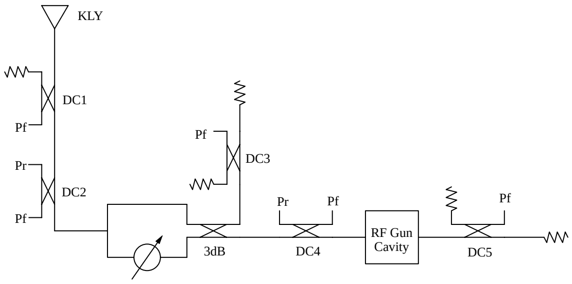

Fig. 2. Block diagram of high power RF system.

2.4 Beam Diagnostic System

As shown in Fig. 3, the beam transport line consists of two solenoid magnets, two pairs of X-Y slits, a wall current monitor, two screen monitors, an energy analyzing magnet and a Faraday cup. All components are mounted on an optical table. We do not use a return yoke plate for the solenoid magnets, because the field distribution of such a coil can be solved easily and included into the simulation code. These magnets are only used to transport the beam with appropriate beam size but not optimized to minimize emittance. Two pairs of X-Y slits are used for emittance measurement.

In the measurements mentioned below, it was found that the field distribution of solenoid magnets was distorted by the optical table which is made of magnetic material. As a result, a horizontal deflection of the beam occurred. A steering magnet was installed to compensate the beam deflection due to the solenoid field. This optical table was replaced with a non-magnetic table and the magnetic field distribution was improved.

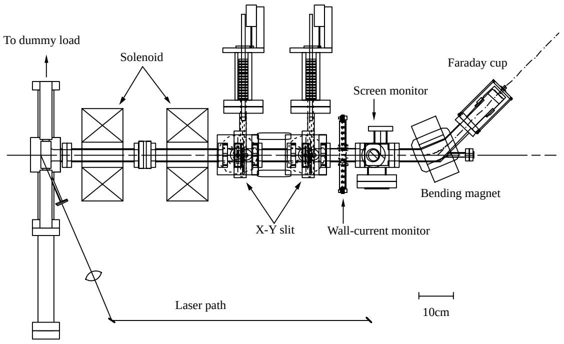

Fig. 3. Layout of beam diagnostic system.

3. High Power Test

The RF conditioning of the cavity was performed with a pulse duration of 1 μsec and a repetition rate of 10 Hz. The vacuum in the cavity was kept lower than 1×10^{-4} Pa during the conditioning. The RF power fed into the cavity reached 18 MW after six hours of operation. The maximum RF power was limited due to klystron problems.

Figure 4 shows typical RF wave forms at the upstream and downstream of the gun cavity. The electric field strength in the cavity saturated within 1μsec, although some reflection effects due to the lack of an RF circulator could be seen on the wave forms. The pulse duration could be shortened during a single bunch mode to reduce dark currents and achieve a more stable operation in a higher field gradient.

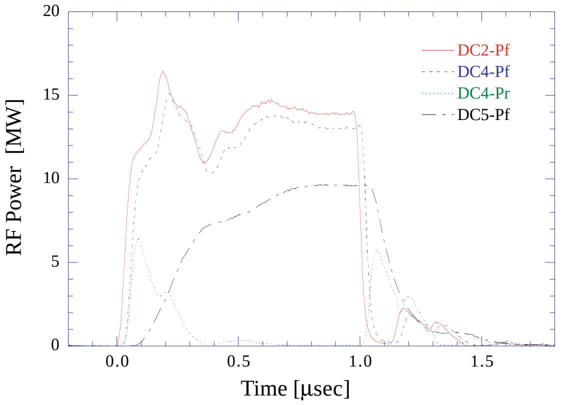

Fig. 4. Typical RF wave forms.

The dependence of the dark current on the field gradient is shown in Fig. 5. Dark currents were measured using a Faraday cup directly connected to the cavity. The peak current increased exponentially with the increase in the field gradient. It reached 10 mA when the field gradient was 121 MV/m. The dark current will decrease largely along the transport line with solenoid fields.

Since no continuous RF breakdowns and beam loading effects on reflection or transmitted RF power from the cavity were observed at this power level, the field gradient could be further increased.

