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Single-Pass Measurements of Injection-Beam Position at the Photon Factory Storage Ring

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Abstract

A single-pass beam position monitor (BPM) system that monitor injection-beam positions is under development. A signal extracted through a button electrode was detected using a high-speed digitizer. Waveform of the button signal was recorded by real-time sampling. The waveform could be measured with enough sensitivity even for positron beam as well as electron beam. The beam position was determined with a resolution of a few hundred microns.

I. INTRODUCTION

Photon Factory ring (PF ring) is a 2.5 GeV electron / positron storage ring dedicated to a synchrotron radiation source. In 1997, reconstruction for a lower emittance lattice is scheduled. [1] The reduced emittance is achieved by replacement of quadrupoles and sextupoles in FODO cells. The brilliance of synchrotron radiation will be increased by a factor of 10. In the normal-cell sections, vacuum ducts are replaced by new ones, and the number of quadrupole magnets and BPMs are doubled. All electronic components related to COD measurements will be also updated. [2]

In the low-emittance configuration, there is a weak point of a small dynamic aperture. The small aperture would demand a strict correction of the injection beam path. A COD correction in advance of beam storage will be inevitable. So a BPM system to monitor the injection beam is being prepared for the sake of efficient commissioning after the large reconstruction. In following sections, we will report about a single-pass measurements of button signals using a digitizing oscilloscope and results of a preliminary position measurement.

II. MEASUREMENT PROCEDURE

We have installed three BPMs in a beam transfer (BT) line between the injector linac and the ring. A schematic cross section of the BPM is shown in figure 1 (a). It has a circular cross section of 38 mm diameter. Four button electrodes of 10 mm diameter are placed as in the figure. In the storage ring, a vacuum duct has a polygonal cross section. Each BPM of the PF ring has six electrodes of 30 mm diameter. The four electrodes numbered in figure 1 (b) were used in the present measurement. An output voltage of these large buttons is estimated to be a factor of four higher than that of the small buttons in the BT line.

A bunch signal extracted by a button electrode was led to a digitizing oscilloscope through a double screened coaxial cable of 20 m long. The cable had an attenuation factor of 3 dB/10 m at the frequency 1 GHz. The digitizing oscilloscope (Tektronix TDS684A) has four channels with four digitizers. Each channel is a 8-bit digitizer with a maximum sampling rate of $5X10^9$ samples/s and a analog bandwidth of 1 GHz. The signals from four buttons were simultaneously recorded in the four channels by a real-time sampling. A time base for the measurement is a trigger pulse of an injection kicker magnet. A maximum record length was 15,000 for each channel. 10 turns of bunch signals that revolving at a period of 625 ns could be recorded turn by turn with a sampling rate of $2.5x10^9$ /s.

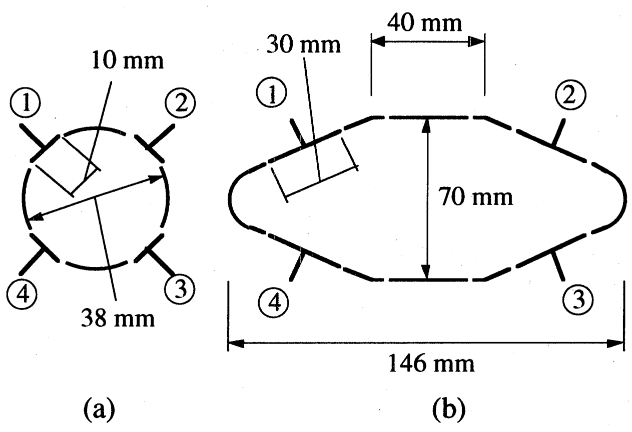


Figure 1. Dimensions of button BPMs installed in the beam transfer line (a) and the storage ring (b).

A beam position is calculated from the peak-height ratios, U and V.

$$U = ((V2+V3)-(V1+V4))/(V1+V2+V3+V4),$$

$$V = ((V1+V2)-(V3+V4))/(V1+V2+V3+V4),$$

where V# means a peak height of the #-th electrode's signal. Because the injection beam position would change with a large amplitude, nonlinear behavior of the ratios has to be taken into account. For the BPM of the storage ring, U and V were computed in a range, 0 mm < X, Y < 16 mm. Figure 2 shows the U vs. V plot. We determine the beam position using following quadratic equations.

$$X\,[mm] = (12.4\,U^2 + 21.8 - 17.7\,V^2)\,U.$$

$$Y\,[mm] = (-79.0\,U^2 + 65.5 + 71.3\,V^2)\,V.$$

These approximations are valid up to 16 mm with an error of about 3%. For the BPM in the BT line, following equations are adopted. These are valid up to 10 mm with an error of 10 %.

