STATUS OF PPI (POHANG PHOTO-INJECTOR) FOR PAL XFEL*

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Abstract

A X-Ray Free Electron Laser (XFEL) project based on the Self-Amplified Spontaneous Emission (SASE) is under progress at the Pohang Accelerator Laboratory (PAL). One of the critical R&D for the PAL XFEL is to develop the low-emittance injector (named as the Pohang Photo-Injector) with the normalized emittance < 1.2 mm-mrad. In order to achieve the required beam quality with high stability and reliability, we will use photocathode with quantum efficiency > 0.1 % and long lifetime. This will greatly lessen the laser energy requirement for producing flat-top UV pulses, and open the possibility of using only regenerative amplifiers (RGAs) to drive the photocathode RF gun. The RGAs can produce mJs output with much better stability than multi-pass amplifiers. Both the Cs_2Te and Mg are under consideration for the possible photo-cathode. To demonstrate the suitability of the Mg and Cs_2Te for the future 4th generation light source application, an improved BNL-type S-band RF gun with a high-performance load-lock system will be developed for the PPI. In this article, we present the design concept of the PPI, the expected performance, and report on its development status.

INTRODUCTION

Given the boundary conditions imposed on the PAL, such as the site constraints and the construction budget in spite of the user demands of shorter and shorter wavelengths, the PAL XFEL aims to achieve 3-Å lasing with 3.7-GeV beam energy [1]. This implies it requires very high-quality beams at the entrance of the undulator. This requirement would be met by careful and systematic design and construction of the machine to ensure two things; 1) Generation of low-emittance beams from injector and 2) Preservation of the emittance during the acceleration, the bunch compression the transport up to the undulator and the beam-radiation interaction in the undulator. Detailed discussions of all relevant issues are out of scope of this article and we would like to concentrate on the generation of low-emittance (or high-brightness) beams which is usually done in photo-cathode rf guns. But the preservation of the emittance in downstream accelerator will necessitate the pre-acceleration of the beam to the energy above which the emittance is dominated by the so-called emittance pressure. And this pre-acceleration should be also mentioned. The term “injector” for the PAL XFEL is thus for the accelerator system comprising the low-emittance electron source and the pre-accelerator. Modern high-brightness injectors are usually designed to have the emittance compensations by the generalized Brillouin Flow (or by the Invariant-Envelope matched beam). In Table 1, we summarize requirements imposed on the PPI.

Table 1: PPI requirements.

Charge	Max. 1 nC
Beam Energy	> 130 MeV
Repetition Rate	30 Hz
Emittance (normalized, rms)	< 1.2 μm rad
Energy Spread (rms)	< 0.1 % (Projected) ~ 10^{-5} (Slice)

As the injector for the PAL XFEL, we are going to adopt the RF photo-cathode gun with the IE emittance compensation scheme. The unique approach at the SCSS (SPring-8 Compact SASE Source) in the SPring-8, which is based on the thermionic DC gun with a single-crystal cathode, will be reserved as the backup or future upgrade plan. The success of the SCSS scheme seems largely depends on the transverse and longitudinal optics design in the low-energy part from the gun exit to the beginning part of the first accelerating structure.

ISSUES AND STATUS

IE Matching & Emittance Meter

The IE matching condition (generalized Brillouin Flow) for the efficient emittance compensation is given by the following equations.

$$\sigma' = 0 \qquad (1)$$

$$\gamma' = \frac{2}{\sigma}\sqrt{\frac{\hat{I}}{2I_0\gamma}} \qquad (2)$$

(1) is to require the beam waist be formed at the accelerator entrance, which is commonly done in linear electron beam devices, e.g., klystrons. (2) is a new requirement determining the accelerating gradient of the structure with given rms beam size, σ and peak current, $\hat{I}$. The constant I_0 in (3) is called the Alfvén current with the numerical value of 17 kA.

The successful realization of the IE emittance compensation would require the followings:

- Low-emittance electron gun (such as the RF gun + high-power laser with profile control capabilities)
- High gradient booster accelerator with good

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alignment

- Solenoids with low field errors and good alignments
- Low-jitter RF system

Sensitivity of various error sources on the injector performance was studied using the PARMELA code and the results are reported elsewhere [2]

The IE matching condition given by (1) & (2) could be best achieved after directly observing the emittance and beam size evolutions after the gun. Extensive archives of such evolution profiles with various operating conditions would be critically helpful to designing and commissioning of the PPI. For this purpose we are building a special diagnostic device called the emittance meter. This includes a longitudinally movable slit-screen system to measure the emittance profile of beams exiting from the gun. Schematic and layout of the emittance meter are shown in Fig. 1. Detailed description of the emittance meter is seen in Ref. [3]

