PAL-XFEL CAVITY BPM PROTOTYPE BEAM TEST AT ITF

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Abstract

To achieve sub-micrometer resolution, The Pohang Accelerator Laboratory X-ray Free electron Laser (PAL-XFEL) undulator section will use X-band Cavity beam position monitor (BPM) systems. Prototype cavity BPM pick-up was designed and fabricated to test performance of cavity BPM system. Fabricated prototype cavity BPM pick-up was installed at the beam line of Injector Test Facility (ITF) at PAL for beam test. Under 200 pC beam charge condition, the signal properties of cavity BPM pick-up were measured. Also, the dynamic range of cavity BPM was measured by using the corrector magnet. In this paper, the design and beam test results of prototype cavity BPM pick-up will be introduced.

INTRODUCTION

The Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL-XFEL) facility will use 10 GeV linac and undulator beamlines to provide X-ray FEL radiation to users. By using the self-amplified spontaneous emission (SASE) schematic, PAL-XFEL will provide X-rays in ranges of 0.1 to 0.06 nm for hard X-ray line and 3.0 nm to 1.0 nm for soft X-ray line [1]. To generate X-ray FEL radiation, the PAL-XFEL undulator section requires high resolution beam position monitoring systems with <1 μm resolution. At first phase, the PAL-XFEL will be operated at a repetition rate of 60 Hz with 0.2 nC electron beam charge [2]. To achieve this high resolution requirement under single electron beam with low charge condition, the PAL-XFEL undulator section will use the cavity Beam Position Monitors (cavity BPMs) for beam trajectory monitoring. Total 49 units of cavity BPM system will be installed in between each undulators with other diagnostics tools. Before fabrication of the PAL-XFEL cavity BPM pick-ups, the prototypes of cavity BPM were fabricated to test the performance of cavity BPM pick-ups.

PAL-XFEL CAVITY BPM PICK-UP DESIGN

The operation frequency of PAL-XFEL cavity BPM system was set as X-band frequency. Due to the limitation of installation space, the compact cavity BPM pick-up was required. To achieve high resolution and compact pick-up size, the X-band operation frequency, 11.424 GHz, was chosen for PAL-XFEL cavity BPM system. Also, for easy installation and maintenance, the PAL-XFEL cavity BPM pick-ups adopt the SMA feed through as output signal port. Under these two conditions, the PAL-XFEL cavity BPM pick-up was designed.

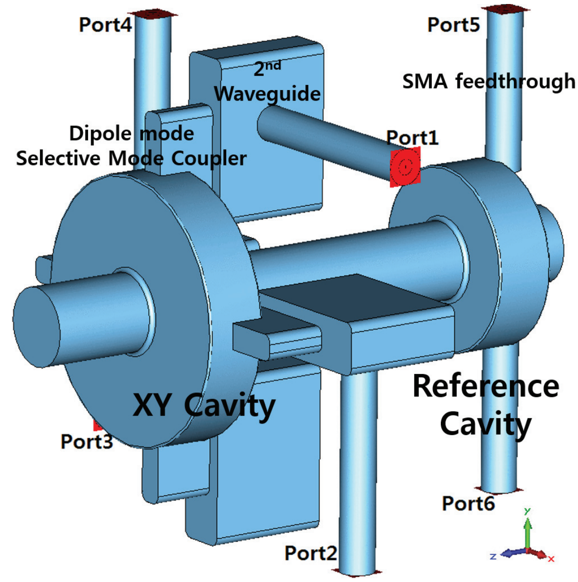

Figure 1: Modeling of PAL-XFEL cavity BPM pick-up vacuum part.

The PAL-XFEL cavity BPM pick-up consists of two cavities, reference cavity and XY cavity. The reference cavity uses TM_{010} mode, monopole mode, of pill box cavity. The amplitude of TM_{010} mode is proportional to the electron beam charge. By using this property of monopole mode, the reference cavity can measure the bunch charge, and this reference cavity signal is used to normalize the amplitude of XY cavity signal. On the other hand, the XY cavity uses TM_{110} mode, dipole mode, of pill box cavity. The amplitude TM_{110} mode is proportional to the bunch charge and offset of electron beam. Thus, the XY cavity can measure beam position by using excited dipole mode of XY cavity and reference cavity signal.

Figure 1 shows the inner structure modeling result of PAL-XFEL cavity BPM pick-up. Reference cavity is designed as simple structure, for easy fabrication. In case of XY cavity, the dipole mode selective coupler for suppressing the monopole mode signal of XY cavity. This dipole mode selective coupler structure was proposed and adopted for LCLS cavity BPM pick-ups [3,4]. Each SMA feed through is installed on the second waveguide of XY cavity. This second waveguide was adopted to minimize the brazing effect on the pill box part of XY cavity.

