BEAM DIAGNOSTICS

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INTRODUCTION

In order to operate an accelerator, it is necessary to be able to accurately measure and control various physical characteristics such as the position, size, energy, amount of charge, and temporal characteristics of the electron beam. To this end, PAL uses various diagnostic tools, each of which has a specialized method and structure for the purpose of measurement. In this paper, some representative diagnostic devices and their principles will be described in detail.

BEAM POSITION MONITOR

Beam Position Monitor(BPM) is a device that measures the position of a beam by detecting an electromagnetic field when an electron beam passes through metal electrodes. In general, electrodes are arranged around an electron beam, and a voltage is generated in each electrode due to the electric charge induced by the beam.

Shoe Box BPM

The Shoe Box BPM has a square-shaped structure, and the decoupling in the vertical and horizontal directions is very good, so the linearity of the location is excellent. This structure minimizes horizontal/vertical coupling and enables very accurate positioning even with a simple structure. The position of the beam can be calculated quantitatively.

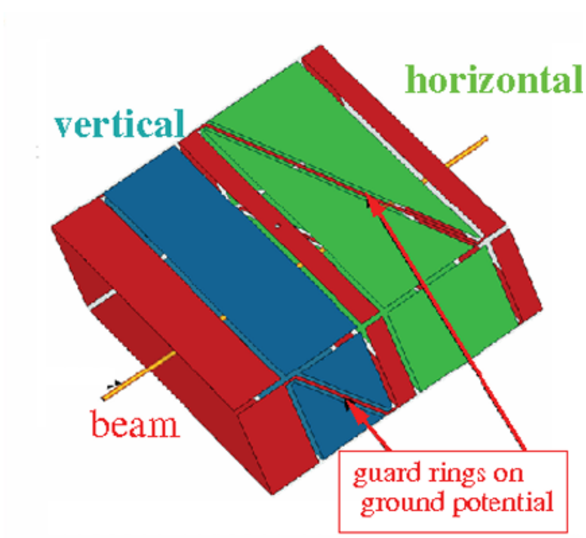

Figure 1: Shoe Box BPM

$$x = a\frac{R-L}{R+L} \tag{1}$$

Here, R and L are the voltages measured at the right and left electrodes, a is the size of the Shoe Box BPM, and x is the degree of deviation form the center. The vertical position can also be calculated using this logic. However, if the bunch length is shorter than the device length, it may be difficult to accurately measure the position. Therefore, the bunch length condition must be checked when in use. Bandwidth operates in the range of 0.1 MHz to 100MHz.

Stripline BPM

The stripline BPM is a device that measures the position of a beam by striplines. Four striplines are symmetrically arranged around the electron beam. The length of the stripline is an important factor in determining the bandwidth of the device. Longer striplines can obtain stronger signals, but this does not necessarily lead to good position resolution. The actual resolution depends more on the noise characteristics of the system and the signal processing method.

Button BPM

The Button BPM structure is simpler than stripline BPM and has a shorter electrode in the shape of a disk. It is suitable for systems with very short signal pulses and very short bunch intervals, such as storage rings. It does not form standing waves like stripline BPM and is effective in measuring beams at high repetition rates.

Cavity BPM

The cavity BPM is a high precision device that measures a position using electromagnetic wave mode generated when a beam passes through the cavity. A specific mode in the resonator, especially dipole mode, is induced in cavity, and the phase and amplitude of this mode react sensitively to the offset of the beam. Using shorter resonant wavelengths improves the resolution in position measurements.

Photon BPM

The photon beam undergoes propagation only and does not emit or carry a surrounding electromagnetic field like charged particle beams do. Therefore, a current is generated by inducing a photoelectric effect by incidenting a photon beam into a specific device. The position can be calculated by comparing the magnitude of the generated current, and these deivce are used as important monitoring tools in the beamline.

WIRE TEST BPM

The BPM should be evaluated for linearity, sensitivity, resolution, and horizontal/vertical decoupling performance before being installed in the accelerator.