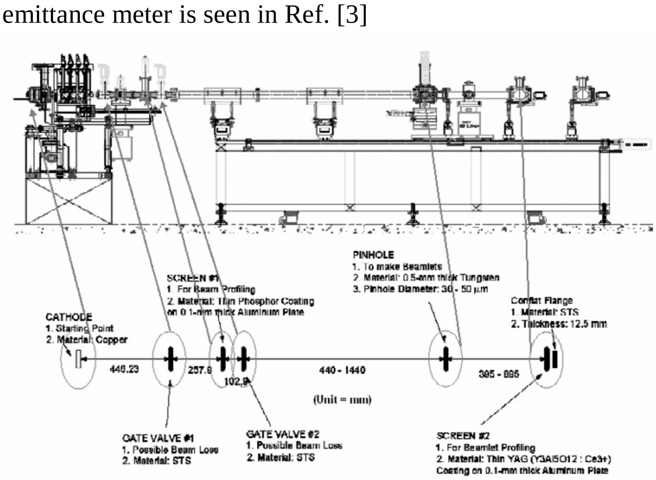

Figure 1: Schematic of emittance meter for measuring the longitudinal profile of beam emittance.

Thermal Emittance

Basic strategy of the PAL XFEL is to generate hard X-ray radition with relatively low beam energy. For this, we would need to reduce the beam emittance < 0.8 mm mrad (projected), and this is quite challenging. At this extremity, the contribution of the thermal emittance to the total one will become significant and one should seriously consider on the reduction of it.

It is known that electrons originating from the bulk of the cathode experience multiple scatterings with other electrons and phonons and are emitted in an isotropic manner outside to the cathode. In contrast to this, electrons emitted from the surface of the cathode do not experience the scattering and most of them are emitted in the direction normal to the cathode. The angular distribution of the surface photo-emitted electrons are given by the $\cos^2\theta$ where, θ is the angle to the normal to the cathode. By defining R as the ratio of the numbers of the bulk emitted electrons to the total (bulk + surface) ones,

$$R = \frac{Q_{bulk}}{Q_{bulk} + Q_{surface}} \tag{3}$$

thus we can write the angular distribution of the whole electrons as,

$$\frac{dN}{d\Omega} = R + (1-R)\cos^2\theta \tag{4}$$

The rms emittance with this angle distribution is calculated as,

$$\varepsilon_n = \sigma_x \sqrt{R\frac{\langle E_{kin}\sin^2\theta\rangle}{m_0c^2} + (1-R)\frac{\langle E_{kin}\cos^2\theta\sin^2\theta\rangle}{m_0c^2}} = \sigma_x\sqrt{\frac{1+3R}{8}\frac{\langle E_{kin}\rangle}{m_0c^2}} \tag{5}$$

where, E_{kin} is the kinetic energy of photo-emitted electron. This is the difference between the photon energy and the cathode work function. Bracket is to averaging over whole electrons.

The factor R in (5) is known to depend not only on the cathode material but also on the polarization and incidence angle of the laser beam. With specific numbers for the Cu cathode and p-polarized 266-nm photon, we have calculated the dependency of the thermal emittance to the laser incidence angle as Fig. 2. Dramatic reduction of the thermal emittance with the use of oblique incidence is clearly foreseen.

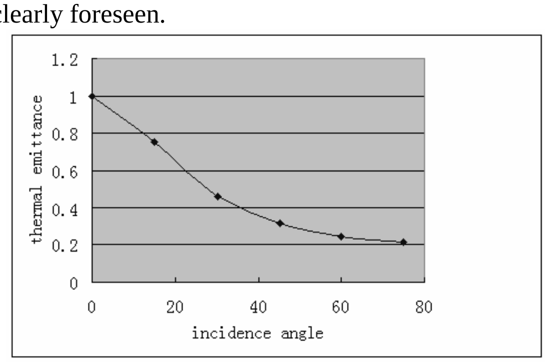

Figure 2: The dependency of the thermal emittance on the (p-polarized) laser incidence angle.

Precision Components Fabrication

All injector components should be fabricated and installed precisely in order to minimize nonlinear fields and wakes. The design of the emittance-compensating solenoid for the PPI is essentially BNL-style and adopts the flux flatteners. Although this is expected to provide good alignment between field and mechanical axes, we are checking by the use of special field measurement bench.

Dark currents should be one of the potential problems in the operation of the PAL XFEL or other facilities. Since most dark current surviving up to the undulator would originate from the electron gun, the suppression of the dark current in the gun cavity is quite important. In this regard, we are going to utilize ultra precision turning lathe for machining the cavity parts. In this case, precise determination of the cavity dimensions is important because no cut-and-try frequency adjustment is allowed.

The quality of the accelerating structures is another important engineering issue. The straightness requirement is expected to be < 50 μm rms. This is not easily achievable with conventional brazing techniques. Diffusion bonding or electroplating could be used although they are very expensive. The transverse kicks beam receives when it pas through the in and output couplers can be avoided by the symmetric couplers.

