DEVELOPMENT OF AN RF ELECTRON GUN FOR ULTRA-SHORT BUNCH GENERATION*

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Abstract

At Waseda University, various researches are done using a photocathode rf electron gun with a 1.6 cell cavity. Now we are developing a new rf cavity specialized for producing an ultra-short electron bunch, with the collaboration of High Energy Accelerator Research Organization (KEK) [1]. We have used SUPERFISH for designing the new rf cavity and PARMELA for beam tracking. The new rf cavity has an extra cell following the 1.6 cell. The extra cell can chirp the energy of electron bunch so we call it ECC (Energy Chirping Cell). ECC chirp the energy because we shortened the length of iris just before the ECC and also the length of ECC itself. Moreover, electric field in ECC is made to be stronger than others. We have confirmed on PARMELA that ECC-rf-gun can generate an 100pC electron bunch less than 100fsec with the energy of 4.5MeV at about 2.5m away from the cathode. Such an ultra-short electron bunch enables us to generate a coherent terahertz light using ultra-short electron bunch by synchrotron radiation or transition radiation. In this report, we would like to introduce the detail of the design of this new ECC-rf-gun, the present progresses and future prospects.

INTRODUCTION

Photocathode RF Gun

We have been developing a photocathode rf electron gun at Waseda University. The cavity structure is based on a BNL TypeIV 1.6 cell cavity and can accelerate electron bunches up to the energy of 5MeV. Photocathode rf gun can generate a high quality electron beam which means low emittance, high brightness, and short pulse. The beam from the gun depends strongly on the laser parameter, so it is able to control the beam's behavior by controlling the laser. In our system, the rf frequency is 2856MHz and the cathode material is Cs-Te. The bunch length is almost the same with the laser pulse width and is about 4ps(rms) in our system.

Ultra-short Bunch

Ultra-short bunch, shorter than 1ps, is required when generating terahertz light by coherent synchrotron radiation (CSR), or coherent transition radiation (CTR). When the bunch length is shorter than the wavelength, the radiation is enhanced by coherent radiation. Ultra short bunch is also useful for improving temporal resolution in pulse radiolysis experiment [2]. As for laser Compton scattering, the luminosity increases, thus producing intense soft X-ray [3]. In general, buncher system is installed after a gun to compress the bunch, but this is not a practical way concerning the small accelerator development. In order to avoid the whole system getting large, it is the best if the electron gun could generate an ultra-short bunch from the beginning.

BUNCH COMPRESSION

In a photocathode rf gun, the initial electron transverse/longitudinal profile is controlled by the laser pulse. One might think of using a femtosecond laser to generate a femtosecond bunch. But in this way, the charge density gets very high and ends up with a bunch length more than 1ps due to the space charge effect. The bunch charge has to be decreased to avoid this effect. Considering of generating terahertz light, we need enough charge because the coherent terahertz light power is proportional to the square of the number of electrons. For these reasons, we conceived ECC-rf-gun, which can compress the bunch after being accelerated enough. In ECC-rf-gun, the ECC is attached right after the 1.6 cell. That means the beam is firstly accelerated around 4-5MeV by 1.6 cell and then energy chirped by ECC. Energy chirp is produced by the off-crest rf phase as shown in Fig. 1.

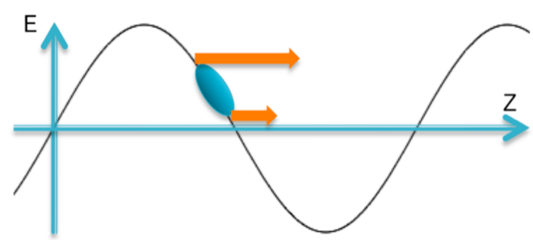

Figure 1: Off-crest rf phase acceleration in ECC.

The cavity structure, especially the length of iris between full cell and ECC(2nd iris), and the length of ECC itself is optimized so that the beam rides on the best phase to acquire energy chirp. The detail of the structure is shown on Table 1. Note that λ stands for the wavelength of rf, 2856MHz (λ~10.5cm). Figure 2 will also help you image these values.

Table 1: Length of Each Cell and Iris in ECC-RF-Gun

Cell	Half 6λ/25 cm	Full 3λ/10 cm	ECC λ/6 cm
Iris	1st λ/5 cm	2nd λ/20 cm	

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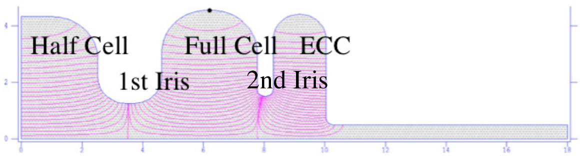


Figure 2: SUPERFISH Drawing of ECC-RF-gun.

