EMITTANCE MEASUREMENTS AT THE PAL-XFEL INJECTOR TEST FACILITY

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Abstract

The PAL-XFEL Injector Test Facility (ITF) at PAL has been operating for experimental optimization of electron beam parameters and for beam test of various accelerator components. It consists of a photocathode RF gun, two S-band accelerating structures, a laser heater system, and beam diagnostics such as ICTs, BPMs, screens, beam energy spectrometers and an RF deflector. Projected and slice emittance measurements were carried out by using single quadrupole scan. In this paper, we present the emittance measurements.

INTRODUCTION

PAL-XFEL is under construction. The building is ready and the accelerator components are being installed. PAL-XFEL will generate 0.1 nm FEL radiation using 10 GeV electron beam at the hard X-ray beamline and 1 nm FEL using 3 GeV beam at the soft X-ray beamline. The design parameter of the injector is 0.4 mm mrad slice emittance at 200 pC [1]. Injector Test Facility (ITF) have been operated to study the injector beam dynamics and to test the accelerator components.

EXPERIMENTAL SETUP

The ITF accelerator consists of an S-band 1.6 cell photocathode RF gun, two S-band accelerating columns, solenoids and beam diagnostics including quadrupoles, ICTs, BPMs, YAG/OTR screens, beam energy spectrometers and an RF deflector. A schematic layout is shown in Fig. 1. A quadrupole and a YAG screen for single quad scan are located at 13.22 m and 15.86 m from the cathode, respectively. We measure the electron beam energy using the beam energy spectrometers and the YAG screens. An RF deflector is located before at the quadrupole for studying longitudinal properties of a bunch. In the RF deflector, the transverse kick varies sinusoidally in time so each part of the electron bunch receives a time-dependent kick[2, 3].

Single Quad Scan

Single quadrupole scan was used for emittance measurents in this paper. The transformation matrix in beam dynamics is described as

$$\begin{pmatrix} x \\ x' \end{pmatrix} = M \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix} = \begin{pmatrix} C & S \\ C' & S' \end{pmatrix} \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix} \quad (1)$$

and

$$\begin{pmatrix} \beta \\ \alpha \\ \gamma \end{pmatrix} = \begin{pmatrix} C^2 & -2CS & S^2 \\ -CC' & CS' + C'S & -SS' \\ C'^2 & -2C'S' & S'^2 \end{pmatrix} \begin{pmatrix} \beta_0 \\ \alpha_0 \\ \gamma_0 \end{pmatrix} \quad (2)$$

Where, M is the beam transport matrix, α, β, γ is the twiss parameters. The transport matrix composed of drift space and quadrupole is represented as

$$M = M_d M_F, \qquad M_d = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix},$$
$$M_F = \begin{pmatrix} 1 & 0 \\ -kl & 1 \end{pmatrix} = \begin{pmatrix} C & S \\ C' & S' \end{pmatrix}$$

M_d and M_F are drift space and quadrupole transformation matrices, respectively with thin lens approximation ($|k|l \ll 1$) [4]. k is the quadrupole strength, l is the effective length of the quadrupole, and L is distance between the quadrupole and screen. The beam emittance is related with the area of ellipse in phase space. Utilizing the definition of the ellipse equation in phase space and beam matrix,

$$\sigma_{11} = C^2 \sigma_{0,11} + 2SC\sigma_{0,12} + S^2 \sigma_{0,22} \quad (3)$$
$$\sigma_{11}\sigma_{22} - \sigma_{12}^2 = \epsilon^2 \quad (4)$$

Where,

$$\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} = \epsilon^2 \begin{pmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{pmatrix}, \qquad \sigma_{12} = \sigma_{21}.$$

Using the above equations, we can get a relation as a function of quadrupole strength k [5]. Therefore, the beam emittance is calculated by measuring the beam size at different quadrupole strengths on YAG screen. The specifications of the quadrupole used for single quad scan is described in Table 1.

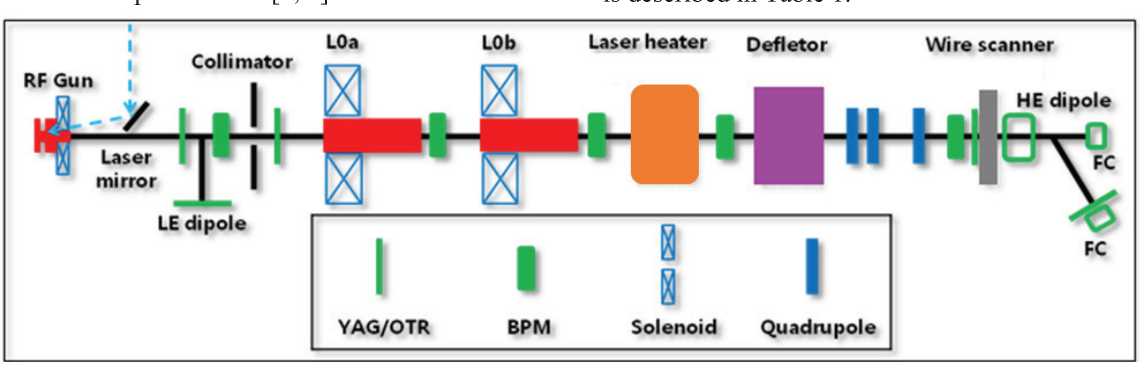

Figure 1: Schematic layout of Injector Test Facility at Pohang Accelerator Laboratory.

