# BEAM TRANSPORT LINE DESIGN FOR EMITTANCE ADJUSTMENT PLS XFEL

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## *Abstract*

Pohang Accelerator Laboratory (PAL), which is running 3rd generation light source, is planning to construct a free electron laser (FEL) facility using the existing linear accelerator. To make the linear accelerator to satisfy the required beam energy and quality, we decided to expand the linac as well as to upgrade the existing linac. The additional linac (which is called W-FEL) will accelerate the electron up to 1.2 GeV. Along with the existing linac (which is called X-FEL) of 2.5 GeV, the final electron beam will be accelerated to 3.7 GeV. At first, two separate beamlines for W-FEL and X-FEL were considered and the beam transport lines (BTLs) were designed to bend the electron beams up to 30 and 20 degrees respectively due to the construction restriction. However, those large bending angles result in severe emittance growth from coherent synchrotron radiation (CSR) effect. So, we design the FEL BTL in the way to reduce emittance growth. This paper presents simulation results of emittance growth and another beam dynamic parameters


## INTRODUCTION

The PAL has a 2.5 GeV full energy injection linac for a storage ring for third generation synchrotron radiation light source. The linac is planned to be up-graded for FEL use. And two beamlines are designed for WFEL (1.2 GeV) and XFEL (3.7 GeV). However, the fact that the linac also should be used for injection to the ring gives the strict limits in constructing the new BTLs and forces us to bend the electron beams to large angle of about 20 ~ 30 degrees. However, we found by simulations that such large angle BTLs give very highly growing beam emittance and energy spread due to the significant CSR [1, 2]. Finally, we changed the design to have only one beamline for both XFEL and WFEL. The following sections will explain the simulation results of BTL.

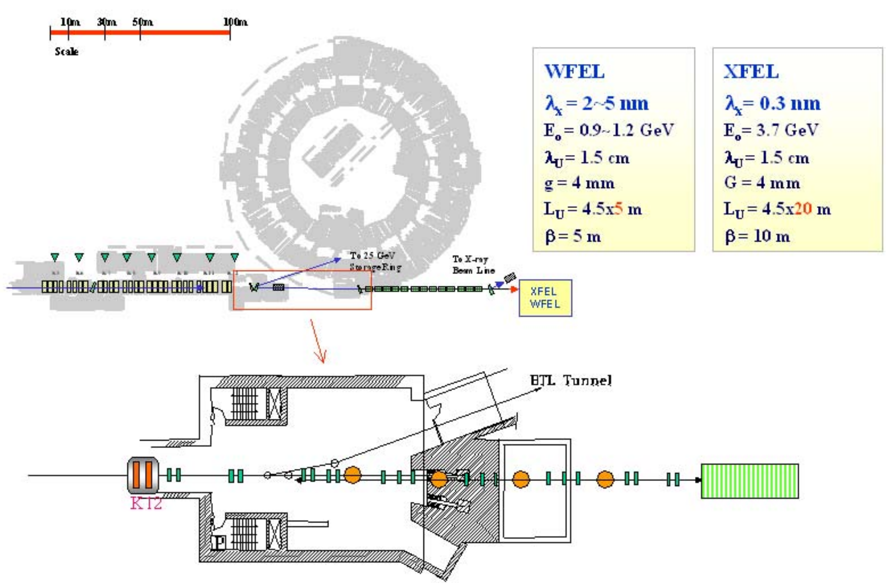


Figure 1: Layout of PAL XFEL BTL

## BEAM DYNAMICS DESIGN

The requirements for beam transport line from the linac to the XFEL undulator are as follows:

- Include bends to suppress dark current without generating significant CSR or other emittance dilution effects,
- Provide adjustable undulator-input beta-matching for the various beam energies (i.e., various radiation wavelengths) desired,
- Not alter the bunch length (must be nearly isochronous),
- Make use of the existing Beam Analyzing Station (BAS) tunnel and its components wherever possible to inject beam to the storage ring.

The net system forms a 4-dipole dog-leg displacing the beamlines horizontally toward the south by 0.27 m. The net $R_{56}$ for the 4-dipole system is set to zero by allowing the dispersion function to reverse sign in half of the bends.

