STUDY ON 2 CELL RF-DEFLECTOR CAVITY FOR ULTRA-SHORT ELECTRON BUNCH MEASUREMENT*

T. Takahashi†, Y. Nishimura, M. Nishiyama, K. Sakaue, M. Washio
Waseda University, Tokyo, Japan

T. Takatomi, J. Urakawa, KEK, Ibaraki, Japan

Abstract

We have been studying on an rf-deflector system to measure ultra-short electron beam bunch length at Waseda University. By using HFSS, we optimized the design of the 2 cell rf-deflector which is operating on π-mode, standing wave, dipole (TM_{110}-like) mode at 2856 MHz. We have finished manufacturing under the collaboration with High Energy Accelerator Research Organization (KEK) and installing the rf-deflector in the accelerator system of Waseda University. It is estimated that this rf-deflector has sufficient performance for measuring the ultra-short electron bunch. Now the experiment has just begun and confirmed electron beam is swept by this rf-deflector. Bunch length measurement will be soon carried out accurately. In this paper, the design of rf-deflector, the estimation for rf-deflector performance, the present progress and the future plan will be described.

INTRODUCTION

At Waseda University, a compact linear accelerator system based on photo-cathode rf electron gun is applied for the various researches and we have two kinds of rf electron guns as beam sources, 1.6 cell S-band Cs-Te photo-cathode rf gun (1.6 cell gun) for the pulse radiolysis [1] and the laser Compton scattering [2], Energy chirping cell attached rf gun (ECC gun) for the generation of coherent THz radiation [3]. It is necessary to measure time structure of electron beam on several picoseconds region on 1.6 cell gun and bunch length of several hundreds femtoseconds on ECC gun in the future. Therefore, we have been developing an rf-deflector system in order to achieve the bunch length measurement with high temporal resolution.

PRINCIPLE OF BUNCH LENGTH MEASUREMENT BY RF-DEFLECTOR

When rf electromagnetic wave is supplied into an rf-deflector, a proper resonant mode is excited. The resonant electromagnetic field in the beam line produces force on the beam. The magnitude of the force which influences on each part of the electron bunch is different in association with temporal change. When this force has vertical direction to the beam line, the beam after the passage of an rf-deflector is tilted as it drifts. This means the longitudinal distribution of the beam is converted to the transverse. The bunch length can be calculated by observing the transverse distribution. The outline of bunch length measurement by an rf-deflector is below (Fig.1).

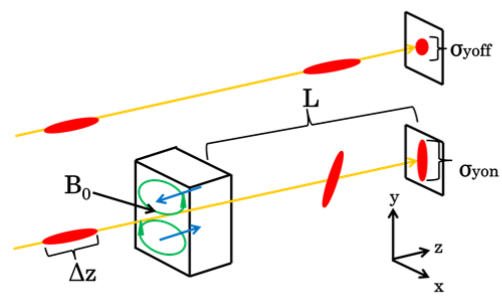

Figure 1: Outline of bunch length measurement.

In Waseda University, we have designed the rf-deflector which produces only Lorentz force to the beam by a magnetic field, using a TM110-like mode. By solving the equation of motion to electron, bunch length Δz is expressed by (assuming the Gaussian profile):

$$\Delta z = \frac{E\sqrt{\sigma_{yon}^{\ 2} - \sigma_{yoff}^{\ 2}}}{2cB_0 L\{\cos(\omega t_0 + \phi) - \cos\phi\}} \qquad (1)$$

where σ_{yon} and σ_{yoff} are the vertical beam size at the profile monitor when the rf-deflector is on and off, respectively, B_0 the peak magnetic field in the rf-deflector, L drift distance between the outlet of the rf-deflector and the profile monitor, φ the rf phase when the bunch enters the rf-deflector, ω the angular frequency of the rf-deflector, E the beam energy, t_0 the traveling time of the bunch in the rf-deflector, c the velocity of light. Then the number of 2 in the denominator represents the 2 cell structure of the rf-deflector. When σ_{yon} is measured, it is supposed that the time resolution becomes higher if the space covered by σ_{yoff} is smaller. So it is important to get large σ_{yon} and small σ_{yoff}. According to Eq. (1), the large magnitude of B_0 or L brings about the progress of time resolution, and ultra-short bunch length measurement could be possible. Because L has the limitation considering the size of the accelerator facility, we have designed the form of the rf-deflector with the larger

*Work supported by JSPS Grant-in-Aid for Scientific Research (A) 10001690 and the Quantum Beam Technology Program of MEXT.
† qwerty-ytrewq@toki.waseda.jp.

magnitude of B_0 and adopted the rectangular-based 2 cell rf-deflector as a result.

