ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME133

BUNCH LENGTH MEASUREMENT WITH 2-CELL RF-DEFLECTOR AT WASEDA UNIVERSITY*

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 a system to measure the length of electron bunch generated by a photocathode rf electron gun at Waseda University. We adopted the rf-deflector system which can convert the longitudinal distribution to transverse by sweeping the electron bunch. By using HFSS, we optimized the design of the 2 cell rf-deflector which is operating on π-mode, dipole (TM210) mode at 2856 MHz. The fabrication and the tuning of the rf deflector have successfully processed. We have installed the rf-deflector in the accelerator system of Waseda University, and performed the measurement of the bunch length. It is confirmed that this rf-deflector has the temporal resolution of 167fs with 700kW supply when the beam energy is 4.8MeV. This means that our rf-deflector system has possibility to measure the ultra-short bunch length. In this conference, the rf-deflector system in Waseda University, the result of the bunch length measurement, the performance of the rf-deflector and the future plan will be reported.

INTRODUCTION

At Waseda University, a compact linear accelerator system based on a 1.6 cell S-band Cs-Te photo-cathode rf electron gun is applied for the various researches, such as pulse radiolysis [1] and laser Compton scattering [2]. By using the rf gun, we can control initial electron bunches as to the laser pulse irradiated to the photo-cathode and generate low emittance and short bunches. Because of acceleration by the radio frequency, the bunch length will change as the rf phase changes. So we should measure the bunch length to the rf phase and consider the effect of rf acceleration, or beam dynamics. Of course, this measurement contributes the development of many researches. Therefore, we have been developing an rf-deflector system in order to achieve the bunch length measurement with high temporal resolution.

*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

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 to 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 horizontal 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).

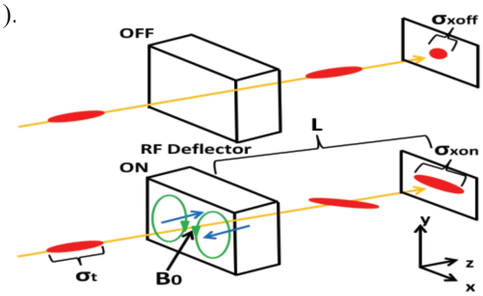


Figure 1: Outline of bunch length measurement.

In Waseda University, we have designed the rf-deflector which produces only Lorentz force to the beam by a magnetic field, using a TM210 mode. By solving the equation of motion to electron, a displacement in x direction Δx is expressed by:

$$\Delta x = \frac{cB_0L}{E}\sin(k\Delta z + \varphi) \quad (1)$$

where c is the velocity of light, B_0 is an integrated value of the magnetic flux density which effects on the electron in the rf-deflector, L is a drift distance between the center of the rf-deflector and the profile monitor, E [eV] is beam energy, k is a wave number, Δz is a position in z direction (the center of an electron bunch corresponds to $\Delta z=0$), φ is a deflector phase [3]. Since the length of laser pulse irradiated to the cathode is 4ps rms and the rf period is 350ps in our accelerator system, it leads $k\Delta z \ll 1$. So the electron bunch is swept linearly when the deflector phase becomes near zero-crossing ($\varphi \approx 0$). Considering the Eq. (1), the bunch length σ_t [s] can be expressed by (assuming the Gaussian profile):

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME133

$$\sigma_t = \frac{E}{cB_0\omega L}\sqrt{\sigma_{xon}^2 - \sigma_{xoff}^2} \quad (2)$$

where σ_{xon} and σ_{xoff} are the horizontal beam size at the profile monitor when the rf-deflector is on and off, respectively, ω is an angular rf frequency. When σ_{xon} is measured, it is supposed that the temporal resolution becomes higher if the space covered by σ_{xoff} is smaller. So it is important to get large σ_{xon} and small σ_{xoff}. According to Eq. (2), the large magnitude of B_0 or L brings about the progress of the temporal resolution, and ultra-short bunch length measurement could be possible. Actually, the temporal resolution σ_{t_res} is defined as the bunch length satisfying $\sqrt{\sigma_{xon}^2 - \sigma_{xoff}^2} = \sigma_{xoff}$, that is:

$$\sigma_{t\_res} = \frac{E}{cB_0\omega L}\sigma_{xoff} \quad (3)$$

Since L has the limitation considering the size of our accelerator facility, we have designed the form of the rf-deflector with the larger magnitude of B_0 and adopted the rectangular-based 2 cell rf-deflector as a result.

