Design and Calibration of Pickup-Electrodes for Beam Position Monitoring at SOR-RING

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Abstract
Described in this paper are the design and calibration of button-type pickup-electrodes, which have been incorporated in the beam position monitoring system (BPM system) at SOR-RING. The BPM system that has been developed as an R&D for a third-generation VUV synchrotron light source is aimed at testing the key components of the system, PIN diode switches. This system is also aimed at measuring the beam position of SOR-RING and correcting it. In addition, briefly described in the paper are ion-clearing electrodes installed in the ring.

1. Introduction

A system of beam position monitors (BPM's) using PIN diode switches was installed in the SOR-RING of ISSP, Tokyo University [1]. Using this BPM system, the closed orbit was measured and then corrected for the first time since the ring construction had been completed in 1974 [2].

The system includes four BPM's fixed on newly fabricated vacuum chambers for quadrupole triplets (see Ref. [2]) and each BPM consists of four pickup-electrodes of a button type. Calibration measurement of BPM's was made on a test bench of the Photon Factory [3] and also with a method of S-parameters [4]. Using a method of BEM (Boundary Element Method) [5], we calculated the response of a BPM to electric field induced by the beam and also compared it with the measured result.

In addition, we designed ion-clearing electrodes and incorporated them into new vacuum chambers. The beam lifetime was found to increase by a factor of two when a few KV was applied to the ion-clearing electrodes [3]. However, the electrode's effect on the beam is not studied in detail.

2. Design and Fabrication

A. Pick-up Electrode

We first designed two types of test BPM's with short chambers; one is a cylindrical type (C-type BPM) and the other is the same type as the BPM's installed in SOR-RING (SOR-type BPM). The button diameter of 20 mm was chosen so as to fit the narrow vacuum chamber of SOR-RING. The diameter is much smaller than 10 cm, the rms bunch length of SOR-RING. At the RF frequency of 120 MHz the response of BPM is almost independent of the bunch length. A pick-up electrode consists of a vacuum feedthrough and a button. We chose the N-type as the vacuum feedthrough because of its robust connection. The tip of central conductor in the feedthrough was specially designed to have a small washer, to which the button was precisely welded. In order to mount the pick-up electrodes flush with the inside wall of a stainless steel block of BPM, a short piece of a ring shape was attached to the feedthrough's outer conductor by welding. The stainless steel block precisely machined to house the electrodes was in turn welded to the vacuum chamber. Figure 1 shows the cross-sectional views of both types of BPM's. The BPM's actually installed in SOR-RING were made almost in the same way as the test BPM's.

B. Selection of Feedthrough

We measured the capacitances of all feedthroughs with a LCR-meter and arranged four feedthroughs for a BPM to be equal in capacitance as far as possible. For test BPM's we also checked the capacitances of pick-up electrodes before and after attached on the vacuum chambers. Table I lists some data of measured capacitance.

Table I. Measured capacitance of test BPM

Feedthrough only (at 10kHz)

	1-A	1-B	1-C	1-D
C[pF]	3.2	3 2	3.2	3.2

Pick-up electrode (at 10 kHz)

	1-A	1-B	1-C	1-D
C[pF]	5.92	5.95	5.83	5.86

C. Ion-Clearing Electrode

The cross-sectional view of a pair of ion-clearing electrodes we designed is shown in Fig. 2. Each of four new chambers has a pair of ion-clearing electrodes. The electrodes and their high-voltage feedthroughs have been designed so that several KV can be easily applied to the electrodes. By using a BEM (Boundary Element Method) we calculated the electric field induced by a DC voltage of 1 KV on one electrode and -1 KV on the other electrode [see Fig. 3]. As mentioned in Sec. 1, these ion-clearing electrodes helped the beam lifetime to increase.

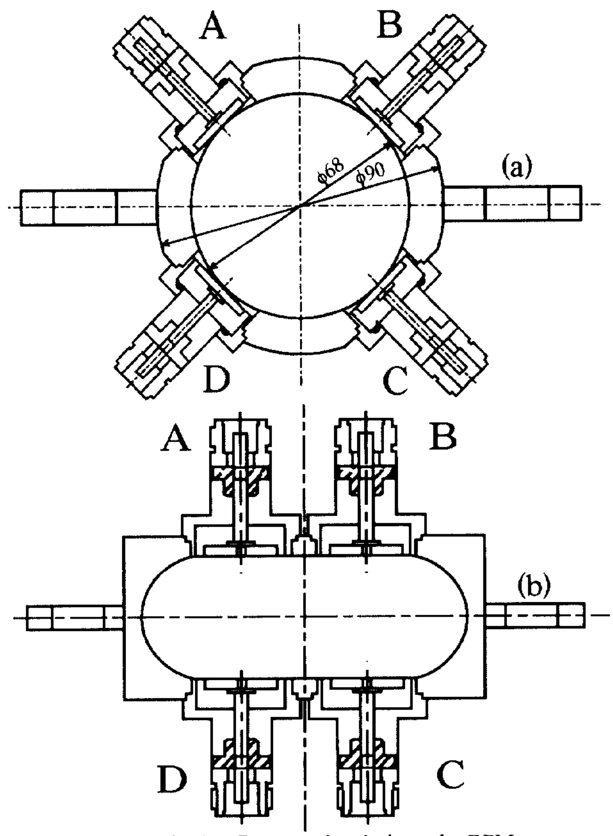

Fig. 1 Cross-sectional view of a BPM
(a) : cylindrical BPM (C-type)
(b) : BPM for SOR-RING (SOR-type)

