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Photocathode RF Gun Study for SPring-8 Linac

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Abstract

A photocathode RF gun has been studied for the upgrade of SPring-8 Linac. The beam characteristics were simulated using MAFIA code and a high power model cavity was designed and under fabrication. A high power test of this cavity is scheduled in next year to study the fundamental characteristics of the RF gun and compare with the simulation.

1 Introduction

A photocathode RF gun has been studied for an optional injector of the SPring-8 Linac[1]. This gun will be used for the future applications[2] of the linac such as a single pass FEL based on the self-amplified spontaneous emission which require smaller emittance and higher peak current than the present one. The simulation study has been done by using a computer code MAFIA[3]. In parallel with the simulation, the preparation of the experimental study is 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 under fabrication. A single cell cavity was chosen because the field distribution is more simple than that of multi cell cavities and preferable for the comparison with the simulation. The surface of the cavity (Cu) is used as a photocathode. The high gradient accelerating field such as 100MV/m is required to minimize the space charge effect and produce smaller emittance beam. Furthermore, higher gradient up to 200MV/m is needed to check the simulation because the simulation predicts the emittance growth due to the RF field at the field gradient of more than 150MV/m[4]. On the other hand, the dark current becomes large as the field gradient becomes higher and causes RF breakdown in the cavity. Therefore, a high pressure ultra pure water rinsing and TiN coating are tested as the surface treatment for the reduction of the dark current.

2 Simulation

A simple single cell cavity is considered to be preferable for the high gradient acceleration because the gradient near the round corner of the gun exit can be smaller and the probability of the discharge will be smaller than the multi-cell cavity. The beam acceleration in a single cell cavity was simulated by using MAFIA code. 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 30 degree. Using an optimum cavity shape described above, the precise simulation was performed changing with the field gradient on the cathode. Parameters used in this simulation are listed in Table 1.

Table 1
Parameters used for MAFIA simulation.

Bunch charge	[nC]	1
Transverse Profile		Flat Top
Spot size on Cathode	[mm]	1
Loguitudinal Profile		Flat Top
Bunch Length	[psec]	10
Initial Emittance	[πmm mrad]	0
Initial RF phase	[deg]	30
Number of Macro Particles		10000

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.

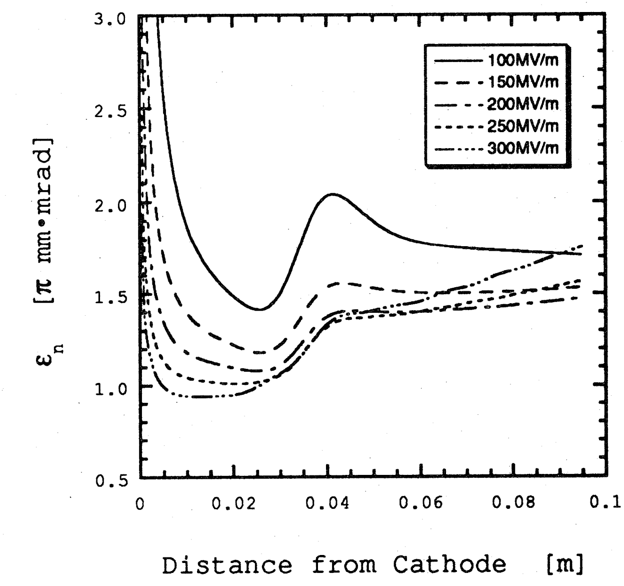

Fig. 1 The normalized emittance in the cavity for different field gradients on the cathode

The bunch length along the beam line is shown in

Fig. 2. The bunch lengthening is significant below the gradient of 150MV/m on the cathode. From these results, the optimum gradient is around 150MV/m.

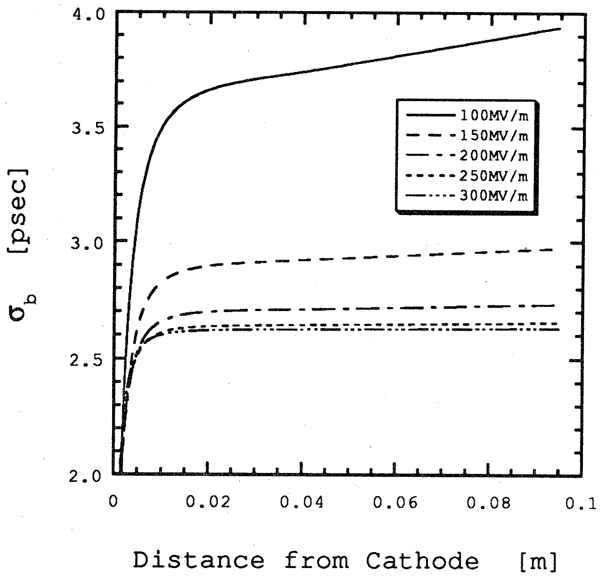

Fig. 2 The bunch length in the cavity for different field gradients on the cathode. The bunch length is shown as the standard deviation of the longuitudinal particle distribution.