DESIGN AND MANUFACTURING OF RF-DEFLECTOR

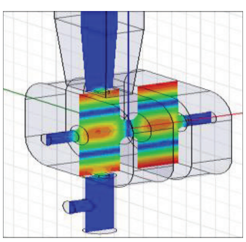


Figure 2: Structure of 2 cell rf-deflector (HFSS).

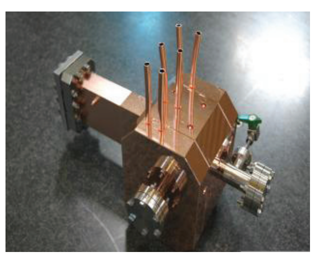


Figure 3: Structure of 2 cell rf-deflector.

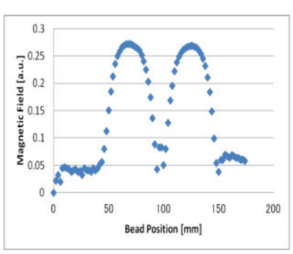


Figure 4: Magnetic field in 2 cell rf-deflector.

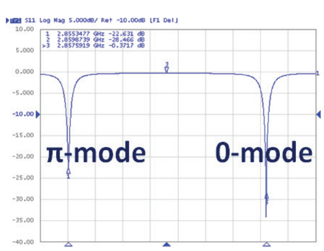


Figure 5: Reflecting method result.

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 a TM210 mode on 2856 MHz. The largest magnitude of B_0 has been obtained by 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 bunches. The structure of the 2 cell rf-deflector is shown in Fig. 2. The magnetic field in each cell has been adjusted in the ratio of 1 to 1 and the coupling with the waveguide has been optimized on HFSS.

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 completed 2 cell rf-deflector is shown in Fig. 3. Some tuners and water pipes are attached to each cell.

For the purpose of the installation in the accelerator system at Waseda University, we have fine-tuned the resonant frequency by the tuners and temperature of the rf-deflector. The results after the fine-tuning are shown in Fig.4 and Fig. 5. Fig. 4 shows that the magnetic field strength in each cell is almost the same by the bead perturbation. Fig.5 shows the results of measurement by reflecting method on network analyzer. This indicates the coupling with the waveguide was adequate. The comparison of the cavity parameters after tuning and the desired values are 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 our accelerator system. The outline of the setup is shown in Fig.6. 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 sideways. This means the beam is tilted in x direction. The rf-power for the rf-deflector is variable in the range of 0~750kW through the attenuator.

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.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME133

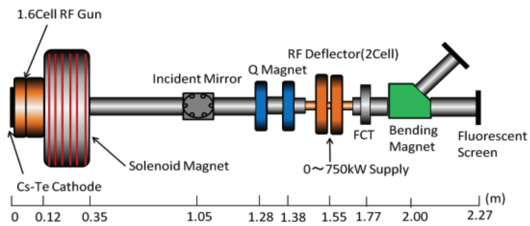
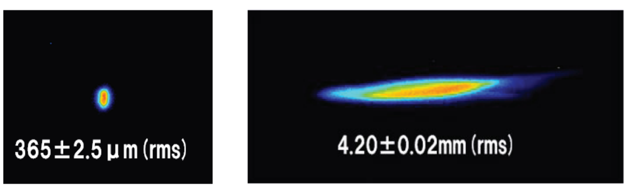


Figure 6: Setup of rf-deflector system.

