DESIGN OF A CHIRPING CELL ATTACHED RF GUN FOR ULTRA-SHORT ELECTRON BUNCH GENERATION*

K. Sakaue,† K. Tamai, M. Washio, RISE, Waseda University, Tokyo, Japan
J. Urakawa, KEK, Ibaraki, Japan

Abstract

We have been developing an S-band photocathode rf electron gun at Waseda university. Our rf-gun cavity was firstly designed by BNL and then, modified by our group. In this paper, we will introduce a newly designed rf-gun cavity with energy chirping cell. To generate an energy chirped electron bunch, we attached extra-cell for 1.6cell rf-gun cavity. Cavity design was done by Superfish and particle tracking by PARMELA. By optimizing the chirping cell, we observed linear chirped electron bunch. The front electron have lower energy than rear. Then transporting about 2m, the bunch can be compressed down to 200fsec electron bunch with the charge of 160pC. This ultra-short bunch will be able to use for generating CSR THz radiation, pumping some material to be studied by pulse radiolysis method, and so on. In this conference, the design of chirping cell attached rf-gun, the results of tracking simulation and plan of manufacturing will be presented.

INTRODUCTION

We have been developing a laser photocahode rf-gun cavity under the collaboration of Waseda university and KEK (High Energy Accelerator Research Organization). Our rf-gun cavity is originally based on BNL TypeIV structure. In our development, improvements of rf tuner structure [1] and enlarging the mode separation [2] has successfully demonstrated. The resulting rf-gun cavity has high Q value (more than 15000) and lower dark current.

A photocathode rf electron gun can produce low emittance beam with energy of about 5MeV, which is useful for applications such as research objects and industrial uses. At Waseda university, we applied this high quality electron beam for pulse radiolysis experiment for analyzing radiation chemical reactions [3] and laser-Compton scattering research for soft X-ray generation [4]. For the applications and/or breaking ground the new applications, an ultra-short electron bunch generation is desired. As for pulse radiolysis experiment, it will improve the temporal resolution. Moreover, the coherent terahertz radiation will be the new application if we achieve the ultra-short electron bunch with less than 500fsec.

This paper describes the newly designed rf-gun cavity especially for ultra-short electron bunch generation. We attached an extra cell to the 1.6cell rf-gun, called Energy Chirping Cell (ECC). ECC was designed to linearly chirp the electron bunch energy, then the bunch is compressed by the velocity difference. The detail of principle of compressing, design of ECC rf-gun, and future prospective is represented.

PRINCIPLE OF ECC-RF-GUN

In a laser photocathode rf-gun, the initial electron transverse/longitudinal profile is controlled by laser pulse, and photocathode unifies the end plate of rf-gun cavity, thus the emitted electron is rapidly accelerated up to relativistic energy. Hence, the high quality and well-controlled electron beam is produced. Concerning the ultra-short electron bunch generation, one can consider to use femtosecond laser. However, the femtosecond bunch is lengthened immediately before being accelerated by the space charge effect. Avoiding this effect, we have to decrease the bunch charge as far as several pC/bunch.

In these backgrounds, we conceived ECC-rf-gun, which can compress the bunch after being enough energy. The ECC-rf-gun initially produces picosecond bunch with 4-5MeV, then compresses down to 0.2ps. Compression is achieved by velocity difference which produced in ECC attached after the 1.6cell rf-gun. ECC and rf-gun is combined and driven by same rf power in order to simplify the system. In ECC, the electron bunch is linearly energy chirped to produce velocity difference in bunch. Owing to this procedure, the ultra-short bunch with more than 100pC bunch charge is achievable.

The schematic of compression is shown in Fig. 1 and principle of producing velocity difference is shown in Fig. 2.

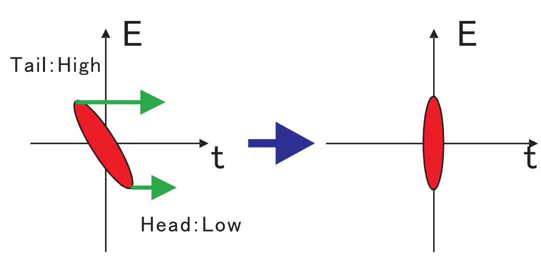

Figure 1: Principle of bunch compression.

