A SINGLE-PASS BEAM POSITION MONITOR FOR THE INJECTION BEAM AT THE PHOTON FACTORY STORAGE RING

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Abstract

A single-pass beam-position monitor (BPM) system to measure the injection-beam positions in the storage ring was developed. Bipolar bunch signals extracted through button electrodes were recorded in real time using a high-speed waveform digitizer, and the beam positions were determined from the amplitudes of the bipolar signals. The beam positions at 8 BPMs were measured at the same time by means of the power combiners. The button signals made discrete pulse trains, and were well resolved on the time axis. The waveform digitizer had a long memory to record the several turns of the bunch signals or the beam positions. The single-pass BPM system was confirmed to have the resolution of a few hundred microns.

1 INTRODUCTION

The Photon Factory ring (PF ring) is a 2.5-GeV electron storage ring dedicated to a synchrotron-radiation source. In 1997, reconstruction to install a lower emittance lattice is scheduled. [1] The reduced emittance is to be achieved by replacing the quadrupoles and sextupoles in the FODO cells. The brilliance of the synchrotron radiation will be increased by a factor of 10. In the normal-cell sections, vacuum ducts are to be replaced by new ones; the number of quadrupole magnets and BPMs will be doubled. In the low-emittance configuration, there is a weak point of a small dynamic aperture. This small aperture would demand a strict correction of the injection beam orbit in the storage ring. Since a COD correction in advance of the beam storage will be inevitable, a BPM system to monitor the injection beams is being prepared for the sake of efficient commissioning after the large reconstruction.

In the following sections we report on the signal processing for the single-pass measurements and some results of the position measurements of the first-turn beam in the storage ring.

2 SIGNAL PROCESSING

The signal processing scheme to obtain the beam position was shown in figure 1. A digitizing oscilloscope (Tektronix TDS684A) was used as a detector for the bunch signals. The oscilloscope has four channels with four analog-to-digital converter (ADC). Each channel is an 8-bit ADC which has a maximum sampling rate of $5X10^9$ samples/s and an analog bandwidth of 1 GHz. The duration of the bipolar bunch signals of the injection beam was 3 or 4 ns, so the sampling rate was fast enough to store the waveform. The signals from the four buttons of one BPM head could be simultaneously recorded in the four channels by real-time sampling. The record length of the

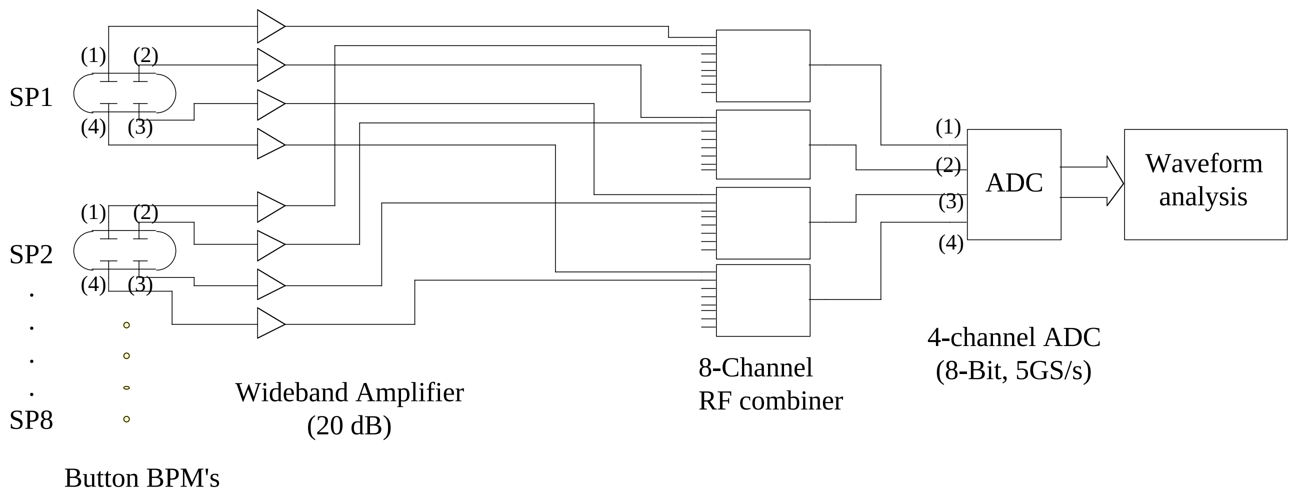


Figure 1 Signal processing scheme of the single-pass BPM system.

oscilloscope was 1.5x10^4 Words for each channel. On the other hand the revolution period of the ring was 625 nm. When the signal is digitized at the maximum sampling rate, about 5 turns of bunch signals could be stored in the memory.

