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# New beam-position monitor system for upgraded Photon Factory storage ring

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Accompanying the brilliance-upgrading project at the Photon Factory storage ring, the beam-position monitor (BPM) system has been renovated. The new system was designed to enable precise and fast measurements to correct the closed-orbit distortion (COD), as well as to feed back the orbit position during user runs. There are 42 BPMs newly installed, amounting to a total of 65 BPMs. All of the BPMs are calibrated on the test bench using a coaxially strung metallic wire. The measured electrical offsets are typically 200 μm in both directions, which is 1/2–1/3 of those of the old-type BPMs. In the signal-processing system, PIN diode switches are employed in order to improve reliability. In the fastest mode, this system is capable of measuring COD within about 10 ms; this fast acquisition will allow fast suppression of the beam movement for frequencies up to 50 Hz using a global feedback system.

**Keywords: beam-position monitors; calibration; electrical-centre offset.**

## 1. Introduction

The Photon Factory (PF) ring is a 2.5 GeV electron/positron storage ring dedicated to synchrotron radiation experiments. It was planned to provide more brilliant synchrotron radiation by reducing the ring emittance from 130 to 27 nmrad, and reconstruction of the various components of the PF ring is now in progress.

Accompanying the brilliance-upgrading project, the beam-position monitor (BPM) system has been renovated. The purpose of the BPM system is to measure accurately the beam position in order to correct it for any closed-orbit distortion (COD), to stabilize the beam position using feedback, and to correct the lattice optical functions such as the betatron or the dispersion functions. The new system was designed to enable precise and fast measurements to correct the COD, as well as to feed back the orbit position during user runs.

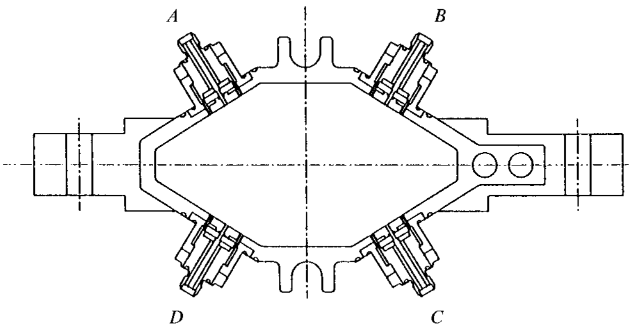


**Figure 1**
Cross-sectional view of a pickup unit for the new PF BPM.

The new BPM system comprises electrostatic pickup units and a signal-processing system. The pickup units include 42 new-type units mounted on a newly fabricated vacuum chamber and 17 old-type units. Calibration measurements of the new BPMs were made on a test stand in order to realize the offset of the electrical centre. In addition, the response of the new BPM to the beam-induced field was calculated using the boundary element method to estimate the position sensitivity.

## 2. BPM system

### 2.1. *Pickup unit*

The pickup units for the normal cell sections are to be doubled in number, according to the addition of the quadrupole magnets in the same sections. The vacuum chambers are also replaced by new ones and accordingly 42 BPMs are newly installed, amounting to a total of 65 BPMs. The newly installed pickup unit has four button-type pickup electrodes.

A cross-sectional view of the new BPM unit is shown in Fig. 1. It was designed to fit into the narrow space between the magnets. A commercial product (from KYOCERA Corporation) was adopted for the electrode assembly, which consists of a button electrode (10.3 mm diameter), a feedthrough and an SMA-type connector. The button is set at the centre of the assembly within ±50 μm. Each BPM unit is fixed to an end of the quadrupole magnet. All of the BPMs are tested at a calibration bench where the electric centre of each BPM is identified with an overall accuracy of about 100 μm using a coaxially strung metallic wire.

### 2.2. *Signal-processing system*

A schematic diagram of the signal-processing system is shown in Fig. 2. These circuit units are to be distributed in 12 local control racks around the ring. The beam signals from the pickup electrodes are transmitted to the processing system, and at the front end of the system one of the signals is selected by RF switches. To improve the reliability, the currently used mechanical coaxial switches are abandoned, and PIN diode switches are adopted. The fluctuation of the insertion loss over many switchings is less than ±0.01 dB, which corresponds to a position error of ~3 μm. The signal-detection circuit consists of a superheterodyne circuit with synchronous detection. The bandwidth of the signal detection is determined by the response time (~3 μs in 10–90% rise time) of a low-pass filter in the final detection stage. In the fastest mode, this system is capable of measuring the COD within about 2 ms, which is determined by the sum of the switching time, the response time of the detection circuit and the conversion time of an analog-to-digital (A/D) converter. This very fast acquisition will allow fast suppression of the beam movement for frequencies up to 50 Hz using a global feedback system (Photon Factory, 1994).

