INTRODUCTION TO BEAM DIAGNOSTICS COMPONENTS FOR PAL-ITF

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Abstract

Pohang Accelerator Laboratory (PAL) is building the 4th generation X-ray free electron laser (XFEL). The Injection Test Facility (ITF) is a test facility established to improve the functions of the laser gun and pre-injector to be installed in XFEL. To improve the effects of ITF, two factors are required. The first is to be able to generate low-emittance electron beams stably at the laser gun, and the second is to control increasing emittance by space charge effect by accelerating electron beams with high energy at the pre-injector. In this way, high-quality electron beams can be materialized.

Various beam diagnostics are installed in the accelerator system for beam diagnostics and measurements. Five kinds of beam diagnostics were installed in the PAL-ITF. These are (1) ICT and (2) Faraday Cup to measure current and electrons charge, (3) Stripline BPM to measure the location of beams, (4) a YAG/OTR Screen Monitor to measure beam energy and transverse profile motion, (5) a Wire Scanner to measure beam size. In this paper, the purposes and properties of each diagnostic unit and measurement results are introduced.

INTRODUCTION

The location of a diagnostic unit is important. The location is determined at the stage of beam optics and parameter design at Beam Physics Group. The group applies the optical theory in the optical planning stage and calculates all conditions (energy, charge, position and shape) of the accelerator system. A diagnostic unit is also installed in a position considered necessary for beam based alignment. When the construction of a diagnostic unit is complete, Beam Physics Group arranges the accelerator system so that its expected value is same as the real measurement value of the diagnostic unit. Figure 1 shows the lattice for PAL-XFEL injector part.

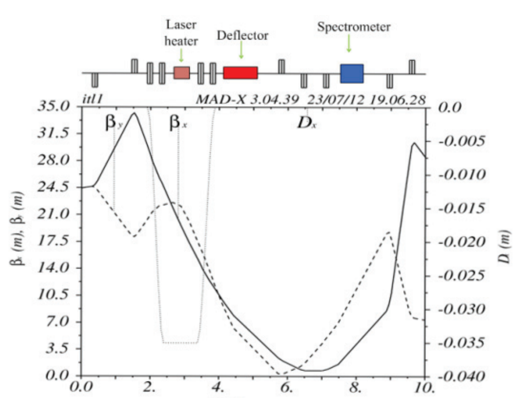


Figure 1: Lattice for PAL-XFEL Injector.

The energy of an electron beam increases as it passes the accelerator system. Voltage (or current) measured at the diagnostic unit differs depending on the measurement location. Measurement signals of the diagnostic unit should be amplified or attenuated depending on the measurement location. If Beam Physics Group calculates the expected value of the measurement device depending on the location, the properties of an electronic circuit are controlled so that the sensor of the measurement device has 100% efficiency, and then a diagnostic device is installed. Please refer to reference [1] regarding the measurement principles of the diagnostic device and a theoretical explanation of the measurement methods. Figure 2 shows the location of the diagnostic device for PAL-ITF, while Fig. 3 shows the PAL-ITF system.

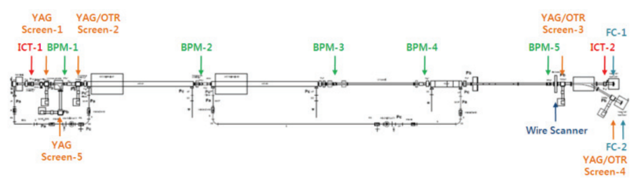


Figure 2: Location of PAL-ITF diagnostic device.

Figure 3: PAL-ITF. (left) Gun & Injector, (right) Klystron & Modulator.

BEAM DIAGNOSTIC DEVICE

ICT

The Integrating Current Transformer (ICT) integrates the charge of pulses having width from less than a picosecond to more than a microsecond. ITF use the In-flange type ICT (ICT-CF4.5"-34.9-070-UHV-05:1). In-flange ICT is mounted directly in the beam line. It's ultra-high vacuum (UHV) compatible. Ceramic gap, shields and wall current bypass are included. Figure 4 shows the In-flange type ICT [2].

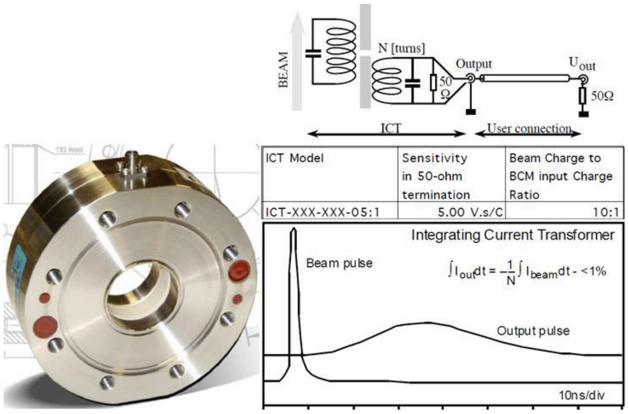


Figure 4: In Flange ICT.

