9th International Particle Accelerator Conference IPAC2018, Vancouver, BC, Canada JACoW Publishing
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMK147

MEASUREMENT OF SLICE-EMITTANCE OF ELECTRON BUNCH USING RF TRANSVERSE DEFLECTOR*

T. Sasaki†, Y. Nakazato, Y. Koshiba, K. Sakaue, M. Washio
RISE, Waseda University, Tokyo 169-8050, Japan

Abstract

We have been studying a high quality electron bunch generated by a photocathode rf electron gun. We are using this electron bunch for many application researches. In those application, it is very important to measure its detailed parameters. Last year, we conducted three-dimensional distribution measurement of electron bunch using RF-Deflector. This year, we have succeeded in evaluating not only the geometric parameters but also the phase space distribution in the slice of electron bunch. In this conference, we report the principle and experimental results of the slice emittance measurement and future prospects.

INTRODUCTION

A photocathode rf gun is now widely used for an injector of large accelerator system in many facilities due to its controllability of initial bunch profile and ability to generate low emittance bunch. At Waseda University, we use it to perform a pulse radiolysis[1], generation of coherent Cherenkov radiation[2], and laser Compton scattering for soft X-ray generation[3]. For these applications, it is very important to measure the precise bunch parameters. Therefore, we have developed the rf deflector system[4] and have performed three-dimensional distribution measurement using CT(Computed Tomography) technique[5]. To analyze the electron bunch multidimensionally, we attempted to measure the slice emittance by utilizing RF-Deflector with Q scan method. In this conference, we report principles of the experiments, experimental setup, results and discussions, and future prospects.

PRINCIPLES

The emittance measurement in this experiment was performed by using the Q scan method. There is a relationship between the convergence force K by the quadrupole magnet and the bunch size σ_y after the drift distance L. It is shown in equation (1).

$$\sigma_y^2 = L^2\sigma_{11}^2\left(K - \left(\frac{\sigma_{12}}{\sigma_{11}^2} + \frac{1}{L}\right)\right)^2 + \frac{L^2\varepsilon^2}{\sigma_{11}^2} \qquad (1)$$

Here, σ_{11} and σ_{12} are the components of the σ matrix at the quadrupole magnet. When changing the K value of the quadrupole magnet with RF-Deflector turned off, σ_y can be fitted with a quadratic function. Here, we define the quadratic function as equation (2).

$$\mathrm{y} = \mathrm{a}(\mathrm{K} - \mathrm{b})^2 + c \qquad (2)$$

By comparing equation (1) with equation (2), the projected emittance in the y direction can be calculated by equation (3).

$$\varepsilon = \sqrt{\frac{ac}{L^4}} \qquad (3)$$

The emittance value described in the experimental results is normalized emittance obtained by multiplying equation (3) by γβ.

Next, we consider the slice emittance by turning RF-Deflector on. When RF-Deflector is turned on, z direction of bunch is projected in the x direction as shown in Fig. 2. From this profile, a bunch is cut out in the range of x larger than the temporal resolution. By changing the K value of the quadrupole magnet and measuring the y-direction bunch size of each slice, we can measure slice emittance as shown in Fig. 2. Note that in Figures 1 and 2 the right side represents the bunch head and the left side represents the bunch tail. In the experiment, when convergence is applied in the y direction by the quadrupole magnet, the divergence force is simultaneously given in the x direction and the bunch size increases. Therefore, in the analysis, the x direction bunch sizes are equalized for all K values so as not to change the slice position. Also, in order to measure the slice emittance from head to tail of the electron bunch, the number of slices and the slice width are adjusted with each data.

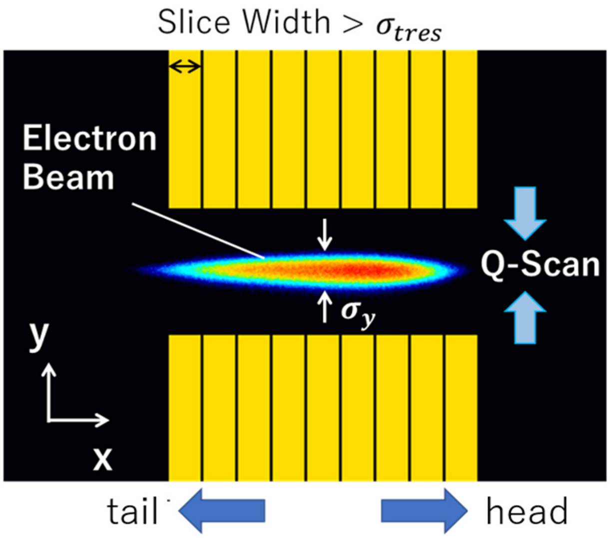

Figure 1: Diagram of slice emittance measurement.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMK147

When determining the slice width, we calculate the length on the profile corresponding to the temporal resolution by using Skewing Strength.

The Q scan method is susceptible to space charge effects and is not suitable for bunches in the low energy region. Therefore, in this experiment, the space charge effect is suppressed by using a low charged beam.

