

SUBMICRON BEAM POSITION MONITORS FOR JAPAN LINEAR COLLIDER

H. Hayano and T. Shintake
 National Laboratory for High Energy Physics
 Oho 1-1, Tsukuba, Ibaraki 305 Japan

Abstract

A beam position monitor (BPM) for Japan Linear Collider (JLC) is required to have around $1\mu\text{m}$ resolution for injector linac, damping ring, bunch compressor and main linac, and to have around 10nm resolution for final focus line. The development study of such a high resolution BPM has been started. A strip line type pickup and a one-shot conversion electronics using pulse stretcher are employed for $1\mu\text{m}$ resolution BPM. The electronics shows $0.35\mu\text{m}$ resolution for multi bunch and $0.7\mu\text{m}$ for single bunch signal. The bench test using simulated beam pulse on a moving wire confirmed that it has at least $2.5\mu\text{m}$ resolution. For around 10nm resolution, a microwave cavity is proposed as a pickup because of its high induced voltage. The design and prototype cavity are described.

Introduction

The transverse position measurement is required for more than 20 multi-bunched beam which has 2×10^{10} electrons in a micro bunch with 2.8ns spacing in JLC. A 2×10^{10} single bunch beam should also include of consideration for a possible operation. The required BPMs can be considered of two categories by its resolution. One should have several μm resolution within $500\mu\text{m}$ from center during optics tuning and have measurement range of few mm. The other is a BPM with several nm resolution for few ten μm region of center. The candidates for those BPMs are a strip line BPM for the former and microwave cavity BPM for the latter. The strip line BPM system, which is an extension of SLAC FFTB's[1], is designed to meet the requirement for multi-bunch beam. The cavity BPMs were developed and studied by several people[2,3]. We reconsider it as a high resolution pickup.

Strip Line Monitor

Pickup and Signal Processing Scheme

Figure 1 shows a pickup chamber and signal processing

electronics diagram. Strip lines were selected as a pickup for their enhanced low frequency response which is almost proportional to the strip line length. After some compromise with electronics speed, 80mm was chosen for its length. One end of the strips is shorted to the chamber wall. The aperture $\phi 30\text{mm}$ was determined to have a beam stay clearance greater than that of accelerator structures. The electrode transverse dimensions were determined with the code "POISSON" to present a 50Ω characteristic impedance.

The strip line pulses are 0.5ns apart which corresponds to twice the length of the strip line. Since the bunch length is a few millimeters, we can treat the induced signal as impulses. The expected signal wave form is calculated by an approximation formula[4] which estimates an impulse response for long dispersive cables. The impulse areas are estimated using the charge in the bunch and the beam coupling coefficient to the pickup electrode. A geometrical coupling coefficient 0.167 is used.

The processing electronics has two identical channels for two pickup electrodes and detects signals by Track&Hold (T&H) circuits. The electronics for two electrodes which measure one direction consists of a pulse stretcher amplifier (called Head Amp), T&H, digitization (NiTNH) and a pulse generator for electronics calibration (TPG). The signals through the long cables are fed into the Head Amp, then amplified and stretched by gaussian low pass filters to get wider pulses with good signal to noise ratio (S/N). In our case, we have to treat both of multi-bunch and single bunch. The multi-bunch signal has an enhancement of low frequency components. It comes from the frequency components of the train width. The elimination of the amplifier gain is required for that. The AM-147 which is the first stage amplifier is skipped for the multi-bunch case. It introduces 17dB gain reduction in Head Amp and 2 times S/N enhancement. The outputs of the Head Amp are connected to the input of the NiTNH by matched RG-223/u cables. Inside the NiTNH, the trigger signal is generated from its input. The input signals are tracked and held at their first extreme by the self-generated trigger. After holding, they are digitized by 16-bit ADCs and latched until the read operation is

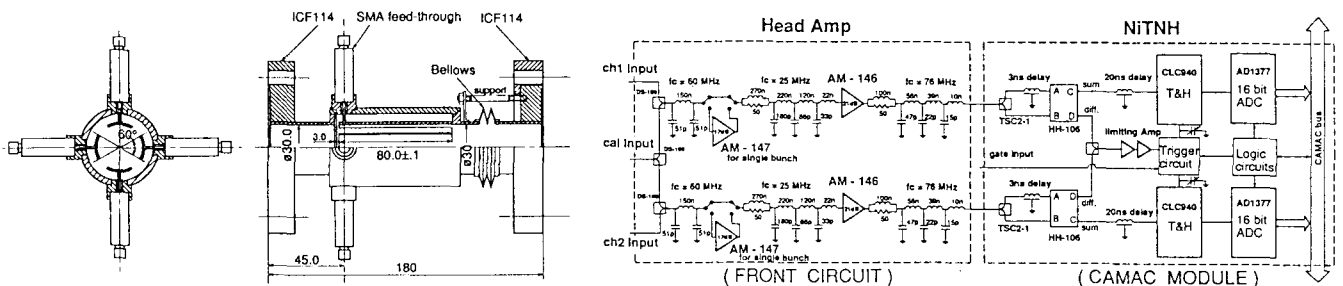


Figure 1 The strip line pickup and the block diagram of the electronics.

completed. To remove the electronics offset, pedestal levels are measured in advance during calibration and subtracted from the readings.