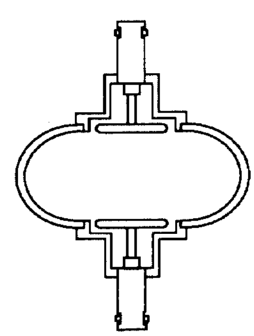

Fig. 2 Cross-sectional view of a pair of ion-clearing electrodes

D. Alignment of BPM

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We did not intend to precisely position the BPM's in the ring, since there is no good reference point for alignment at SOR-RING and also the aim of this R&D is to test PIN diode switches incorporated in the BPM system. We also have to isolate the BPM's as well as vacuum chambers from the ground, since the ring is baked out by directly passing AC current through the vacuum chambers. The BPM blocks were therefore sandwiched between the magnet poles of quadrupoles with precisely machined insulators, as shown in Fig. 4. The alignment error of BPM to the center of quadrupole magnet was expected to be around 0.1 mm.

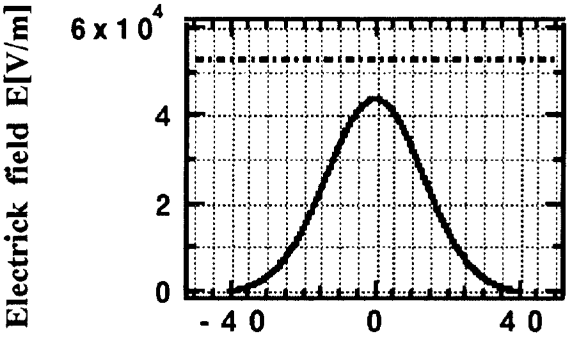

Fig. 3 Field calculation of ion-clearing electrodes
The dash-dotted line is for infinitely extended electrodes.

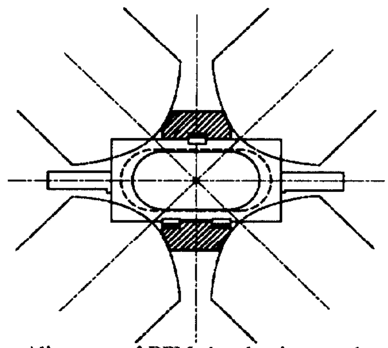

Fig. 4 Alignment of BPM chamber in a quadrupole magnet

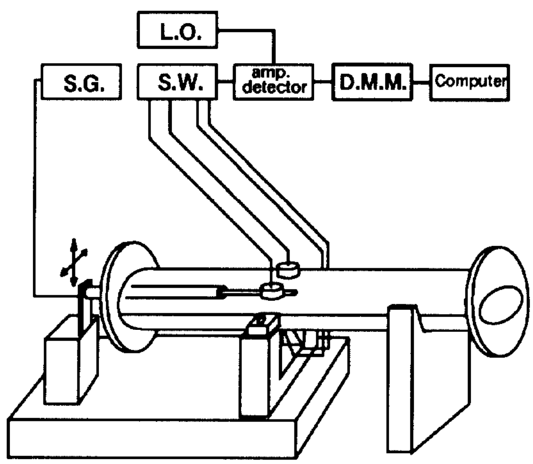

Fig. 5 Calibration setup for BPM

3. Calibration Measurement

A. Test BPM

Before fabricating the BPM's for SOR-RING, the position sensitivities of two types of test BPM's were measured by scanning an RF antenna on the BPM test bench of the Photon Factory [3], as shown in Fig. 5. Data were taken mainly at 120.83 MHz and 500 MHz. Presented in this paper are data for 120.83 MHz. The results of sensitivity measurement for the C-type BPM are shown in Fig. 6. This sensitivity map shows the transformation of the physical (x, y)-plane of the beam center to the (U,V)-plane and to the (U1,V1)-plane, where U and V are defined as,

$$U=\frac{(B+C)-(A+D)}{A+B+C+D}\ ,\quad V=\frac{(A+B)-(C+D)}{A+B+C+D}\ ,$$

and U1 and V1 are also defined as,

$$U1=\left(\frac{B-A}{B+A}\right)+\left(\frac{C-D}{C+D}\right)\ ,\quad V1=\left(\frac{B-C}{B+C}\right)+\left(\frac{A-D}{A+D}\right)\ .$$

Here A, B, C and D stand for the detected voltages of the corresponding pickup-electrodes in Fig. 1. Figure 7 shows the sensitivity map in the case of the SOR-type BPM.