In addition to the shortened iris and cell, electric field at ECC is made to be 1.5 times higher than other cell. These features are needed to control the phase and chirp the energy linearly and intensely. After the energy is chirped, the bunch gets shorter and shorter as it drift through the beam line because of the difference of velocity. At the energy of 5MeV the velocity of electron is approximately 99.5% of light velocity, so the energy chirp produces enough velocity difference to compress the electron bunch with a few meters of drift space. This method of compression is called velocity bunching[2]. This could be explained by the rotation of phase space distribution. Figure 3 shows the schematic of bunch compression.

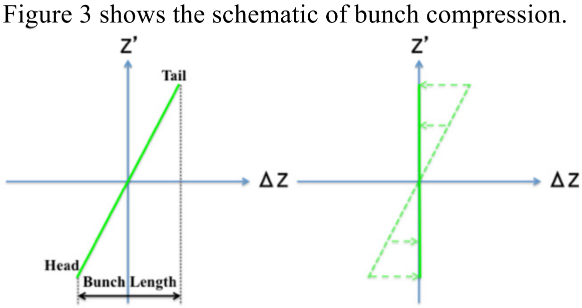


Figure 3: Bunch compression in phase space.

The left picture in Fig. 3 describes the ideal longitudinal phase space distribution at the exit of ECC-rf-gun, while the right one describes the most compressed bunch. If the energy chirp were linear, the bunch would be compressed perfectly.

DESIGN OF ECC-RF-GUN

Cavity Design

We designed the cavity structure of ECC-rf-gun by SUPERFISH and checked the performance by PARMELA. The cavity structure by SUPERFISH is already shown in Fig. 2. The horizontal axis is the z-axis, in other words, electron orbit. The white part was set to copper. Cathode was placed at z=0. Before reaching this final structure, we have tried many other structures that have different iris and cell length to optimize. SUPERFISH expected that this cavity would have more than 13000 of Q-value.

Beam Tracking by PARMELA

We have used PARMELA for checking the beam parameters from the ECC-rf-gun. Table 2 shows the parameters of PARMELA simulation.

Table 2: PARMELA Simulation Parameters

Initial bunch length 4ps (rms)	Charge 100pC
Field at cathode 100MV/m	Laser spot size 0.6mm (rms)
Phase 135deg	Solenoid field 1030G

Figure 4 is the beam line setup in PARMELA. The beam line setup in PARMELA consisted of ECC-RF-gun, solenoid magnet, and drift space.

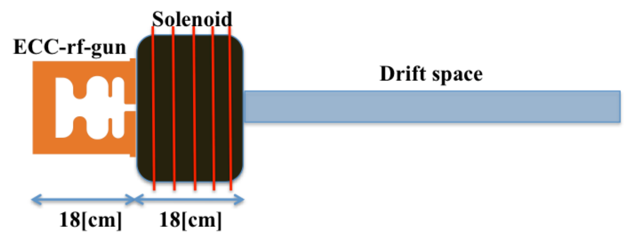


Figure 4: PARMELA beamline.

Figure 5 shows the bunch length (blue line) and transverse beam size (red line) as a function of distance from cathode.

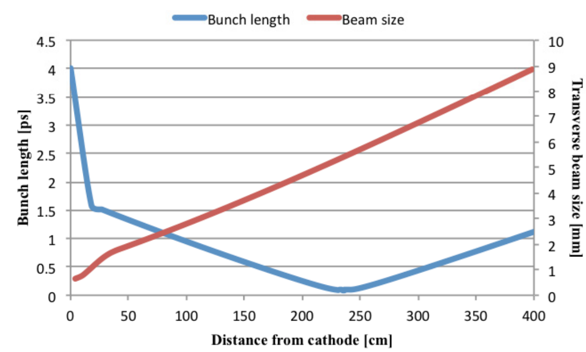
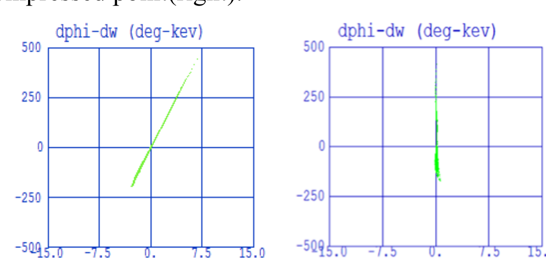


Figure 5: Bunch length and Beam size as a function of distance from cathode.

By the PARMELA simulation, we can say that the bunch length is compressed down to 86fs(rms) at the distance of 236cm. At this point the transverse beam size is 5.4mm, transverse normalized emittance is 4.3πmm-mrad, and the beam energy is 4.5MeV. Figure 6 is the phase space distribution at the exit of ECC-rf-gun(left) and the most compressed point(right).



