CHARACTERISTICS OF A PHOTOCATHODE RF GUN IN HIGHER FIELD GRADIENT

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Abstract

In order to investigate a photocathode RF gun as a low emittance electron gun, a single-cell test cavity was built and has been studied at SPring-8. Recently an 80 MW klystron and modulator was installed for the RF gun to increase the beam energy and investigate phenomena in a higher gradient field. The RF conditioning had been successfully carried out and the beam energy reached up to 4.1 MeV where the maximum field gradient on the cathode was 175 MV/m. The present dark current was measured and compared with the previous data obtained two years ago. Though the cavity was conditioned at higher gradient fields, the dark current and a field enhancement factor did not changed significantly. A computer simulation predicts a higher gradient field is able to reduce the emittance especially in a beam with higher charge.

1 INTRODUCTION

A photocathode RF gun has been studied as a low emittance electron source for future applications of the SPring-8 linac. Single cell test cavities with copper cathode had built in 1997 to study phenomena in a high gradient field in excess of 100 MV/m and measure the fundamental beam characteristics such as beam energy, emittance, bunch length and so on. Furthermore, technical issues including RF source, vacuum and UV laser for the operation of the RF gun were investigated using these test cavities.

First beam with an energy of 2.1 MeV had been measured in February 1999[1]. After the installation of the Ti: Sapphire laser system (April 2001)[2], a transverse laser profile had been flattened using a homogenizing system with a microlens array, and a normalized emittance of 2.3 πmm-mrad had been obtained at a charge of 0.1 nC per bunch[3].

In December 2001, a 35 MW klystron (Mitsubishi PV-3035) and its modulator were replaced with an 80 MW klystron (Toshiba E3712) system. After an RF conditioning of the cavity, the beam energy was increased up to 4.1 MeV where the maximum field gradient on the cathode reached at 175 MV/m.

In this paper, characteristics of the RF gun in higher gradient field up to 175 MV/m are described.

2 CHARACTERISTICS OF RF CAVITY

The RF cavity of this gun was designed for high field gradient tests and investigating the fundamental beam characteristics. For this purpose, a single-cell cavity was chosen because of its simple field distribution which was considered to suit a comparison with computer simulations.

By connecting a dummy load to an output 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 reduction of dark currents. A higher gradient is needed to check the simulation results.

A schematic drawing and the relevant parameters of the cavity are shown in Fig. 1 and Table 1, respectively.

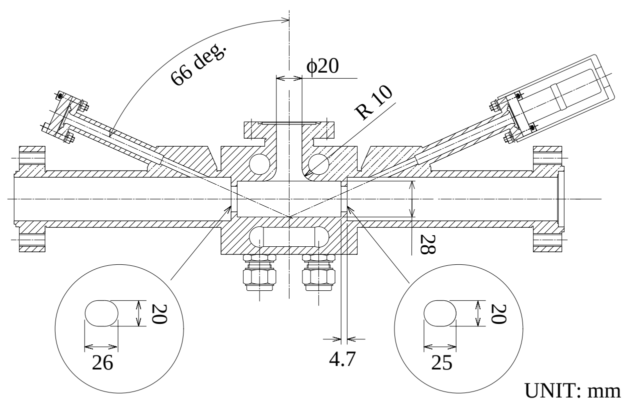

Figure 1: Schematic of RF gun cavity.

Table 1: Parameters of the RF gun cavity

Frequency	2856 MHz
Intrinsic Q value	12400
External Q value for output port	3684
External Q value for input port	2786
Coupling coefficient for input port	1.01
Filling time	0.16 μsec
Shunt impedance (for β=1)	1.16 MΩ

The field distribution in the cavity was calculated with using MAFIA. The maximum field gradient on the cavity surface appears near a round corner at the gun exit as shown in Fig. 2. It is higher than the field gradient at the center of the cathode with a factor of 1.09.

The photocathode of the RF gun was chosen as copper and it was a part of cavity wall itself. The cavity was rinsed with ultra pure water before brazing in order to remove dusts and contaminations on the cavity surface.

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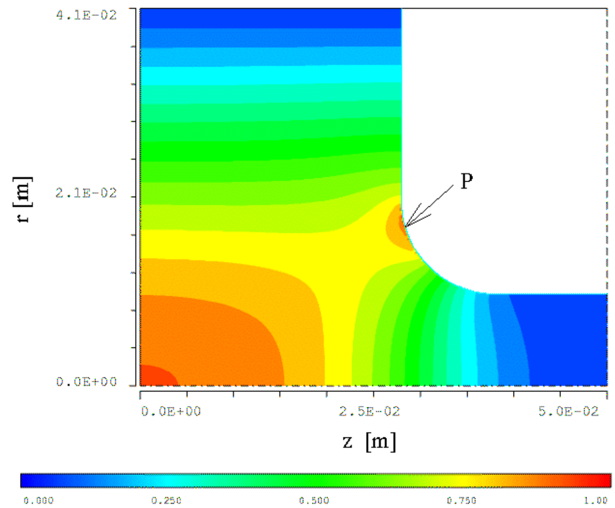

Figure 2: Electric field strength distribution in RF cavity of the gun. The maximum peak field on the cavity surface appears around the point indicated as P.