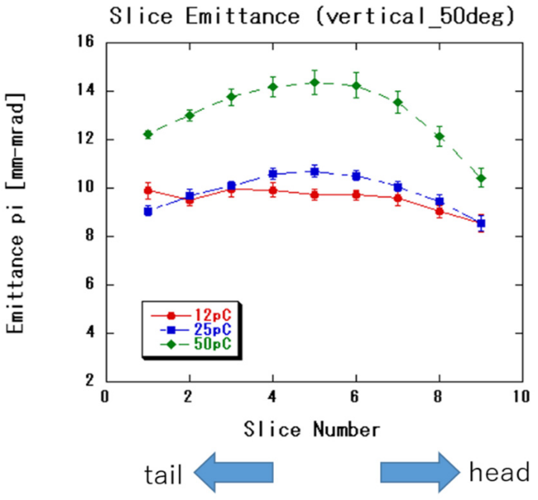

Figure 2: An example of slice emittance measurement.

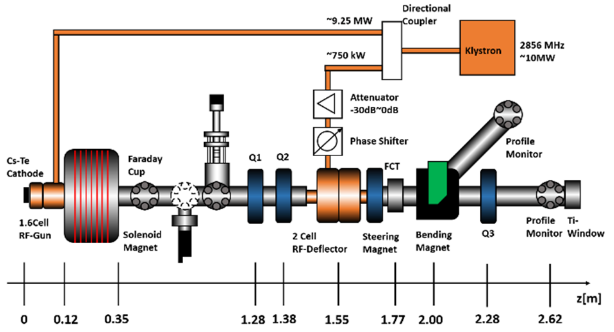

Figure 3: Experimental setup of slice emittance measurement.

EXPERIMENTAL SETUP

The setup of the slice emittance measurement is shown in Fig. 3. The solenoid magnet and the two upstream quadrupole magnets (Q1, Q2) are used for bunch convergence. The measurement of the bunch charge and the bunch energy are carried out by using the FCT (Fast Current Transformer) and the bending magnet, respectively. Q scan is performed with a quadrupole magnet Q3 installed at 2.28m from the cathode. The drift distance L from Q3 to the screen is 0.34m.

RESULTS AND DISCUSSION

By changing the acceleration phase of RF-Gun to 10, 20, 30, 40, 50 deg and the bunch charge to 12, 25, 50 pC, the slice emittance was measured. Laser injection was carried out in two ways, perpendicular injection and oblique injection.

As for the acceleration phase, the phase at which electron bunch starts to be observed at perpendicular injection is defined as 0 deg, and the acceleration phase is adjusted so that the energy plot by phase at perpendicular injection and oblique injection coincide. The result of emittance in this paper is the normalized emittance, and the unit is mm - mrad.

Table 1 shows the slice emittance setup parameters at perpendicular injection. The current value of the solenoid magnet is constant at 110A, and the bunch is converged in the x direction by using Q1 and Q2 in order to increase the time resolution in the slice emittance measurement.

Table 1: Setup Parameters at Perpendicular Injection

Charge[pC]	Phase[deg]	Q1[A]	Q2[A]
12	10	0.3	0.5
	20	0.2	0.35
	30~50	0.2	0.3
25,50	10~50	0.35	0.5

The results were separated for each acceleration phase, and slice emittance by bunch charge was compared. The results are shown in Fig. 4. In the figure, the scale of the vertical axis is unified. In the slice emittance measurement, the bunch is divided into 9 slices (or 7 slices), and for those with the same number of slices, the bunch length is almost the same. Since the bunch length becomes small at low charge and low phase, there are less slices in these conditions due to the temporal resolution. As shown in the figure, the slice emittance increases as the charge increases at each acceleration phase, but the difference becomes smaller as the acceleration phase increases. Therefore, it can be considered that the space charge emittance is dominant at low acceleration phase, whereas the RF emittance also appears greatly at high acceleration phase.

Table 2 shows the setup parameters at oblique injection. The current value of the solenoid magnet is constant at 95A, and the bunch is converged in the x direction by using Q1 and Q2 in order to increase the temporal resolution in the slice emittance measurement.

Table 2: Setup Parameters at Oblique Injection:

Charge[pC]	Phase[deg]	Q1[A]	Q2[A]
12,25,50	10~40	0.5	0.62
	50	0.55	0.65

The results were separated for each acceleration phase, and slice emittance by charge was compared. The results are shown in Fig. 5. As with perpendicular injection, the slice emittance increases as charge increases for each acceleration phase, but it turns out that the difference decreases as the acceleration phase increases as same as perpendicular injection.

Figure 6 shows the comparison of slice emittance at perpendicular injection and oblique injection. The slice emittance was larger at oblique injection regardless of the bunch charge. Since the sizes of the incident lasers are unified, the initial bunch size in the y direction should be the same, but at oblique injection, the initial bunch size increases in the x direction. Thus, we can consider that the bunch is influenced laterally by the accelerating electric rf field and the bunch size after acceleration is increased. Since the x direction and the y direction are mixed by the solenoid magnet, the resulting emittance also increased in the y direction.

