# 3 BPM STUDY AT PAL ITF

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*Abstract*

Pohang Accelerator Laboratory (PAL) is building the 4th generation X-ray free electron laser (XFEL) machine. To examine the efficiency of various diagnostic devices an injector test facility (ITF) was constructed. The last part of the ITF is dedicated for evaluation of beam position measurement devices. A “3-BPM-study” was done with 3 Libera Single Pass E BPM modules that were connected to the 3 equidistantly positioned stripline sensors. The aim of the test was to measure the performances of the Libera Single Pass E devices with beam conditions similar to the real pal XFEL machine.

## INTRODUCTION

The Pohang Accelerator Laboratory X-ray Free-Electron Laser (PAL-XFEL) project started in 2011. The final machine will consist of a 10-GeV electron linac based on S-band normal conducting accelerating structures and five undulator beamlines. The goal of the project is the production of 0.1 nm coherent X-ray laser to photon beam users.

An injector test facility (ITF) for the Pohang Accelerator Laboratory X-ray free electron laser has been constructed to demonstrate the performance of sub-systems far in advance of the PAL-XFEL construction. One of the subsystems is also a BPM system with feed-forward calculation and magnet control capability.

In February 2014 extensive testing was carried out at the PAL ITF facility. Three Libera Single Pass E BPMs (Electron Beam Position Processors) were efficiently implemented in a PAL ITF control system and connected to three dedicated stripline sensors. Extensive two day testing session followed.

## LIBERA SINGLE PASS E

Libera Single Pass E (see Fig. 1) system is based on uTCA modular technologies with IPMI platform management. The system is therefore developed on multiple AMC modules, with each module covering different functionalities [1].


Figure 1: Libera Single Pass E front panel.

On the top layer, Libera Single Pass E provides the MCI with a development package and Command Line utilities for open interaction in different control systems. This interface was developed to facilitate the integration of Libera Single Pass E into the accelerator’s control system software. On top of the MCI, various adaptors to different control systems can be implemented (EPICS, Tango, etc.).

### *Data processing*

The data processing is initiated by the external event signal. The short signal from the detector is first shaped by the analog front-end filtering, designed in relation to the accelerator parameters.

Through the configuration of various software parameters, Libera Single Pass E offers processing of various beam types (flavors). After the hardware trigger signal which announces the arrival of the bunch, the search of the bunch signal is started. The bunch signal is detected in comparison with the threshold parameter, then a useful part of the signal is defined with the pre-trigger and post-trigger parameters. The sum of the pre-trigger and post-trigger defines the processing window. The signal energy is calculated from the signal as defined by the processing window. After calculating the four signal amplitudes – Va, Vb, Vc and Vd – the beam position is calculated using formulas for X and Y. Four options can be used for position calculation:

- Diagonal pickup orientation – Linear formula
- Diagonal pickup orientation – Polynomial formula (3$^{rd}$ order)
- Orthogonal pickup orientation – Linear formula
- Orthogonal pickup orientation – Polynomial formula (3$^{rd}$ order):

### *Typical measuring performances*

Measurement performance mostly depends on the Libera front-end configuration [2]. Its parameters are set in accordance with other accelerator parameters. The standard type of Libera Single Pass E, used during the testing session at PAL ITF, implements 500 MHz SAW filters with 10 MHz bandwidth. At operational beam charges, the position measurement resolution is close to 1 µm for a single-bunch beam structure (see Fig. 2).

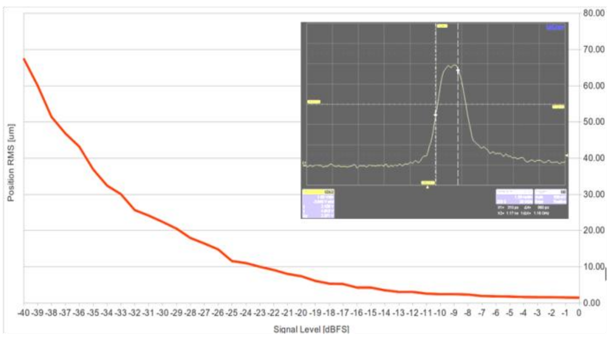


Figure 2: Measurement performance versus input signal level (0 dBFS = 5 V peak).

## INTEGRATION IN THE PAL ITF CONTROL SYSTEM

EPICS based control system environment of PAL ITF is built in Control System Studio user interface framework. Seven Libera Brilliance Single Pass units (Libera platform A instruments) are already integrated in the PAL ITF control system and fully operational. The plan was to temporary replace three existing units with the new Libera Single Pass E instruments. From the data acquisition principle point of view, there is no significant difference between the two instruments. EPICS interface is part of the standard Libera software package. Since both instruments implement it and work in a similar way, it was not a difficult task to remap the essential parameters in an existing control system BPM GUI. Libera platform with three BPM modules was time successfully integrated in PAL ITF control system and ready for operation in a couple of hours.

