SLICE EMITTANCE MEASUREMENT USING RF DEFLECTING CAVITY AT PAL-XFEL ITF

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Abstract

One of key characteristic for operating PAL-XFEL is the time-dependent transverse properties of a bunch, slice emittance. To achieve the design FEL performance of PAL-XFEL a slice emittance of 0.4 mm mrad at 0.2 nC is required. An Injector Test Facility (ITF) was constructed to study beam properties. In addition to projected emittance measurement, slice emittance measurement is being done using a transverse RF deflecting cavity. We presents results of slice emittance measurement at ITF and future plan for the optimization of operating condition.

INTRODUCTION

The aim of ITF is to study beam dynamics and to produce low emittance electron beams for required future operating condition of PAL-XFEL. The required slice emittance for PAL-XFEL at the exit of injector is 0.4 mm-mrad at 0.2 nC and the acceptable emittance is 0.6 mm-mrad [1]. ITF has been operated to measure emittance and to optimize the elements of injector required for designed condition of PAL-XFEL. Maintaining a low emittance is necessary and one of the principal challenges. The ITF accelerator consists of an S-band 1.6-cell photocathode RF gun, two S-band accelerating columns, solenoids and diagnostic components including quadrupoles and transverse RF deflector [2]. The laser heater is planned to be installed in September 2014. A schematic layout of current ITF elements map is shown in Fig. 2. The Quadrupole for quad scan and YAG screen are located at 13.22 m and 15.86 m from the cathode, respectively. Using the transverse RF deflecting cavity, we can observe an image of the streaked beam at the YAG screen and then measure the slice emittance by the technique of quad scan. The details of the transverse RF deflecting cacity is introduced in the next section. Recently slice emittance has been measured at ITF. In this paper, the results of the slice emittance measurement are described.

EXPERIMENTAL SETUP

The measurements of slice emittance have been performed at the end of ITF with 81.7 MeV of the beam energy at 0.2 nC. The phase of RF photocathode gun is set to 34 ± 0.05 degree. The acceleration phase of two S-band accelerating columns located at 2.14, 5.72 m from cathode is set to on crest. Using the transverse RF deflecting cavity the beam can be streaked at YAG screen. The measurement is carried out by quad scan. The calculation of the slice emittance is fulfilled by using MATLAB code.

Transverse RF Deflecting Cavity

The RF deflecting cavities have been widely studied and used in the accelerator field for the high energy physics research and beam diagnostics of Free Electron Laser and many others. In RF deflecting cavity, as the transverse kick varies sinusoidally in time, each part of the bunch receives a different kick due to finite bunch width. Generally the phase of transverse RF deflecting cavity is chosen to have a zero crossing of RF phase at the middle of the bunch. According to this principle, the bunch gets no net deflection but is streaked vertically at a zero crossing phase of RF field [3]. Therefore we can observe a longitudinal image of the beam. The S-band transverse RF deflecting cavity is described in Fig. 1 and the specifications of it is in Table 1.

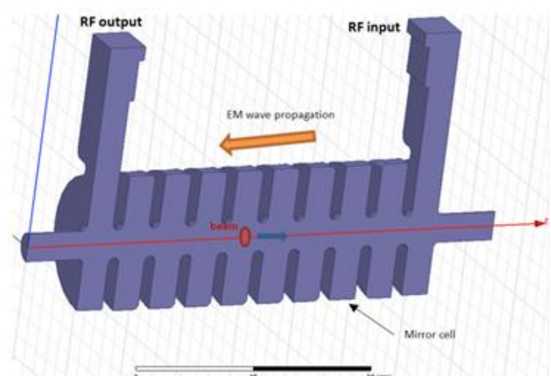

Figure 1: Schematic diagram of Transverse RF Deflecting Cavity.

Table 1: Specifications of Transverse RF Deflecting Cavity

RF parameter	Value	Unit
Frequency f	2.856	GHz
Transverse shunt impedance	28.7	MΩ/m
Unloaded Q	13,400	
Number of cells N	28 (L~1m)	
Attenuation constant α	0.158 (m^{-1})	
Group velocity v_g	0.014 c	
Kick/√power	2.7	MV/√MW

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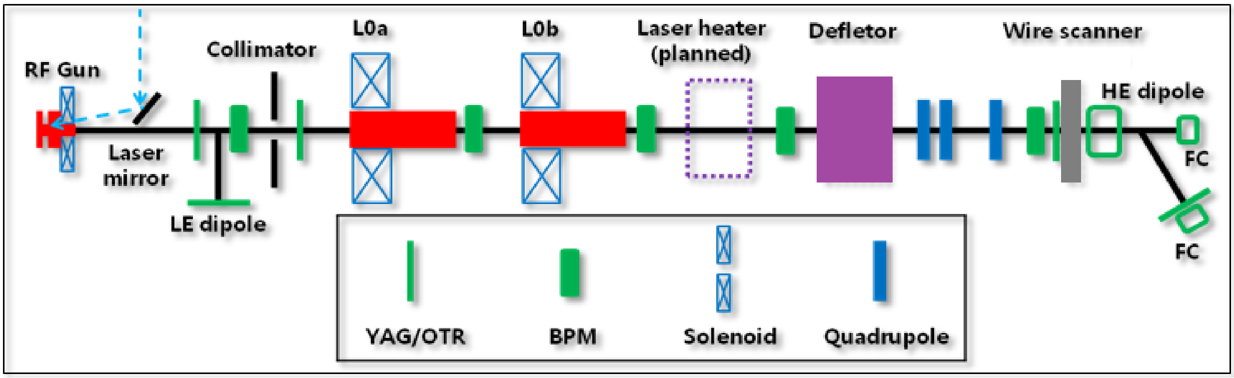

Figure 2: Schematic layout of Injector Test Facility at Pohang Accelerator Laboratory.

