INJECTOR DESIGN FOR THE PAL-XFEL PROJECT*

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Abstract

One of the key components of the Pohang Accelerator Laboratory X-ray Free-Electron Laser (PAL-XFEL) project is the injector. For the generation of a high quality electron beam we adopt a photocathode RF gun as electron source. The beam is further accelerated through two 3 m long traveling-wave structures, where the beam reaches 139 MeV. The gun cavity and accelerating tubes operate at a resonant frequency of 2.856 GHz. We present the layout and beam dynamics optimization.

INTRODUCTION

The Pohang Accelerator Laboratory X-ray Free electron Laser (PAL-XFEL) project [1] started in 2011. This project aims at the generation of X-ray FEL radiation in the range of 0.1 to 10 nm for users. The machine consists of a 10 GeV linear accelerator and five undulator beamlines. The system will operate at a repetition rate of 60 Hz. Building construction starts in summer 2012.

The injector consists of an S-band photocathode gun, two 3 m long S-band constant-gradient traveling-wave structures, focusing solenoids, and a laser heater system. The gun was tested at a temporal gun test facility (GTF) for RF commissioning and basic beam parameter measurements without further accelerating sections [2, 3]. The injector test facility (ITF) is under construction for starting beam commissioning in autumn 2012. The baseline gun is developed at PAL, which has 1.6 cells and a high power RF coupler on the side of the second cell. Two RF input holes are made with mirror symmetry and two additional holes are made for better RF field symmetry [4]. This gun will be used for the baseline injector. The baseline injector layout is shown in Fig. 1. A next stage gun development, targeting the achievement of a lower transverse emittance, is under preparation.

BASELINE INJECTOR

An electron beam is generated by a laser pulse at the rear wall of the gun first cell. The oxygen-free Cu wall of the gun is used as photocathode. A Ti:Sapphire drive laser system provides a transversely uniform and temporally flat-top laser pulse.

A 120 MV/m peak RF field is applied at the rear wall of the gun cavity for immediate acceleration of a beam generated at the cathode. The 1.6 cell gun accelerates the beam to 5.7 MeV, so that the beam is weakly sensitive to the space charge effect. The 0.2 m long gun solenoid located downstream of the gun. This solenoid compensates the emittance increase due to the space charge force after the beam emission and also matches the beam into the linac section. The peak magnetic field of the solenoid is about 0.26 T at the beam axis. No bucking solenoid is needed for magnetic field compensation at the cathode because the field tail of the gun solenoid at the cathode is very small.

A laser mirror to reflect a laser pulse to the cathode, electron beam diagnostics, and a dark current collimator follow the gun solenoid. A Faraday cup for bunch charge, screens for beam size and shape, a spectrometer dipole for energy, BPMs for position, and a phase monitor for arrival time measurements are positioned between the gun and the 1st accelerating section.

Two 3 m long accelerating structures further accelerate the beam up to 139 MeV. J-type quasi-symmetric high power RF couplers are used for minimizing higher-order RF modes. The 1st accelerating section starts at 2.2 m from the cathode. Each section has a 1 m long focusing solenoid around the structure. These solenoid keep the beam size small through the structure and match the beam at the entrance of the laser heater system.

At the injector exit, the slice energy spread of a beam is a level of keV, which is so small and possibly produces microbunching instability problems. A laser heater system is to be installed for increasing the slice energy spread to a level of 10 keV. A magnetic chicane deflects an electron beam from the main beam axis by 30 mm. A 0.5 m long undulator is positioned between the 2nd and 3rd bending magnets. The undulator period is 5 mm. Two quadrupoles before the 1st bending magnet control the x, y beta functions through the laser heater system for the beam size matching to the laser beam size.

BEAM DYNAMICS

Beam dynamics simulation using the ASTRA code [5] is carried out to optimize machine parameters for a minimum transverse emittance. High peak current and symmetry of the longitudinal distribution at the injector end are also taken into account. Beam launch phase at the gun, accelerating section position, field amplitude and phase, gun solenoid strength, and accelerating section solenoid strength are variable for optimization. 200k macro particles are used for beam tracking.

Drive laser pulse is temporally pseudo-flat-top and 8 ps long for the 200 pC case. The longitudinal shape is achieved by stacking eight Gaussian pulses with a 0.45 ps rms length (see Fig. 2). The peak-to-peak modulation is 9%. Spatially uniform laser profile is assumed. Thermal

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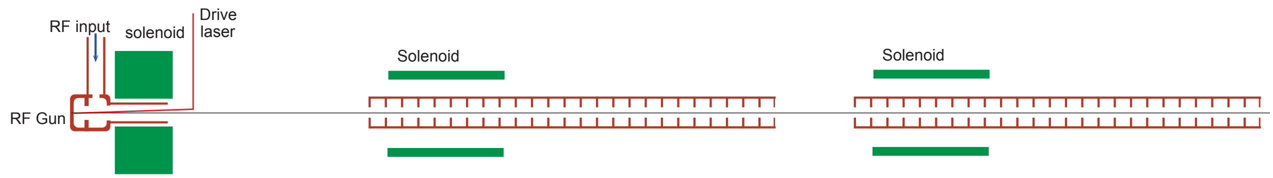

Figure 1: Layout of the injector consisting of an RF photocathode gun, focusing solenoids, two accelerating sections, and a laser heater system (not shown here).

