STUDY ON TWO-CELL RF-DEFLECTOR CAVITY FOR ULTRA-SHORT ELECTRON BUNCH MEASUREMENT*

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Abstract

We have been developing an S-band Cs-Te photocathode rf electron gun system for pulse radiolysis and laser Compton scattering experiment at Waseda University. These researches demand for high quality and well controlled electron beam. In order to measure the ultra-short electron bunch, we decided to use rf-deflector cavity, which can convert the longitudinal distribution to that of transverse. With this technique, the longitudinal bunch profile can be obtained as the transverse profile. We used the 3D electromagnetic simulation codes HFSS for designing rf-deflector cavity and GPT for beam tracking. The cavity has 2 cell structures operating on π mode, standing wave, dipole (TM_{120}) mode at 2856 MHz. We have confirmed on HFSS that 2 cell rf-deflector cavity can produce 660 G magnetic field per cell on beam line with 750 kW input rf power. This field strength is equivalent with our target, which is 100 fs bunch length measurement at 4.3 MeV. In this conference, we will present the cavity structure design, the present progresses and future plan.

INTRODUCTION

At Waseda University, we have developed rf electron gun for generating a high quality electron beam which means low emittance, high brightness and ultra-short pulse. The cavity structure is based on BNL type-IV 1.6 cell rf-gun which can accelerate electron bunch up to 5 MeV with the bunch length 4 ps(rms). In our system, operation rf frequency is S-band 2856 MHz and the cathode material is Cs-Te. Using this rf-gun, we have been developing various researches such as generation of soft X-ray by laser Compton scattering and study for the fast chemical reaction of ionizing radiation in a material by pulse radiolysis experiment. In these researches, it is demanded that electron bunch length become shorter to femtosecond order. As for laser Compton scattering, the luminosity increases and high intensity soft X-ray are generated [1]. Ultra-short electron bunch can also improve temporal resolution in pulse radiolysis experiment [2]. Therefore at our laboratory, a new rf-gun cavity specialized for producing an ultra-short electron bunch have been developed and installed for various beam operation [3]. This new cavity has an extra cell which is called ECC (Energy Chirp Cell) following the 1.6 cell.

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These application researches demand for high quality and well controlled electron beam. In order to measure the ultra-short electron bunch, we decided to use rf-deflector cavity, which can convert the longitudinal distribution to transverse. Using this technique, the longitudinal bunch profile can be obtained as the transverse profile. The outline of rf-deflector bunch length measurement system is below (Fig.1).

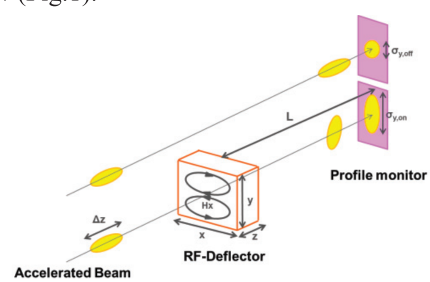

Figure 1: outline of rf-deflector system.

In our system, 1.6 cell rf-gun usually produce electron bunch with energy of 5 MeV and bunch length of 4 ps(rms). In addition, ECC-rf-gun will be able to produce approximately 100 fs bunch length with energy of 4.5 MeV after the drift length 2.5 m away from cathode [3]. Thus, our rf-deflector cavity is targeted for these electron beam bunch measurement.

RF-DEFLECTOR SYSTEM

For ultra-short electron bunch measurement, we have developed rf-deflector cavity which can produce horizontal rf-magnetic-field on the beam line and kick the electron bunch to vertical direction by the Lorenz force. In the case of zero-crossing phase, rf-deflector cavity gives a linear transverse deflection from head to tail of the bunch, as shown in Fig.2. Thus, we can achieve the longitudinal bunch profile by observing the transverse profile.

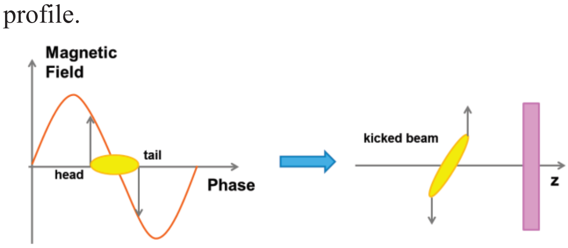

Figure 2: Effect of the transverse magnetic field generated by rf-deflector cavity.

