CONSTRUCTION OF INJECTOR TEST FACILITY (ITF) FOR THE PAL XFEL*

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Abstract

An injector test facility (ITF) for the PAL-XFEL has been successfully constructed and its commissioning is under way. The facility is to demonstrate beam performances required by the PAL XFEL (beam energy of 139 MeV, projected rms emittance of < 0.5 mm mrad @ 200 pC, and beam repetition rate of 60 Hz) with good enough stabilities. We have constructed a dedicated building for the facility in which a radiation-shielding tunnel (19.2-m long, 3.5-m wide, and 2.4-m high inner space), a klystron-modulator gallery, a laser room, and a control room are installed. The injector consists of an in-house-developed photo-cathode rf gun, a 30-mJ Ti:Sa laser system, two accelerating structures (as well as two sets of klystron-modulator systems), and various diagnostics as well as magnets & instrumentations. The installation of a transverse deflecting cavity (S-band, 10-fs resolution) and a laser heater is scheduled in 2013. In this article we report on the facility construction and some of the early commissioning results.

INTRODUCTION

PAL XFEL is the 4th-generation light source based on the SASE principle [1]. The injector of the machine is required to provide electron beams with their emittance better than 0.5 mm mrad (rms normalized, projected) at the charge of 200 pC [2]. Major specifications for the PAL XFEL injector are summarized in Table 1.

Table 1: Major Specifications for the PAL-XFEL Injector

Parameters	Specifications
Energy	139 MeV
Charge	200 pC
Emittance	< 0.5 mm mrad
Energy Spread	$\sim 10^{-4}$
Repetition Rate	60 Hz
Bunch Length	10 ps (nominal)

In PAL various efforts have been exercised to realize the PAL-XFEL injector for last 10 years. Major efforts were devoted to key devices R&Ds and the construction of the injector test facility (ITF). The former was to develop a high-brightness photocathode rf gun, learning their diagnostic methods and skills as well as cultivating manpower. The latter was to demonstrate sub-systems performances far ahead of the PAL-XFEL construction, which had been recognized to be highly beneficial for ensuring reliable injector operations and achieving better beam performances than the baseline specifications. These two major efforts have been in parallel with beam-dynamics investigations for achieving good machine layouts and tolerance analyses. All these efforts will continue and have to be eventually interconnected to the beam commissioning and operation of the PAL XFEL.

CONSTRUCTION

The PAL-XFEL ITF was established in a new building built by expanding an existing test lab for the PLS-II (Pohang Light Source-II [3]) facility. Fig. 1 is the plain view of the ITF and its location in this laboratory shown together with an artistic view for the PAL-XFEL.

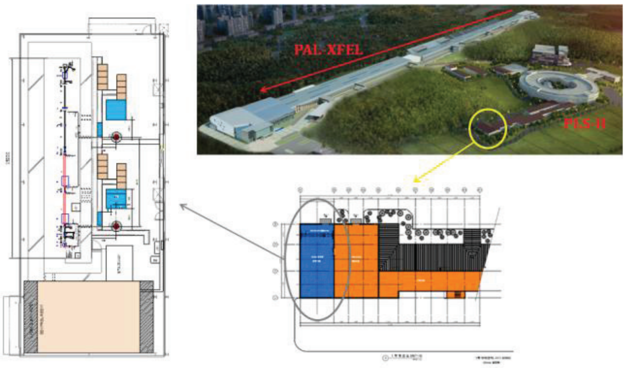

Figure 1: Location of the PAL-XFEL ITF in PAL.

The ITF consists of an accelerator tunnel, klystron gallery, and laser & control rooms (see Fig. 2). The accelerator tunnel is made of concrete walls (thickness of 0.8 ~ 1.5 m) and ceilings. In the gallery we installed two sets of klystron & modulator systems and various equipments and instruments. The laser room is located close to the gun in order to minimize optical transport. There is a 0.8-m-thick concrete wall between the laser room and the accelerator tunnel and we drilled a hole at 0.8-m height from the ground. Operation is done in a control room which was built on the 2nd floor to the laser

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room. Monitoring and control signals are provided by the EPICS-based control system. Cooling water with temperature stability of +/- 0.1° C is supplied by an independent cooling station outside the ITF building. Precision water temperature control is accomplished by separate heater modules installed in the tunnel. Fig. 3 is a 3D model for the accelerator, shown without auxiliary systems. See Table 2 for the specifications of major accelerator components.

