RF DESIGN OF A CARTRIDGE-TYPE PHOTOCATHODE RF GUN IN S-BAND LINAC

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Abstract

We have been developing a compact-sized cartridge-type photocathode system, which is able to replace a cathode without breaking the vacuum of RF gun and use a high quantum efficiency photocathode such as Cs_2Te. Following the experimental results of this system with a single cell pillbox-type RF cavity, we have developed the compact-sized system capable of installing our BNL-GUN-IV RF gun. The purpose of implementing the system is to increase beam charge for the applications such as pulse radiolysis experiment. Prior to installing the system in our linac, we have designed the total system, performed the numerical RF design of the cavity, and simulated the beam dynamics in the linac with the system. From the PARMELA simulation results, we confirmed that the bunch width of the beam delivered from the linac with the system didn't almost degrade compared to that from the present linac, and that a beam of 5 nC/bunch can be transported from the cathode to the end of linac. The bunch width of 1nC and 5nC beam delivered from the linac with the system is 2.4 ps and 8.7 ps, respectively.

INTRODUCTION

The application of ultrafast electron bunches has been an attractive research in the field of electron accelerators. Its remarkable progress of femtosecond bunches generation has made great contributions to many research projects such as X-ray free electron lasers, a high energy linear collider, and ultrafast beam based pump-and -probe analysis.

At Nuclear professional School, University of Tokyo, we have been conducting picosecond-time-resolved pulse radiolysis and femtosecond laser pump-and-probe analysis, using femtosecond laser and femtosecond electron beam delivered from an S-band linac [1], [2]. The S-band Linac consists of a BNL-GUN- IV 1.6 cell photocathode RF gun, an accelerator tube, transport magnets, and a chicane-type magnetic compressor. The femtosecond electron beam is generated by the photocathode RF gun with Mg cathode, using a 100 fs Ti:Sapphire laser (266 nm, 3rd harmonics), and accelerated up to 22 MeV by the accelerator tube. The electron bunch of 2 nC is compressed by the magnetic compressor up to the bunch width of 440 fs, typically 700 fs (FWHM) [3]. We have achieved 340 fs (short period) and 660 fs (long period) in the synchronization between the probe laser and the pump electron beam [4]. The total time resolution of the pump-and-probe analysis is less than 10 ps and the maximal resolution reaches 4 ps. The time resolution will increase further by improving the S/N ratio of the pump-and-probe experiment. In order to improve the S/N ratio, high brightness and high charge beam is required as pumping beam. We aim to increase beam charge first. There are several ways to increase beam charge, for example, an increase of laser intensity and the use of high quantum efficiency (QE) photocathode material. We have trouble increasing laser intensity due to cathode ablation and optics mismatch. Therefore, we decide to introduce a high QE cathode to the RF gun. The QE of our Mg cathode in current use is 1.3×10^{-4}, which is less than that of the Mg cathode at BNL ($1.0\text{-}2.0 \times 10^{-3}$) [5], [6]. One of the main reasons for the degradation of QE is believed that oxide-layer was formed on the surface of the cathode due to exposure to the atmosphere. In the case of high QE cathode such as Cs_2Te, it is indispensable to set up a system in which we can handle a cathode in vacuum throughout the preparation of the cathode, such as a load-lock system with cathode preparation chambers [7], [8], [9] or a cartridge-type photocathode system with a cartridge-type vacuum tube [10], [11]. We have to put the system within 70 cm × 50-80 cm (width × length) owing to the limited space behind the RF gun of our linac. It is impossible to introduce the load-lock system to our linac due to its size. Therefore, we determine to install the compact-sized cartridge-type photocathode system, which fits into the limited space. Following the experimental results of the cartridge-type photocathode system with a single cell pillbox-type RF cavity [10], [11], we have been developing the compact-sized system capable of installing our BNL-GUN-IV RF gun. This paper describes the total design of the RF gun with the cartridge-type photocathode system, the calculation results of electromagnetic field in the 1.6 cell RF gun, and the simulation results of beam dynamics when the system is installed in our S-band linac.

