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DEVELOPMENT OF 8 STRIPLINE BPM FOR MEASUREMENT OF MOMENTUM SPREAD OF ELECTRON BEAM AT INJECTOR TEST FACILITY OF POHANG ACCELERATOR LABORATORY

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Abstract

A stripline beam position monitor has been developed with 8 feedthroughs in order to nondestructively measure the momentum spread of beam. The beam momentum spread causes the variation of transverse beam width at a dispersive section and can be detected by the multipole moment based analysis of the beam-induced electromagnetic field. The feasibility of such a device will be tested with electron beam generated in the beamline of Injector Test Facility (ITF) at Pohang Accelerator Laboratory (PAL). The experimental preparation with electron beam test will be presented and the future plan for an application to bunch compressors at X-ray Free Electron Laser (XFEL) of PAL will be followed.

INTRODUCTION

A beam position monitor was proved that it enables to nondestructively measure an energy spread of an electron beam with multi-striplines by T. Suwada *et al.* [1]. At a dispersive section such as a bending point with dipole magnet, the transverse beam width is varied in the bending plane depending on a momentum spread of beam so that the quadrupole moment becomes non-negligible in the transverse plane. R. H. Miller demonstrated the beam position monitor can be used to measure the quadrupole moment [2].

The 8-stripline BPM has been developed to nondestructively control the momentum spread of electron beam for X-ray Free Electron Laser at Pohang Accelerator Laboratory (PAL-XFEL). The stiplines were designed to match the characteristic impedance as 50 Ω following [3, 4]. It is tested with a conducting wire and thin Cu sheet for the resolution to quadrupole moment before the electron beam test.

Beam dynamics simulations were also performed to predict the relation between the quadrupole moment and momentum spread of PAL-XFEL electron beam with the `ELEGANT` [5].

The deivce is implemented for the electron beam test at the Injector Test Facility (ITF) of PAL [6]. The PAL-ITF consists of a photocathode RF gun, a booster cavity (accelerates up to 70 MeV), dipole and quadrupole magnets within about 10 meter space [7].

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MOMENTUM SPREAD AND MULTIPOLE MOMENT ANALYSIS

When the particle beam travels at a dispersive section such as a dipole magnet, the path length of particles differ with its longitudinal momentum so that the transverse distribution will be changed at the exit. For example, if a particle is bent in the horizontal plane (x), the particle position will be changed as

$$x_f = x_i + D_x\left(\Delta P_x / P_0\right). \tag{1}$$

with x_i, x_f for the initial and final horizontal positions. D_x is the dispersion function at dispersive section and $(\Delta P/P_0)$ is the fraction of momentum deviation to the total momentum, P_0.

The difference of squared RMS beam size defines a quadrupole moment and it can be written as

$$\sigma_x^2 - \sigma_y^2 = \beta_x\epsilon_x - \beta_y\epsilon_y + D_x^2\langle(\Delta P/P_0)^2\rangle. \tag{2}$$

where $\left(\sigma_x^2 - \sigma_y^2\right)$ in the L.H.S is the quadrupole moment. In the R.H.S, the β_x, β_y are the beta functions in x and y direction. ϵ_x, ϵ_y are the RMS emittances in x and y directions, respectively, and $\langle(\Delta P/P_0)^2\rangle$ is the RMS momentum spread.

The RMS momentum spread can be figured out by the measurement of quadrupole moment defined as above nondestructively with the stripline monitor.

Multipole Moment Analysis

A charged particle beam induces an image current on a surface of surrounding conducting chamber and the image current density is described by the series representation as below

$$\begin{aligned} J \;=\; & \frac{I_{\text{beam}}}{2\pi r}\left[1 + \frac{2\rho}{r}\cos(\theta-\phi)\right. \\ & \left. + \; \frac{2\rho^2}{r^2}\cos(2\theta-2\phi) + 2\frac{\sigma_x^2-\sigma_y^2}{r^2}\cos(2\theta+2\alpha)\right]. \end{aligned} \tag{3}$$

In the Eq.(3), the (r, θ) and (ρ, ϕ) represent the position of electrode and beam centroid, respectively, and the I_0 is the beam current and α is the skew angle of transverse beam distribution.

