SIMULATION FOR NEW INJECTOR TEST FACILITY OF PAL-XFEL*

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Abstract

For the preparation of PAL-XFEL, Injector Test Facility (ITF) has been constructed and required beamline components are being installed for the test of the injector system. ITF components include an RF gun, two accelerating columns, solenoids and basic diagnostic components such as spectrometers, quad scan system, BPMs, a wire scanner. Passing through the two accelerating columns an electron beam is accelerated up to 139 MeV with a charge of 200 pC and an emittance under 0.5 μm. For optimization of operation modes and precise diagnostics simulation for ITF beamline has been carried out with the ASTRA code. In this paper simulation results and discussion related to emittance measurements will be shown.

INTRODUCTION

ITF consists of an S-band 1.6-cell photocathode RF gun, two S-band accelerating columns, solenoids and diagnostic components. In particular, quadrupoles will be installed downstream of the 2nd accelerating column for quad scan. And also a laser heater system and an RF deflector for longitudinal phase space measurement will be installed next year. Assembling all components except the laser heater system and the deflector will be ready by the end of August. Beam commissioning will be started soon and the generation of a beam with an emittance under 0.5 μm is the first plan for this year. A schematic layout of the ITF beamline is shown in Fig. 1.

Diagnostics for ITF

Diagnostics for ITF will be conducted mainly in two energy regions, i.e. the Low Energy (LE) region with an energy of 6 MeV and the High Energy (HE) region with an energy of 139 MeV. Detailed diagnostic components are as follows:

- LE dipole & HE dipole for energy measurement.
- ICTs & Faraday cup.
- BPMs & phase monitors.
- quadrupoles for quad scan.
- wire scanner.
- RF deflector.

Quad scans will be carried out by one HE quadrupole and two LE quadrupoles. The LE quadrupoles, HE quadrupole and screen are located at 9.15 m, 9.55 m, 13.22 m and 15.86 m from the cathode respectively. Two LE quadrupoles are not mainly installed for quad scan and the locations of them are not optimized for quad scan. Thus additional quadrupoles will be installed upstream of the existing HE quadrupole if necessary. Detailed specification of the quadrupoles are listed in Table 1.

Table 1: Specification of the Quadrupoles for Quad Scan

Component	effective length	Max. quadrupole strength
LE quadrupole	8 cm	7.21 /m^2
HE quadrupole	14.7 cm	27.97 /m^2

QUAD SCAN

Quadrupole scan is mostly used for emittance measurement of a beam with high energy. It is non beam destructive way to measure and can be affected by the nonlinear field of the quadrupole thus the quadrupoles should be properly arranged, say, they should have enough drift space longer than their focal length.

Let's consider a beam transfer matrix as follows:

$$M = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} \quad (1)$$

This matrix is generally a product of various matrices describing drifts, quadrupoles, etc. In our case each element is the function of focal length, that is, the strength and effective length of quadrupole and distance between components of beam optics we consider and also we already know. For 2nd moments of a certain position of the beamline there exist beamsize which corresponds to certain focal length and distance. Therefore if someone measure at least three different beamsize corresponding to different beam optic functions 2nd moments in phase space can be calculated by numerical method. This can be expressed as follows [1],[2]:

$$\begin{pmatrix} x_0^2 \\ x_0 x_0' \\ x_0'^2 \end{pmatrix} = \begin{pmatrix} m_{11(1)}^2 & 2m_{11(1)}m_{12(1)} & m_{12(1)}^2 \\ m_{11(2)}^2 & 2m_{11(2)}m_{12(2)} & m_{12(2)}^2 \\ \vdots & \vdots & \vdots \\ m_{11(N)}^2 & 2m_{11(N)}m_{12(N)} & m_{12(N)}^2 \end{pmatrix}^{-1} \begin{pmatrix} x_{(1)}^2 \\ x_{(2)}^2 \\ \vdots \\ x_{(N)}^2 \end{pmatrix} \quad (2)$$

Here subscript stands for number of cases with different beam optics, that is, the number of combinations of quadrupoles with different strength or position. Calculation will be more accurate for more measurement conducted. From calculated 2nd beam moments normalized transverse beam emittance can be evaluated by a formula as:

*Work supported by the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (MEST) (Grant No. 2008-0059842).
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ISBN 978-3-95450-123-6