DESIGN AND MANUFACTURING OF RF-DEFLECTOR

We have used HFSS simulating 3D full-wave electromagnetic fields for the design of the rf-deflector [4]. An rf-deflector is a kind of cavity, and proper resonant modes related to the form of a cavity are conducted by solving Maxwell equation. We have determined the cavity parameters to make TM110-like mode on 2856 MHz. The largest magnitude of B_0 has been obtained, adjusting the sizes of x and y directions.

We have improved the structure from 1 cell to 2 cell for the further progress of temporal resolution. The π-mode operation of 2 cell cavity provides larger tilt for electron bunch. The structure of the 2 cell rf-deflector is shown in Fig. 2. The magnetic field in 2 cell rf-deflector (Fig. 3) and the coupling with the waveguide have been optimized on HFSS.

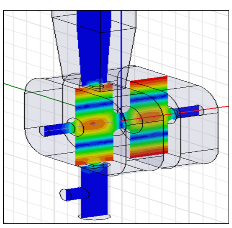

Figure 2: Structure of 2 cell rf-deflector (HFSS).

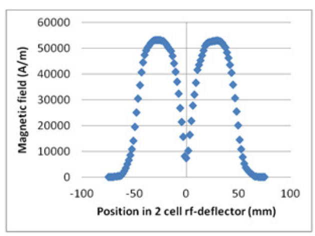

Figure 3: Magnetic field in 2 cell rf-deflector with 750 kW supply (HFSS).

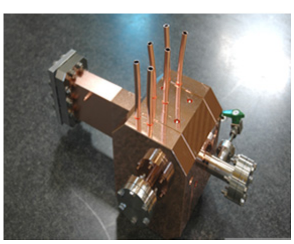

Figure 4: Structure of 2 cell rf-deflector.

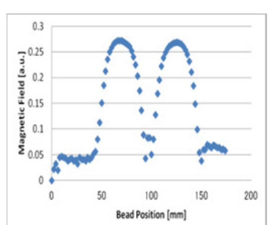

Figure 5: Magnetic field in 2 cell rf-deflector.

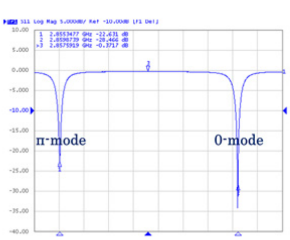

Figure 6: Reflecting method result.

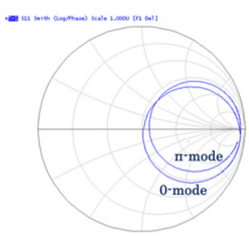

Figure 7: Smith chart.

On the basis of this design by HFSS we have manufactured the 2 cell rf-deflector under the collaboration with High Energy Accelerator Research Organization (KEK). The cavity was processed the fabrication-coordination of rf frequency iteration 4 times. After achieving the desired frequency, the each part was brazed. The finished 2 cell rf-deflector is shown in Fig. 4. Some tuners and water pipes are attached to each cell.

For the purpose of the installation in the accelerator system at Wasede University, we have tuned the rf-deflector by the tuners and temperature of the rf-deflector. The results after the tuning are shown in Fig. 5, Fig. 6, and Fig. 7. Figure 5 shows that the magnetic field strength in each cell is almost the same by the beads method. Figures 6 and 7 show the results of measurement by reflecting method and the smith chart on network analyzer. These indicate the coupling with the waveguide is suitable. The comparison of the cavity parameters after tuning and the desired value is shown on Table 1. The desired value has been set under air condition. The fabrication and tuning of the rf-deflector have successfully processed, as shown in Table 1.

Table 1: Target Parameters of RF-deflector Design

Parameters	Result	Desired value
π mode	2855.348MHz	2855.372MHz
0 mode	2859.874MHz	2859.922MHz
Δf	4.526MHz	4.55MHz(HFSS)
Q value on π mode	16298	17282(HFSS)
Ratio of magnetic field	1:0.9875	1:1
Coupling constant β	0.839	1.000

SETUP AND EXPERIMENT

After establishing the rf-deflector, we have installed in the accelerator system. The outline of the setup is shown in Fig.8 and the accelerator system after installation shown in Fig. 9. We can measure the beam energy by the bending magnet and the charge by the FCT in the downstream of the rf-deflector. Because of our systematic condition, we have installed the rf-deflector falling sideways. This means the beam is tilted in x direction, so we think of the beam size in x direction as σ_{yon} and σ_{yoff}. The rf-power for the rf-deflector is variable in the range of 0~750kW through the attenuator.

