Photocathode RF Gun Development for SPring-8 Linac

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1. Introduction

A photocathode RF gun is under development for an optional injector of the SPring-8 Linac. Since an electron bunch emitted from a photocathode by laser is accelerated rapidly in an RF cavity, the emittance growth due to the space charge force is suppressed compared to DC gun system. This new electron gun system is needed for future applications of the linac such as a single pass FEL based on the self-amplified spontaneous emission which requires smaller emittance and higher peak current.

In order to design a prototype RF cavity, the beam dynamics in the cavity has been studied by using a computer simulation code MAFIA[1]. It was found that the high gradient accelerating field such as 100MV/m is required to minimize the space charge effect and produce smaller emittance beam. On the other hand, the dark current becomes large as the field gradient becomes higher and causes RF breakdown in the cavity. Furthermore, the simulation predicts the emittance growth due to the RF field at the field gradient of more than 150MV/m.

The preparation of an experimental study is also started. The purposes of this experiment are (i) to confirm a stable operation of the RF cavity under the high gradient field environment, (ii) to confirm the effectiveness of surface treatments for the reduction of the dark current and (iii) to accelerate photoemitted electron beam and compare the beam characteristics to those obtained from the simulation.

For this experiment, a single cell cavity was designed and fabricated. A single cell was chosen as a cavity structure because the field distribution is more simple than that of multi cell cavities and preferable for the comparison with the simulation. Copper was chosen as a photocathode material because the laser power is enough to produce the electron charge of 1nC/bunch and the structure of cavity can be very simple. In order to reduce the dark current, a pure water rinsing and TiN coating are tested as the surface treatment.

2. Simulation Study

The beam acceleration in a single cell cavity was simulated by using a 2D PIC code, MAFIA TS2. In order to obtain an optimum shape of the cavity, the beam characteristics was surveyed by changing the initial RF phase at which the bunch is on the cathode. It was found that the emittance was minimized for the initial RF phase of 40 degree. The nose radius at the gun exit was determined so that the peak surface field became maximum at the cathode.

Using an optimum cavity shape described above, the precise simulation was performed changing with the field gradient on the cathode. Fig. 1 shows the normalized rms emittance as a function of the distance from the cathode. The beam energy is 2.2MeV at the gun exit in the case that the electric field on the cathode is 100MV/m. As seen from the figure, the emittance growth due to the space charge effect near the cathode is reduced as the field gradient becomes higher. However, the emittance at the gun exit becomes larger as the field gradient is more than 250MV/m. Fig. 2 shows the bunch length along the beam line. From these results, the optimum gradient is around 150MV/m.

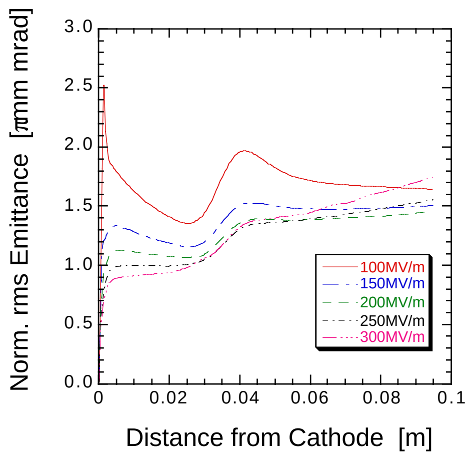

Fig. 1 The normalized rms emittance as a function of the distance from the cathode. Electric field gradient on the cathode is varied from 100MV/m to 300 MV/m.

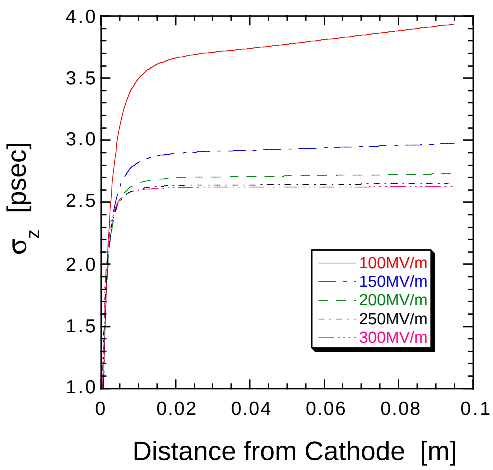

Fig. 2 The standard deviation of the bunch length as a function of the distance from the cathode.