A beam position will be calculated by

$$X = k * \frac{V2 - Gx*V4}{V2 + Gx*V4}$$

$$Y = k * \frac{V1 - Gy*V3}{V1 + Gy*V3},$$

where k is geometrical coefficient and Gx and Gy are the gain ratios $V2c/V4c$ and $V1c/V3c$ respectively between two channels, which are obtained by calibration in advance.

For high resolution electronics, the thermal noise in the signal had to be reduced. For high precision, the electronics was required to have good linearity within a dynamic range for off-centered beam. The design effort was made on the noise reduction, linearity of circuit and position offset, and it was described elsewhere[1].

Performance of the Electronics

We now have a prototype stripline pickup, a Head Amp and a NiTNH. The electronics test was carried out by using a HP pulser. The input signal which simulated only a single bunch was split into both channels as a centered beam. The position calculation is done by;

$$X = k * \frac{V2 - V4}{V2 + V4},$$

where V2 and V4 were pedestal subtracted, conversion coefficient $k=7854 \mu\text{m}$ was used. The test for multi-bunch circuit scheme was done by much higher amplitude than that of single bunch pulse. In order to estimate a resolution, we made 50 position measurements during each signal amplitude and took the standard deviation as a resolution. Figure 2 shows the result of the resolution measurements. The resolution plot was rearranged by estimated signal level for 50m length of cables, and plotted as a function of estimated equivalent beam charge. We can obtain about $0.7\mu\text{m}$ resolution for 2×10^{10} single bunch beam and $0.35\mu\text{m}$ for multi bunch.

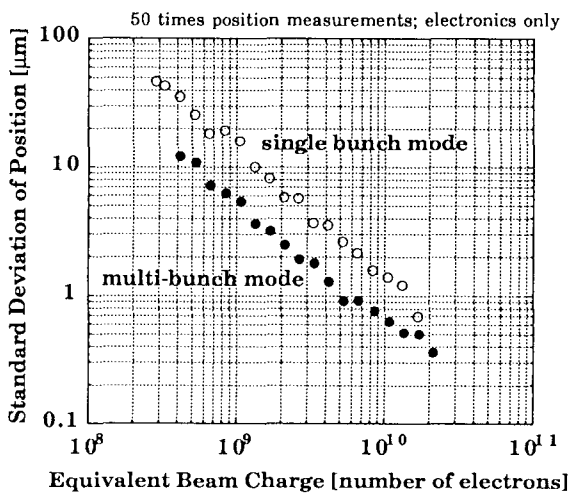


Figure 2 Measured resolution of the electronics for 50m RG-223/u, single bunch and 20 bunch train.

The resolution demonstration using a $\phi 50\mu\text{m}$ wire mover was performed at the test stand. The mover has a

$0.1\mu\text{m}$ precision and repeatability. The test pulse on the wire was fed using a fast and high voltage pulser of 400ps width and 450V amplitude. Figure 3 shows a detected wire position calculated using measured conversion coefficient as a function of the mover position with $2.5 \mu\text{m}$ step. Though the signal amplitude was not enough to get high resolution because of miss-match into the thin wire, a wire movement could be easily distinguishable in case of $2.5\mu\text{m}$ resolution.

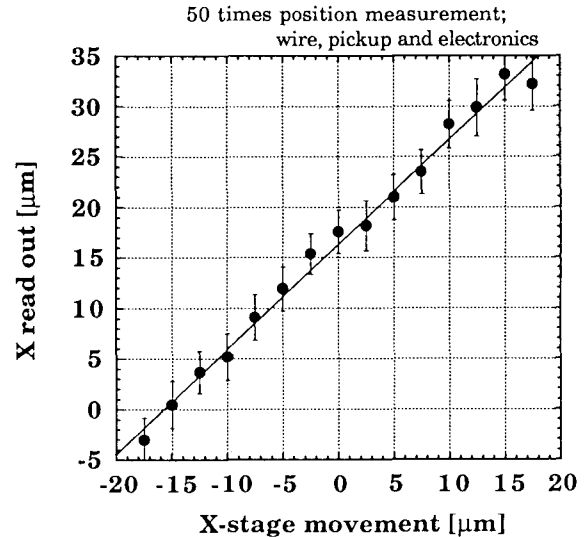


Figure 3 Measured wire position by the pickup.