The wire test is a method that can verify the performance of BPM without an electron beam. Instead of electron beam, a thin metal wire which RF current flows simulates the accelerator system. When a RF current flows through this

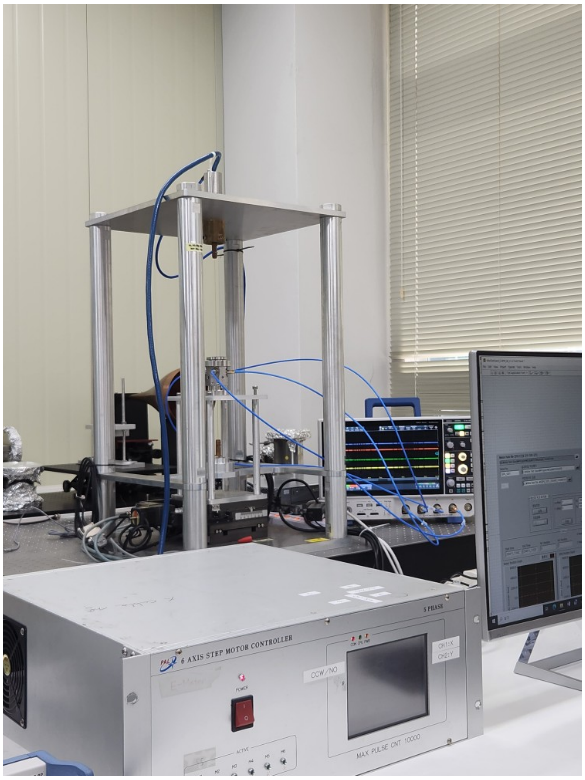

Figure 2: Wire Test stand: A thin wire with a diameter of several hundred μm or less is installed in the center of cavity. By supplying a high frequency signal to the wire, an electromagnetic field induced in an actual beam is implemented. It makes it possible to move the position fo the wire precisely.

wire, an electromagnetic field is generated around it, and the electrodes of the BPM can detect this electromagnetic field and measure the position of the wire. The wire can be moved in a horizontal or vertical direction using a high precision motor system, and the relationship between the actual travel distance(motor position) and the position value output by the BPM can be compared to evaluate the linearity and horizontal/vertical coupling performance of the BPM.

BUNCH LENGTH MEASURE

The bunch length of an electron beam generally has a very short time structure ranging from tens to hundreds of femtoseconds, and in order to measure this, a device with a time resolution of less than picoseconds is required. In general, since the time resolution is not good, the time information is back-calculated after securing spatial information by manipulating the beam.

Transverse RF Deflecting Cavity

Transverse RF deflecting cavity(TDC) operates similarly to general acceleration cavity, but uses vertical or horizontal electromagnetic mode instead of acceleration direction. This modes is one of the eigenmodes determined by the cavity shape, and the beam is bent when the electron beam passes through the TDC.

Streak Camera

Bunch length can be analyzed through the photon beam generated by the electron beam. In the diagnostic beamline, one radiation light is divided into two paths through the beam splitter, one to the stretch camera and the other to another optical device such as an interferometer. A sweep

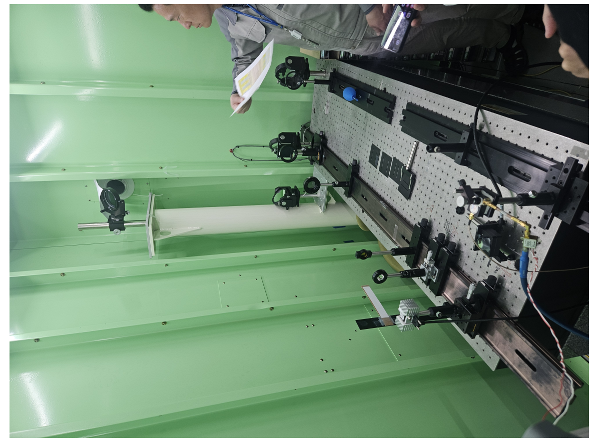

Figure 3: Diagnostic beam line

electrode is mounted inside the stretch camera, and when a photon reaches a photo-cathode inside the camera, it is converted into electrons. These electrons move in a vertical direction over time by the sweep voltage, and are observed by converting time information into a spatial information as they finally enter the screen.