Thus, the quadrupole moment will be reconstructed from the measurement with multiple striplines (in this proceeding,

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8 were used), even though the quadrupole moment contributes very weakly to the total signal as it is inversely proportional to the square of the radius of chamber.

PARTICLE SIMULATION FOR RECONSTRUCTION OF QUADRUPOLE MOMENT

It is demonstrated in the particle simulation with the beam dynamics code `ELEGANT` [5] that there is a the feasibility of reconstructing the momentum spread from the quadrupole moment. The simulation aims to reconstruct the momentum spread at the bunch compressor of PAL-XFEL which consists of 4 dipole magnets as a chiance structure. In the bunch compressor, the transverse beam distribution is expected to be manipulated as the Fig. 1 in which the quadrupole moment is large because of the momentum spread.

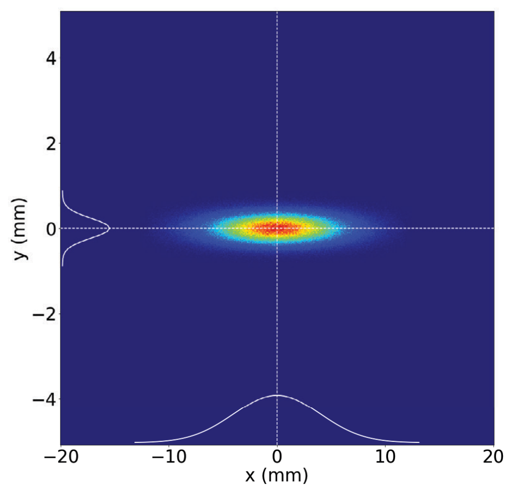


Figure 1: Transverse beam distribution after dispersive section.

In the simulation result (Fig. 2), it is expected that the multipole moment analysis enables to measure the momentum spread of around 0.2 ~ 0.4% for 200 pC electron beam of PAL-XFEL since the quadrupole moment is around a few squared milli-meter level.

FABRICATION AND BENCH TEST OF 8-STRIPLINE BPM

Design of Stripline BPM

Following P. Forck [4], the mechanical dimension of stripline is optimized to match the characteristic impedance to 50 Ω. In order to comply with the beamline dimension of PAL-XFEL, the structure is fabricated as the Fig. 3 with the dimensions as listed below and the design work is carried out with the `Computer Simulation Technology Particle Studio` (CST PS).

- Chamber diameter: 22 mm
- Stripline radius: 19 mm
- Opening angle of stripline: 23°
- Stripline thickness: 1 mm

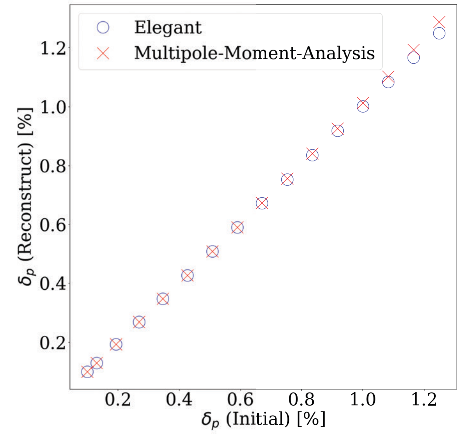
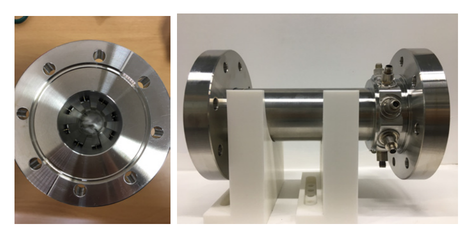


Figure 2: Momentum spread determined from quadrupole moment.

- Stripline length: 120 mm
- End-to-end length: 180 mm



(a) (b)

Figure 3: Fabricated prototype BPM.

Time Domain Reflectometry

After the fabrication, it is tested with the time domain reflectometry to characterize the impedance of striplines. The results in the Fig. 4 show that the electrodes are designed to well match the characteristic impedance to 50 Ω with slight discrepancies.

