INTRODUCTION TO THE TEST RESULT OF TURBO-ICT IN PAL-ITF*

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Abstract

Pohang Accelerator Laboratory (PAL) built a PAL-ITF (Injector Test Facility) at the end of 2012 to successfully complete PAL-XFEL (X-ray Free Electron Laser) in 2015. The PAL-ITF is equipped with various kinds of diagnostic equipment to produce high-quality electron bunches. The three main parameters that an injection testing facility should measure are charge, energy and emittance. Although integrated current transformer (ICT) and Faraday Cup were installed to measure beam charge, the noise generated in a klystron modulator not only interrupted accurate measurement but prevented low charges under tens of pC from being measured. Due to the changes in the overall voltage level of ITF, integration of ICT measured value failed to maintain perfect accuracy in terms of methodology (measured value continuously changed by +/- 5pC). Accordingly, to solve the noise problems and accurately measure the quantity of electron beam charge, Turbo-ICT was installed. [1] This paper focuses on the processes and test result of electric bunch charge quantity measurements using Turbo-ICT.

PURPOSE OF BCM INSTALLATION

As shown in Figure 1, A charge generator or a device which accelerates or uses charge has its absolute amount of charge. In other words, knowing the amount of charge which a charge generator produces and a charge accelerator or a charge-based device uses would allow users to check where charge loss occurs and to decide the final amount of charge they will be supplied with. The coulomb (C) is a unit of electrical charge and is also the derived unit of International System (Système International d'unités, SI) of Unit. A bunch charge monitor (BCM) shall be installed after it is calibrated to measure the absolute amount of charge.

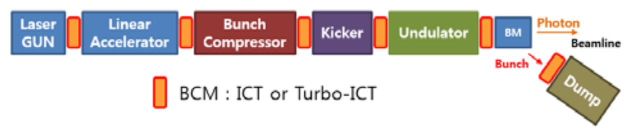

Figure 1: Locations where BCM installation is required.

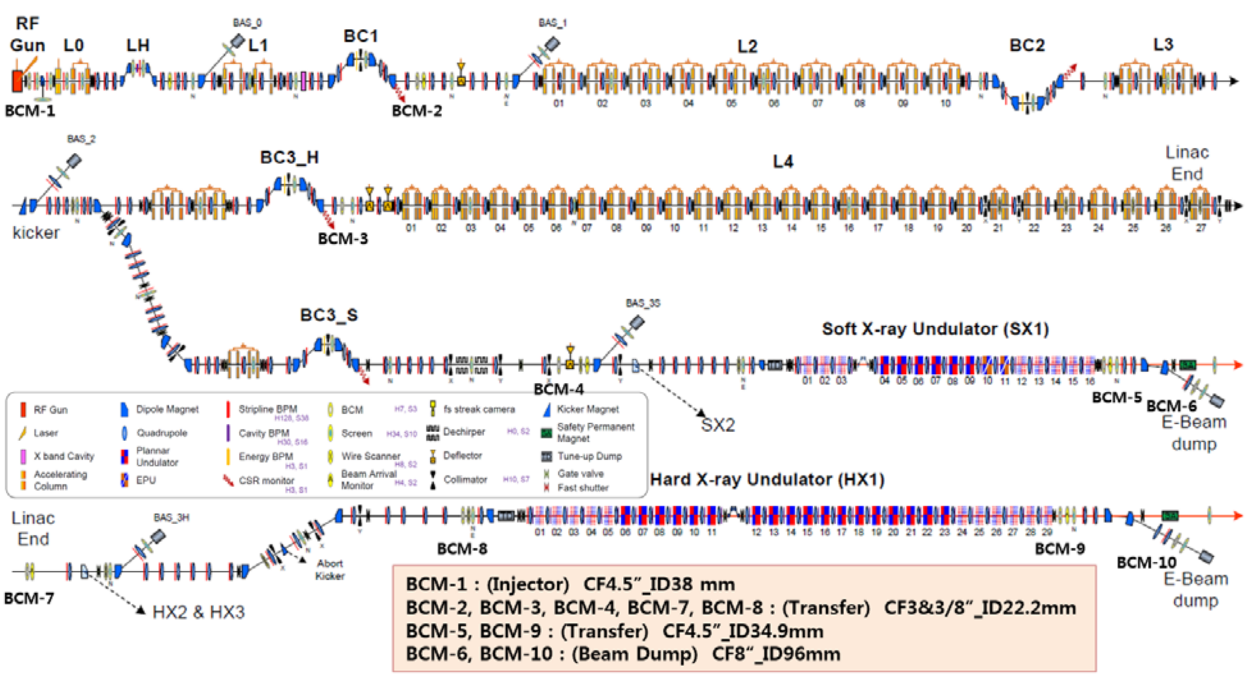

Figure 2: Locations of BCM installed on PAL-XFEL.