(A) (B)

Figure 6: Phase space distribution by PARMELA (A): Gun exit (B): z=236cm.

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As shown in Fig. 6, we confirmed that the energy is linearly chirped and well compressed as shown in Fig. 3. The results of PARMELA simulation are summarized on Table 3.

Table 3: Results of PARMELA Simulation

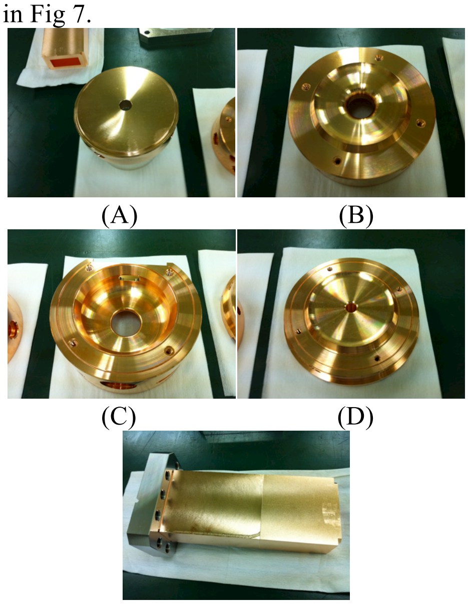
Phase	Charge	Distance	Bunch Length
135deg	100pC	236cm	86fs(rms)
Energy	Energy Spread	Beam Size	Emittance
4.5MeV	2.5%(rms)	5.4mm	4.3πmm-mrad

The beam size and transverse normalized emittance is estimated to be a bigger value than the 1.6 cell rf gun. This is caused by the space charge effect, which is more effective due to the bunch compression. However, the beam size is able to reduce by placing a quadruple magnet right behind the compression point.

MANUFACTURE OF ECC-RF-GUN

Process

We have confirmed by simulation that ECC-rf-gun is worth making and we are under manufacture of the gun now. Here, I would like to introduce the process of manufacture. The gun is composed of several parts, and those parts will be brazed and form a gun. Those parts are shown in Fig 7.



(A) (B) (C) (D) (E)

Figure 7: Parts of ECC-rf-gun (A): End plate (B): Half cell (C): Full cell (D): ECC (E): Waveguide.

At first, these parts are made to be a little bigger which means that the inside cavity is a little smaller. Then the resonant frequency is measured using a network analyzer. At this point, the parts are not brazed, just fixed, as shown in Fig. 8.

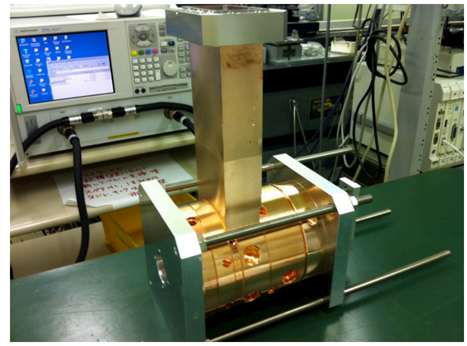


Figure 8: ECC-RF-gun before braze.

The resonant frequency should be higher than 2856MHz at this point. From the measured resonant frequency we decide the value of cutting the cell. The cut is done using a diamond turning so that the surface inside is clean, thus reducing dark current. The cut and measurement are repeated until we achieve the target frequency. After we achieve the target frequency, we braze the parts and make them together. After brazing the parts together, we braze some other parts such as water pipe and tuner. After brazing, we cannot cut the cell any more, so frequency change is done using a tuner. Resonant frequency tends to change a little after brazing, so we have to tune it and optimize it. This is how ECC-rf-gun is manufactured.

SUMMARY AND FUTURE PLANS

In this paper we described about specially designed photocathode rf gun, ECC-rf-gun, that can generate a ultra-short bunch, shorter than 100fs. We have evaluated the gun by PARMELA simulation and confirmed that 86fs(rms) bunch would be generated at the distance of 236cm from the cathode surface. Encouraged by this simulation result, we are now manufacturing this ECC-rf-gun. For future plans, we are going to install this ECC-rf-gun in Waseda's system and check the real ultra-short bunch by measuring the radiation from the ultra-short bunch. We are also planning to generate coherent terahertz light by CSR or/and CTR.

REFERENCES

[1] K. Sakaue et al., "Design of a chirping cell attached rf gun for ultra-short electron bunch generation," IPAC2011, TUPC058, (2011)

[2] K.Ogata, et al., Proc. of IPAC'11, THPS090, (2011)

[3] K.Sakaue, et al., Radiat. Phys. Chem. 77.1136-1141(2008)

[4] L. Serafini and M. Ferrario, AIP Conference Proc. 581(2001)87.