## 3. Simulated response of the new BPM

In order to measure the beam position precisely, the position sensitivity and the electrical centre of the BPM should be known before installing into the storage ring. In the calibration measurement, an antenna, which is connected to an RF source, is used to simulate the field of the high-energy beam. However, the electromagnetic field produced by the antenna is somewhat different from that induced by a real beam. Thus, we calculated the response of the BPM to estimate the position sensitivity.

Using the boundary element method (Brebbia, 1978; Shintake *et al.*, 1987), we simulated the response of the BPM to the electric field induced by the beam. The potential and induced charge density of each element were calculated and summed to the induced charges of the four electrodes $A$–$D$. The beam-position data are given as the ratio

$$U = [(Q_A + Q_D) - (Q_B + Q_C)]/(Q_A + Q_B + Q_C + Q_D)$$

and

$$V = [(Q_A + Q_B) - (Q_C + Q_D)]/(Q_A + Q_B + Q_C + Q_D)$$

of these induced charges. The simulated results are shown in Fig. 3. The position sensitivities ($S_x$ and $S_y$) are given by the derivatives of $U$ and $V$ with respect to the beam position at the centre of the BPM,

$$S_x = \partial U(x, 0)/\partial x, \qquad S_y = \partial V(0, y)/\partial y.$$

The derived values of the horizontal and the vertical BPM sensitivity are $S_x$ = 0.0575 mm$^{-1}$ and $S_y$ = 0.0283 mm$^{-1}$, respectively.

The various distortions of the BPM assembly during the fabrication, especially the fluctuation in the thickness of the BPM duct, will generate the offset of the electrical centre. The typical value of this fluctuation is less than 200 μm, and will result in the simulated offset of ∼200 μm.

## 4. Calibration measurement

Before installing the new-type BPMs, each BPM assembly was calibrated on a test stand in order to determine the electrical centre of the BPM relative to its mechanical centre. A precise determination of the offset of each individual BPM is important for commissioning and operating the storage ring.

### 4.1. *Test stand for calibration*

Shown in Fig. 4 is the test stand used for the calibration. The BPM assembly was mounted vertically on the stand. A steel wire of diameter 300 μm was strung coaxially and simulated the beam. Both ends of the wire were connected to *N*-type connectors. The wire was precisely aligned using a spring-tensioning device located at the lower end. The calibration was performed at a frequency of 500 MHz, *i.e.* the signal-detection frequency of the BPM electronics. The RF signals emerging from the button electrodes were multiplexed in an SP4T switch and transmitted to a network analyser for measuring their intensities. The electrical offsets were then obtained using the BPM sensitivity, which was derived from the simulation based on the boundary element method.

### 4.2. *Distribution of the measured offsets*

Fig. 5 shows the distribution of measured electrical-centre offsets for the new-type BPMs. The horizontal and the vertical offsets of each BPM are shown as closed circles. All of the measured offsets are less than 500 μm, and typically 200 μm, in both directions. This is in good agreement with a simulated result of ∼200 μm. The offsets of the electrical centres for old-type BPMs are also shown in Fig. 5 for comparison. The offsets for the new-type BPMs were about 1/2–1/3 of those for the old type.

Both the horizontal and the vertical offsets of the new-type BPMs are nearly zero on average, which indicates that no systematic errors were introduced in the course of fabricating the $Q$-ducts and the BPM assemblies. These measured offsets for all the BPMs will be stored on computer and used to calculate the beam position.