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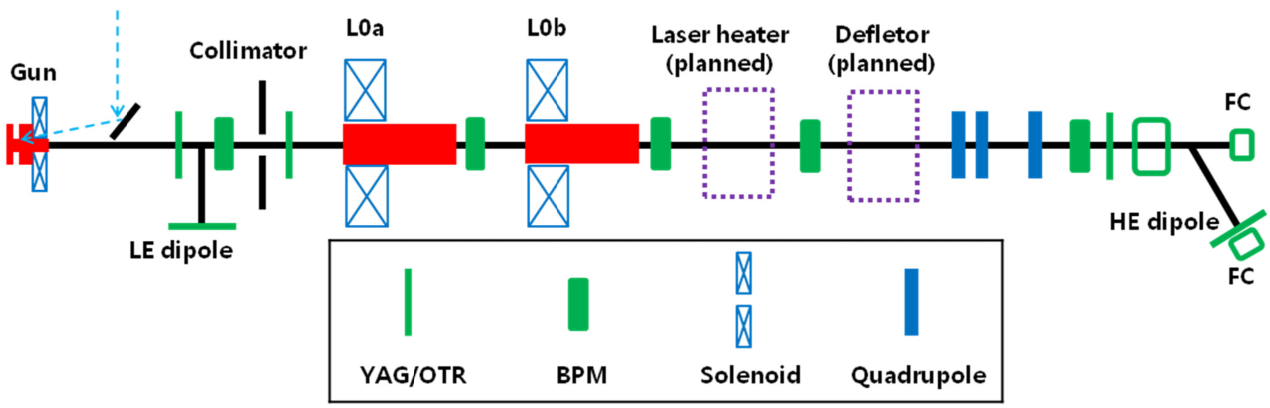


Figure 1: Schematic layout for the ITF beamline.

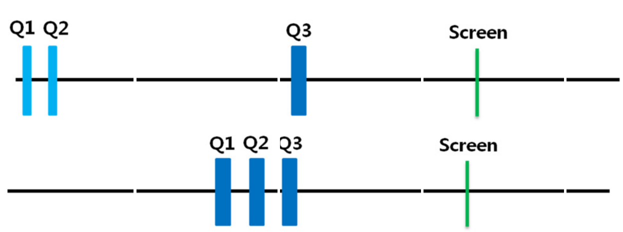
$$\varepsilon_N = \beta\gamma\sqrt{x_0^2 x_0'^2 - \left(x_0 x_0'\right)^2} \qquad (3)$$

Here β and γ are relativistic factors.

Phase advance of a beam is changed when it passes through the quadrupole and the transfer matrix is also changed. The key of quad scan is to measure accurate beamsize and to generate a proper phase advance to get sufficient number of samples of beam size. Basically quad scan can be carried out with one quadrupole because it is also sufficient to generate proper change of phase advance. But there is limitation of beamsize related to the resolution of the screen. Multi-quad scan is easy to change the phase advance of a beam relatively in short range while the beamsize can be controlled thus it is quite free from limitation of beamsize measurements due to the screen size or the screen resolution [3],[4].

ASTRA SIMULATION

ASTRA simulation has been conducted ahead of real measurement to find a proper quadrupole setup to measure emittance accurately. Simulation has been carried out mainly with two quadrupole setups, i.e. one is the setup with single HE quadrupole(Q3) and the other is the setup with one HE quadrupole and two LE quadrupole. current setups with quadrupole position are shown in Fig. 2.



Setup	Q1	Q2	Q3	Screen
Current setup	9.15 m	9.55 m	13.22 m	15.85 m
Modified setup	12.22 m	12.72 m	13.22 m	15.85 m

Figure 2: Current quadrupole setup (Top) and modified quadrupole setup (middle). Light blue stands for LE quadrupole and dark blue for HE quadrupole.

Electron beams passing through combination of quadrupole with various strength was simulated first. And then with the calculated transfer matrices and simulated beamsize the normalized rms emittance was calculated according to the formulas above. Matlab was used for matrix calculation. Not all the combinations were used during the calculation of emittance and they were chosen by the beamsize, phase advance and beta function. For instance, combinations showing beamsize smaller than 30 µm which is comparable to the resolution of current screen are eliminated before emittance calculation.

Single Quadrupole Setup

Before simulation with current quadrupole setup simulation with single quadrupole has been carried out first. It was also the original plan for quad scan. The values of quadrupole strength used in simulation are -4.0/m^2 to 4.0/m^2 with 0.25/m^2 scan step. Beamsize and phase advance at the screen position are shown in Fig. 3. Plots on the left in the figure show the values before elimination and those on the right show values after elimination. It is not possible to calculate emittance accurately with all the cases on the left because cases which have similar phase advance values make errors increase during numerical calculation thus some cases with similar phase advance values, say, overlapped cases should be eliminated. Here the cases with beamsize less than 30 µm are eliminated due to screen resolution. Also the cases with phase advance less than 5 degrees and larger than 175 degrees are eliminated for accurate numerical calculation. After elimination the calculated emittance is 0.267 µm and it is almost the same as the simulated value 0.282 µm which should be the value at the emittance measurement position, that is, 9 m downstream from the cathode. The difference is quite considerable but still better to use smaller scan step.