3 RF CONDITIONING

The installation of the 80 MW klystron and modulator was completed in December 2001 and the measurement and control system were ready for the experiments in January 2002. As shown in Fig. 3, the vacuum system of the RF gun consists of two 100 l/s ion pumps and two NEG pumps (SAES getters, CapaciTorr-D 400, 400 l/s for hydrogen) installed at input and output waveguides, respectively. The vacuum system was separated from that of klystron waveguide with an RF window. The pressure was measured by a cold cathode gauge (CCG) installed at the waveguide near the cavity. In the beam line, another NEG pump was installed at the first beam slit.

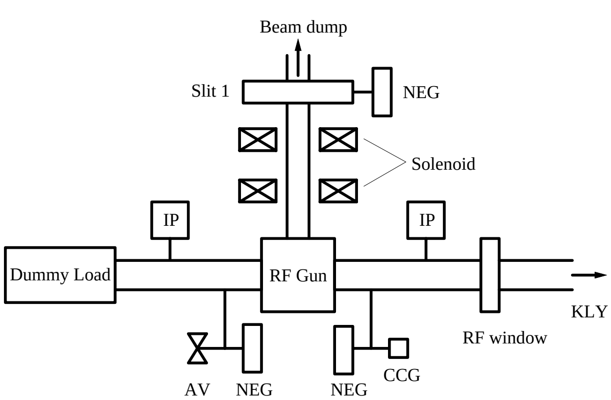

Figure 3: Vacuum system of the RF gun.

After a base pressure in the RF cavity was reached below $5x10^{-8}$ Pa, the RF conditioning was started with a pulse width of 500 nsec and a repetition rate of 10 pps. At the beginning of the RF conditioning, the vacuum pressure in the cavity increased up to $2x10^{-7}$ Pa when an RF power was fed into the cavity and the interlock level was set to $5x10^{-6}$ Pa. The RF conditioning was continued intermittently and the field gradient on the cathode and the maximum surface field gradient were reached up to 175 M/m and 191 MV/m, respectively after a conditioning time of 280 hours totally. The vacuum pressure with and without RF decreased to $5x10^{-8}$ Pa and $2x10^{-8}$ Pa, respectively. The dark current at this field gradient was 0.15 nC/bunch.

During the conditioning, the radiation level at the back of the cathode plane was the highest around the cavity. This seemed to be caused by the dark current emitted from the maximum gradient point indicated as P in Fig. 2.

The conditioning was continued and the beam energy had reached up to 4.3 MeV. But the dark current was significantly increased after an RF breakdown occurred. Therefore, we decreased the input RF power down to the power level which gave a beam energy of 4.1 MeV. After an RF conditioning for several hours, the dark current recovered the previous level. The field gradient of 175 MV/m seemed to be the maximum gradient for a stable operation of our test cavity at present.

4 DARK CURRENT

The first RF conditioning of the cavity was performed in March 2000 with a pulse width of 1 μsec and a repetition rate of 10 pps. Dependence of dark currents on the field gradient was measured by using a Faraday cup located just after the cavity. Fig. 4 shows Fowler-Nordheim (F-N) plots for the dark currents. The peak current I was obtained from DC current normalized with the pulse width. However, the peak current did not agree between the data of 500 nsec and 1 μsec since the pulse shape of the RF pulse was not flat temporally.

After 6 hours from the beginning of the conditioning, the field gradient reached at 102 MV/m and a field enhancement factor β which obtained from a slope of a F-N plot was about 113 (solid circle in Fig. 4). As the conditioning proceeded, the dark current decreased and β became smaller. The field gradient has been reached at 141 MV/m and β becomes 75 after 18 hours conditioning.

In January 2002, the cavity was conditioned up to 175 MV/m with a pulse width of 500 nsec. The dark current was measured at the field gradient up to 140 MV/m with 1μsec pulse and 175 MV/m with 500 nsec. As shown in Fig. 4, the current and β did not changed significantly though it was slightly reduced in higher gradient region. Therefore, it seems that the cavity is well conditioned and the dark current will not decrease more.

After the conditioning, the cathode was observed from the gun exit side. A photograph of the cathode is shown in Fig. 5. The optically mirrored condition of the cathode surface became worse and there were small damaged sites on the cathode. However, the effect of this damage on the emittance could not be observed. The authors are preparing an analysis of the physical and chemical state of the cathode surface.