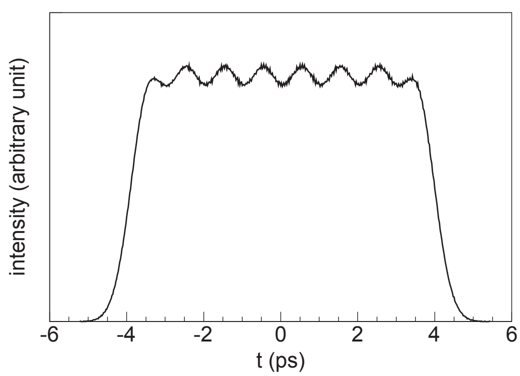

Figure 2: Longitudinal profile of a drive laser pulse. Eight Gaussian pulses with a 0.45 ps rms length are stacked.

emittance which occurs during the electron emission from the cathode is assumed to be 0.89 mm mrad per 1 mm rms laser beam size for ASTRA simulations. The initial beam size is 0.21 mm rms, which produces 0.19 mm mrad rms thermal emittance.

Normalized rms projected transverse emittance evolution as function of distance from the cathode is shown in Fig. 3. At the injector end, the projected emittance is

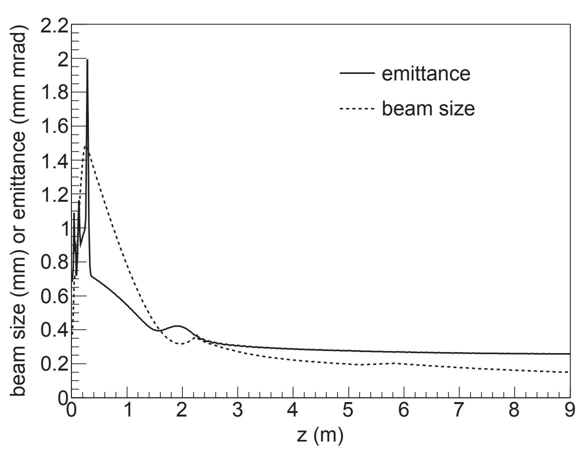

Figure 3: Normlized rms transverse emittance and rms beam size of a 200 pC bunch vs. distance from the cathode.

0.26 mm mrad. The projected emittance goes further down to 0.25 mm mrad at 15 m position because a full emittance compensation is achieved downstream of the injector in this design.

The normalized rms slice emittance at the injector end is shown in Fig. 4. At the central slices of a bunch, the slice emittance is below 0.25 mm mrad. Since the mismatch parameter over the bunch is close to one except the head and tail of the bunch, the projected emittance is close to the slice emittance.

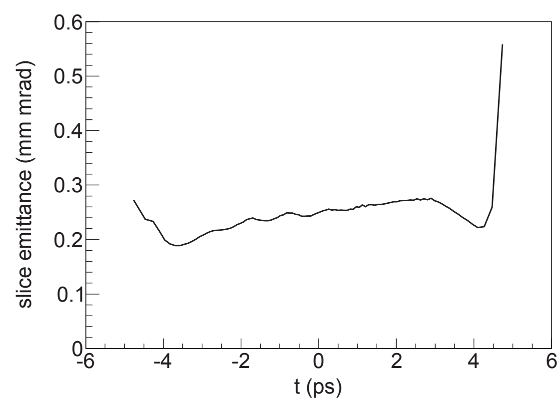

Figure 4: Rms slice emittance of a 200 pC bunch at the injector end.

At the injector end, the peak current is 26 A and the fwhm length is 8 ps. The temporal distribution of a bunch is shown in Fig. 5. The initial intensity modulation is smeared out at the injector end. This electron bunch is to be compressed down to 100 fs or shorter through the PAL-XFEL main linac by three magnetic bunch compressors [6].