As shown in Figure 2, Ten BCMs are installed on PAL-XFEL: Laser gun generator, the rear part of a bunch compressor with the possibility of charge loss, Kicker-based bunch branch part, the end of a linear accelerator (Starting point of an undulator), the end of an undulator, and beam dump part. A BCM is a calibrated device for measuring the absolute amount of charge. Sometimes Stripline-BPM Sum Value and Cavity-BPM Reference Value are complementarily used to measure the amount

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of charge. Monitoring the fluctuation in the amount of charge using BCM and BPM can systematically record and control the locations of charge loss on XFEL and contribute to improving XFEL performance. To minimize the fluctuation in the amount of charge and ensure steady and stable supply of charge, BCM readings are transmitted to a laser system through Fast Feed-forward Network.

The Figure 3 is an important parameter required by the beamline experiments. The flux related to charge.

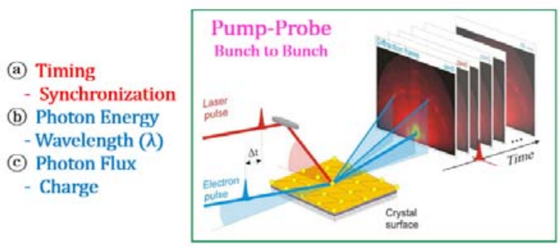

Figure 3: Important parameter on the Pump-Probe.

When installing a BCM on an accelerator (20mm in internal diameter), ICT-CF3"3/8-22.2-40-UHV-Turbo1-316LN-H with 22.2mm in internal diameter will be used to minimize the influence of Wakefield by spatial change. The layout of ICT-CF3"3/8 shown in Figure 4.

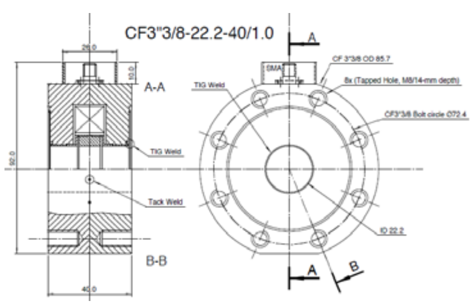

Figure 4: Bergoz's ICT-CF3"3/8 Drawing.

ICT ORGANIZATION AND PRINCIPLE OF PHYSICAL MEASUREMENT

As show in Figure 5, BCM system consists of (1) integrating current transformer (ICT), (2) cables, (3) electronic integrators, and (4) interface electronics to the control system. [2]

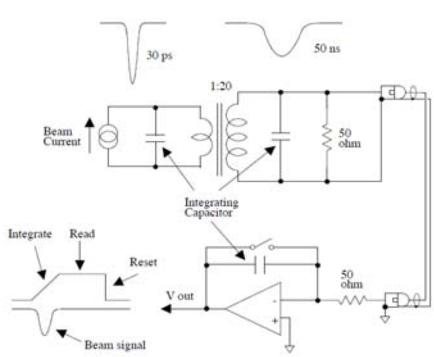

Figure 5: Simplified diagram of a BCM.

As the physical concept of pickup is important to all the beam diagnostic systems, understanding the physical concepts of a BCM is important to designing and operating suitable electronics. [3] As show in Figure 6, A toroidal core is a piece of magnetic material (Amorphous cobalt alloy cores) and plays the same role as a magnet when the magnetic field, which is generated when the beam bunch passes, induces magnetic flux momentarily. Then the magnetic flux flowing in the toroidal core is proportional to the amount of charge in the beam bunch. [4][5][6]

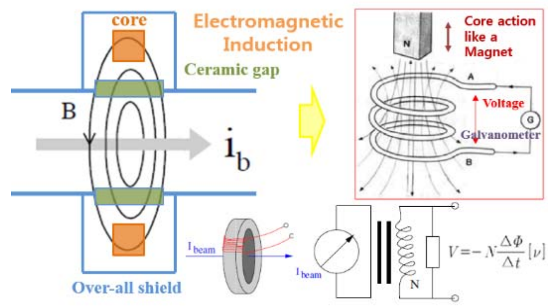

Figure 6: Concept of core induction in the magnetic field generated in an electron beam.