A shorted one-turn current transformer loads the bunch charge in a series of low-inductance capacitors distributed evenly around the transformer toroid. The full bunch charge is instantly loaded in those capacitors. A readout transformer transfers the charge loaded in the capacitor to its readout winding, at a slow pace determined by the RC time constant loading the winding. As a result of this very low frequency transfer, the eddy-current losses in the cores are negligible. Alloys used to assemble these cores are specially annealed to lower their coercive field and further minimize core loss. Measure the output waveform of ICT using an oscilloscope. For the electron beam current, integrate the scope of the measured waveform and then multiply the calibration factor.

Faraday Cup

Faraday Cup is a charge diagnostic tool that measures the charge in low power electron beams. It is capable of stopping 139MeV electrons with a maximum power handing of 10W. with a 50Ω matched impedance, the Faraday Cup has a faster response than simpler beam stops allowing individual pulse charges to be observed on low-repetition rate beams. The stopper has a diameter of 26mm and s stopping length of 144mm [3]. Figure 5 shows the Faraday Cup.

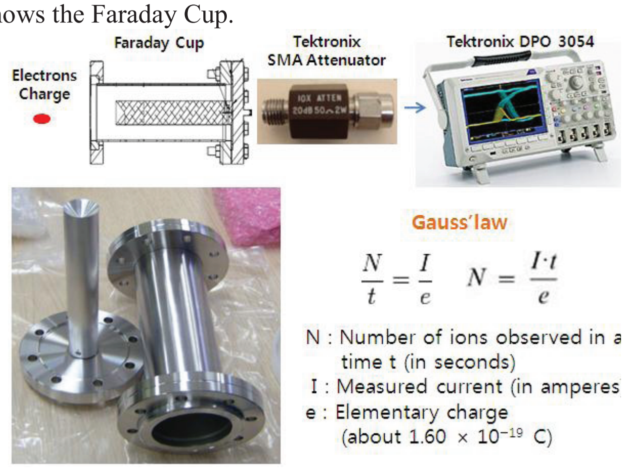


Figure 5: Faraday Cup.

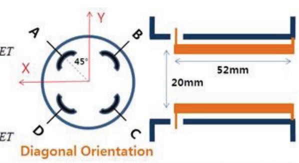
The beam energy generated from the ITF is 139Mev (Pulse Width 10ps, Beam charge Max. 200pC) and the momentary voltage generated from the Faraday Cup (50 ohm) is about 1kV. The high voltage pulse attenuator of 46dB should be applied to measure 5V at the oscilloscope while minimizing the waveform modification of the momentary voltage. As the electron beam as the form of an impulse has a wide frequency spectrum (DC ~ several GHz), the DC~10GHz bandwidth attenuator was used. The current of an electron beam can be determined by measuring the waveform of Faraday Cup using an oscilloscope, integrating the scope of the measured waveform and then multiplying the calibration factor.

BPM

The BPM (Beam Position Monitor) is most frequently used for measuring the location of an electron beam at the accelerator system. The Stripline BPM was selected to measure the location of low-energy electron beams of 200pC or lower. The signal of the Stripline BPM is conveyed to the Libera Brilliance Single Pass system [4]. The Libera system transfers the Stripline BPM signals to ACD and calculates the location of the 2D (XY coordinates) electron beam using FPGA. The resolving power and signal sensitivity of the Stripline BPM were confirmed at BPM Test-stand through a measurement experiment. Fig 6 shows the Stripline BPM and BPM Test-stand.

$$X = K_X \frac{((V'_A + V'_D) - (V'_B + V'_C))}{(V'_A + V'_B + V'_C + V'_D)} - X_{OFFSET}$$

$$Y = K_Y \frac{((V'_A + V'_B) - (V'_C + V'_D))}{(V'_A + V'_B + V'_C + V'_D)} - Y_{OFFSET}$$



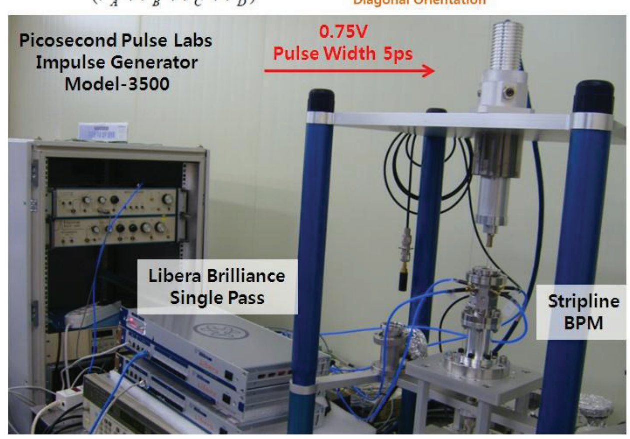


Figure 6: Stripline BPM and BPM Test-stand.