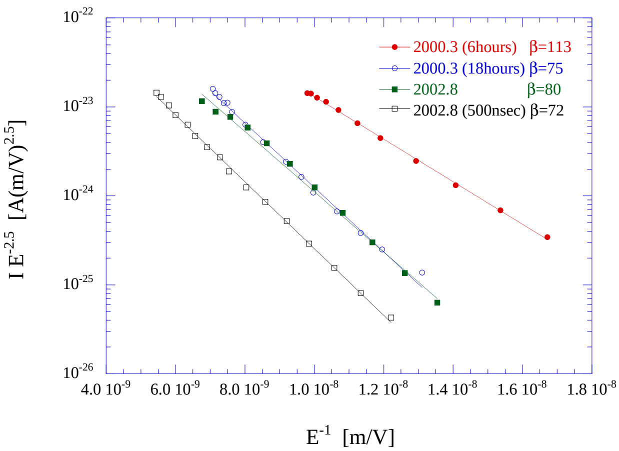

Figure 4: Fowler-Nordheim (F-N) plot for dark currents where E is the maximum field gradient on the cathode and I is the peak current. Solid and open circle data were taken after 6 and 18 hours during the first RF conditioning of the cavity, respectively. Solid and open square data are dark currents with pulse width of 1 μsec and 500 nsec after the conditioning up to 175 MV/m, respectively.

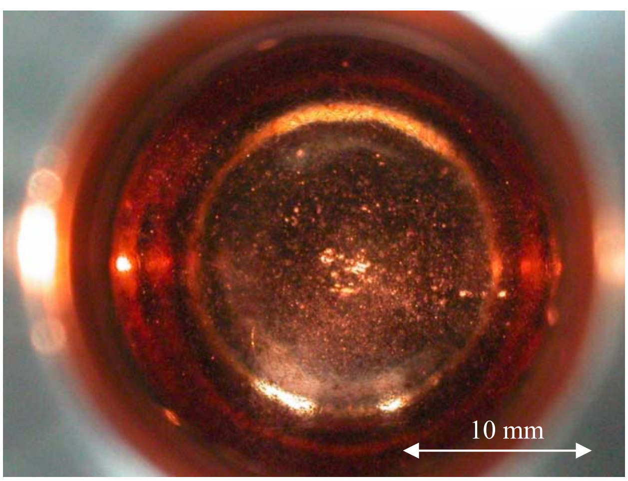

Figure 5: Photograph of the cathode surface viewed from the gun exit.

5 EMITTANCE

The transverse emittance of the beam depends on several parameters such as the RF phase at which the laser pulse is irradiated on the cathode, the accelerating field gradient, spatial and temporal profiles of the laser pulse, solenoid fields and so on. To investigate the effect of the accelerating field gradient, a computer simulation[4] was performed for a beam with a charge of 0.2 nC and 0.5 nC per bunch. The minimum emittance was surveyed with changing the solenoid fields for each field gradient where other parameters were fixed as followings. The RF phase was 85 degrees, the transverse profile of a laser pulse on the cathode was a Gaussian distribution with $1\sigma = 0.3$ mm, the temporal profile of the laser pulse was a Gaussian distribution with $1\sigma = 2.21$ psec and truncated with a full width of 10 psec, and the injection angle of the laser pulse into the cathode was 66 degrees. The result is shown in Fig. 6.

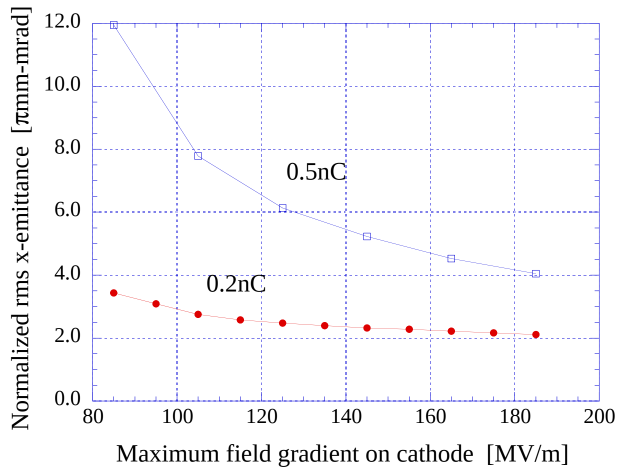

Figure 6: Dependence of normalized rms x (horizontal) emittance of a beam with a charge of 0.2 and 0.5 nC per bunch on the field gradient on cathode.

The emittance is reduced as the field gradient becomes higher. The effect becomes prominent for an electron bunch with a higher charge.

6 CONCLUSION

The test cavity for the photocathode RF gun has been able to produce a field gradient of 175 MV/m on the cathode. The dark currents was measured and compared with the previous data. It was found that the dark current did not decrease with an RF conditioning over a field gradient of 140 MV/m. According to the results obtained with a computer simulation, a higher gradient field is preferable for a reduction of the beam emittance in a higher charge region. In order to study the cathode surface, a cavity with a removable cathode is going to be built.

7 REFERENCES

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