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Single-pass BPM system of the Photon Factory storage ring

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At the 2.5 GeV ring of the Photon Factory, a single-pass beam-position monitor (BPM) system is being prepared for the storage ring and the beam transport line. In the storage ring, the injected beam position during the first several turns can be measured with a single injection pulse. The BPM system has an adequate performance, useful for the commissioning of the new low-emittance lattice. Several stripline BPMs are being installed in the beam transport line. The continuous monitoring of the orbit in the beam transport line will be useful for the stabilization of the injection energy as well as the injection beam orbit.

Keywords: single-pass beam-position monitors; injection beam orbits; KEK PF ring; beam transport lines; injection bumps.

1. Introduction

The Photon Factory (PF) ring is a 2.5 GeV electron storage ring dedicated to a synchrotron radiation source. Synchrotron radiation has been supplied to research experiments for about 15 years, since 1982. A large upgrade of the PF ring to a low-emittance lattice is now in progress with a scheduled shutdown of 10 months (Katoh & Hori, 1996). The beam emittance will be reduced by a factor of five, otherwise the brilliance of the synchrotron radiation supplied to users will be too high. As part of the upgrade program, the beam-position monitors (BPMs) and the orbit feedback system are being updated completely. The electronics for the closed-orbit-distortion (COD) measurement are designed to achieve high data-acquisition rates in order to realize a fast beam-position feedback up to 50 Hz (Nakamura *et al.*, 1995). Furthermore, the single-pass BPM system has also been prepared for investigating the injected beam position. Measurement of the injection orbit will be indispensable at the commissioning stage of the new lattice. In this paper we describe the method and the performance of this single-pass BPM system.

2. Signal processing

The single-pass BPM system of the PF ring is constructed using a high-speed waveform analyser compatible with the VXI bus. The signal of the injected beam extracted through the button or the stripline electrode forms a bipolar shape of a few nanoseconds duration. The beam signal can be recorded in real time by the waveform analyser, which has a maximum sampling rate of 5 GS s^{-1} and an analog bandwidth of 1 GHz. The four button (or stripline) signals of one BPM are simultaneously accumulated in the four channels of the analyser. The intensity of each button signal is determined as a peak-to-peak amplitude of the bipolar signal, and the beam position is calculated from the peak-height ratios (Honda & Katoh, 1996). As shown in Fig. 1, we use a set of eight-channel RF power combiners in the path of signal transmission in order to measure signals from eight BPMs with a single waveform analyser. If an interval of two adjacent BPMs is 10 m or more, the signals from the two BPMs are well separated on the temporal axis and can be measured without any interference. The record length of the analyser is 15 k words for each channel. On the other hand, the revolution period of the PF ring is 625 ns. When the signal is measured at the maximum sample rate, about 3 µs or four turns of injection orbit can be detected with a single injection beam.

The digitizers of the waveform analyser have 8-bit resolution. This value corresponds to about 0.5% for the resolution for the amplitude measurement. The beam position is calculated as a product of the amplitude ratio and the conversion coefficient, the latter of which is a function of the geometrical arrangement of the BPM electrodes and the vacuum duct. If the coefficient has a

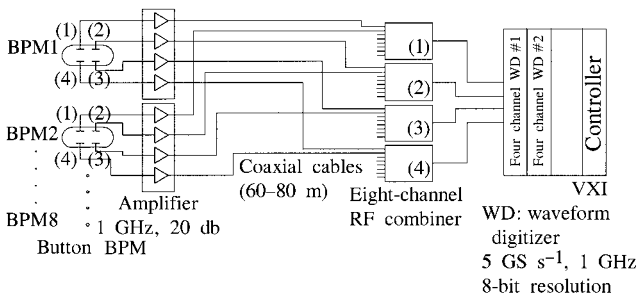

Figure 1
Signal-processing scheme for the single-pass BPM system.

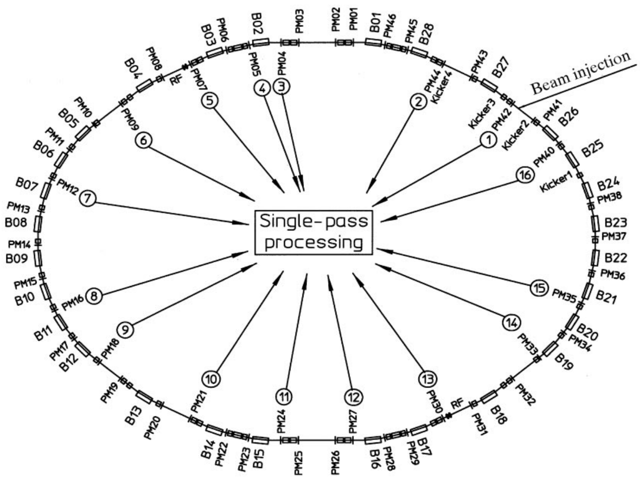

Figure 2
Arrangement of the BPMs in the PF ring. 16 BPMs, which are indicated by the circled numbers, can be switched to the single-pass processing system.

value of 20 mm, a typical value for the button BPM, the relative resolution for the beam position can be estimated to be about 0.1 mm.