Table 1 shows the RF parameters of PAL-XFEL cavity BPM pick-up. The RF parameters of each cavity were calculated by using CST Microwave Studio module [5]. Both cavities were designed as high Q value and over coupled structure. Also, R/Q value of each cavity, one of factor de-

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Table 1: Simulation Results of PAL-XFEL Cavity BPM Pick-up Properties

	Reference Cavity	XY Cavity
Frequency [GHz]	11.424	11.424
Q_L	2290	2544
Q_{ext}	3470	3882
β	1.94	1.90
R/Q	114.13 Ω	3.77 Ω/mm^2

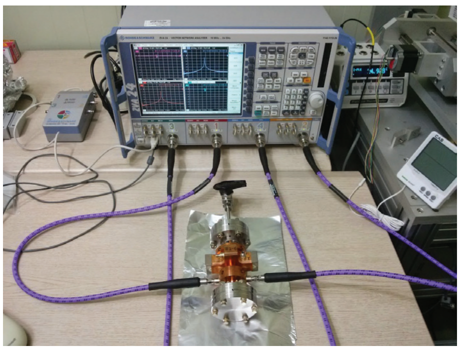

Figure 2: Fabricated prototype cavity BPM pick-up.

ciding the output signal amplitude, is enough to meet the high resolution of cavity BPM system.

CAVITY BPM PICK-UP FABRICATION AND MEASUREMENT RESULTS

The prototypes of cavity BPM pick-up were fabricated to test RF parameters of pick-up. Also, usual commercial SMA feed through does not support X-band region. Due to this reason, the SMA feed through was designed and fabricated for X-band cavity BPM pick-up. The prototype of PAL-XFEL cavity BPM pick-up was fabricated by using these SMA feed through

Table 2 and Table 3 show the measured result of one of prototype cavity BPM pick-up. To measure the RF parameters of each port, the vector network analyzer was used. In case of reference cavity, the simulation and measured value of Q-factors have difference. At first fabrication test, the Q_L factor of reference cavity was decreased after brazing process, lower than 2000. Due to close distance between pill box cavity and brazing point of feed through comparing with XY cavity, the reference cavity structure was highly sensitive to the brazing process error. To decrease the brazing process effect on the quality factor, the brazing points and dimension of reference cavity were modified and Table 2 shows the

Table 2: RF Parameters of Prototype Cavity BPM #02 – 06 Reference Cavity Measurement Result

	f[GHz]	β	Q_L	Q_{ext}
Port1	11.424	2.241	2876.61	4160.52
Port2	11.424	2.534	2887.96	4027.74

Table 3: RF Parameters of Prototype Cavity BPM #02 – 06 XY Cavity Measurement Result

	f[GHz]	β	Q_L	Q_{ext}
Port1	11.4242	2.394	2534.01	3592.54
Port2	11.4242	2.020	2532.51	3786.17
Port3	11.4242	1.934	2525.06	3830.41
Port4	11.4242	2.291	2526.84	3629.78

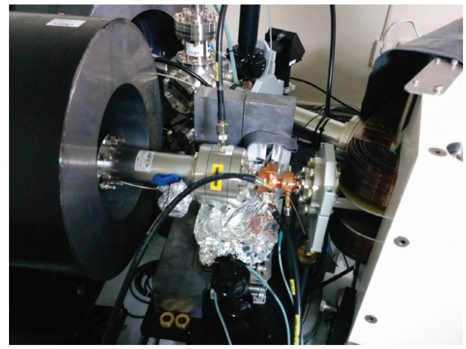

Figure 3: Installed prototype cavity BPM pick-up at ITF dump section.

modified version result. On the other hand, the XY cavity measurement result is quite similar to simulation result.

BEAM TEST AT ITF

After measuring RF parameters, the prototype cavity BPM pick-up was installed in the beam line of Injector Test Facility (ITF) at PAL. ITF can provide 200 pC electron beam [6] to the prototype cavity BPM pick-up, and by using this electron beam, the output signal properties of pick-up can be measured. The cavity BPM pick-up was installed at the dump section of ITF due to small diameter beam pipe of cavity BPM pick-up, as 9 mm. Three coaxial cables, RF signal amplifier and oscilloscope were used for monitoring response of XY cavity and reference cavity.