For the sake of the COD measurement, 46 of BPMs are installed in the PF ring, 187 m in circumference. 8 of them were selected for the single-pass measurement. The signals from the 8 BPMs were merged using the 8-channel power combiners. Then all button signals could be recorded in the four channels of the oscilloscope. Distance between the two adjacent BPMs was about 20 m in average, or the time interval between the two signals were about 70 ns. Because the duration of each bunch signal was only a few ns, the pulses from the different BPM were well separated on the temporal axis and could be measured without any interference.

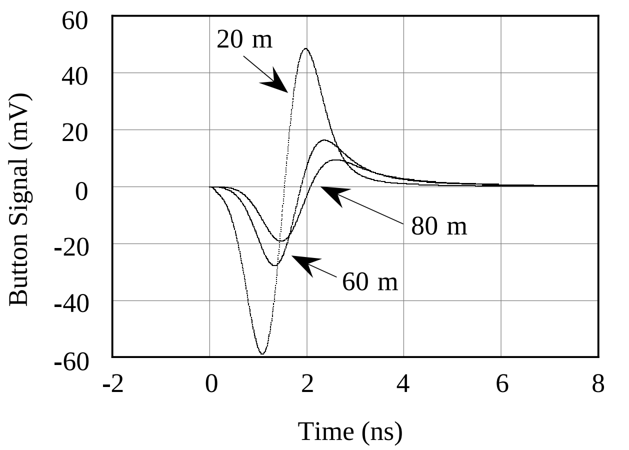


Figure 2 Simulation of the signal attenuation in the coaxial cable.

The power combiners and the oscilloscope were installed at the center of the machine room, the basement floor of the PF ring. The maximum length of the signal cables amounted to 80 m. As the signal cable, we used the double screened coaxial cable of 5.5 mm in diameter. Its attenuation factor was 29 dB/100 m at a frequency of 1 GHz. Figure 2 shows an estimation of the signal attenuation in the long coaxial cable. The calculations were based on the approximate impulse response of the dispersive coaxial lines.[2] The gaussian bunch profile of the beam was assumed, and the amplitude of the bipolar button signal was fitted to the measured value when a 20 m long cable was used. After the transmission of 80 m, the bipolar shape is well preserved but the peak height attenuate by about 10 dB. In addition, the 8-channel power combiner had an total insertion loss of about 10 dB. In order to keep a good signal-to-noise ratio, a wideband amplifier of 20 dB was inserted in the each signal path. The transmission distance between the amplifiers and the BPM heads were kept as short as possible. The bandwidth of the combiners and the amplifiers were 1 GHz also.

The intensity of the specific button signal was determined as a peak-to-peak amplitude of the bipolar shape, and the beam position was calculated from the peak-height ratios, U and V for the horizontal and vertical directions, respectively.

$U = ((v_2 + v_3)-(v_1 + v_4))/\Sigma v_i$ and

$V = ((v_1 + v_2)-(v_3 + v_4))/\Sigma v_i$,

where v_i represents the intensity of the i-th button. The ratios were converted to the beam position (X,Y) by multiplying the factors, Gx(U,V) or Gy(U,V). At the center of the BPM head, Gx and Gy were equal to 21.8 mm and 65.5 mm, respectively. The injection beam would take an orbit with a large deviation from the center. Correction of the large nonlinearity in the conversion factors are inevitable. A quadratic approximation was adopted to deducing the Gx (Gy) as a function of U and V in the present measurement. [3]

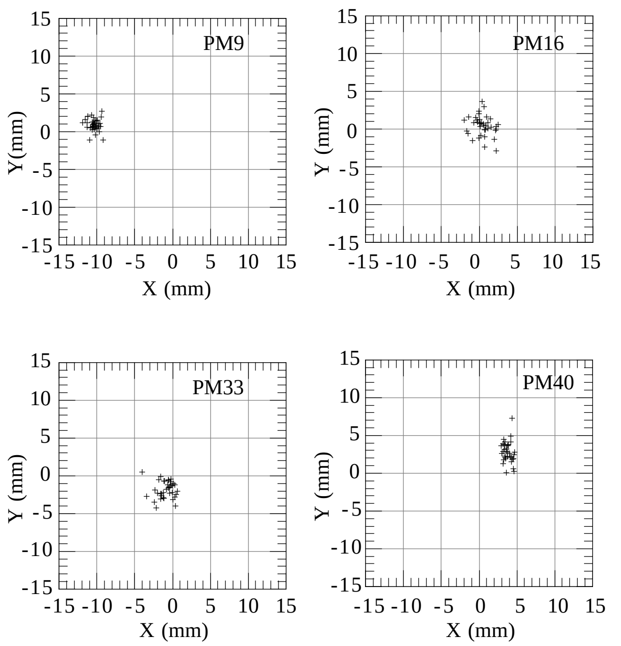
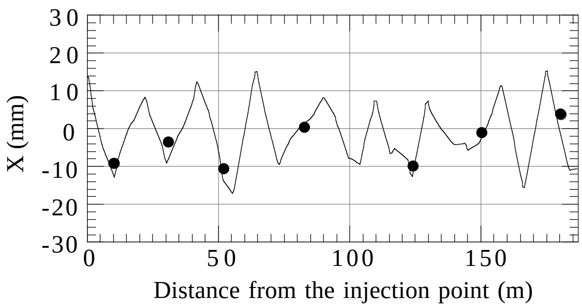


Figure 3 Examples of the beam-position measurements at the first turn in the ring. Distribution of the positions of 50 injection pulses were plotted in the each graph.