As show in Figure 7, if magnetic flux flows around toroidal cores, varying magnetic fields cause electromagnetic induction. The induced electromotive force is subject to Michael Faraday's Law: The induced electromotive force in any closed circuit is equal to the time rate of change of the magnetic flux through the coils and the number of turns of coil. The electrical properties of ICT which measures the charge amount of beam bunch depends on core properties and turns ratio. Based upon the facts, pickup's equivalent circuit is made and an electrical circuit diagram for ICT measurement is designed. [7][8]

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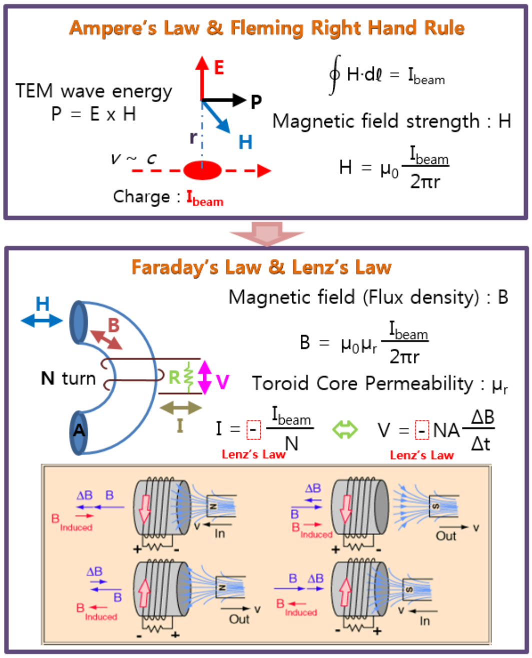

Figure 7: Physical principle of ICT.

As show in Figure 8, the area of pulse generated by beam bunch is equal to the charge amount. If the amount of charge increases, the induced current may have rise and droop time owing to the physical properties of pickup. As shown in the below figure, the readings of ICT output voltage reveals that ICT output pulse extends more widely towards time axis than beam pulse. To get the precise value of charge amount in ICT, integrate ICT output pulse area in DAQ.

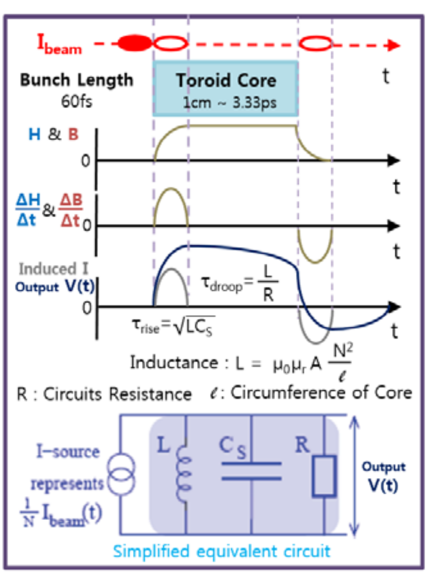

Figure 8: Output voltage of ICT

TURBO-ICT ORGANIZATION AND PRINCIPLE OF OPERATION

As show in Figure 9, Turbo-ICT system consists of (1) In-flange Integrating Current Transformer, (2) BCM SMA-SMA radox cable, and (3) BCM-RF-E & RF-Shielded powered chassis.

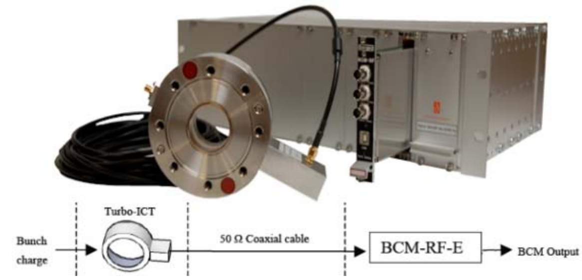

Figure 9: Simplified diagram of a Turbo-ICT.