## INSTALLATION AND SETUP

Three Libera Single Pass E BPM modules were connected directly to the stripline BPM sensors installed in the PAL ITF (see Fig. 3).

Figure 3: Libera Single Pass E connected to three stripline BPMs

Three stripline sensors were equidistantly mounted in the last section of the PAL ITF (see Fig. 4). The distance between the adjacent striplines was 377.6 mm (see Fig. 5). Small distance between the sensors and absence of active components, that would bring interferences in the setup, made the 3 BPM study reliable.

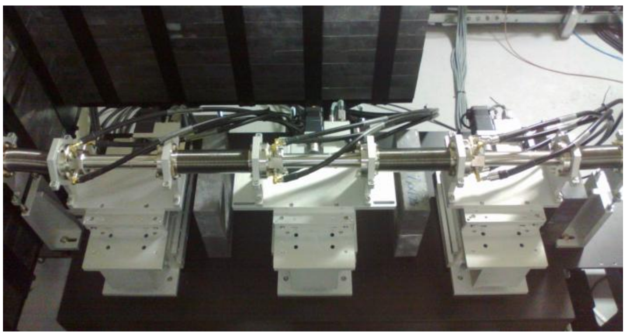

Figure 4: Three equidistantly mounted stripline BPMs

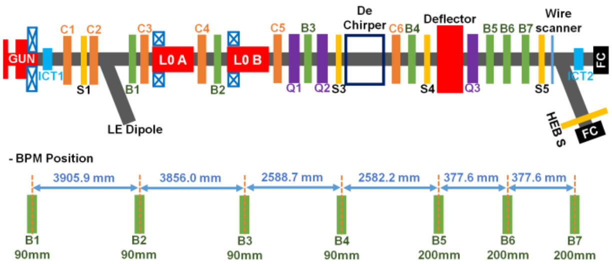


Figure 5: ITF component map. BPMs B5, B6 and B7 were connected to the Libera Single Pass E

## BPM MAPPING

In order to calibrate the system, BPM 5 sensor was moved by the stepper motors in horizontal and vertical plane in the total range of 6 mm per plane. The first mapping was done with default setting of Libera calibration coefficients. Once the scan was completed, new calibration coefficients were calculated (kx = ky = 0.666 mm). Position scan was redone after setting the Libera Single Pass E calibration coefficients kx and ky to a new value. Results with calibrated unit are presented on the figure below.

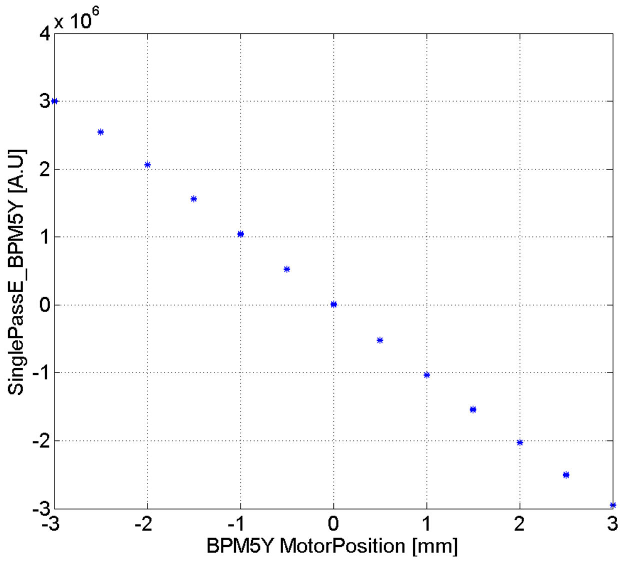


Figure 6: Position scan with calibrated Libera Single Pass E unit

## 3 BPM STUDY

The crucial requirement for the PAL-XFEL BPM is the measuring accuracy and resolution. The latter is required to be in the range of some micrometers. With the so called “3-BPM” study, the position resolution can be obtained by measuring the correlation of three BPM readings. In this way the actual beam jitter can be completely excluded and pure BPM electronics measuring resolution can be estimated.

The beam charge during the beam test was 400 pC, 200 pC, 120 pC and 40 pC. The measured BPM position resolution was varying from the results close to one micrometer for 400 pC beam down to ~7 micrometers for

40 pC. However the focus was put on the measurements at 200 pC, which is the PAL XFEL operational charge.

During each measurement 1000 horizontal position readings were synchronously acquired per BPM module. Later the data was analyzed by using two different methods described below.