Jitter requirements of the PPI are directly connected to the stability of the klystron modulator. The stability of the charging power supply is expected to be better than 0.1 % which is marginal with present-day technologies. At the PAL R&D efforts have been done to improve the inverter charging power supplies that have been in-house developed.

The stability and reliability of gun drive laser is also one of the prime issues. The modern regenerative amplifiers can produce 2 – 3 mJ pulse energy at IR. With 10 % efficiency for conversion to UV and 50 % for transporting to the cathode, the available UV energy at the cathode becomes 100 - 150 μJ. This is marginal for producing 1-nC charge with conventional Cu cathodes. Possible solutions to this are; 1) use high QE cathodes such as Cs_2Te and Mg. 2) increase the quantum efficiency of the Cu cathode by special surface cleaning techniques. For example, bombardment with Argon ions is known to provide QE > 10^{-4}. Both of methods require the load-lock system in which the cathodes are *in-situ* fabricated or cleaned. One of the issues in designing the load-lock system is the in-vacuum transportation and claming mechanisms of the cathodes to the half cell of the gun cavity.

PPI Status

Ground breaking for the PAL XFEK building construction is schedule in April 2006. The installation of the PPI will start roughly 5 months after this time when the injector room is finished. For the on-schedule installation of the PPI, we have already started to construct the GTS (Gun Test Stand) facility. The facility is composed of a BNL-style photo-cathode rf gun, a Ti:Sapphire laser system (Spectra-Physic Tsunami + Spitfire-Pro), a modern rf source system, a emittance diagnostic system (the emittance meter). The first beam is scheduled in August this year. After completing the GTS we will proceed to develop the PPI gun with improved stability and reliability. The installation and commissioning of the PPI will be done at the PAL XFEL tunnel.

We summarize the PPI status as follows:

1. Fabrication of solenoid magnets is finished (Fig. 3).
2. Precision field measurements are under way.
3. Final dimension of gun cavity has been determined.
4. Gun cavity brazing is near finishing (Fig. 3).
5. Ti:Sapphire laser system is being installed (Fig. 4).
6. RF source system will be installed with in-house developed 66-MW klystron + 200-MW Modulator.
7. Emittance meter for measuring emittance evolution in longitudinal direction is being built.
8. Investigation of thermal emittance might be possible with (femto-second) electron diffraction [4][5].

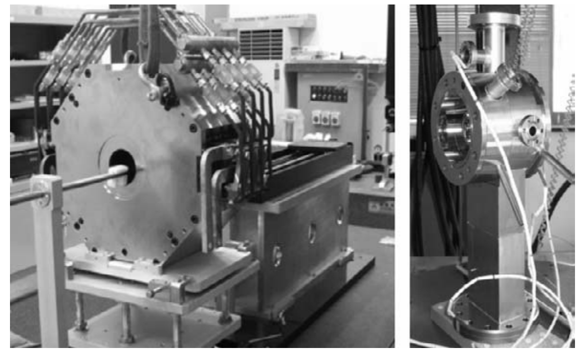

Figure 3: Fabricated GTS solenoid and rf gun.

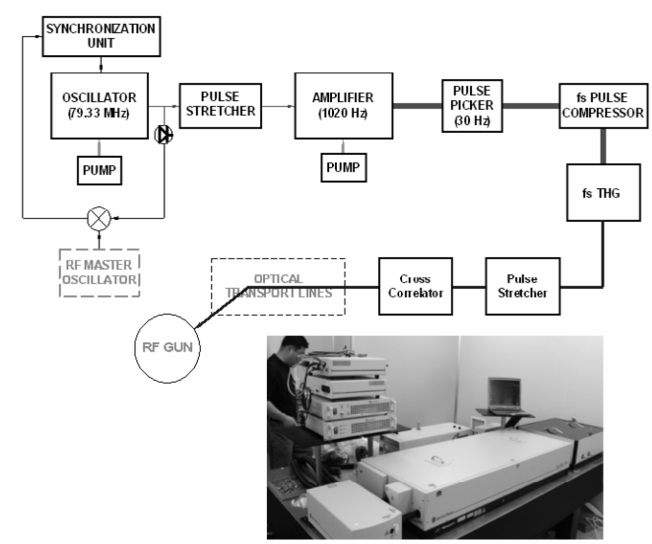

Figure 4: Schematic of GTS laser system.

CONCLUSION

Given the boundary conditions imposed on the PAL, we are striving to get hard X-ray SASE with relatively low beam energy. Successful completion of this would necessitate careful and systematic planning of the generation and preservation of ultra low-emittance beams. This is quite challenging and exciting.

ACKNOWLEDGEMENT

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