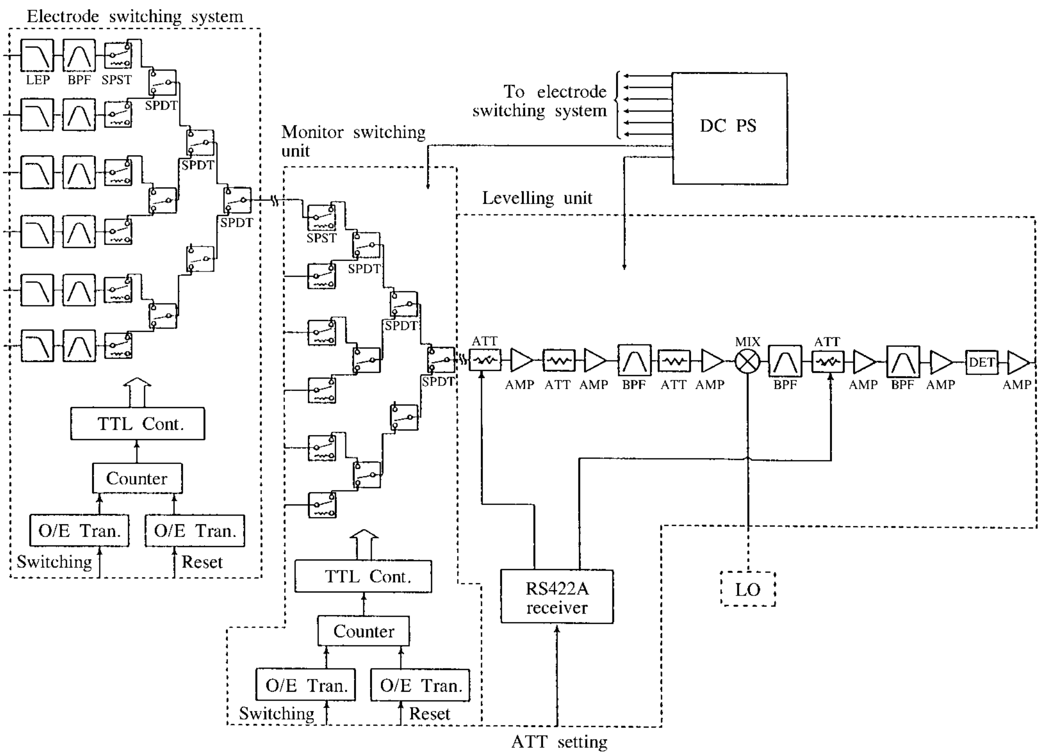


**Figure 2**
Schematic diagram of the signal-processing system.

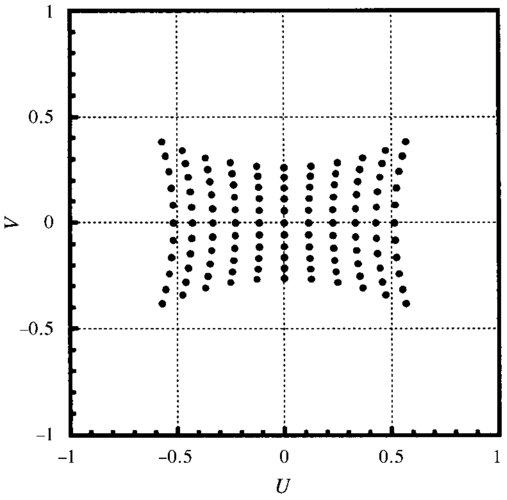


**Figure 3**
Simulated response of the new BPM.

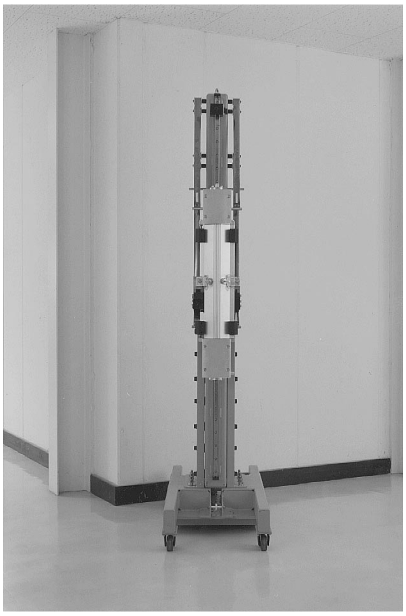

**Figure 4**
The test stand for calibrating the new BPM.

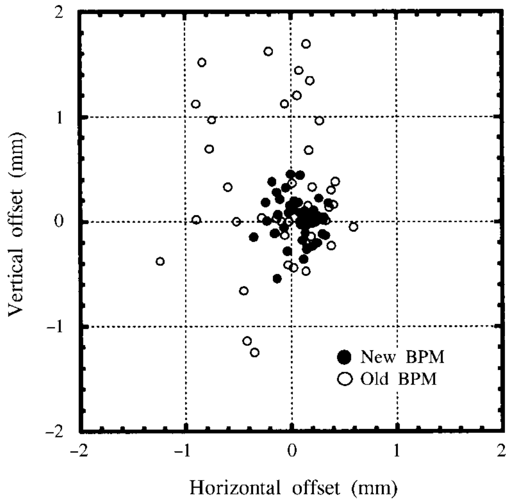


**Figure 5**
Distribution of the measured offsets of the electrical centre relative to the mechanical centre.

## 5. Conclusions

The BPM system has been renovated for the upgraded PF ring. All the measured electrical offsets are typically 200 μm in both directions, which is 1/2–1/3 of those of the old-type BPMs. PIN diode switches have been adopted in order to improve reliability, and the fluctuation of the insertion loss is less than 0.01 dB, which corresponds to a position error of 3 μm. The fast acquisition mode of this system will allow the suppression of the beam movement for frequencies of up to 50 Hz using a global feedback system.

In order to determine the BPM offsets accurately, a beam-based calibration method seems to be very useful. This method has the advantage of eliminating various error sources, such as the mechanical alignment errors of the BPM assemblies and the residual offsets of the signal-processing electronics.

## References

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