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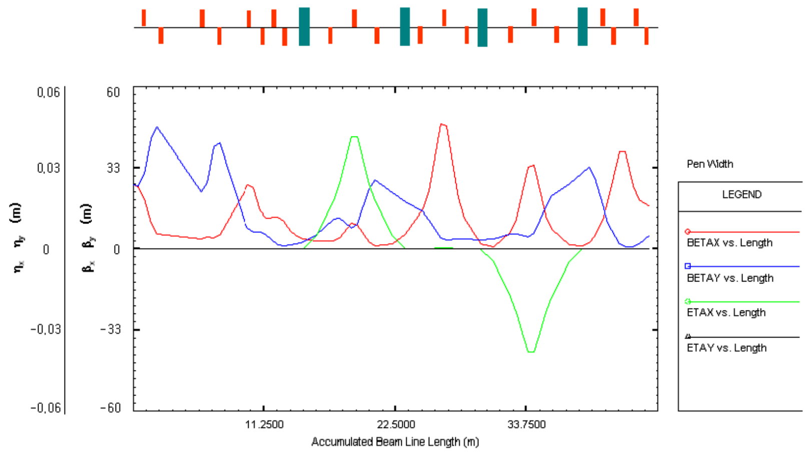


Figure 2: dispersion and beta function through beamline up to undulator entrance.

The BTL parameters are summarized in Table 1. Beta function and dispersion are shown in Figure 2.

## *Coherent Synchrotron Radiation*

The emittance growth is calculated using Elegant code. The Elegant calculations, with a gaussian temporal distribution, result in an emittance growth of 0.7 %. The growth predicted with elegant using the tracked temporal distribution of Figure 3 is 4.6 % (including all particles, and for $\gamma\varepsilon_0 = 1$ µm), but this is mainly due to the sharp current spikes of bunch head and tail.

Table 1: XFEL BTL parameters

| parameter | Value | Unit |
|---|---|---|
| Nominal electron energy | 3.7 | GeV |
| Total horizontal beamline reflection | 0.27 | m |
| Nominal rms bunch length | 80 | µm |
| RMS core relative energy spread | < 0.01 | % |
| Net momentum compaction | 0 | m |
| Length of each of the four dipole magnets | 1.1 | m |
| Bending angle of each four magnets | 0.5 | deg |
| Magnet Field of each four dipole magnets | 0.98 | kG |
| Maximum dispersion | 0.038 | m |
| Projected emittance dilution due to CSR | 4.6 | % |

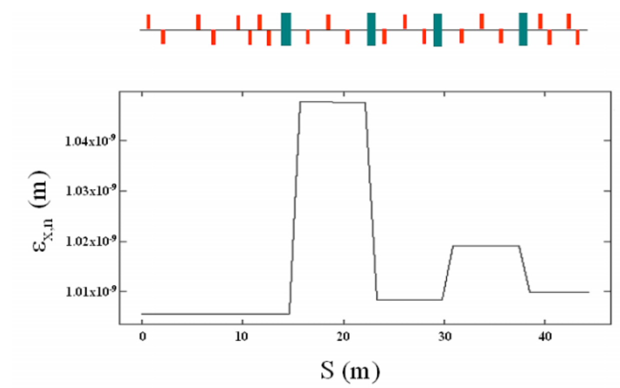


Figure 3: The normalized horizontal emittance

## *Calculation of Bunch at Undulator Entrance*

More complete calculations of the CSR effects on the bunch through BTL have been made using Elegant code [3]. The code uses time domain treatments that include field transients at entrance and exit of the bends. The electron distribution in a bunch is Gaussian as shown in Figure 4.

Figure 5 shows the calculated bunch distribution at exit of linac. The bunch distribution is used as the input beam for BTL to achieve more ‘real’ bunch distribution. Figure 6 shows the bunch distributions at the undulator entrance as the results of the simulation. There is no significant growth of slice emittance and energy spread of the bunch.

## SUMMARY

PAL Beam Transport Line for XFEL is designed to avoid significant emittance growth and energy spread at the undulator entrance. Calculation results of the output beam of the BTL show that the CSR effects of bends are negligible. But more detailed analysis of the beam is required. And, another beam optics for W-FEL (1.2GeV) should be designed on the similar ground.

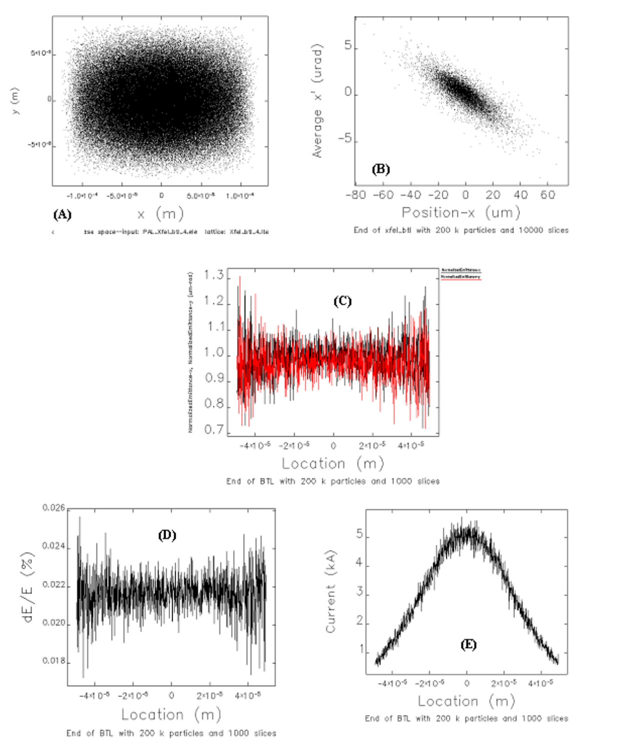


Figure. 4: Phase space at undulator entrance used temporal Gaussian bunch as input data, (A) is x-y plane, (B) is x-x' plane, (C) is normalized emittance along the bunch, (D) is energy spread along the bunch, (E) is current along the bunch.