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. 7. The peak position of the beam doesn't move compared with Fig 7 (A) at the zero-crossing phase. The beam parameters are about 4.8MeV and 270pC. In Fig. 10, σ_{xoff} is about 365μm and σ_{xon} is about 4.20mm. This result indicates that the rf-deflector is operating properly and has the sufficient capacity for the bunch length measurement.



(A) (B)

Figure 7: Observed beam profiles. (A): deflector is off, (B): deflected bunch at the zero-crossing phase.

The rf-deflector system has to be calibrated for evaluating the bunch length accurately. In other words, we need to determine the integrated value of the magnetic flux density B_0. From Eq. (1), the displacement of the beam center position should be sinusoidal to the deflector phase and the amplitude corresponds to the coefficient cB_0L/E. This factor is 12.15mm on the calibration result with L=0.72m, E=4.8MeV, the rf power 70kW supply (Fig. 8). Substituting σ_{xoff} =365μm and cB_0L/E =12.15mm for Eq. (3), the calculated temporal resolution was 1.67ps. When 700kW is supplied, the rf-deflector acquires 167fs of the temporal resolution.

We have carried out the bunch length measurement on the basis of the above consideration. The result is shown in Fig.9. The standard error of each bunch length is less than 0.2ps. The case of Fig. 7 corresponds to the plot on 40 deg in Fig. 9. It is supposed that the measured bunch length is not influenced by space charge effect so much owing to the short drift distance L=0.72m, though the maximum charge is 270pC. The optimum operating condition is on 20 deg because of maximum energy and minimum energy spread. The bunch length shortens by about 1ps on that phase considering the initial bunch length is 4ps. Each bunch on the rf phase less than 50 deg is bunched by rf acceleration. In other words, the bunching effect appears on the rf phase which generates higher energy. De-bunching will happen on the rf phase over 50 deg, but it is difficult to measure the bunch length because of larger energy spread. The bunch length is linearly increased to the rf phase. Concerning the bunch length on 50 deg, it is slightly longer than on 40 deg, although each charge is almost the same. Probably, the larger energy spread on 50 deg caused the expansion of the bunch.

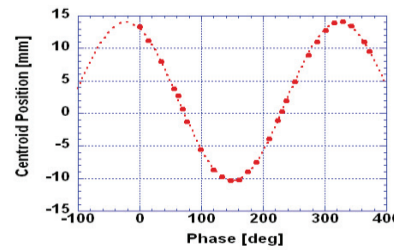


Figure 8: Displacement of beam centroid position to deflector phase.

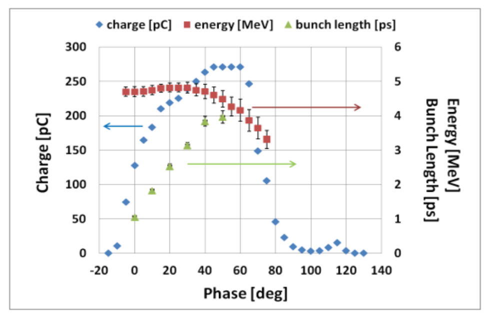


Figure 9: Bunch length measurement.

CONCLUSIONS AND PROSPECTS

In this paper, we introduced the rf-deflector system for the bunch length measurement and described the procedure for 2 cell rf-deflector. Moreover, we could consider about the beam dynamics of 1.6 cell rf gun through the bunch length measurement. We think this rf-deflector with high temporal resolution is also very useful for studying the beam dynamics of ECC rf gun [5] which can generate ultra-short bunches. In near future, we plan to obtain the phase space distribution by a combination of the bending magnet and the rf-deflector with 1.6 cell rf gun.

RFERENCES

[1] Y Hosaka, et al., Radiation. Phys. Chem. 84, 10(2013).
[2] K. Sakaue, et al., Radiation. Phys. Chem. 77. 1136 –1141 (2008).
[3] P. Emma, et al. SLAC Report, No. LCLS-TN-00-12, (2000).
[4] Y. Nishimura, et al., Nucl. Instrum. Meth., A, under review.
[5] K. Sakaue, et al., Phys. Rev. S. T. Accel. Beams, 17, 023401, (2014).