Microwave Cavity BPM

Overview of cavity BPM

Differently from a case of two opposed electrodes which have to subtract one signal from another for position detection, the TM₁₁₀ resonant mode in a cylindrical cavity automatically does such a subtraction. The amplitude of excited oscillation is almost proportional to the distance from a nodal point within a central region. If a beam impulse current is quite large and its width is enough short, the amplitude of TM₁₁₀ excitation is so large that we can resolve very small beam movement. The key point of high resolution position detection is to draw a damped oscillation out from the cavity with low loss as possible as we can. In order to couple the mode to external load strongly, we introduced two coupling slots on the wall of the sensor cavity. Two slots on the one side of wall are for x direction, and the other with 90 degrees rotation are for y direction. The slots are located 90 degrees rotation from the E field maxima couple into external by the H field with opposite phase each other. The next cavity of thin coaxial shape placed on the outer side of the sensor cavity is coupled by the two slots. This cavity works as a resonant wave guide excited by the two coupling slots with 180 degrees opposite phase. Since the fields excited with the same phase on the two slots cancel out in that cavity, it works as a common mode rejection cavity at that frequency, also works as a band pass filter. The signal comes out from the common mode rejection (CMR) cavity

is then drawn into a rectangular wave guide and band pass filter, then into coaxial cable. The common mode rejection is necessary because that it is detected as a background signal which does not depend on the beam position. If there is a common mode leakage into the TM110 difference mode position signal, the node point will be shifted and the detected position will walk around independent with the beam position. The design details will be described elsewhere[5].

Expected signal amplitude and resolution

The frequency of TM110 mode in the sensor cavity was chosen to 6426MHz which is 18th harmonic of bunch spacing frequency. It is also chosen apart from the harmonics of accelerating frequency 2856MHz in order to avoid interferences with leakage fields of an accelerating rf power and parasitic excitations by a dark current. The peak excitation amplitude V_c of TM110 in a pillbox cavity (radius $b=27\text{mm}$, height $h=10\text{mm}$) can be estimated by using impulse excitation on a equivalent circuit, that is;

$$V_c = \omega (R/Q) M_b T q_0,$$

where

ω : a TM110 angular frequency,
 R/Q : shunt impedance of TM110,

$$R/Q = \frac{2\zeta h}{\pi b \rho_{11}} (J_1^{\max} / J_1(\rho_{01}))^2 = 28.8\Omega (\zeta=376.7\Omega),$$

M_b : beam coupling coefficient,

$$M_b = \frac{\rho_{11}\Delta}{2bJ_1^{\max}},$$

Δ is the beam position from the center,

T : beam transit time factor,

$$T = \frac{\sin(kh/2)}{kh/2},$$

q_0 : beam charge.

For the nominal charge of 2×10^{10} single bunch, V_c will be 0.42 mV for 1 nm beam displacement. If we can succeed the common mode rejection, the spatial resolution we can get is determined by a thermal noise in a circuitry which will be comparable or smaller than the signal.

Signal Detection Scheme

The TM110 signal comes out from the CMR cavity is rectified by a synchronous detection circuit. The reference signal which is used for synchronous detection is obtained from another pickup. A synchronous detection is necessary to identify a polarity of position displacement. After the rectification, the peak amplitude of the signal is sampled and held, and then digitized. Several filters are used to reject unwanted frequency components. Since the signal is lost due to coupling out to transmission line from the cavity, filtering loss, coaxial cable loss and synchronous detection loss, low noise amplifiers are required to obtain a high signal to noise ratio.

Prototype cavity BPM

Figure 4 shows the prototype BPM cavity for a cold test. It consists of four pieces; two are coaxial cavities for common mode rejection and filtering, one is TM110 sensor cavity which has one end plate with two coupling slots, and the rest is another end plate of sensor cavity. The CMR cavities have coupling windows which couple to rectangular wave guides. The dimension of wave guide is 34.84 mm width by 10 mm height. The width is taken to match with WR-137 in order to use standard components. So the cutoff frequency is 4.29 GHz which cut out lower side of TM010 common mode resonance (4.36 GHz). The frequency of TM110 is measured to 6.38 GHz and Q_L is about 510. The first study was concentrated on the common mode rejection. Though the dimensions of CMR cavity were determined to couple and to resonate 6.4GHz TM110 mode by a differential excitation, it had a common mode resonance in neighbor (6.0GHz and 7.6GHz). So the obtained common mode rejection ratio (CMRR) was -7dB at the target frequency. To obtain high CMRR we tried to use CMR cavity with dual coupling port on both sides and made CM rejection by external anti-phase combiner. In this case, dual port CMR cavity itself had -18dB rejection rate, and total -48dB rejection was obtained with additional external anti-phase combiner. The further study will be going on to get nm resolution.

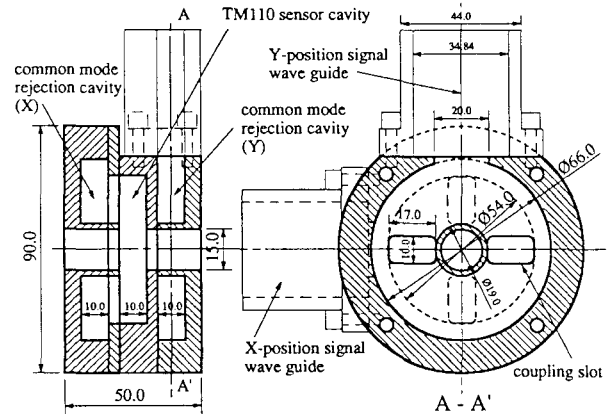


Figure 4 Prototype cavity BPM for cold test.

Acknowledgements

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