# **UPGRADE OF A PHOTOCATHODE RF GUN AT SPRING-8**

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#### Abstract

A new test bench for a photocathode RF gun has been built to verify the beam characteristics in higher energy regions up to 30 MeV and develop a sophisticated injector system for practical use. The accelerator room has been expanded, and two beam lines including a 3-m long accelerating structure, have been installed. A clean room for the driving laser system was also expanded in which the air temperature control was improved and higher humidity could be maintained to reduce the charge-up on the optical elements. RF conditioning has been completed and the electric field gradient on the cathode of the RF gun reached up to 183 MV/m. The first beam has been successfully commissioned and a new emittance monitor using the quadrupole scan has been tested. We have investigated a new gun cavity system to improve the emittance in higher charge regions exceeding 1 nC/bunch. Presently we are investigating a multi-cavity system, in which the current single-cell cavity is used as the first cavity. According to a simulation result, the normalized emittance of 2.4  $\pi$ mm•mrad can be achieved in a two-cavity system at a charge of 1.4 nC/bunch. The second RF cavity and a high power distributor system have been also designed.

#### INTRODUCTION

A photocathode RF gun has been investigated at SPring-8 to develop a low-emittance and short-bunch injector for the linac. We commenced this R&D with a single-cell cavity in which the inner copper wall was used as a photocathode. This cavity has an output port for extracting a part of the RF power and the loaded Q is lowered. This enables to shorten the filling time and achieve a higher-gradient field.

Using this cavity, we have examined dependences of beam characteristics on RF, solenoid fields and laser

parameter and phenomena in a high-gradient field situation such as RF breakdown, dark current and so on. In these experiments, the lowest emittance of  $2\pi$  mm•mrad at a beam charge of 0.1 nC/bunch [1] and a maximum field gradient of 175 MV/m at the cathode surface has been achieved [2] and we understood how to control parameters to minimize the beam emittance.

The next step of this R&D project is to verify the beam performance, especially the emittance, in the higher beam energy region because the single-cell cavity can only accelerate beams up to 4.1 MeV and the emittance can easily grow in this energy region. There were some problems in the laser system. A fluctuation of the air temperature in the clean room made the laser unstable and a charge up on optical elements collected dust and cause damages. To improve these problems, a new test bench has been constructed that includes an expanded radiation shield and an air temperature- and humiditycontrolled clean room for the driving laser system. The construction began in March 2003 and was completed in December of that year. In parallel with the experiments using this facility, a new gun system is under investigation to achieve a lower emittance in highercharge regions.

### NEW TEST BENCH

As shown in Fig. 1, the test bench is located in Machine Laboratory building, which can be connected with the linac building at the L1 beam transport line (250 MeV) by removing a concrete plug. Therefore, in the future it will be possible to inject the electron beam produced by the photocathode RF gun into the 1-GeV linac.



Figure 1: Location of new RF test bench. (a: Clean room for driving laser system, b: Radiation shielded accelerator room, c: Klystron and modulator) #ihcuinat@spring8.or.jp



Figure 2: Layout of 30-MeV linac with photocathode RF gun.

A 3-m travelling wave structure has been added after the RF gun and the approved maximum beam energy has been increased from 4.5 MeV to 30 MeV. The thickness of the concrete shield has been increased from 0.5 m (partly 1.0 m) to 1.4 m, while the floor area of the accelerator room has been expanded to make it three times larger. This test bench will be used not only for the photocathode RF gun R&D but also for high-gradient tests in collaboration with other institutes and highpower tests of RF components before installation in the 1-GeV linac and so on.

There are two accelerators in the radiation shield. One is a 30-MeV linac with the photocathode RF gun and the other is a standalone RF gun for photocathode experiments. The latter includes experiments for cartridge-type electric tube with Cs2Te cathodes [3]. The layout of the 30-MeV linac is shown in Fig. 2.

The RF source is an 80 MW klystron (Toshiba E3712), and the RF power is distributed into two RF gun cavities and a 3-m long travelling wave accelerating structure, which is the same one as is used for the SPring-8 1-GeV linac.

As shown in Fig. 3, the high-power RF distributing system comprises magic-tees, 3-dB directional couplers, phase shifters, dummy loads, RF windows and so on. A combination of a magic-tee, a phase shifter and 3-dB directional coupler divides RF power into two waveguides in an arbitrary ratio. Therefore, the RF power and phase for the two RF gun cavities and the travelling wave structure are variable in this distributing system.



Figure 3: High-power RF distribution system. (G1: RF gun cavity #1, G2: RF gun cavity #2, KLY: 80 MW klystron, ACC: 3-m travelling wave structure)

A feature of this system is that there is no circulator to protect the klystron from the reflected RF power because the loaded Q value of the RF gun cavity is lowered to one fourth of that for typical standing wave cavities by extracting some of the power, and then the reflected power is much smaller -- like travelling wave structures.