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In bunch length measurement using rf-deflector cavity, bunch length Δz is expressed by (assuming the Gaussian profile):

$$\Delta z = \frac{E\sqrt{\sigma^2_{y,on} - \sigma^2_{y,off}}}{2cB_0 L(\cos(\omega t_0 + \varphi) - \cos\varphi)} \quad (1)$$

where $\sigma_{y,on}$ and $\sigma_{y,off}$ are the vertical beam size at the profile monitor when an rf-deflector cavity is on and off, respectively, B_0 is the peak magnetic field in rf-deflector cavity, L is drift length between center of the rf-deflector cavity and the profile monitor, φ the rf-phase when the bunch enter the rf-deflector cavity, ω the angular frequency of the rf-deflector cavity, E the beam energy, t_0 the traveling time of the bunch in rf-deflector cavity, c the velocity of light.

DESIGN OF RF-DEFLECTOR

Our design target is to measure 100 fs bunch length with 1.0 m drift, 750 kW rf-power, and 2856MHz operation frequency. According to Eq. (1), total magnetic field of rf-deflector cavity needs 1280 G with 1 cell deflector cavity The detail of the beam parameters are shown on Table 1.

Table 1: Target Parameters of RF-Deflector Design

Target bunch length Δz 100 fs	Beam energy E 4.36 MeV
Beam size $\sigma_{y,off}$ 0.3 mm	Beam size$\sigma_{y,on}$ 0.58 mm
Drift length L 1.0 m	Total magnetic field 1280 G

Because of our systematic condition, the rf-power for deflector cavity is limited by 750kW, which can produce more than 1300 G magnetic field. Therefore, we have adopted a 2 cell standing wave structure operating on the π mode, dipole (TM_{120}) mode at 2856 MHz. In this section, the cavity shape optimization by single-cell cavity, 2 cell rf-deflector cavity design, and GPT beam tracing results will be reported.

Single-Cell RF-Deflector Cavity

Firstly, we optimized single-cell design in advance. For designing rf-deflector cavity, we have used the 3D electromagnetic field codes HFSS (High Frequency Structure Simulation). At first, changing the aspect ratio can improve a Q-value of cavity and the peak transverse magnetic field. As a result, we determined that the aspect ratio (x/y) is 1.36, and round shape corners also increase the Q-value. Then, each length has been adjusted to set the resonant frequency at 2856 MHz. The single-cell z length is equal to $\beta c/2\omega$ to synchronize the bunch passage. The inner diameter of the beam transport pipe is designed as narrow as possible (15 mm) to avoid the leakage of the magnetic field while that of the transfer line is 38 mm. The optimized single-cell structure is shown in Fig.3.

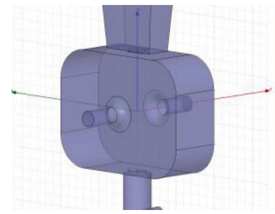


Figure 3: Single-cell structure of the rf-deflector.

We confirmed on HFSS simulation that this structure could reach a peak transverse deflecting magnetic field of more than 960G with the input rf-power of 750 kW. Scaling this structure to 2 cell rf-deflector cavity, we can expect that total magnetic field of more than 1300 G would be achieved with the same input power. Therefore, we start the design of 2 cell rf-deflector cavity by uniting this single-cell structure.

2 Cell RF-Deflector Cavity

In 2 cell rf-deflector cavity, as mentioned, we adopted π-mode as an operating mode at 2856 MHz. Firstly, we show the final design of 2 cell rf-deflector cavity in Fig. 4. We call the upstream cell "Cell A" and the downstream one "Cell B" on the beam transport line, respectively.

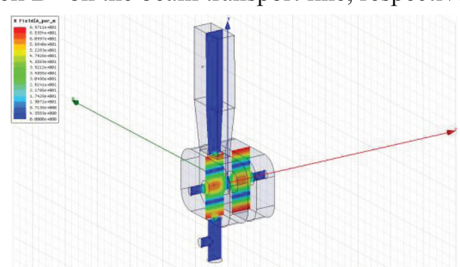


Figure 4: Magnetic field distribution in 2 cell rf-deflector cavity by HFSS.

Fig.4 shows the magnetic field distribution in the cavity in YZ plane, and we can confirm that the same magnitude of magnetic field is produced on the beam line. A mode separation which means resonant frequency separation between π-mode and 0-mode needs more than 4 MHz. To optimize the mode separation, we have adjusted the length and inner diameter of iris, and got 4.55 MHz mode separation in this procedure while the transverse magnetic field of the each cell is the same magnitude (Fig.5).

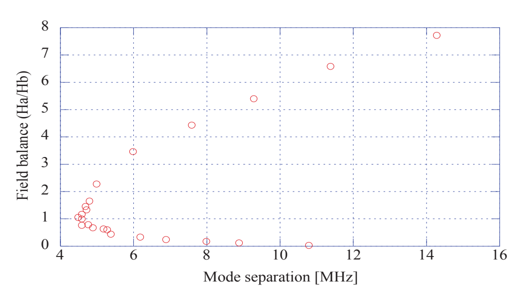


Figure 5: Field balance as a function of mode separation

Moreover, to optimize the rf-kick in the 2 cell rf-deflector cavity, we have used GPT (General Particle Tracer) for beam tracking and decided the z length of the cavity [4]. The reflection plot by the HFSS is shown in Fig.6, then the coupler waveguide is attached and the monitor port is done on the reverse side of the cell A for keeping the symmetry of electromagnetic field.