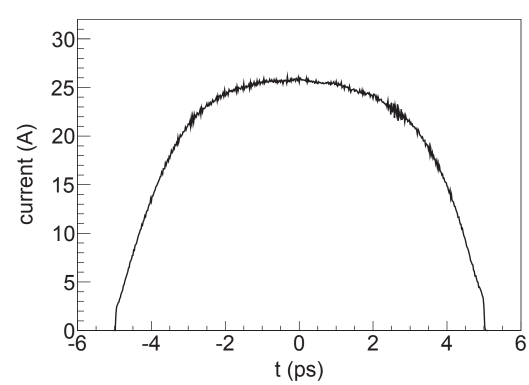

Figure 5: Current profile of a 200 pC bunch at the injector end.

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For the 20 pC case, four Gaussian pulses with a 0.45 ps rms length are stacked to make a 4 ps pulse. The initial beam size is 0.09 mm rms, which produces 0.08 mm mrad rms thermal emittance. At the injector end, the normalized rms projected transverse emittance is 0.1 mm mrad. The normalized rms slice emittance at the injector end is shown in Fig. 6. At the central slices of a bunch, the slice emittance is about 0.09 mm mrad.

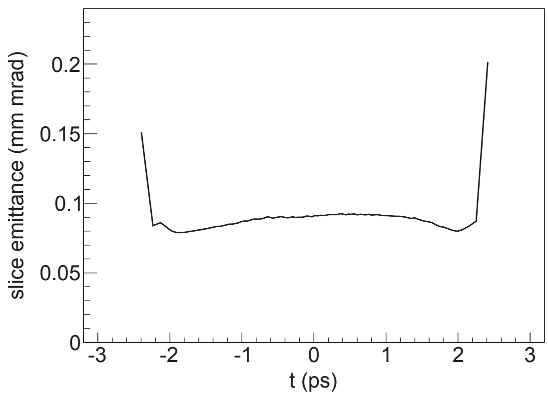

Figure 6: Rms slice emittance of a 20 pC bunch at the injector end.

At the injector end, the peak current is 5 A and the fwhm length is 4 ps. The temporal distribution of the bunch is shown in Fig. 7.

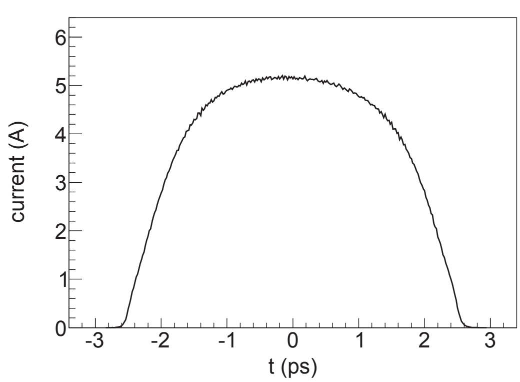

Figure 7: Current profile of a 20 pC bunch at the injector end.

The machine and beam parameters for the 200 pC and 20 pC cases at the baseline injector are summarized in Table. 1.

INJECTOR TEST FACILITY

An injector test facility (ITF) is under construction for starting beam commissioning in autumn 2012. The new ITF building is located at the north-east end of the PLS injector linac building. The baseline injector system will be fully commissioned there and new accelerator components including drive laser, gun, cathode, RF, diagnostics, laser heater and timing systems will be tested and commissioned before the installation to the PAL-XFEL main linac. The ITF tunnel is ready. The laser clean room and operation office are under preparation. Laser and RF components are being delivered.

Table 1: Simulation Parameters of the Baseline Injector

Bunch charge (pC)	**200**	**20**
Laser/cathode		
Fwhm length (ps)	8	4
Rise/fall time (ps)	0.8	0.8
Rms size (mm)	0.21	0.09
Thermal ε (mm mrad)	0.19	0.08
Gun		
Peak field at cathode (MV/m)	120	120
Beam launch phase from 0-crosing	34°	34°
Accelerating section		
Gradient of 1st section (MV/m)	20	20
Gradient of 2nd section (MV/m)	25	25
Phase of 1st section from on-crest	$-10°$	$-10°$
Phase of 2nd section from on-crest	0°	0°
Electron beam, simulation		
100% rms projected ε (mm mrad)	0.26	0.1
Slice ε at center (mm mrad)	0.25	0.09
Fwhm bunch length (ps)	8.2	4
Peak current (A)	26	5
Mean E (MeV)	139.1	139.1

SUMMARY AND FUTURE PLANS

The layout and optimized parameters of the baseline injector were described. The baseline injector utilizes the S-band photocathode gun already developed at PAL. The beam parameters of the baseline injector fully satisfies the beam quality requirement (a transverse emittance of 0.5 mm mrad) of PAL-XFEL. Full beam commissioning and new accelerator components test will be carried out at ITF from autumn 2012.

A new gun with coaxial high power RF coupler [7] is under preparation. With an optimized gun solenoid position, achievement of even lower emittance will be possible. An exchangeable photocathode plug will be adopted at the new gun. Studies for high quantum efficiency and/or low thermal emittance cathode will be done.

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