Quadrupole Scan

The emittance of beam can be obtain from both the beam size and beam divergence which are not able to be directly measured. While the beam size can be measured by using quadrupoles [4]. The method of emittance measurement is based on the quadrupole scan technique using a matrix [5]. It is destructive way to measure beam emittance and can be affected by the nonlinear field of the quadrupole thus they have to be properly arranged [2]. The Quadrupole for quad scan is the third quadrupole shown in Fig. 2. The transformation matrix can be described as follows:

$$R = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}. \tag{1}$$

Using the matrix form, the propagation matrix from the quadrupole to the screen can be written as:

$$\sigma^{s} = R\sigma^{q}R^{T}. \tag{2}$$

where σ is the beam matrix describing drifts, quadrupole, etc. q, s stand for entrance of the quadrupole and screen respectively. The beam size at screen is $\sqrt{\sigma_{11}^{s}}$, then the equation can be written in accordance with σ_{11}^{q}, $\sigma_{12}^{q} = \sigma_{21}^{q}$ and σ_{22}^{q}:

$$\sigma_{11}^{s} = R_{11}^{2}\sigma_{11}^{q} + 2R_{11}R_{12}\sigma_{12}^{q} + R_{12}^{2}\sigma_{22}^{q}. \tag{3}$$

The transformation matrix *R* is altered by the quadrupole strength *k*, subsequently the normalized beam emittance is easily obtained by using relation, $\epsilon = \gamma\beta\sqrt{det(\sigma^{q})}$, where γ and β are the energy and the velocity of beam respectively. The beam size can be obtained from image on the YAG screen. We have performed to measure slice emittance by a single quadrupole scan technique. The specification of quadrupole is shown in table 2.

Table 2: Specifications of the Quadrupole for Quad Scan

Quadruploe parameter	**Value**	**Unit**
Effective length	14.7	cm
Max. quadrupole strength	27.97	/m^2

Measurement

Before performing measurements, the phase of the RF photocathode gun set up to experiment phase first. The phase of two accelerating columns is adjusted step by step. The orbit of beam can be aligned using several of corrector magnets which also are used to control the bunch to centre on the YAG screen located at 15.86 m. The bunch is properly focused to have round shape on YAG screen by RF gun solenoid current. For quad scan, a sufficient current range should be found by varying the quadrupole current. The total charge of the bunch is checked at all times through a turbo ICT and should be kept as 0.2 nC during measurements. The bunch passes through the RF deflecting cavity with close to a zero crossing phase of RF field. The streaked beam image is presented on YAG screen. In order to examine how to be affected the slice emittance by gun solenoid current, the slice emittance is measured by changing RF gun solenoid with four or five step. Moreover the beam energy can be altered by adjusting the modulator power of first accelerating column. The five beam images take at each quadrupole current step and are averaged without noise background by MATLAB code. The noise background is eliminated before taking a beam image. The bunch is divided by twenty slices. We can obtain the beam size calculated from each slice image and gain a value of the slice eimttance.

EXPERIMENTAL RESULTS

The slice emittance has been measured at 0.2 nC with 81.7 MeV of the beam energy. Figure 3 shows the beam images vertically streaked by transverse RF deflecting cavity on the YAG screen. The top of the bunch is head.

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The electron bunch at the YAG screen is divided by twenty slice.

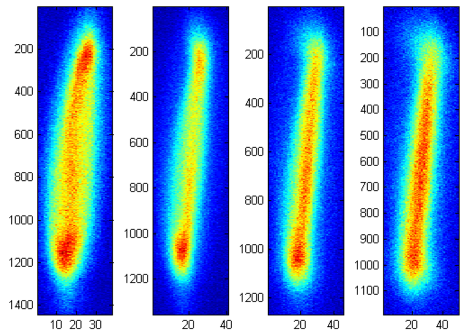

Figure 3: Streaked beam image on YAG screen located 15.86 m with different quadrupole strength *k*. The upper side is the head of electron bunch.

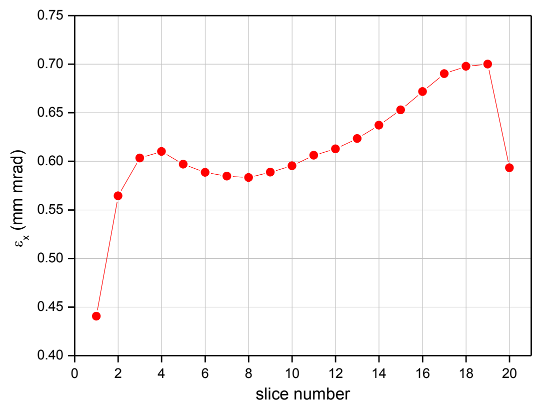

Figure 4: An example of measured slice emittance (95%).

The slice emittance is shown in Fig. 4 and its value is about 0.65 mm mrad (95%) for 0.2 nC at core of the electron bunch. However it is not enough for the designed slice emittance of PAL-XFEL performance. It needs to be analysed and adjusted the elements of injector. The optimization of machine parameters as the gun solenoid current, the phase of each elements and the position of elements in injector should be carried out more precisely for meeting the design emittance of PAL-XFEL.

CONCLUSION

The understanding of slice eimttance plays a significant role in the optimization of high brightness electron sources. The measurements of the slice emittance at ITF of PAL have been successfully done. While we have problem to optimize the elements of injector for the requirements of PAL-XFEL. We will accelerate the electron beam later up to 135 MeV after passing two accelerating columns and the laser heater system will be installed in September this year. These are possible to lower projected and slice eimttance. Furthermore we expect that the emittance is close to the design emittance of PAL-XFEL.

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