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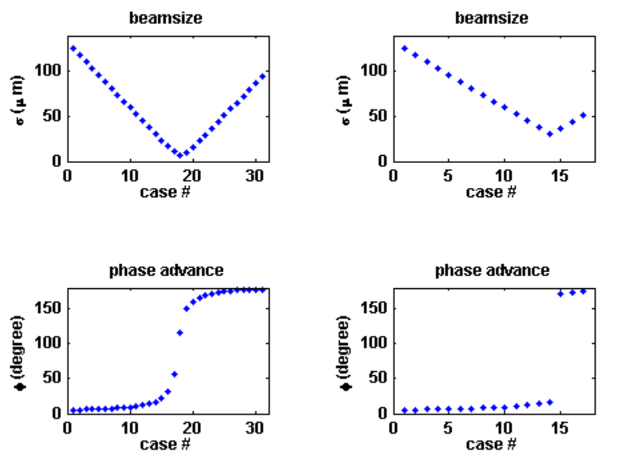

Figure 3: Simulation result with single quadrupole. Beamsize (top left) and phase advance (bottom left) at the position of the screen with different quadrupole strength. quadrupole strength values are -4/m^2 to 4/m^2 with 0.25/m^2 step from left to right. Beamsize after eliminating overlapped cases (top right) and its phase advance (bottom right).

Current Quadrupole Setup

Simulation with the current quadrupole setup has been carried out and the results are shown in Fig. 4. Plots on the left show results before elimination overlapped cases and plots on the right show results after elimination. Calculated emittance values are 0.745 μm and 0.244 μm respectively. After elimination emittance gets more accurate but there is still larger difference with simulation value 0.282 μm. Elimination condition was same as single quadrupole setup case. Quadrupole strength values are -3.0/m^2 to 3.0/m^2 with 1.0/m^2 scan step for all three quadrupoles, Q1, Q2 and Q3.

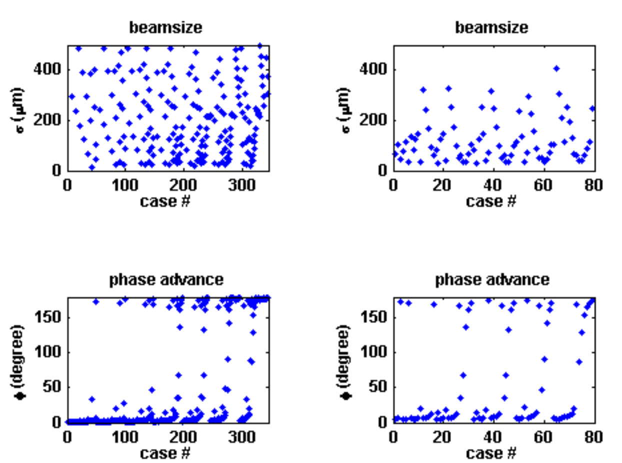

Figure 4: Simulation result with current quadrupole setup. Beamsize (Top) and phase advance (Bottom) at the position of the screen with different quadrupole strength. The quadrupole strength values are -3/m^2 to 3/m^2 with 1/m^2 step from left to right. Beamsize after eliminating overlapped cases (top right) and its phase advance (bottom right). Interesting thing is that emittance calculation can be more accurate and it depends on elimination condition. If cases with phase advance less than 20 degrees and larger than 160 degrees are eliminated during matrix calculation evaluated emittance is 0.275 μm and it becomes much more accurate.

CONCLUSION

Transverse emittance in the horizontal direction has been calculated with beamsize values from ASTRA simulation. Relatively accurate results were evaluated even though not many cases were used for numerical calculation. But it is verified again how to generate proper phase advance is main key according to this simulation. Smaller scan steps are also need to increase accuracy of emittance calculation. And calculations with a variety of error sources are needed for real measument. It is considered to use MAD to find proper optics to generate phase advance range we want. This study is still in progress.

ACKNOWLEDGMENT

Author thank Prat Costa Eduard, Bolko Beutner and Reiche Sven for very helpful discussions.

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ISBN 978-3-95450-123-6