Table 2: Specification of Major Accelerator Components

Components	Quantity	Specifications	Remark
Gun	1	1.6 Cell 2.856 GHz, 6 MeV, Cu Cathode	4-Hole Field Symmetri-zation
Accelerating Structures	2	J-type Dual Coupler	Provided by Mitsubishi Heavy Industries
Klystrons	2	80 MW, 60 Hz	Toshiba E3712
Modulators	2	Stability better than 50 ppm	Inverter Charging Power Supplies
LLRFs	2	Accuracy better than 0.05°	
Transverse Deflecting Cavity	1	2.856 GHz, Temporal Resolution ~10 fs	Turn-key Provided by "Radiabeam Technologies"
Screens	5	100-μm thick YAG, 1-μm thick OTR	
Wire Scanner	1	25-μm thick Tungsten Wire, BGO Scintillators	
Magnets	2 Bends, 3 Quads, 6 H/V Correctors	Field Offsets for Quads ~50 μm, Field Errors for Bends 5E-4 ~ 1E-3	
Bolts & Nuts	~ 1500		

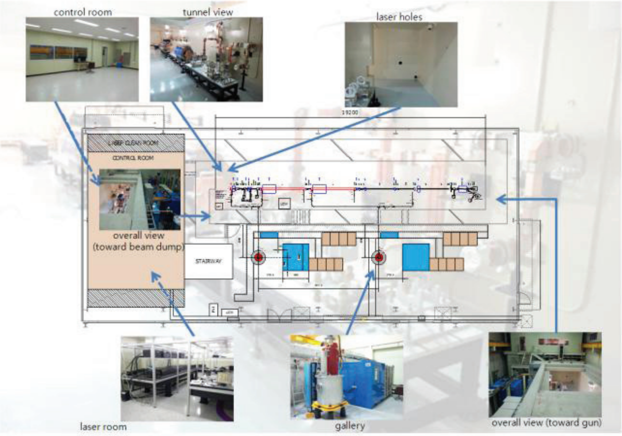

Figure 2: Detail view of PAL-XFEL ITF.

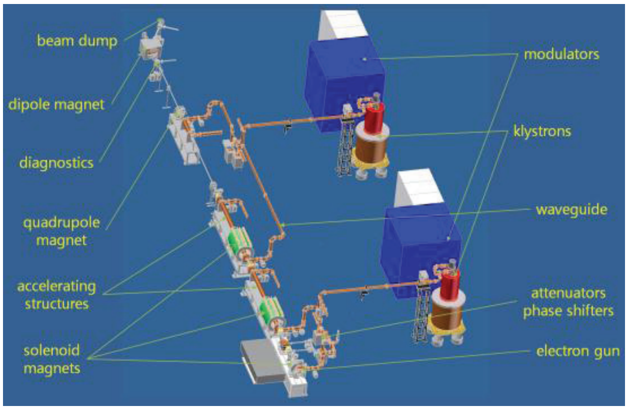

Figure 3: 3D Model of the PAL-XFEL ITF (shown without auxiliary systems).

The gun had been designed to have 4 holes in its full cell for symmetrizing the electromagnetic fields [4]. The emittance measured by the slit-screen method was about 1.0 mm mrad (rms normalized, projected) [5]. We have developed a sexless waveguide flange which enabled reliable vacuum & rf sealings as well as easy assembling. See Fig. 4 for its appearance. Waveguide attenuators and phase shifters which were provided by the NKC (Nihon Koshuha Co., in Japan) have been reliable and accurate in operation. Their position accuracy is +/- 10 μm (0.05° or 0.001 dB per step).

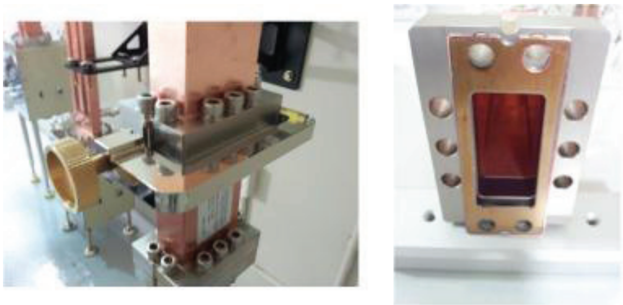

Figure 4: PAL-XFEL waveguide flange.

COMMISSIONING

Before the rf processing of gun bake-out was done in order to ensure good vacuum in it. The ultimate pressure of 2E-10 Torr was obtained at the ion gauge in pumping manifold. Fig. 5 is the history of the gun bake-out.