3. Single-pass BPM of the storage ring

There were 45 button-type BPMs installed in the previous PF ring, as shown in Fig. 2. The number of BPMs is increased to 65 at the low-emittance lattice. The signals of 16 BPMs can be switched to the single-pass processing system, which is equipped with two waveform analysers and eight sets of signal combiners. When the bunch signal is amplified by 20 dB and 1 GHz bandwidth, a bipolar waveform of about 50 mV in amplitude is detected for the typical electron injection beam of 0.2 nC and 2 ns duration. The resolution estimated from the distribution of the measured positions was to be 0.13 mm and 0.39 mm for the horizontal and vertical directions, respectively. The conversion coefficients were found to be 22 mm and 65 mm for the horizontal and vertical directions, respectively. So it was found that the 8-bit resolution of the waveform analyser is supposed to limit the resolution of the single-pass BPM.

Fig. 3 shows a sample of the measured beam positions during the first four turns following the injection. The measurement was performed without the RF acceleration and the values averaged for 20 injection pulses are plotted. The origin of the horizontal axis corresponds to the injection point. The horizontal (X) and the vertical (Y) beam positions are shown as solid circles in the topmost and middle graphs, respectively. The summation of the four button signals of each BPM is shown in the bottom graph as a measure of beam loss, although small fluctuation due to the different sensitivity of each BPM was not compensated. There are 16 data points plotted in each turn. The solid line in the topmost graph is the injection orbit calculated based on the design parameters of the ring, not including the injection bump. Under normal operation conditions, the measured points were well on the calculated line and no beam loss was observed during the first several turns (Honda *et al.*, 1997). In the present measurement, the horizontal orbit oscillates with a large amplitude compared with the solid line because one of the horizontal steering magnets was abnormally excited. Most of the charges disappeared suddenly halfway through the second turn. The beam loss point could be fixed between the ninth and tenth BPM, where the horizontal aperture took a local minimum near the superconducting vertical wiggler. An orbit correction, based on the single-pass measurement, was possible using, for example, the best corrector method (Honda *et al.*, 1997).

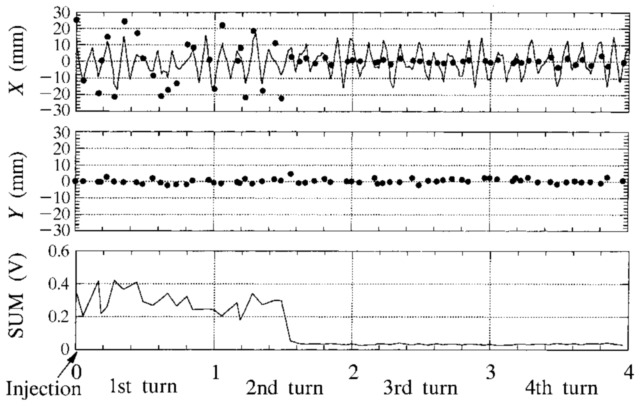

Figure 3
Example of the injection orbit measurement.

Fig. 4 shows the measurement of the injection kicker bump using a stored beam of about 0.1 mA. The duration of the injection bump was about 5 μs at the previous PF ring, though a faster kicker system with a pulse length of 350 ns is being installed for the high-brilliance project. The first and the last BPM of each turn were placed on the kicker bump. The pulse bump was observed to continue during several turns. No large orbit distortion was detected outside of the kicker bump, or the injection bump was well closed. When the timing or the amplitude balance of the four kickers were wrong, large CODs occurred outside of the bump. It was possible to adjust exactly the kicker operation using the stored beam monitoring in this way.

4. BPM system of the beam transport line

In the beam transport line, five stripline BPMs are being installed, and the BPM system will work after the commissioning of the low-emittance lattice. The BPM is constructed of four stripline electrodes, which have a characteristic impedance of 50 Ω. The signal-processing scheme is the same as that of the storage ring, but no amplification in the path of the transmission is necessary because the stripline signals are an order of magnitude larger than the button signals. The conversion coefficient for the stripline BPM is estimated to be about 17 mm both in the horizontal and the vertical directions. The resolution of the beam position is expected to be about 0.1 mm. Two of the above BPMs are installed near the entrance of the beam transport line at an interval of about 4 m, and two others just before the septum magnets, also at an interval of 4 m. Using the two sets of BPMs, the angle of injection beam orbit will be detected with a resolution better than 50 μrad. The last BPM is installed at the place where the energy dispersion function takes a maximum value. At the BPM, variation of the horizontal beam position is induced by the energy fluctuation of the injection beam. The absolute value of the energy dispersion function is about 5 m, so the resolution for the beam energy is expected to be 0.02%. By monitoring the horizontal position continuously, an energy feedback will be possible for the slow energy fluctuation of the linac injector.

5. Summary

A single-pass BPM system has been prepared for the PF storage ring and the beam transport line. The performance of the BPM of the storage ring was confirmed to be practically useful for the adjustment of injection parameters at the commissioning stage of the low-emittance lattice. Using the same signal-processing scheme, the injection beam in the beam transport line will be continuously monitored after the commissioning.

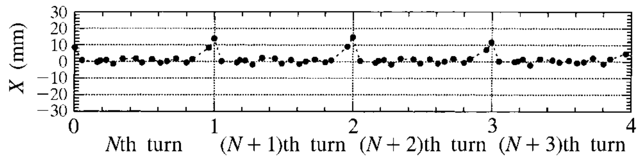

Figure 4
Observation of the injection bump when the stored beam was kicked by the kicker magnets.

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