As shown in Fig. 1, ECC produces linear energy chirp and velocity difference compresses the bunch through a drift space i.e. rotates the phase space. At the energy of 5MeV, the velocity of electron is 99.5% of light velocity,

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† kazuyuki.sakaue@aoni.waseda.jp

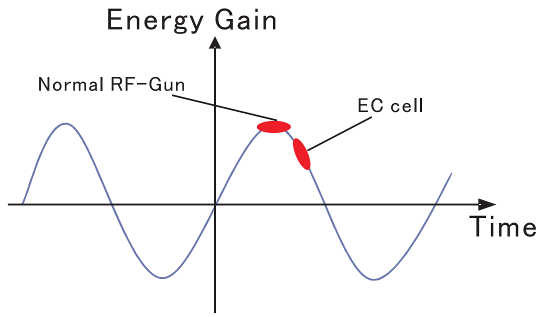

Figure 2: Schematic of ECCell.

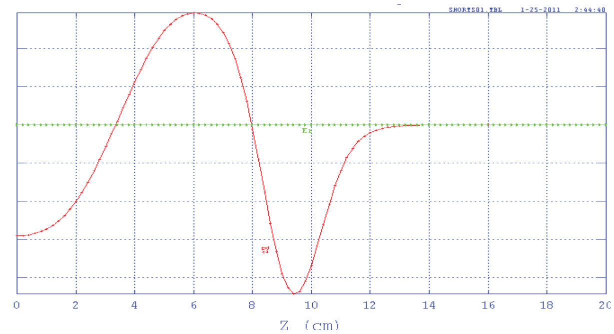

Figure 5: Field distribution of ECC-RF-gun.

thus the bunch can be compressed through the several meters of drift space.

Figure 2 shows the principle of energy chirping in ECCell. After accelerated up to 4-5MeV in 1.6cell rf-gun, ECC is attached. The normal rf-gun was designed to gain the maximum energy i.e. the crest of the rf phase. In contrast, ECCell aggressively chose the deflected phase (See Fig. 2) and the electron energy can be chirped. The rf phase in each cell is determined by lengths of cell and iris.

DESIGN OF ECC-RF-GUN

Cavity Design by SUPERFISH

We designed such an ECC-rf-gun cavity by SUPERFISH and tracked a generated beam by PARMELA. The normal 2.6cell rf-gun and designed ECC-rf-gun are shown in Figs. 3 and 4.

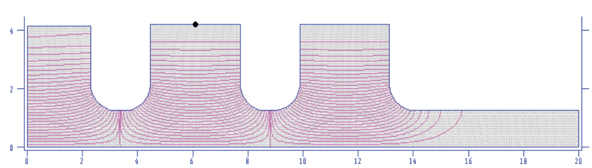

Figure 3: Structure of normal 2.6 cell RF-gun.

The horizontal axis is the z-axis, which is electron orbit. A cathode is mounted on z=0 position and both cavities are designed to operate with π-mode at 2856MHz. On the normal rf-gun, cell to cell length is adjusted half of rf wavelength in order to gain the maximum energy. We call these cells, from left side, Half Cell (HC), Full Cell-1 (FC1) and Full Cell-2 (FC2).

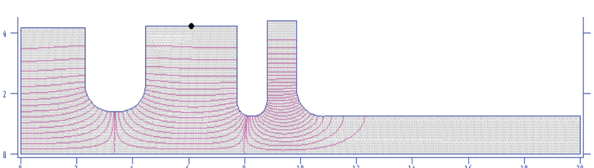

Figure 4: Structure of ECC-RF-gun.

As shown in Fig. 4, the lengths of iris between FC1 and FC2 and FC2 are shortened. This modification can adjust the accelerating phase in final cell. On ECC-rf-gun, we reduced the iris to half and FC2 to one-third. In addition, by tuning the field strengths in cell, we can regulate the chirping strength. The optimized field strength was 1-1-1.5 (HC-FC1-ECC) as shown in Fig. 5.

Beam Tracking by PARMELA

Then we calculated the beam from this ECC-rf-gun by PARMELA. Note that we optimized ECC-rf-gun by iterating both SUPERFISH and PARMELA. The results of PARMELA calculation are shown below.

Figures 6-8 show the longitudinal phase space distribution at each position and Fig. 9 shows the bunch length variation as a function of position from the photocathode. The horizontal axis of phase space is phase of rf frequency (2856MHz)[1] and vertical axis is energy in keV. The head of the bunch is described to the left and right side is the tail of the bunch. As shown in Fig. 6, the energy distribution of the bunch is linearly chirped and suitable for the velocity compression. Fig. 8 represents the phase space of compressed bunch. The resulting bunch length was 0.2psec in rms. After the Fig. 8, the bunch was lengthened by the velocity difference as shown in Fig. 7.