Figure 5: History of gun bake-out.

It took about 5 weeks to rf-process the whole accelerator rf components (@ 10 Hz). At the end of the processing rf power inputs to the gun and 1st/2nd accelerating structures were 12 and ~35/60 MW respectively. Fig. 6 shows the first two-week history of the rf processing. The whole accelerator has been processed to generate 139 MeV at the repetition rate of 10 Hz. Although the gun had been pre-processed to 60 Hz at a separate test stand most of the beam commissioning so far has been done at 10 Hz.

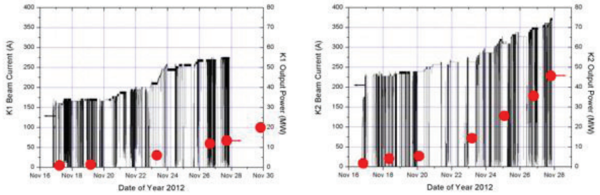

Figure 6: Beginning part of rf-processing history.

We have adopted a ferrite-type isolator [6] for absorbing transient rf reflections from the gun. It provides a 20-dB isolation which results in clean reflection waveform as shown in Fig. 7.

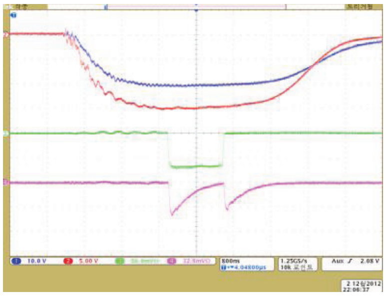

Figure 7: Forward (green) and reflection (magneta) rf waveforms measured at a directional coupler installed close to the gun. Blue and red traces are klystron beam voltage and current waveforms respectively. Operating rf pulse length was 1.5 µs.

The first beam was measured at the screen 1 on December 7, 2012 [7]. At this moment measured beam energy was about 3.5 MeV at the rf power input of 3.5 MeV to the gun.

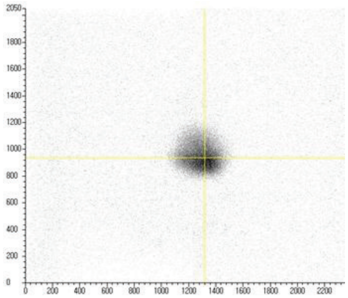

Figure 8: First beam at the screen 1. Horizontal and vertical axes are in pixel numbers. Pixel size is about 8 µm.

Table 3 summarizes best emittance values achieved as of now, shown together with measurement conditions. Large differences between 100% and 90% emittances are believed to be due to beam halos of which origin not known yet.

Table 3: Best Emittances Achieved as of March 14, 2013

Parameters	Values
ε_x	0.71 mm mrad (100%) 0.39 mm mrad (90%)
ε_y	0.78 mm mrad (100%) 0.43 mm mrad (90%)
Beam Energy	133 MeV
Charge	200 pC
Laser Injection Phase	25°
Gun energy	5.6 MeV

CONCLUSION

The PAL-XFEL ITF, an injector test facility for the PAL XFEL has been constructed and its commissioning is under way. The 90% emittance achieved so far is more or less 0.4 mm mrad, which is roughly half of 100% emittance, already satisfied the requirement. Efforts to reduce the 100% emittance are on-going; re-calibrating diagnostics, reinforcing alignment hardwares, repeating beam-based alignments, and improving laser profiles. The ITF is routinely operated for various beam experiments and devices testings for the successful completion of the PAL XFEL project.

ACKNOWLEDGMENT

The on-time construction of the ITF greatly owes to the well-established technical resources in the PAL. Furthermore stable operation of the PLS-II enabled focused efforts. The author would like to express thanks to Dr. Alex Murokh and his colleagues in the RadiaBeam Technologies, (http://www.radiabeam.com), for their supports for magnets and diagnostics.

REFERENCES

[1] Conceptual Design Report of PAL XFEL (2011).
[2] Technical Design Report of PAL XFEL (2012).
[3] S. Shin et. al., J. of Instrum. 8, P01019 (2013).
[4] M. S. Chae et al., PRST-AB 14, 104203 (2011).
[5] J. H. Hong et. al., IPAC2012.
[6] AFT microwave GmbH, http://www.aft-microwave.com
[7] J. H. Han et. al., in these proceedings.