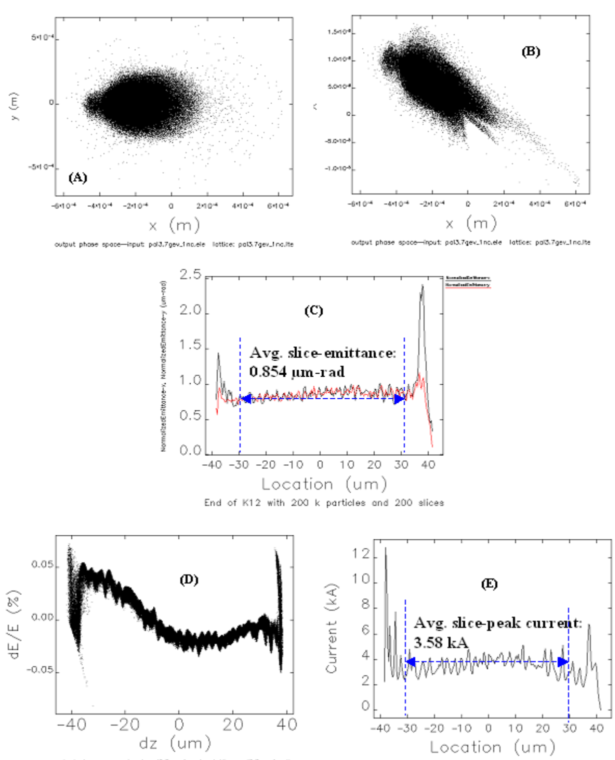


Figure. 5: Phase space at the BTL entrance, (A) is x-y plane, (B) is x-x' plane, (C) is normalized emittance along bunch, (D) is energy spread along bunch, (E) is current along bunch

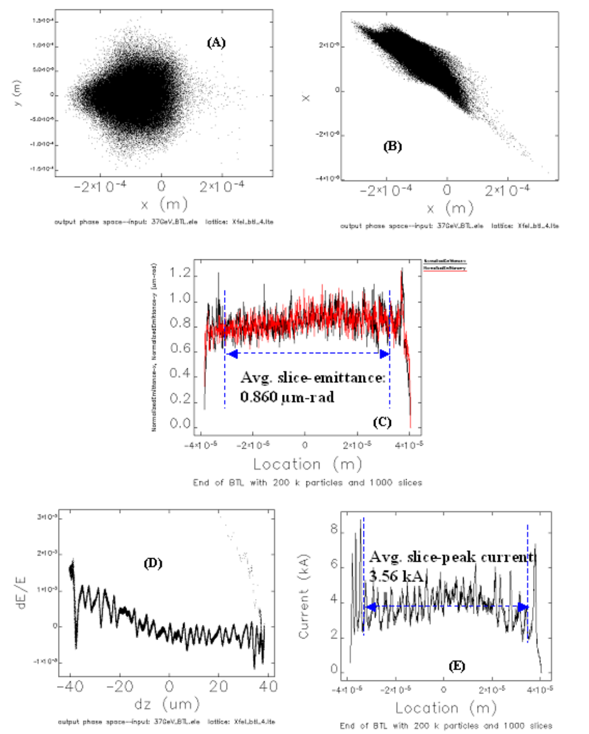


Figure. 6: Phase space at the undulator entrance with linac output data as input, (A) is x-y plane, (B) is x-x' plane, (C) is normalized emittance along bunch, (D) is energy spread along bunch, (E) is current along bunch

## REFERENCES

[1] Ya. S. Derbenev, J. Rossbach, E. L .Saldin, and V. D. Shiltsev, "Microbunch Radiative Tail-Head Interaction" DESY Print, TESLA-FEL95-05, Hamburg (1995).

[2] E. L. Saldin, E. A. Schneidmiller, "Coherent Radiation of an Electron Bunch Moving in an Arc of a Circle", Proc. 1998 IEEE PAC, p. 1658.

[3] Linac Coherent Light Source (LCLS) Conceptual Design Report, SLAC-R_593, April 2002, UC-414.