The trace of bunch compression is shown in Fig. 9. There are three plots, the green line shows the normal rf-gun trace, the blue is the cavity which is only shortened the iris, and red is the ECC-rf-gun trace which is shortened both iris and cell. On normal rf-gun cavity, shown in green, the initial bunch length is 4.25psec (rms) and compressed in rf-gun. After the rf-gun cavity, the bunch length was slightly incresing. It is clear that the bunch length is compressed along with the drift space on ECC-rf-gun as shown in red. The shortest bunch length was 0.2psec (rms) at z=403cm. The parameters and results of this calculation are shown in Table 1.

[1] Because time is represented by rf phase advance in PARMELA

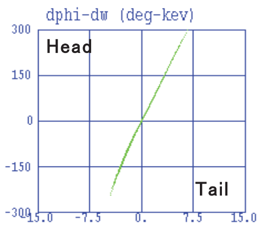

Figure 6: Phase space distribution at z=20cm.

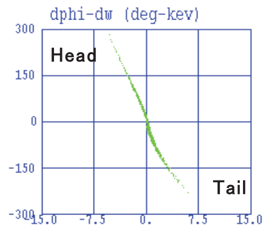

Figure 7: Phase space distribution at z=658cm.

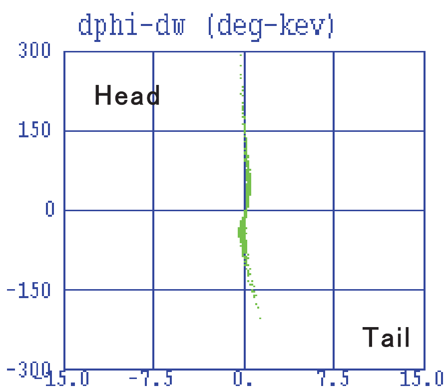

Figure 8: Phase space distribution at z=403cm.

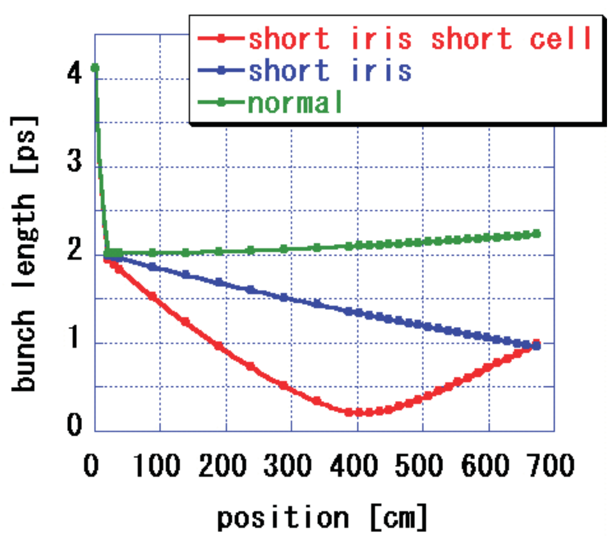

Figure 9: Bunch length as a function of distance from cathode.

According to Table 1, ultra-short electron bunch with enough charge (100pC/bunch), enough energy, and enough transverse emittance is achieved by this ECC-rf-gun. 0.2psec bunch is enough for application research and coherent terahertz generation.

Table 1: PARMELA Simulation Parameters and Beam Parameters

Initial bunch length	Charge
4.25ps (rms)	100pC
Field at cathode	Energy
80MV/m	4.5MeV
Emittance	Bunch length (min)
4.2πmmmrad	200fs (rms)

SUMMARY AND FUTURE PROSPECTIVE

This paper described specially designed photocathode rf-gun cavity for producing ultra-short bunch electron beam. By shortening the iris and cell length, the rf phase in specified cell is adjustable. To adjust the phase to gain the energy chirping, the bunch can be compressed to 0.2psec by velocity difference after the drift space.

In this paper, we mentioned as to be used alone, but this can be used as a injector of accelerator system. Resulting phase space distribution indicates that it would apply for velocity bunching in accelerating structure described in Ref. [5] to add the linear accelerator.

Present design needs 4m-drift space to compress the bunch. We will optimize the cavity structure, initial beam parameters, and beam line layout in order to achieve compression within 2.5m. After comfirming the design, we will manufacture ECC-rf-gun. We will demonstrate an ultra-short electron bunch by ECC-rf-gun and evaluate the beam parameters in near future. Then we hope to apply ECC-rf-gun for the coherent terahertz radiation source [6].

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