Regarding the driving laser system, a highly stabilized and profile-controlled system has been under development in a new clean room with a cleanness of class 1000 [4]. The total floor area of the clean room becomes 2.7 times larger than the previous one. The air temperature near the laser table is stabilized within 0.6 degree and the humidity is kept at around 55% R.H. to minimize the charge-up and avoid damages on the optical elements. The down-flow of the air is dispersed to decrease the fluctuation of the laser path. To maintain the cleanness of the air, the previous clean room is used as an anterior chamber of the new one.

### **RECENT PROGRESS**

Following the installation of the accelerator system, automated RF conditioning for waveguides and RF cavities was performed successfully.

We tested a chemical etching method for surface treatment of the RF gun cavity to improve the quantum efficiency (QE) and high-gradient performance qualities such as the RF breakdown rate and dark currents. As a result, the conditioning time was clearly shortened, achieving a maximum QE of  $8.6 \times 10^{-3}$ % for our cathode and a maximum field gradient on the cathode of 183 MV/m [5].

Beam acceleration was also successful, and an emittance measurement by using the quad-scan method was tested for a 24.5-MeV beam [6].

R&D concerning the driving laser system is focused on laser pulse shaping in both the spatial and temporal dimensions which is required for the emittance reduction. A deformable mirror system for spatial shaping and a spatial light modulator based on a fused-silica plate for temporal shaping, are under development [4].

# **MULTI-CAVITY RF GUN**

We are currently investigating an RF gun system that can attain lower emittance in higher-charge regions. In order to reduce space charge induced emittance growth at higher bunch charge while maintaining a high-gradient acceleration using our low-Q cavity, an addition of RF cavities after the current cavity has been investigated. The acceleration by single-cell cavities will also be effective for the emittance reduction because a field gradient can be higher than that of the disk-loaded accelerating structures. In the following subsections, the result from a computer simulation, a design of the RF cavity and a new configuration of the high power RF distributor are described.

#### Simulation

The beam dynamics in a two-cavity RF gun have been investigated by using a simulation code PARMELA. As a result of an optimization for the RF phase and field strength, it was found that the beam emittance could be lowered to 2.4  $\pi$ mm•mrad at a charge of 1.4 nC/bunch, which is lower than that of current single-cell cavity system. Fig. 4 shows an example of the beam emittance along the beam line.



Figure 4: Simulated result for emittance in a twocavity RF gun.

# Design of RF cavity

In the simulation, optimum RF phase and field strength for the two cavities are obtained. Then a realistic RF cavity for the second one was designed using a 3D field solver code, MAFIA.

To maintain high-gradient performance and employ the present RF distribution system, a low-Q type cavity is adopted. The external Q value for the output port was determined considering the RF distribution system described in the next subsection. Relevant parameters for the second cavity are listed in Table 1.

Table 1: Design parameters for second and third cavities.

Radius of beam pipe	10 mm
Curvature radius of cavity nose	5 mm
Cavity length	38 mm
Q <sub>0</sub>	15,800

Q <sub>ext</sub> for input port	3,160
Q <sub>ext</sub> for output port	3,950
Loaded Q	1,580
Shunt impedance for $\beta=1$	5.3 MΩ
Maximum accelerating field gradient	100 MV/m

# High-power RF system

We are currently investigating the two-cavity system, but simulation results indicate an effectiveness of threecavity system for the emittance reduction. Therefore, a high power RF distributor for the three-cavity RF gun has been designed. If we adopt the low-Q type cavity, the required total RF power will exceed the maximum power of the klystron, i.e., 80 MW. One option for solving this problem is to install an RF compression system such as SLED. However, we selected another system that utilize the output power from our low-Q type cavity and minimizes the cost. However, the filling time of the first cavity becomes longer. Fig. 5 illustrates the high-power RF distribution system for the three-cavity RF gun.



Figure 5: High-power RF distribution system for the three-cavity RF gun system. (C1~C3: Three-cavity RF gun, G2: RF gun cavity #2, KLY: 80 MW klystron, ACC: 3-m travelling wave structure)

This system can divide the RF power and feed it into the second and third cavities in any arbitrary ratio. The output power from the second and third cavities are subsequently recombined in a power distributor and fed into the first cavity, which requires the highest RF power of all three cavities. Use of this system enables the RF power and phase for the three cavities being tuneable.

For a fast switching between the experiments using the 30-MeV linac and that using RF gun #2, we will install a vacuum-type waveguide switch in the waveguide before the second cavity.

## CONCLUSION

The construction of the new test bench for the photocathode RF gun R&D has been completed, and the 30-MeV linac and the standalone RF gun for the cathode development are now ready for further experiments.

We are planning to measure and optimize the emittance of the beam that is produced from the RF gun and accelerated up to 30 MeV. The optimization includes a shaping of laser pulses in both the spatial and temporal dimensions, RF phase and field strength of each cavities, solenoid fields and so on.

To attain practical use of a photocathode RF gun, a new cavity system is under development that is designed to lower the beam emittance in higher-charge regions exceeding 1 nC. Presently a multi-cavity RF gun is a

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promising candidate for the above requirement with simulation work and RF design continuing.

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