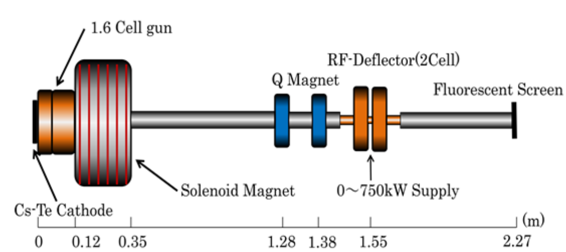

Figure 8: Setup of rf-deflector system.

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ISBN 978-3-95450-138-0

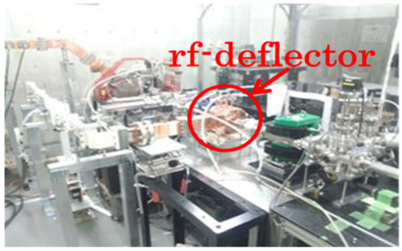
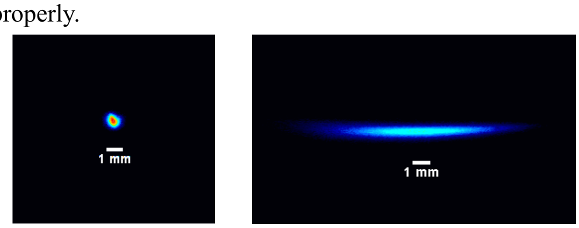


Figure 9: RF-deflector system.

Now the experiment has just begun. First of all, we had to confirm the rf-deflector is operating properly. We have observed the focused beam on the screen with the rf-deflector off to optimize the currents in the solenoid magnet and Q magnets. The deflected beam has been observed at the zero-crossing phase with the rf-deflector when 175kW rf-power was supplied. These profiles are shown in Fig. 10. The peak position of the beam doesn't move compared with Fig 10 (A) at the zero-crossing phase. The beam parameters were about 4.8MeV and 3pC. In Fig. 10, σ_{yoff} is about 220µm and σ_{yon} is about 3.26mm. This result indicates that the rf-deflector is operating properly.



(A) (B)

Figure 10: Observed beam profiles. (A): deflector is off, (B): deflected bunch at the zero-crossing phase.

Because B_0 is 320G with 175kW supply on HFSS simulation, the bunch length can be estimated to be 2.07ps from Eq. (1). The temporal resolution of the rf-deflector means the limitation of measurable bunch length and is derived as the bunch length in the case that σ_{yon} equals σ_{yoff}. Therefore, the temporal resolution is approximately 140fs from σ_{yoff}, σ_{yon}, and the bunch length.

The B_0 that we discussed above is not correct value. The actual B_0 in the rf-deflector is now under calibration, otherwise the accurate bunch length and temporal resolution can not be calculated. The B_0 calibration is accomplished by fitting the displacement about the peak of the beam, Δy, to the rf-deflector phase, φ_0. The displacement Δy is expressed by:

$$\Delta y = \frac{c^2 B_0 L}{E\omega}\{\sin(\omega t_0 + \phi_0) - \sin\phi_0\} \qquad (2)$$

These parameters are the same as described in Eq. (1). Since the actual B_0 is probably smaller than the value on HFSS due to the loss of the rf-power, the accurate bunch length and temporal resolution will come to be larger. However, the simulation result may not have much difference, thus we can estimate that this rf-deflector system has a capability of measuring ultra-short bunch. Concerning the short bunch beam, which has the several picoseconds length, the temporal structure of the electron bunch can be observed. The precise bunch length measurement will be soon carried out.

CONCLUSIONS AND PROSPECTS

In this paper, we introduced the rf-deflector system for the bunch length measurement with high temporal resolution and described the procedure for 2 cell rf-deflector. We have achieved 2 cell rf-deflector which will be able to measure several hundreds of femtoseconds bunch. Now we have finished installation in our accelerator system and confirmed the rf-deflector operating properly. The precise bunch length measurement and dynamics studies of rf-gun will be soon carried out.

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