YAG/OTR Screen Monitor

The longitudinal direction pattern of an electron beam can easily be measured using the YAG/OTR screen monitor. While YAG (Yttrium Aluminium Garnet) shows physical responses even at low-energy electron beams, OTR (Optical Transition Radiation) reacts at electron beams with comparatively high energy. Therefore, only YAG was installed at low-energy locations. YAG and OTR release visible rays in linear proportion to the current of electron beams. The size of electron beams can be calculated by taking a picture of the visible rays

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released by YAG and OTR with CCD, and processing images using the value of image pixel intensity. Figure 7 shows the YAG/OTR Screen Monitor. [3]

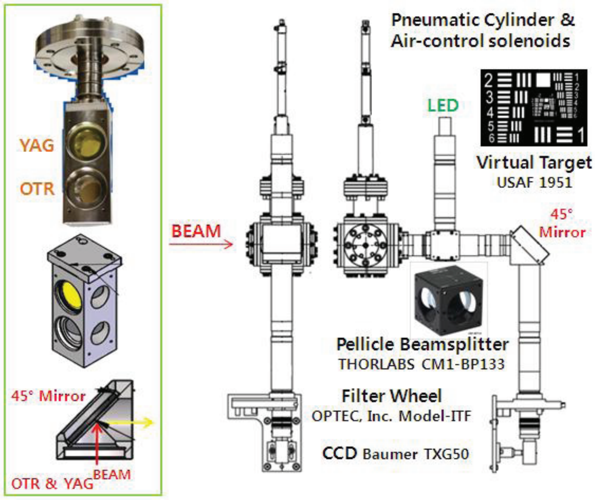

Figure 7: YAG/OTR Screen Monitor.

The energy of electron beams can be determined by bending electron beams using the bending magnet. The energy of electron beams can be calculated by checking the bended location of electric charges depending on the power of bending magnet and then determining the bended distance. Figure 8 shows the electron beam energy measurement method for calculating the energy of electron beam [5].

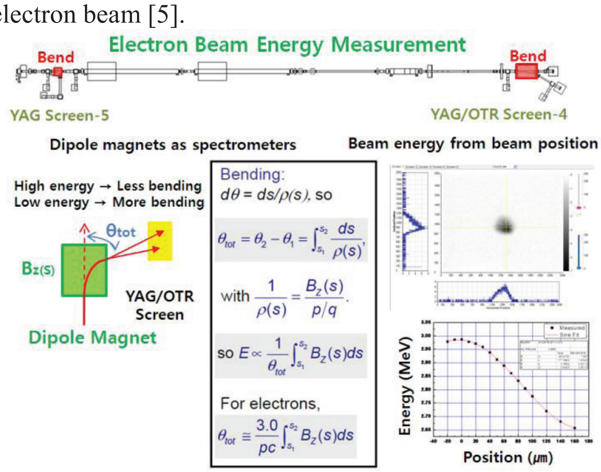

Figure 8: Electron beam energy measurement.

Wire Monitor

The wire scanner is a diagnostic tool used to create a 2D transverse profile of a charged particle beam by scanning tungsten wires (Diameter 25 microns) across the beam and measuring the resulting bremsstrahlung radiation (Scintillator : BGO crystal [6] mounted on PMT [7]). More radiation measured indicates a more intense position of the beam at that wire position. Three wires at different orientations are used - horizontal, vertical, diagonal - to measure the beam's vertical and horizontal spot size, as well as any x-y correlation that indicate a rotated beam. [3] For analysing the gamma energy, use the Inter-Winner 7.0 Software. Figure 9 shows the Wire Monitor.

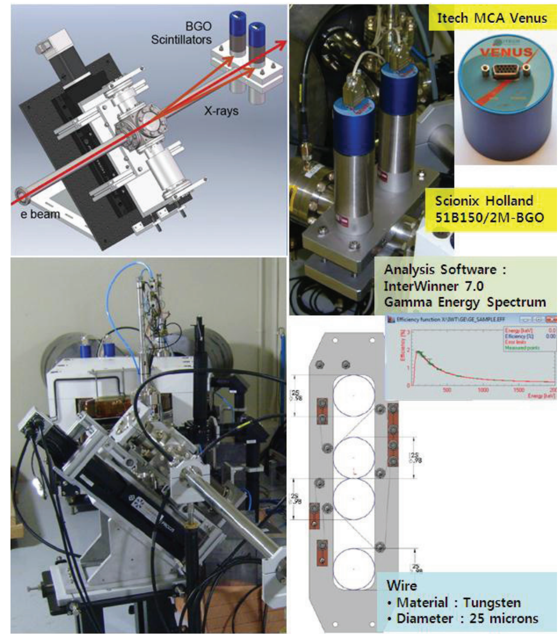

Figure 9: Wire Monitor.

CONCLUTION

The PAL-ITF system was constructed from 2011 to October of 2012 and commissioning began on Nov. 1. The current of an electron beam generated from the laser gun was detected, and acceleration at the pre-injector was checked using the diagnostic device. To achieve the target current (200pC) and beam energy (139MeV) of the PAL-ITF, minute adjustment work to optimize microwave and magnet systems taking a role of accelerating and focusing is continuously required.

ACKNOWLEDGMENT

I deeply thank all of my colleagues who participated in the successful construction of ITF. The ITF is a starting point for the successful construction of PAL-XFEL. [8] PAL-XFEL, as a large-scale piece of scientific equipment, is expected to make a great contribution to Korean R&D of basic science.

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