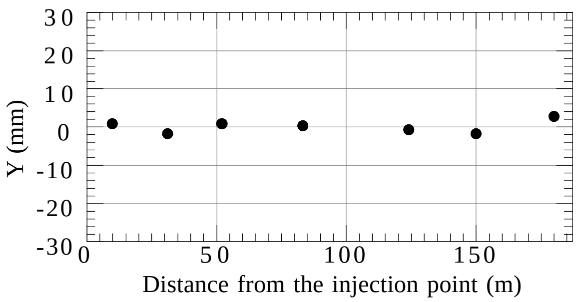
3 MEASUREMENT RESULTS

At the PF ring, electron beam of about 2x10^{-10} C is supplied from the 2.5-GeV linac injector. By using the present signal processing method, the amplitude of the bipolar signal detected at the ADC was about 100 mV or less, typically. In order to estimate the resolution of the single-pass measurement, the stored-beam positions were measured at the very low current of about 100 μA, although the duration of the signal observed for the stored bunch was slightly shorter than that of the injection beam. The stored beam is stable enough to deduce the error resulting from the single-pass measurement. The measurement error, ΔU ($\sim\Delta V$), of 0.6 % was observed in the situation that the signal was 50 mV in amplitude. This value corresponds to ΔX = 0.13 mm and ΔY = 0.39 mm, respectively. The 8-bit resolution of the ADC seems to limit the performance of this system.

During the injection period, electrical noise synchronized to the operation of the pulse magnets occasionally cause problems to various beam diagnostics. In the present measurement, small noise signals were observed in a short time when the kicker magnets started their operation. The injection pulse arrives at about 5 μs after the start of kicker magnets, so the beam signal was not at all interfered by that noise.



(a)



(b)

Figure 4 Injected-beam positions of the first turn. (a) horizontal beam positions. Solid line is the calculated orbit. (b) vertical beam positions.

Distributions of the injection-beam positions are shown in figure 3. The measurement results at the four BPMs are displayed as an example. The positions of 50 pulses were plotted in the each graph. The single-pass measurements were done without the RF acceleration, so no beam was accumulated during the experiments. And the frequency of the injection was 25 Hz or less, no charge was left in the ring when the next pulse was injected. The measured dispersion well reflected the lattice parameters at the BPM. At the PM9, the standard deviation in the horizontal and the vertical directions were 0.6 mm and 0.7 mm, respectively. The deviations in the horizontal direction at PM16 and PM33 were large, about 1 mm in σ. The dispersion function at the PM16 and PM33 is twice as large as that of the other ones.

The average beam positions in the first turn obtained from the previous measurements were shown in figure 4. The operating parameters of the ring was the same as the usual operation. The beam could be well accumulated if the RF acceleration is turned on. The origin of the horizontal axis of the figure 4 corresponds to the injection point and the maximum is 187 m, the circumference of the ring. The solid line in the figure (a) is the calculated horizontal orbit in the first turn of the injected beam. The measured positions (solid circles) coincide well with the calculated orbit. In the vertical direction, there are no distortion of the orbit at the normal condition. The measured vertical positions settled within the range of 2 mm. In the present measurements, the correction on the difference in the amplifier gain and the insertion loss of the combiners were not taken into account yet. There were differences of about 0.5 dB at maximum among the channels. That value would cause some 0.5 mm offset in the absolute position.

4 SUMMARY

The single-pass BPM system was developed, and the injected beam positions at the first turn were detected. The resolution of the present method was estimated to be 0.6 % as the voltage ratio, ΔU, or 0.15 mm to 0.4 mm in the real space. It will be useful for the orbit correction without any stored beam. We are replacing the digitizing oscilloscope by the waveform digitizer compatible with the VXI bus system. The data transfer time would be saved and the total processing time would greatly shortened. The number of BPMs processed with the single-pass measurement is to be increased in order to investigate the injection orbit more precisely.

REFERENCES

[1] M. Katoh and Y. Hori, in these proceedings.

[2] J.-C. Denard, G. Oxoby, J.-L. Pellegrin and S. Williams, IEEE Trans. Nucl. Sci. NS-30, p2364, 1983.

[3] T. Honda, “Single-pass measurements of the injection-beam position at the Photon Factory storage ring”, KEK Preprint 95-128, 1995.