Figure 4 shows the y-direction port signal of XY cavity BPM under the 200 pC electron beam condition. However, due to sampling rate of oscilloscope, the 11.424 GHz output port signal was down-converted as 200 MHz. The measured

Figure 4: Raw signal of cavity BPM pick-up y-direction port. This output signal was down converted as 200 MHz and measured by using oscilloscope.

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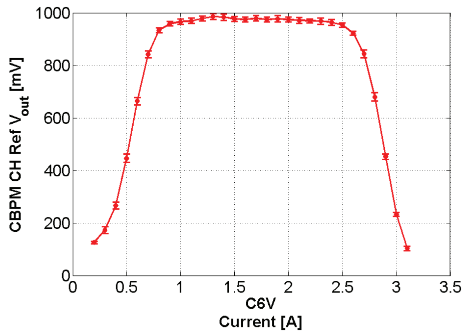

Figure 5: Reference cavity output voltage response to corrector C6V.

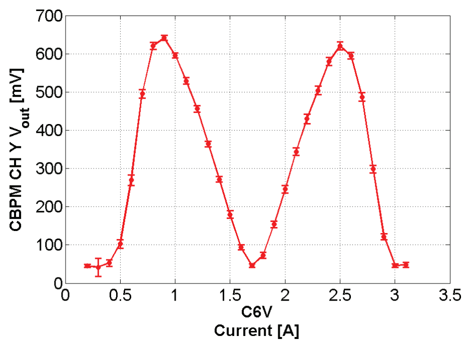

Figure 6: XY cavity *y*-direction output voltage response to corrector C6V.

decaying time of *y*-direction port signal was 30 ns. Comparing with the calculated decaying time of XY cavity, 35 ns calculated based on the measurement result by using network analyzer, the down-converted signal also gives similar values.

After measuring the raw signal of each port, dynamic range of cavity BPM pick-up was measured by using corrector magnet of ITF. However, there are no corrector magnets near the ITF dump section to scan precisely. Also, there was installation space limitation, the cavity BPM could not installed with its own support system. Due to these reasons, the linearity scan of pick-up could not be done within the interest region, ±1 mm. Instead, the dynamic range of cavity BPM pick-up was measured over than ±4 mm.

For the dynamic range measurement, the frequency mixer, oscilloscope and RF power detector were used. Due to the trigger problem of frequency mixer, the measurement by using oscilloscope was unstable. For stable pick-up signal measurement, RF power detector was used during the data acquisition. On the other hand, the beam offset at the cavity BPM was changed by using Cor6 corrector magnet. Also, two stripline BPMs are used to monitor the beam position. Considering distance between two stripline BPMs and cavity BPM pick-up, estimated beam offset change of the cavity BPM is 4.594 mm for Cor6 MPS 1 A current change. As shown Fig. 5 and Fig. 6, the cavity BPM pick-up response to Cor6 current change is similar to the monopole and dipole mode electric field distribution. For the reference cavity, the response of cavity BPM pick-up is almost constant and its amplitude does not depend on the beam offset change. On the other hand, the XY cavity, near the center, the *y*-direction port shows a good linearity to the beam offset change. However, the minimum output signal of the XY cavity is not zero for both ports. This non-zero value can be caused from the angle of the beam trajectory. On the other hand, the response of the cavity BPM pick-up is taken to 2.5 A current change of Cor6 MPS. This can be calculated as ~ 11 mm at the cavity BPM position. This value is bigger than the beam pipe of the cavity BPM. Thus, decreasing *y*-direction port signal at both end side of scan could be caused from the beam charge loss. Also, maximum reference cavity port signal is maintained for 1.7 A current change of Cor6 MPS current. This current change can be converted to ~ 7.8 mm beam offset changing. By considering the error of calculation and the beam size at the dump section, the dynamic range of this cavity BPM pick-up will be ~ ±4 mm. However, by using this beam test, the output voltage change ratio within ±10 µm region cannot be measured with high precision.

RESULTS

The prototype PAL-XFEL cavity BPM pick-up was designed and fabricated to test the performance of X-band cavity BPM pick-up. After fabrication, the resonance frequency and Q-factors of cavity BPM pick-up were measured. In case of XY cavity, the measurement results shows good agreement with simulation results. Also, the prototype cavity BPM pick-up was installed in the beam line of ITF to measure the raw signal properties and dynamic range of cavity BPM pick-up. The measured decaying time of XY cavity signal was 30 ns and the dynamic range was ~ ±4 mm. These value show good agreement with simulation results and Q-factor measurement results.

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