3 High Power Model Cavity

3.1 RF Design

For the purposes mentioned above, a single cell S-band cavity was designed. The schematic drawing of this cavity is shown in Fig. 3. The accelerating gap of the cavity was determined so that the emittance became minimum in MAFIA TS2 simulation.

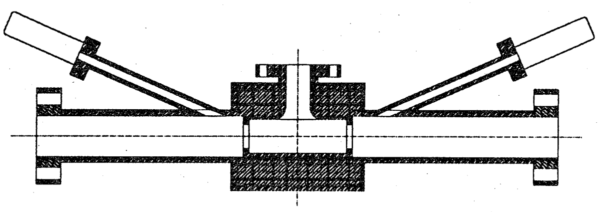

Fig. 3 The cross section schematic of high power model cavity. There are two windows for the laser injection. The incident angle is 24 and 90 degree.

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 as shown in Fig. 4.

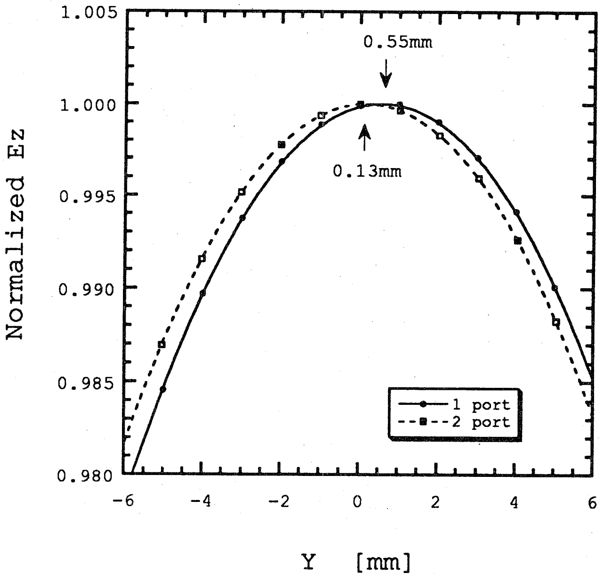

Fig. 4 Asymmetry of accelerating field in RF gun cavity. In the case of 1 port, the center of field shifts 0.55mm to the coupling port side. For the 2 port cavity, this is reduced to 0.13mm.

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 10The 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 30mm 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 relevant parameters are shown in Table 2.

3.2 Surface Treatment

The reduction of the dark current is needed for a

Table 2
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 b=1)	[MΩ]	1.16
Emax / Ecathode		1.09
Incident angle of laser	[deg]	90 / 24

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[5]. To confirm the effectiveness of these treatment, three types of cavity with different surface treatments, normal treatment, high pressure ultra pure water rinsing and TiN coating, are under fabrication. The magnitude of the dark current depends on the cleanliness of the cavity surface. A high pressure ultra pure water rinsing removes dusts and impurities. We will use a water rinsing system with the pressure of 80-90kg/cm^2 and the electric resistivity of 18MΩcm. After the rinsing, the cavity is assembled as a closed vacuum system in a class 1 clean room to avoid contamination. 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 will adopt TiN coating on the surface. Only the surface area which is perpendicular to the electric field is coated and the thickness of TiN is controlled less than 100 nm to reduce the surface loss as small as possible.

3.3 High Power Experiment

A high power test station with a 35MW klystron and a modulator will be built in the Machine Experiment Hall at SPring-8. The stage for 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 waveguides. As a first step, the beam monitor system consist of a profile monitor, an energy analyzing magnet, a slit and Faraday cups to measure the dark current and its energy spectrum. The laser pulse will be introduced from out of shield and injected through a quartz window.

4 Conclusion

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 next year and beam production by introducing laser pluses will start in the second quarter. Three dimensional simulation has been started to investigate the beam dynamics in a more realistic cavity field. In parallel with these studies, an RF gun system which achieves the beam characteristics required for the SPring-8 linac will be studied.

References

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