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Table 1: Specifications of the Quadrupole for Single Quad Scan

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

Beam Profile Measurement

Longitudinal and transverse shapes of a UV laser pulse dominate the electron beam formation right after beam emission from the cathode. Laser pulse lengths of 3 ps and 5 ps are used to measure projected and slice beam emittance. The measured longitudinal UV laser profile is shown in Fig. 2. A Gaussian fit was used for the pulse length measurements.

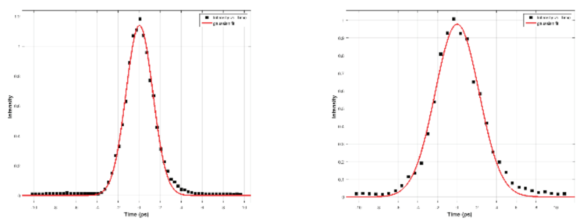

Figure 2: Longitudinal profiles of UV laser pulses. σ and FWHM of 3ps pulse are 1.27 and 3.00 ps, respectively (left). σ and FWHM of 5ps pulse are 2.22 and 5.23 ps, respectively (right).

For the emittance measurements, the phase of the gun was set to 34° from zero-crossing. The phase of the accelerating column was set to on-crest. Bunch charges of 20, 50, 100 and 200 pC were used for the projected emittance measurements. Bunch charge was monitored using the Bergoz Turbo-ICT during the measurements. A beam was accelerated to 68 MeV using the 1st accelerating column. The beam energy was measured using the spectrometer at 15.86 m.

Emittance measurements were done using the quadrupole and YAG screen at 13.22 and 15.86 m downstream of the cathode, respectively.

Slice emittance measurements were carried out using the same way as projected emittance measurements except for using the deflecting cavity for longitudinal streaking. The beam streaking was checked by measuring the beam

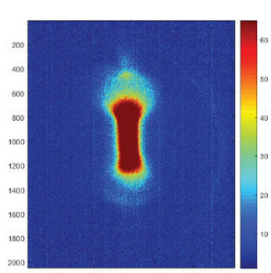

Figure 3: Streaked beam image by the RF deflector on the YAG screen. The head of a bunch is streaked to the top.

image on the YAG screen as the RF power in the deflecting cavity was changed (see Fig. 3). For the slice emittance measurements, a bunch was divided longitudinally to twenty slices. For each measurement, five beam images were taken and averaged.

RESULTS

Projected Emittance

The measurements were repeated using various machine conditions. Two laser pulse lengths, 3 and 5 ps FWHM, and four laser beam size, 0.5, 0.6, 0.8 and 1.0 mm full width, were used at 200 pC. Solenoid current of the RF gun was optimized in order to obtain best emittance value for each measurement.

The result of measurements is shown in Fig. 4. The solid lines represent 3 ps UV laser pulse length and the dashed lines represents 5 ps one. It shows a tendency that the projected emittance using a 3 ps laser is smaller than the one using a 5 ps. The smaller transverse laser size, the lower projected beam emittance.

Unfortunately, the projected emittance is generally higher than 0.8 mm mmrad and it is higher than the expected values from numerical simulations assuming ideal cases. The emittances at lowest beam charges converges towards some range. It may explain the thermal emittance of the photocathode, but its values are bigger than expected ones.

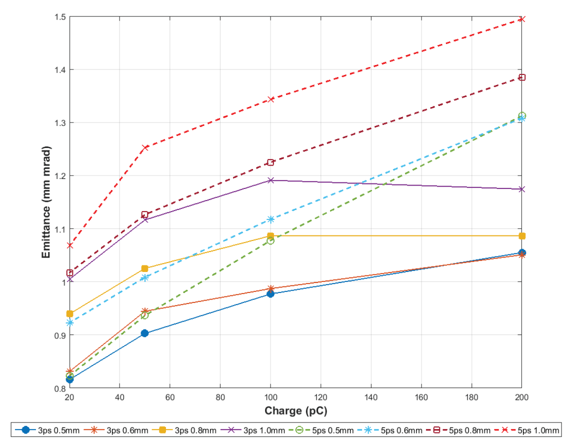

Figure 4: Measured projected emittances at different beam charges, UV laser sizes and pulse lengths. Solid lines describe the UV laser 3ps pulse length and dashed lines describe 5 ps.

Slice Emittance

An electron beam was accelerated up to 102 MeV after the second accelerating column. The phase of 2nd accelerating column was set to on crest. The beam was streaked using the RF deflector. As mentioned before, the slice emittance measurements were carried out using similar conditions as the projected emittance measurements. But, various phases of the 1st accelerating columns were used for the slice emittance measurements.

In case of a 5 ps UV laser, a central slice emittance has a

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lowest value at conditions that are +34 degree RF gun phase, on crest 1st accelerating column phase and 0.8 mm transverse UV laser size. The top and middle figure in Fig. 5 were measured at 0.8 mm of laser size.