The charge amount of PAL-XFEL ranges between 1~200pC (Max. 300pC). An improved system like Turbo-ICT is required to measure the small amount of charge in XFEL. First of all, ICT induces a small amount of charge and the output pulse is relatively low. As the amount of charge fluctuates greatly owing to modulator noise, it is difficult to measure its amount precisely by transmitting a low voltage of current in ICT through cables. To solve this problem, the Turbo-ICT use a bandpass filter to limit the output bandwidth to small band 180MHz. The result is a short resonance at 180MHz that is amplified in a low noise amplifier before transmission. It show on Figure 10. [9]

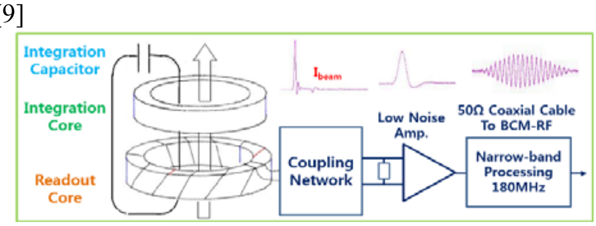

Figure 10: Turbo-ICT Pickup.

As show in Figure 11, Inside BCM-RF-E are a filter which removes noise infiltrating ICT signals and Log. Envelope detector for logarithmic signal. Log scale increase the detector dynamic range of input signal. The PIC integrated on BCM-RF for digital output on USB port. The micro-calibration of related electronic circuits is done by Bergoz's precision electric charge measuring system. [10]

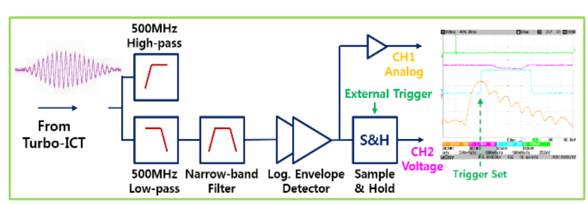

Figure 11: BCM-RF-E.

Timing synchronization is required to measure the charge amount of beam bunch in BCM-RF-E. For this purpose, event trigger signals are authorized in BCM-RF-E. There are three ways of reading charge amount in BCM-RF-E: (1) Read output waveform in CH1 or (2) calculate it according to a given equation after reading

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DC value in CH2, and (3) LabVIEW GUI program on USB cable.

As show in Figure 12, Bergoz's support the useable LabVIEW GUI (graphical user interface) program for configuration setting and beam charge monitoring of Turbo-ICT.

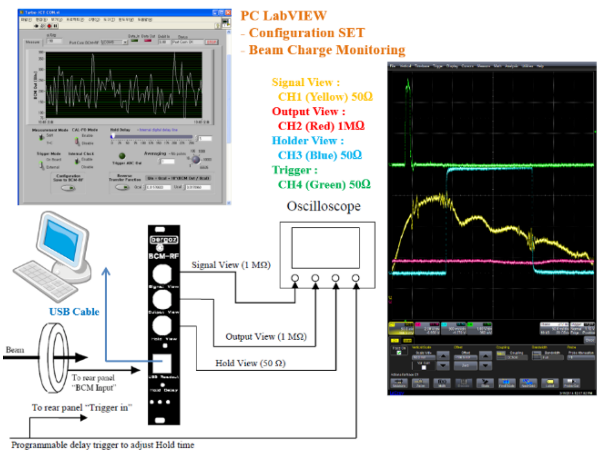
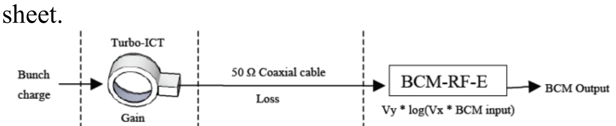


Figure 12: Configuration set and charge monitoring.

Turbo-ICT is manufactured by the purchaser production (custom make) method. All components of Turbo-ICT including cables should be carefully managed as a concept of set. The calculation formula of Turbo-ICT charge amount is shown in Figure 13. Parameters for calculation are included in suppliers' calibration data sheet.



Direct transfer function:

BCM Output = Vy * log((Bunch charge * Gain charge * Loss) / Vx)

Calibration Factor for the PAL-ITF Turbo-ICT

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Sample and Hold mode :
Turbo-ICT input charge(pC) = Qcal*10^(BCM Out(V)/Ucal)
Qcal = 0,015766
Ucal = 0,817896
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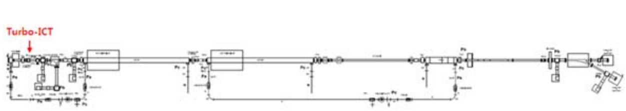
Input charge (pC) = 0.015766 X 10^(BCM Out (V) / 0.817896

Figure 13: Calculation formula of Turbo-ICT charge amount.

PAL-ITF INSTALLATION & TEST RESULTS

The requirements of PAL-XFEL is: (1) 300pC (the minimum charge amount for measurement is uncertain owing to noise in a modulator), (2) Bunch repetition rate 60Hz, and (3) bunch length 60fs. This time not ordered the two-bunch mode.