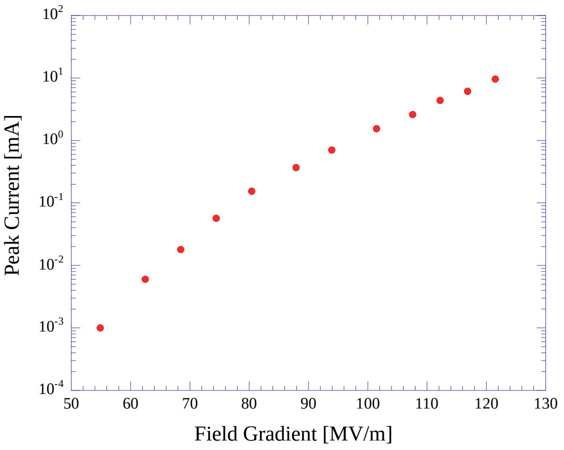

Fig. 5. Dark current as a function of field gradient.

4. Beam Measurement

4.1 Energy

After the RF conditioning of the cavity, a laser pulse was irradiated on the cathode and the photo-electrons were accelerated. The center beam energy was 2.6 MeV and energy spread was about 10% when the input RF power was 18 MW. The field gradient on the cathode reached 127 MV/m. These results agreed with the simulation results.

4.2 Quantum Efficiency

The effective quantum efficiency was measured by connecting a Faraday cup directly to the cavity. A pulsed signal of the current was flattened by an RC filter with a time constant of 1.7 second. The contribution of dark currents was subtracted.

Figure 6 shows the bunch charge as a function of irradiated laser energy when the field gradients were 90 and 124 MV/m.

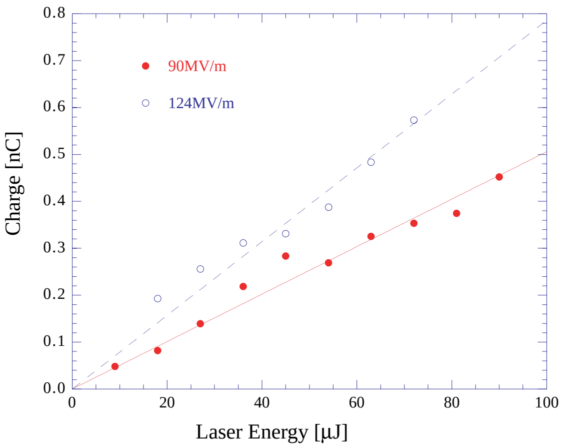

Fig. 6. Beam charge as a function of laser energy.

The RF phase was adjusted to obtain a maximum charge. From the slope of these data, the effective quantum efficiency for 90 MV/m case was found to be 2.4×10^{-5}. It was enhanced to 3.7×10^{-5} in the case of 124 MV/m by Schottky effect. Though the laser power was sufficient to produce a charge of more than 1 nC under this condition, it was not possible to transport whole charge against the space charge force without solenoid magnets. In order to improve the quantum efficiency, a laser cleaning of the cathode and change of laser polarizing angle will be effective.

4.3 Emittance

Beam emittance was measured using double slits. The result is shown in Fig. 7. The minimum emittance of about 17πmm mrad was obtained at an initial RF phase around 60 degrees and was almost consistent with the simulated result. The simulation predicted that a higher field gradient would decrease the emittance. It can be about 7.5πmm mrad if the field gradient becomes 140MV/m which is possible after klystron improvement.

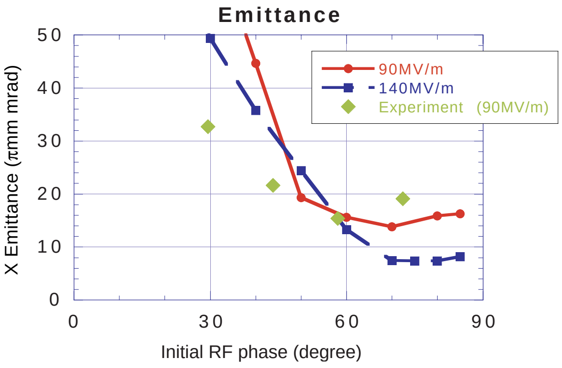

Fig. 7. Emittance as a function of initial RF phase.

5. Conclusion

The fabricated gun cavity showed the expected performance in experiments conducted so far. In order to investigate the beam characteristics in a higher field gradient, klystron power needs to be increased. Present laser power is not stable enough for measurement. Precise measurement of emittance and bunch length will be major activities in the next phase of this experiment. Furthermore, another two cavities will be evaluated to confirm the effectiveness of surface processing on the reduction of dark current.

References

[1] A. Mizuno *et al.*, Proc. of 1999 Particle Accelerator Conference, p.2749, New York, April 1999.