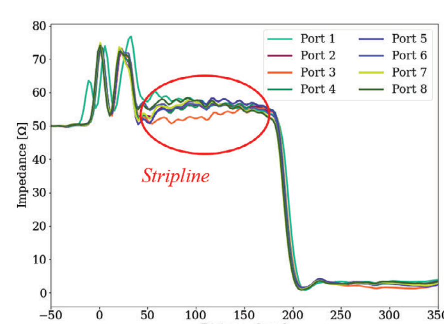


Figure 4: Result of Time Domain Reflectometry.

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Bench Test

The stripline BPM is inserted by a conducting wire or a thin Cu sheet. Then, a pulsed signal is sent from the signal generator and the output data is transferred to the digital oscilloscope Fig. 5.

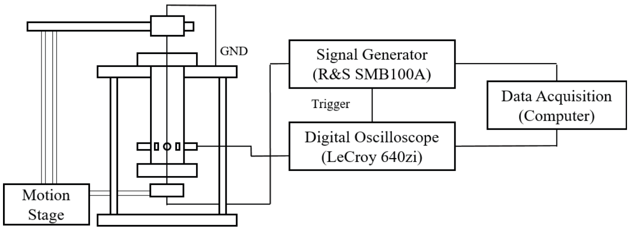
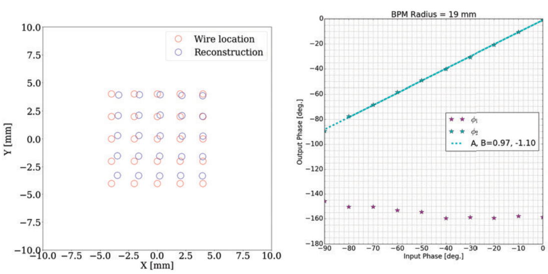


Figure 5: Schematic diagram of test stand.

Using the wire or Cu sheet, the device has been tested for the resolution of centroid position and skew angle. As a result, the resolutions were achieved as 1 milli-meter and 1 degree as shown in the Fig. 6. It will be further tested with electron beam at the Injector Test Facility of PAL, which provides 70 MeV electrons via an RF photocathode gun and an S-band cavity.



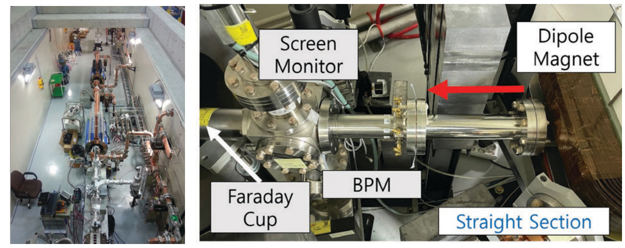
(a) Position (b) Skew angle

Figure 6: Resolution results of bench test.

Injector Test Facility of PAL

Figure 7 shows the ITF beamline where the RF photocathode gun is found in the bottom.

The RF photocathode gun is developed with 1.6 cell 2.856 GHz cavity. The electrons are emitted at the wall of gun first cell with a laser pulse driven by Ti:Sapphire laser system. After emitted from the cathode, the electrons are accelerated up to 70 MeV through a traveling wave structure for which the klystron and modulator provide an RF power [7]. The magnets and various instruments are followed by the accelerating cavity, for instance, the dipole and quadrupole magnets. Transverse deflecting cavity and many diagnostic systems are installed.



(a) (b)

Figure 7: PAL-ITF beamline.

The 8-stripline BPM is implemented at the behind of dipole magnet in the end of beamline as shown in Fig. 7(b). The electron beam will be measured with the stripline BPM and screen monitor, and dumped at the Faraday cup after controlled by the dipole and quadrupole magnets and the accelerating cavity.

CONCLUSION AND FUTURE PLAN

The stipline BPM has been developed with 8 feedthroughs in order to non-destructively measure the momentum spread of electron beam at PAL-XFEL. Following the particle simulation with the `ELEGANT`, it is shown that it can be applicable for the electron beam of PAL-XFEL with the resolution of 0.2 ~ 0.4% for the RMS momentum spread. After it was tested with the conducting wire and Cu sheet, it has been installed at the beamline of PAL-ITF for the further electron beam test.

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