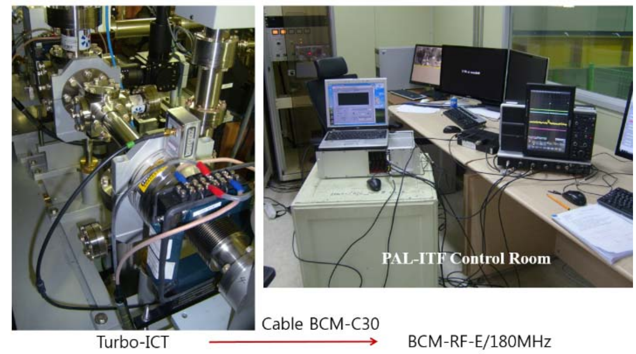


Figure 14: Turbo-ICT installed on PAL-ITF.

As shown in Figure 14, a Turbo-ICT was installed on PAL-ITF and Gun's output charge amount was measured together with Stripline-BPM while changing the Half-wave plate angle of the laser system. It shown on Figure 15.

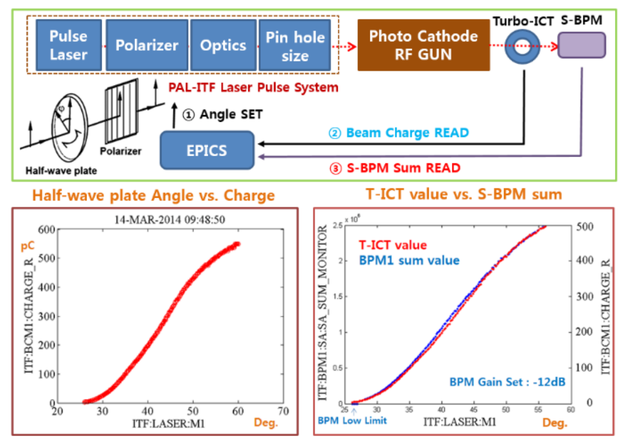


Figure 15: Turbo-ICT following charge control by laser system and BPM Sum value measurement results.

Figure 16 show the modulator noise problem. Turbo-ICT's minimal range of measurement for charge amount is limited by the noises of peripherals including Klystron Modulator. The results of tests on PAL-ITF have shown that in spite of modulator noise's influence it met the requirements of PAL-XFEL, or 1~200pC (Max. 300pC). The test result shown on Figure 17.

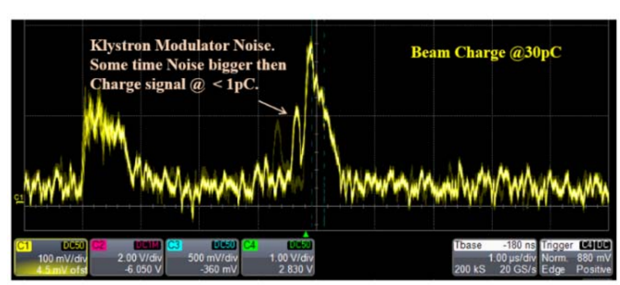


Figure 16: Influence of Klystron modulator Noise.

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Turbo-ICT input charge (pC)	BCM Out (V)
426,5501	3,640
307,9428	3,516
220,0240	3,384
152,2194	3,254
108,7602	3,140
78,3376	3,021
55,0136	2,886
39,3070	2,766
27,2251	2,645
19,6097	2,536
14,0110	2,414
9,6265	2,275
6,8781	2,161
4,9542	2,055
3,4274	1,930
2,4489	1,810
1,7178	1,685
1,2387	1,579
0,8851	1,477
0,6123	1,363
0,4375	1,260
0,3155	1,157
0,2198	1,064

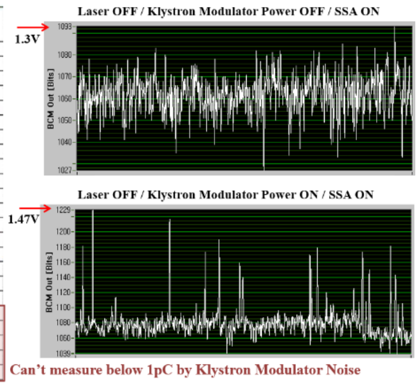

Figure 17: Problems of Klystron modulator noise and measured value of Turbo-ICT on PAL-ITF.

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