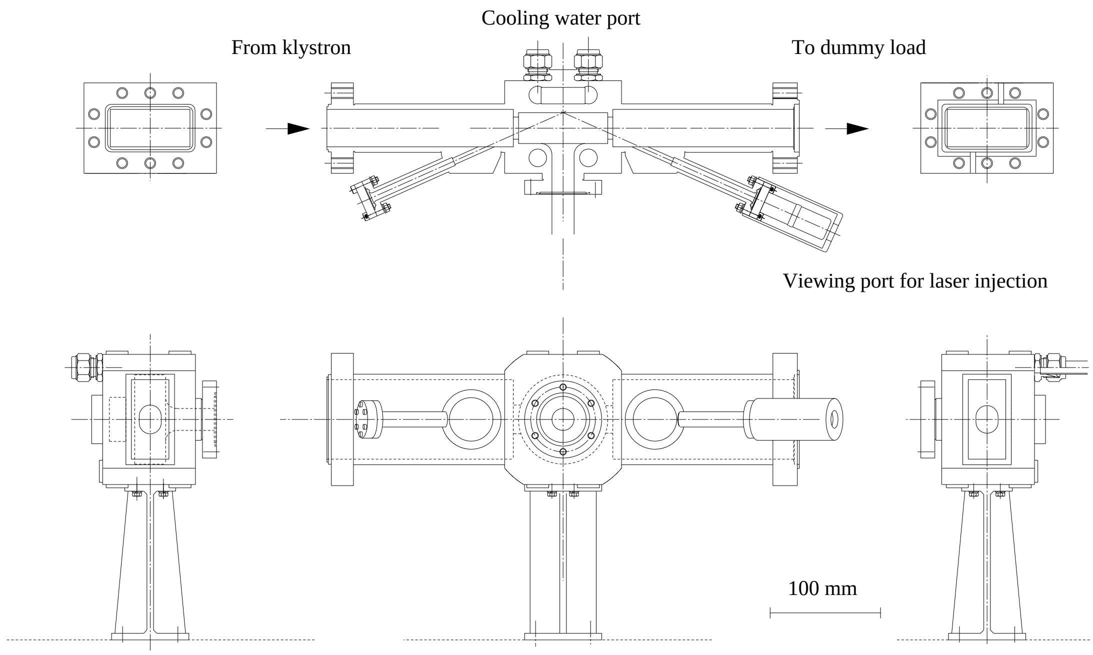

Fig. 3 The schematic of high power model cavity.

3. High Power Model Cavity

A single cell S-band cavity was designed. The schematic drawing and design parameters of this cavity are shown in Fig. 3 and Table 1 respectively.

Table 1
Design parameters of high power model cavity.

Frequency	[MHz]	2856
Number of cells		Single
Accelerating gap	[mm]	28
Bore diameter	[mm]	20
Intrinsic Q value		13000
External Q value for output port		3684
External Q value for input port		2786
Loaded Q value		1414
Filling time	[μsec]	0.16
Shunt impedance (for β=1)	[MΩ]	1.16
E_{max} / $E_{cathode}$		1.09
Incident angle of laser	[deg]	90 / 24

The accelerating gap of the cavity was determined so that the emittance became minimum in MAFIA TS2 simulation.

There are two coupling port in this cavity to improve the field symmetry and shorten the filling time. The field symmetry is important to avoid the transverse kick effect due to the dipole component of the accelerating field. The displacement of the field center to the cavity center was calculated by MAFIA and it was 0.13mm as against 0.55mm in the case of one port.

The shorter filling time enables the higher field gradient or more stable operation. By connecting a dummy load to one coupling port, the Q value of the cavity can be reduced and the filling time becomes shorter. In this design, it is shorter than one fourth of the one port case. Furthermore, the matching condition of the input port is kept in this cavity even if the beam loading of the dark current becomes larger. This allows the absence of the circulator between the cavity and klystron.

The couplings between the cavity and the waveguides were determined by a simulation of Slater's tuning method using MAFIA. At first, the external Q for the output port, Q_{ext1}, was calculated, then the external Q for the input port, Q_{ext2}, was tuned so that $1/Q_{ext2}=1/Q_0+1/Q_{ext1}$. The calculated value agreed with the measured one within 10%.

The cell radius, by which the resonant frequency of the accelerating mode was tuned, was roughly estimated by using MAFIA and finally determined by a measurement of a low power model cavity. The discrepancy between MAFIA calculation and the measurement was within 2MHz that is about 30μm in the cell radius.

The maximum field gradient appears near the rounded corner at cavity exit. The ratio of the maximum gradient and that on the center of the cathode is 1.09. The accelerating field gradient can be lager as this ratio is smaller. In the single cell cavity, it becomes smaller than that of disk-loaded cavities.

The reduction of the dark current is needed for a stable operation in a high field gradient. Furthermore, the dark current produces undesirable gamma-ray background for the inverse Compton scattering.

The cavities are machined from OFHC copper blocks in which micro pores are reduced by Hot Isostatic

Pressing (HIP).

It was demonstrated that the high pressure ultra pure water rinsing and use of Ti were effective for the reduction of the dark current.[2] To confirm the effectiveness of these treatment, three types of cavity with different surface treatments, normal treatment, pure water rinsing and TiN coating, was fabricated.

The magnitude of the dark current depends on the cleanliness of the cavity surface. A pure water rinsing removes dusts and impurities.

Use of Ti for the cavity surface is also effective for the reduction of the dark current since its secondary field emission coefficient is less than unity. The technique demonstrated before was to braze Ti on the top of disk, however, we adopt TiN coating on the cavity surface. The thickness of TiN is controlled less than 100 nm to reduce the surface loss as small as possible.

4. High Power Experiment

A high power test facility for the RF gun is under construction in the Machine Experimental Hall connected to the linac building at 250 MeV point. A 35MW klystron and a modulator which had been installed at M1 section (positron converter) of the linac were moved to the Machine Experimental Hall. The beam line which consists of the cavity and monitor system is located in a clean booth of class 1000 to avoid the dust contamination during the assembly of cavity and to protect optical elements.

As a first step, a profile monitor, an energy analyzing magnet, beam slits and Faraday cups will be installed to measure the dark current and its energy spectrum. The laser pulse is introduced from out of the radiation shield and injected to the cathode through a quartz window.

5. Conclusion

Simulation and experimental study of photocathode RF gun is going on. High power model cavity for RF gun was designed to study the beam characteristics and phenomena in a high gradient field environment. Two kinds of surface treatment are adopted to reduce the dark current. RF processing of cavities will start in 1998 and beam production by introducing laser pluses will start in the third quarter.

References

[1] M. Bartsh et al., Comp. Phys. Comm. 72, 22-39 (1992).

[2] H. Matsumoto, Proc of the 1996 Int. Linac Conf., Geneva, August, 1996.