CARTRIDGE-TYPE CATHODE

We have been developing the compact-sized cartridge-type photocathode system in collaboration with Hamamatu Photonics. Figure 1 shows the schematic view

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of the RF cavity with the cartridge-type photocathode system. The cartridge-type photocathode system is composed of a cartridge-type vacuum tube with a cathode plug, a linear feeder to transport the tube in vacuum, a RF cavity with a back plate that has a centre hole for the replacement of a cathode, and a gate valve between the RF cavity and the linear feeder. Figure 2 is the picture of the cartridge-type vacuum tube. The cartridge-type vacuum tube consists of a Mo cathode plug with a cathode surface layer, flanges made of Kovar on the both sides of the tube, and a vacuum bellows to move the cathode plug. A cathode formed on the plug is sealed in the vacuum tube. The diameter of the plug is 7.2 mm. Vacuum tubes are produced in a factory and the tubes of high QE cathode are selected from these tubes. The vacuum tube is set in the linear feeder and transported to the back plate. A pair of cutters before the back plate cut the Kovar foil and then the cathode is inserted into the hole. While exchanging the cathode, the RF cavity is not exposed to ambient air, since the gate valve between the RF cavity and the linear feeder is closed. The cartridge-type photocathode system is very useful for the performance test of cathode because of the easiness of exchanging the cathode.

First demonstration experiment of the cartridge-type photocathode system was carried out at SPring-8, using a single cell pillbox-type RF cavity with Cs_2Te photocathode. The result of the experiment was that the initial QE of 3% was halved to 1.5% in 5 h and finally settled to 1% after 15 h [10], [11].

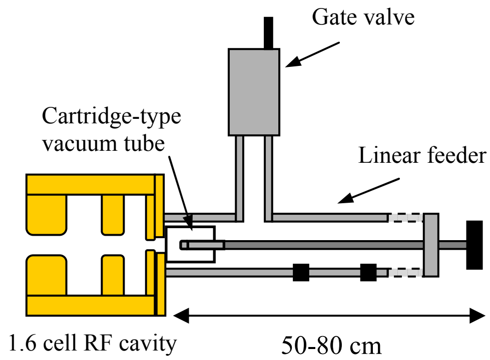


Fig. 1 Schematic view of RF cavity with a cartridge-type photocathode system

Fig. 2 Pictures of cartridge-type vacuum tube

DESIGN OF RF GUN

The cartridge-type photocathode system needs the back plate with a centre hole to insert the cathode into the RF cavity. The design drawing of the back plate is shown in Fig. 3. The back plate can be connected to the linear feeder by a connection flange. A Helicoflex is used to form a seal at the joint between the RF cavity and the back plate, and between the back plate and the connection flange. The diameter of the hole is 7.8mm. The material of the back plate and the connection flange is oxygen free copper.

We calculated the electromagnetic field of the RF cavity with SUPERFISH, using the design of the back plate (Fig. 3). We calculated the parameters of three type cavities: a normal cavity, a cavity with a hole, and a cavity with a gap. The gap is the space between the back plate hole and the cathode plug, which is made when the plug is inserted into the RF cavity. The width and depth of the gap is 0.3mm and 4.1 mm, respectively. Figure 4 shows the electric field distribution of pi-mode in each cavity. Table 1 shows the parameters of each cavity. Q value and shunt impedance in the cavity with a gap decreased to 85% of the normal cavity together. These parameters in the cavity with a gap are, however, acceptable enough to operate the RF gun.

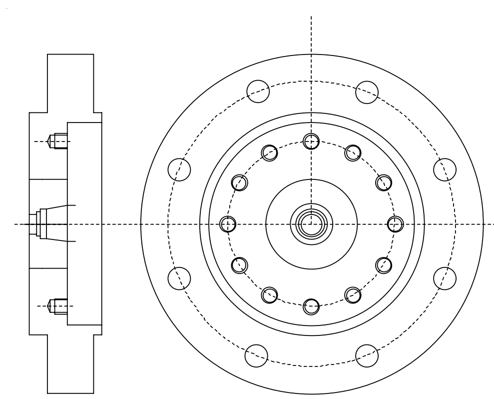
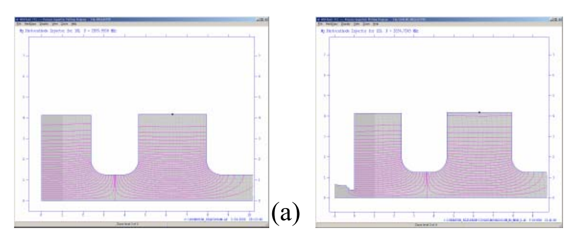


Fig. 3 Design drawing of the back plate with a hole


(a) (b)

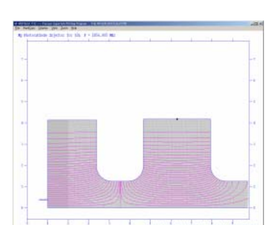

(c)