BEAM SIZE MONITOR, INTERFEROMETRY

The size of the beam may be measured by applying the interference technique of visible light among the emitted light. This is based on a concept similar to that of an optical double slit interference experiment.

In the case of a completely coherent point source (point source), the double slit interference pattern has a sharp maximum and minimum, but if the light source is spatially extended, the contrast of the interference pattern decreases and the local minimum does not reach 0. Using these characteristics, the size of the light source(electron beam) can be estimated.

The light passes through the slit and causes interference. It is designed to focus through the lens placed thereafter and reach the CCD camera. The beam size can be calculated by fitting the observed interference pattern through the equation below while changing the slit.

$$I = I_0 [\frac{sin(u)}{u}]^2 [1 + |\frac{2J_1(v)}{v}| cos(\delta)] \tag{2}$$

$$u = \frac{kax}{R}, \quad v = \frac{k\xi d}{L}, \quad \delta = \frac{kdx}{R}$$

k : Wavenumber

a : Aperture size of the slit

ξ : Source size

d : Distance between slit and screen

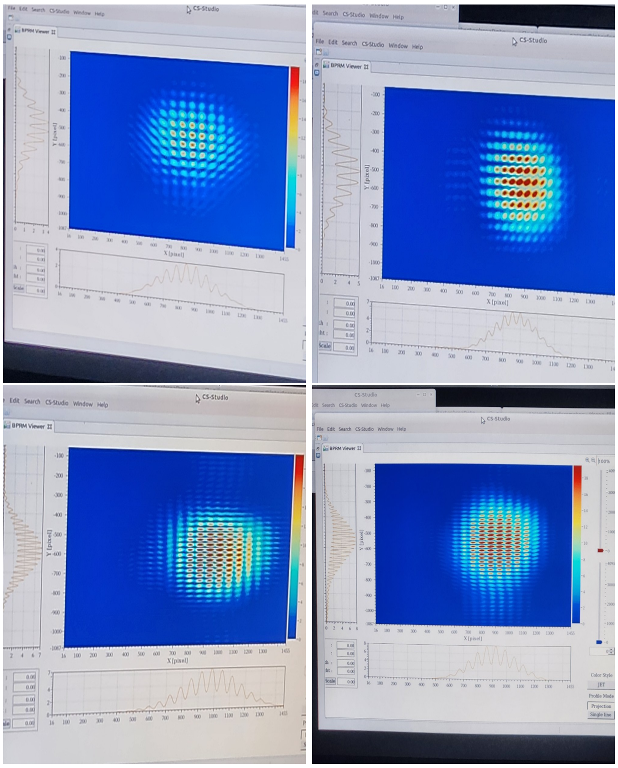

Figure 4: Photon beam from CCD camera throught the 15mmX18mm, 15mmX22mm, 15mmX35mm, 15mmX40mm slit

CONCLUSION

Accurate beam diagnostics are essential for the reliable operation, control, and optimization of accelerator systems. In this report, we reviewed various diagnostic techniques. Advanced optical diagnostics, including interferometers and streak cameras, further enable femtosecond-level temporal resolution and nanometer-scale spatial measurements, which are critical for characterizing ultrafast electron bunches and X-ray pulses. The integration of diagnostic beamlines also allows non-invasive, high-precision measurement of photon properties.

REFERENCES

[1] Changbeom Kim, *Lecture Notes on NUCE719P*, DIVISION OF ADVANCED NUCLEAR ENGINEERING, POSTECH, PowerPoint presentation, 2025.