## *3 BPM calculation method*

In this method two BPMs are used to predict the position of the third one; the resolution is taken to be the standard deviation of the residual between this predicted position and the position as measured by the third BPM [3]. If the three BPM sensors are equidistantly positioned as in our case, than the calculation of the predicted BPM 6 position can be done with the following formula (see Eq. 1).

$$\mathrm{BPM6X}_{\mathrm{predicted}} = \frac{1}{2}(BPM\ 5X + BPM\ 7X) \quad (1)$$

The figure below presents the result using 3BPM calculation method. Position measurement resolution of 1.4 µm was achieved.

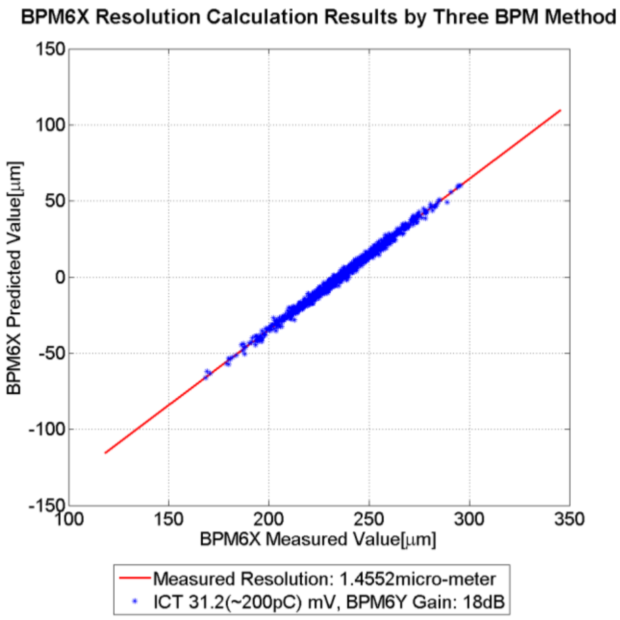


Figure 7: Achieved measuring resolution in horizontal plane using 3 BPM calculation method.

## *SVD calculation method*

Also in this case the predicted value of BPM 6 is calculated on the bases of position information acquired from BPMs 5 and 7, but here the singular value decomposition (SVD) method is used. In the previous method we assume that all three beam position monitors have the same measuring resolution, but in the case of SVD method this assumption is not needed what diminishes the chance of calculation error.

The figure below presents the result using SVD calculation method. Position measurement resolution of 2.3 µm was achieved.

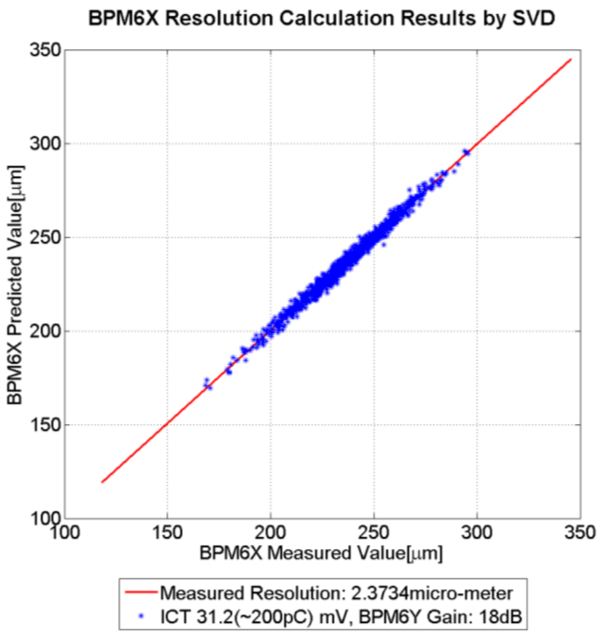


Figure 8: Achieved measuring resolution in horizontal plane using SVD calculation method.

## CONCLUSION

One of the crucial requirements for the 4$^{th}$ generation linacs is the actual measurement resolution under specific conditions, which must be in the range of some micrometers.

The so-called "3BPM study" gave an elevated position measurement resolution of 1.4 µm (3 BPM method) and 2.3 µm (SVD method) at PAL-XFEL planned beam charge of 200 pC.

Excellent results prove that the Libera Single Pass E is a suitable candidate for the PAL-XFEL beam position monitoring system.

## REFERENCES

[1] Instrumentation Technologies, "Libera Single Pass E User Manual v1.00", Solkan (September 2011)

[2] M. Znidarcic, "Libera single Pass E", Libera Workshop (2012)

[3] C. J. Swinson, "Development of Beam Position Monitors for Final Focus Systems at International Linear Collider", Oxford (2010)