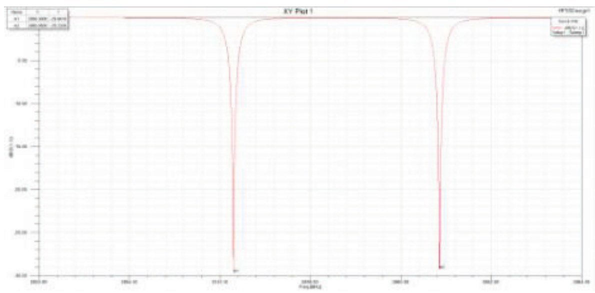
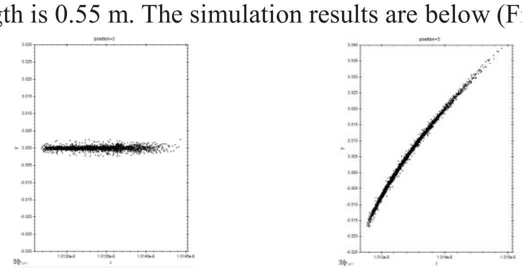


Figure 6: Reflection simulation result of 2 cell rf-deflector cavity by HFSS

This figure shows that the resonant frequency of π-mode and 0-mode are 2856.3 MHz, 2860.85 MHz and the mode separation is 4.55 MHz. This result agrees with Table 2. Q-value calculated by the resonant width of π mode is 17282. And this cavity could produce the total magnetic field 1324 G with the input rf-power of 750 kW, which is satisfied with our requirement.

Beam Tracking on GPT

We have used GPT for beam tracking. Then, we used 1.6 cell rf-gun with the energy of 3.97 MeV and the bunch length of 3.3 ps as an electron source, solenoid magnet and Q-doublet as a transport line, and the drift length is 0.55 m. The simulation results are below (Fig.7).



(A) (B)

Figure 7: Bunch profile of TY plane (A): deflector is off, (B): deflected bunch at the zero-crossing phase

Fig.7 shows that electron bunch is linearly deflected by 2 cell rf-deflector cavity after drift length. On GPT studies, we confirmed that 2 cell cavity deflection is about 1.4 times stronger than single-cell at the same rf power input. That means we have correctly achieved the design of scaling single-cell to 2 cell cavity structure.

MANUFACTURE OF RF-DEFLECTOR

Since we confirmed on HFSS and GPT simulation that this structure is worth making, we are under manufacture of 2 cell rf-deflector cavity with the collaboration of High Energy Accelerator Research Organization (KEK). This cavity is composed of several parts and parts are formed by brazing. Some tuners and water pipes are introduced at the phase of detailed design. After brazing, 2 cell rf-deflector cavity is formed as shown in Fig.8.

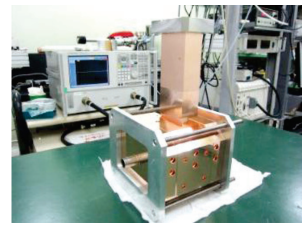


Figure 8: Photo of 2 cell rf-deflector cavity

The rf-measurement results by network analyzer are shown in Fig.9. This figure shows that the resonant frequency of π-mode and 0-mode were 28555.387 MHz, 2859.892 MHz and the mode separation is 4.505 MHz under air condition.

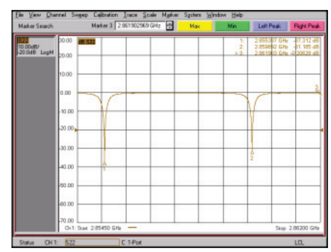


Figure 9: rf-measurement result by network analyzer

The results were agreed with Fig.6 in vacuum condition, thus we confirmed the manufacture was successfully completed.

CONCLUSIONS AND PROSPECTS

In this paper, we introduced the rf-deflector system for ultra-short electron bunch measurement and described the design procedure for 2 cell rf-deflector cavity. Finally, we have achieved 2 cell rf-deflector cavity which is able to measure 100 fs bunch with 4.36 MeV. Now, the cavity was almost completed and it will be installed in our accelerator system in this summer.

RFERENCES

[1] K. Sakaue, et al., Radiation. Phys. Chem. 77. 1136 – 1141 (2008).

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

[3] Y. Koshiba, et al., “Development of an rf electron gun for ultra-short bunch generation”, IPAC2012, TUPPD058,(2012).

[4] The General Particle Tracer, http://www.pulsar.nl/gpt/

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