CONCLUSIONS

We successfully measured the slice emittance using RF-Deflector with Q scan method. Experimental results show that the factor of the slice emittance increase is the space charge emittance and the RF emittance received inside the accelerator. When the charge increases, the slice emittance around the center of the bunch increases due to space charge effect. Moreover, we found that the RF emittance appears to be dominant at higher phases. As for comparison of the laser injection method, we found that the slice emittance is larger at oblique injection. This is because the initial bunch size increases in the x direction by oblique injection.

In this experiment, we were succeeded in measuring the slice emittance at low charge. Therefore, we are going to measure it at high charge in the near future. We think that the knowledge obtained by this experiment will not only serve other applied researches but also will be a guide for the understanding of the acceleration mechanism of RF-Gun itself and the design of a new accelerating structure.

REFERENCES

[1] Y. Hosaka, R. Betto, K. Sakaue, R. Kuroda, S. Kashiwagi, K. Ushida, and M. Washio, Construction of nanosecond and picosecond pulse radiolysis system with supercon-tinu-um probe, Radiat. Phys. Chem. 84 (2013) 10-13.

[2] K. Sakaue, M. Nishida, R. Kuroda, and J. Urakawa, Generation of a coherent Cheren-kov radiation by using electron bunch tilting, in Proceedings of 7th International Particle Accelerator Conference, Busan, Korea (2016), pp. 1870-1872.

[3] K. Sakaue, T. Gowa, H. Hayano, Y. Kamiya, S. Kashiwagi. R. Kuroda, A. Masuda, R. Moriyama, J. Urakawa, K. Ushida, X. Wang, and M. Washio, Recent progress of a soft X-ray generation system based on inverse Compton scattering at Waseda University, Radiat. Phys. Chem. 77 (2008) 1136-1141.

[4] Y. Nishimura, K. Sakaue, M. Nishiyama, T. Takahashi, M. Washio, T. Takatomi, and J. Urakawa, Design of a two-cell rf-deflector cavity for ultra-short electron bunch meas-urement, Nucl. Instrum. Methods Phys. Res. A 764 (2014) 291-298.

[5] Yusuke Nakazato, Tomonori Sasaki, Y.Koshiba, Kazuyuki Sakaue, Masakazu Washio, Measurement of three-dimensional distribution of electron bunch using rf transverse deflector, in Proceedings of 8th International Particle Accelerator Conference, Copenhagen, Denmark (2017), pp. 285-287.

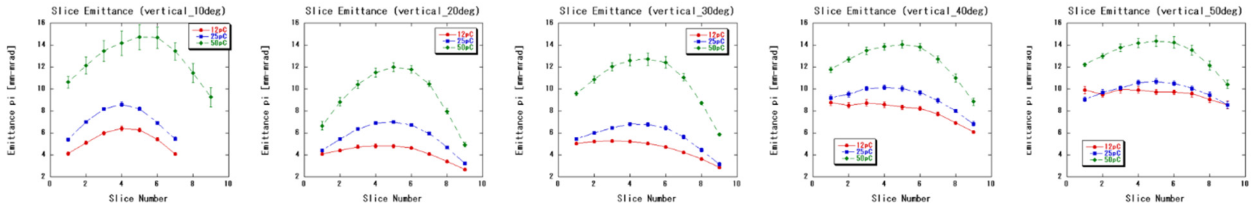

Figure 4: Experimental results at perpendicular laser injection.

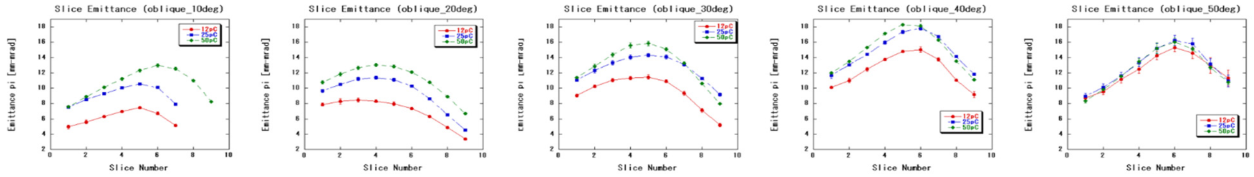

Figure 5: Experimental results at oblique laser injection.

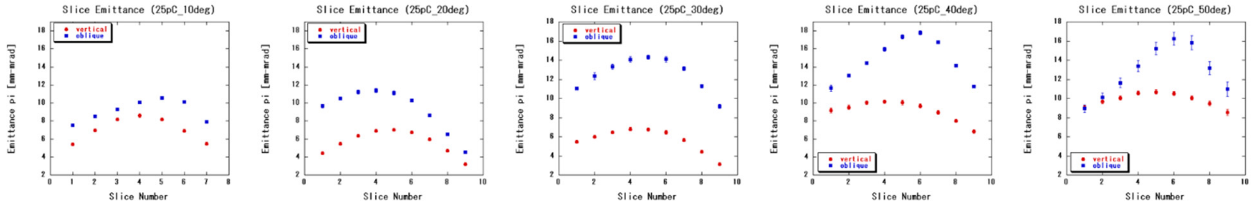

Figure 6: Comparison of slice emittance at perpendicular laser injection and oblique laser injection.