$$X\,[mm] = (13.5\,U^2 + 12.4 - 15.0\,V^2)\,U$$

$$Y\,[mm] = (-15.0\,U^2 + 12.4 + 13.5\,V^2)\,V$$

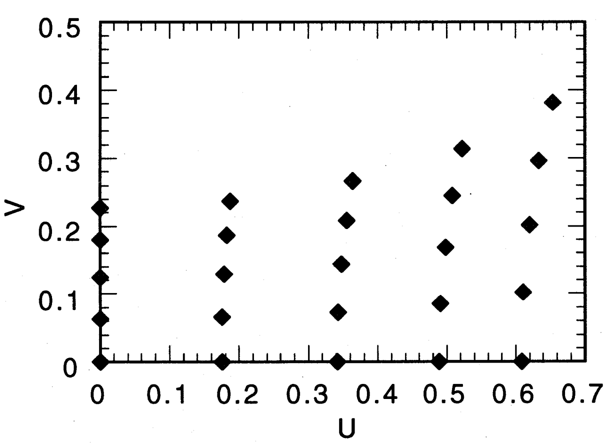
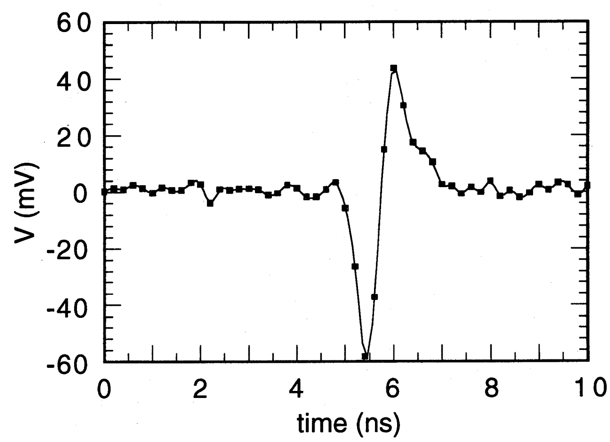


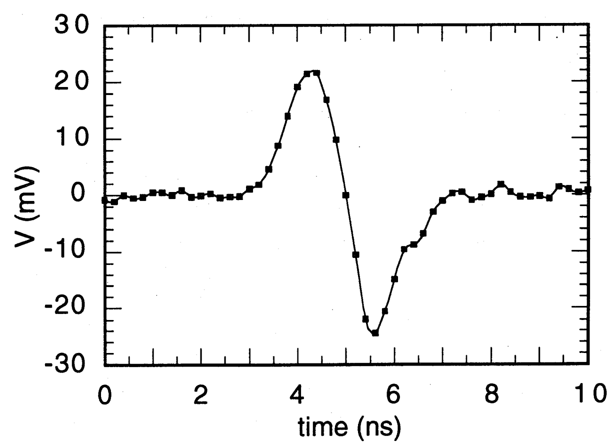
Figure 2. A (U,V) plot for the BPM of the storage ring. Solid squares are plotted by a 4 mm step for a (X,Y) range from 0 mm to 16 mm.

III. MEASUREMENT RESULTS

An injector of the PF ring is a 2.5-GeV linac. Positron or electron beam is available for usual operation. Measured waveforms for electron and positron pulses are shown in figure 3 (a) and (b), respectively. Those were records of the first-turn's signals observed with one button in the storage ring, while RF acceleration system was not powered. Solid squares in the graphs are the sampling points at a rate of $5X10^9$ samples/s, and the solid lines are curves drawn by a 3rd order spline interpolation. Charge per bunch for the electron beam was about $2X10^{-10}$ C, that was estimated from an output of a current transformer in the BT line. Charge of positron beam was an order of magnitude less than that of electron beam. The waveform of the positron bunch was measured with an amplifier of 20 dB gain and 1 GHz bandwidth. The amplifier was located in the neighborhood of the BPM in order to keep a good signal-to-noise ratio. Compared with simulated waveforms of the button signals based on a Gaussian approximation, bunch lengths (standard deviation) of the electron and positron beams were estimated to be about 0.4 ns and 0.7 ns, respectively. For the both injection beams, the present measurement system had a enough sensitivity to deduce peak heights from the button signals.