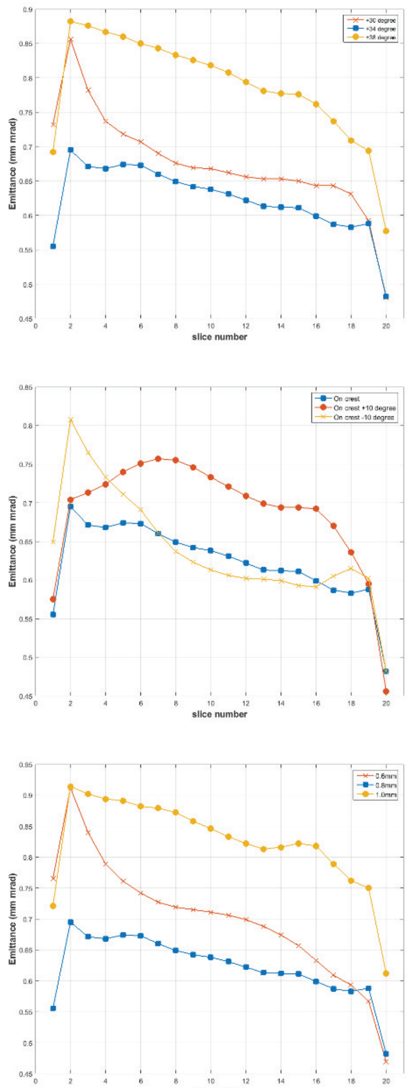

Figure 5: Measured slice emittance using laser 5 ps pulse length at different phase of RF gun (top), 1st accelerating column (middle) and UV laser size (bottom). The measurements of top and middle figure are performed at 0.8 mm laser size.

Measurements using 3 ps laser pulses are almost performed at 1.0 mm transverse laser size. A lowest central slice emittance was obtained under the conditions that are +30 degree of RF gun, -10 degree of 1st accelerating column phase from on crest. But the difference of slice emittance at the central slices through phase variation of the 1st accelerating column is unclear (see middle of Fig. 6). The central slice emittance at 0.8 mm transverse laser size represents a lowest value by comparison with 1.0 mm transverse laser size at +30 degree of RF gun phase and at on crest of 1st accelerating column phase (Fig. 7).

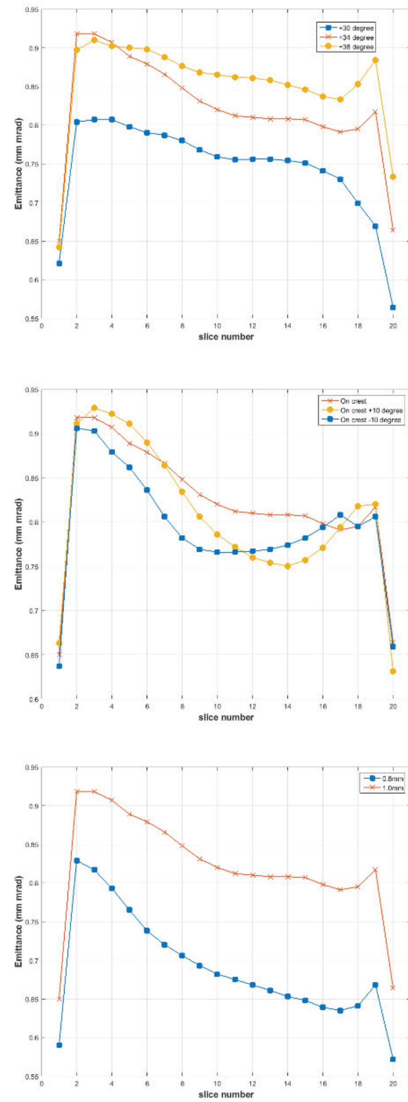

Figure 6: Measured slice emittance using laser 3 ps pulse length at different phase of RF gun (top), 1st accelerating column (middle) and UV laser size (bottom). The measurements shown in the top and middle figures were performed at 1.0 mm laser size.

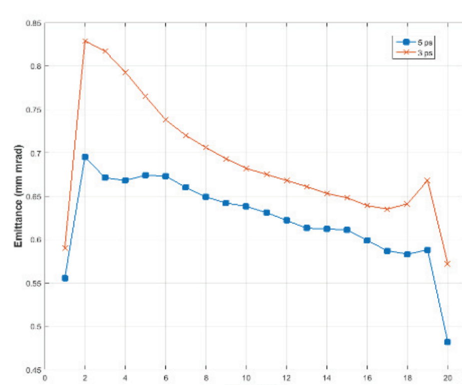

Figure 7: Comparison of optimized slice emittances with laser pulse 3 and 5 ps.

CONCLUSIONS

Projected and central slice emittances were over 1.0 mm mrad, 0.6 mm mrad at optimized conditions at 200 pC. It seems that the thermal emittance is higher than usually considered value, 1 mm mrad per 1 mm laser size. Additional effects from the non-perfect RF field and magnetic field might be the reason of the higher emittance as well.

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