Fig.4 Electric field distribution of pi-mode:
(a) Normal cavity
(b) Cavity with a hole
(c) Cavity with a gap

Table 1 Parameters of three cavities

	Normal cavity	Cavity with a hole	Cavity with a gap
Frequency (MHz)	2855.99383	2856.73451	2856.00503
Q value	16028.7	13032.6	13575.8
Shunt impedance (Z) (MOhm/m)	53.835	24.301	45.602
Transit-time factor (T)	0.5873117	0.8013186	0.5874288
Z*T*T (MOhm/m)	18.57	15.604	15.736
Stored energy (Joules)	0.0023106	0.0071486	0.0023103

SIMULATION OF BEAM TRANSPORT

We simulated the beam dynamics from the RF gun to the end of linac with PARMELA. Simulations for the 1.6 cell RF gun were performed using the field maps generated by SUPERFISH. We used the field map of the normal cavity for the present RF gun and the field map of the cavity with a gap for the RF gun with the cartridge-type photocathode system. In this simulation, we excluded the chicane-type magnetic compressor.

We simulated the beam dynamics in the present linac at a charge of 1 nC and in the linac with the cartridge-type photocathode system at a charge of 1 nC and 5nC. In Fig. 5, we show the PARMELA simulation of the bunch width along the linac. The bunch width at the end of the linac is: 2.3 ps in present linac (1 nC), 2.4 ps in linac with the system (1 nC), 8.7 ps in linac with the system (5 nC). In Fig. 6, we show the PARMELA simulation of the bunch width along the linac. The emittance at the end of the linac is: 24 mm mrad in present linac (1 nC), 32 mm mrad in linac with the system (1 nC), 100 mm mrad in linac with the system (5 nC)

DISCUSSION

At a beam charge of 1 nC, the bunch width of the beam delivered from the linac with the cartridge-type photocathode system was almost same as that from the present linac according to RF phase adjustment. The emittance of the beam delivered from the linac with the system became a little worse than that of the present linac.

At a beam charge of 5 nC, which is an immediate target charge when Cs_2Te is used as photocathode, we adjusted following simulation parameters: the RF phase of the injector, the magnetic field intensity of the solenoid coil, and the magnetic field intensity of the Q magnets. According to the PARMELA simulation, bunch width and emittance increased by a factor of 4. We expect that the bunch width of 8.7 ps will be compressed up to 2-3 ps by the magnetic compressor. In our linac the emittance is bad, but we don't put an emphasis on beam emittance as for the application of pulse radiolysis.

CONCLUSION AND FUTURE TASK

According to the PARMELA simulation, the bunch width of the beam delivered from the linac with the system at a charge of 1 nC was almost same as that from the present linac. With regard to the beam at a charge of 5 nC, we may have to optimise the beam line of the linac.

We are going to produce the back plate with a hole, the cartridge-type vacuum tubes, and the linear feeder. We will conduct the frequency test of the RF gun in summer and the beam test with the cartridge-type photocathode system in autumn.

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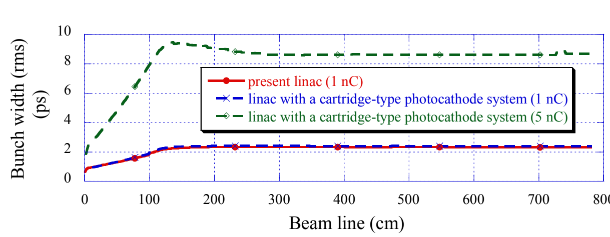

Fig.5 PARMELA simulation of the bunch width (rms) along the linac. The bunch width at the end of the linac: 2.3 ps in present linac (1 nC), 2.4 ps in linac with a cartridge-type photocathode system (1 nC), 8.7 ps in linac with a cartridge-type photocathode system (5 nC)

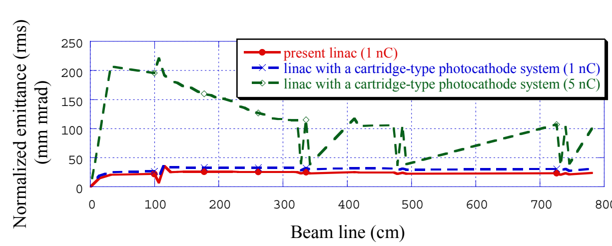

Fig.6 PARMELA simulation of the emittance (rms) along the linac. The emittance at the end of the linac: 24 mm mrad in present linac (1 nC), 32 mm mrad in linac with a cartridge-type photocathode system (1 nC), 100 mm mrad in linac with a cartridge-type photocathode system (5 nC)