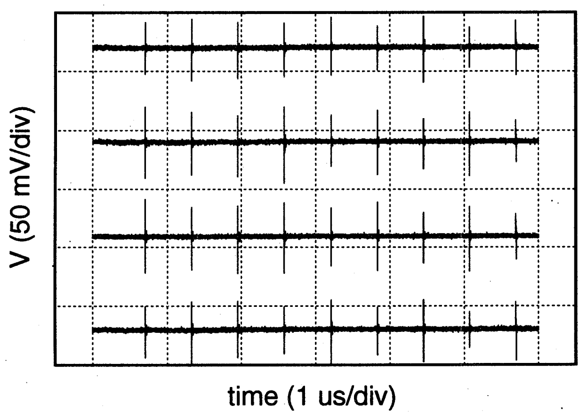
(a)



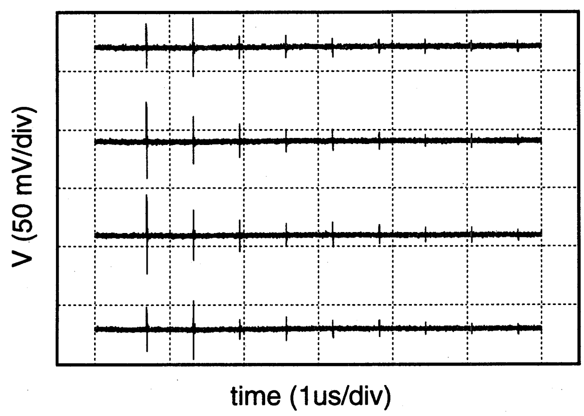
(b)

Figure 3. Measured waveforms for electron (a) and positron (b) injection beam pulses.

Figure 4 is records of revolving injection beams (positron) observed with one BPM in the storage ring. Four lines in a figure were signals of the 4-button electrodes, and they consist of 15000 points at an rate of $2.5x10^9$ samples/s. Nine spike-like peaks at an interval of about 600 ns correspond to the first- to ninth-turn's signals after the injection. Figure 4 (a) was a record measured when all operation conditions of the storage ring were the same as the usual ones except for the RF acceleration system. Beam would be possible to be stored if the RF system is powered. On the other hand, figure 4 (b) was a record measured when an abnormally high octupole fields were applied. At this condition, no more storage was possible because of the very small dynamic aperture. Rapid attenuation of the peak heights were observed in the several turns.



(a)



(b)

Figure 4 The first 9-turn signals from four electrodes of one BPM in the ring measured with usual condition (a) and with abnormally high octupole fields (b).

Beam positions of the first nine turns deduced from the records in the figure 4 (a) were plotted in figure 5. The BPM used in the present measurement was located just upstream the injection point. Numbers beside the solid circles means the data of the N-th turn. The peak heights were determined by interpolated curves for the sampled data, and the approximation equations described above were adopted to the calculation of positions. A horizontal injection bump generated by the kicker magnets had a duration of about 5 us. A timing of the injection pulse was adjusted to the center of the bump duration. The bump would disappear just before the fourth-turn pulse go back to the injection point. It seems that a large horizontal oscillation occurred after the bump disappeared. A resolution of the position measurement was estimated from variations of data in measurements for large number of injection pulses. For the BPM of the ring, the resolution for horizontal and vertical measurements were 0.3 mm and 0.8 mm, respectively. The poor value for the vertical was mainly due to a rectangular arrangement of the four electrodes. It is not the case for the BPM in the BT line that has the same position sensitivity for both directions.

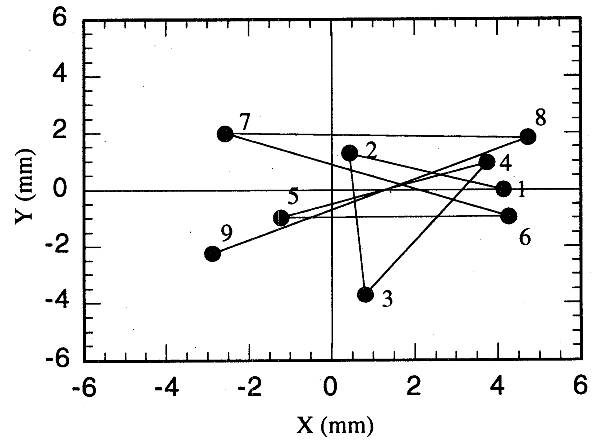


Figure 5. The first 9-turn beam positions deduced from the peaks in the figure 4 (a).

IV. SUMMARY

In the present measurement, it would be confirmed that the button signal of the injection beams could be measured with good sensitivity to determine the beam position. Now, we are going to develop single-pass BPM systems for the BT line and the storage ring on the basis of the present method. When any number of button signals from different BPMs are combined to one channel, the peaks for every buttons can be recorded at the same time. [3] So using a small number of high speed digitizers, the BPM system that extended over the whole ring would be constructed.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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[3] M. Tejima, private communications.