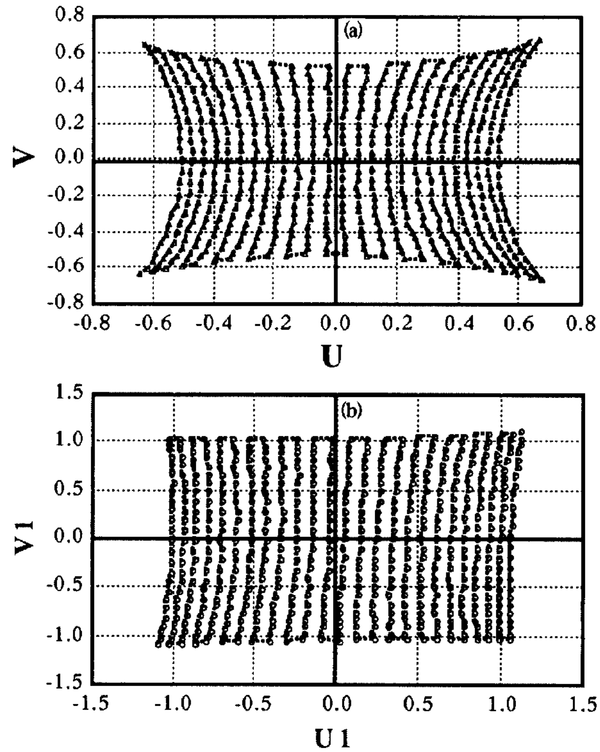

Fig. 6 Measured response of the cylindrical BPM
(a) : (U,V)-map, (b) : (U1,V1)-map

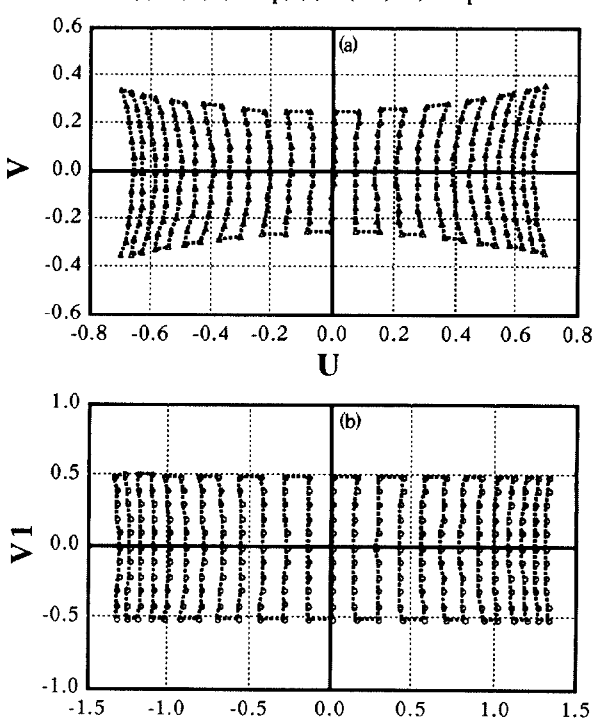

Fig. 7 Measured response of the SOR-RING's BPM
(a) : (U,V)-map, (b) : (U1,V1)-map

We carefully measured the electric offset of the center of the SOR-type BPM. Since the RF-antenna of the old test bench was slightly bent, we decided to measure the offset both for the normal setup of BPM and for the reverse setup in order to remove the position error of the antenna itself.

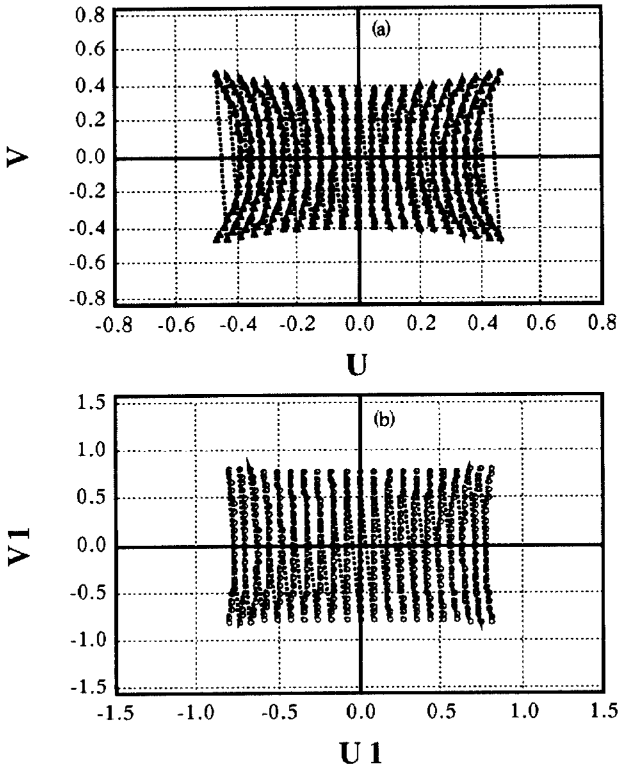

Fig. 8 Calculated response of the cylindrical BPM
(a) : (U,V)-map, (b) : (U1,V1)-map

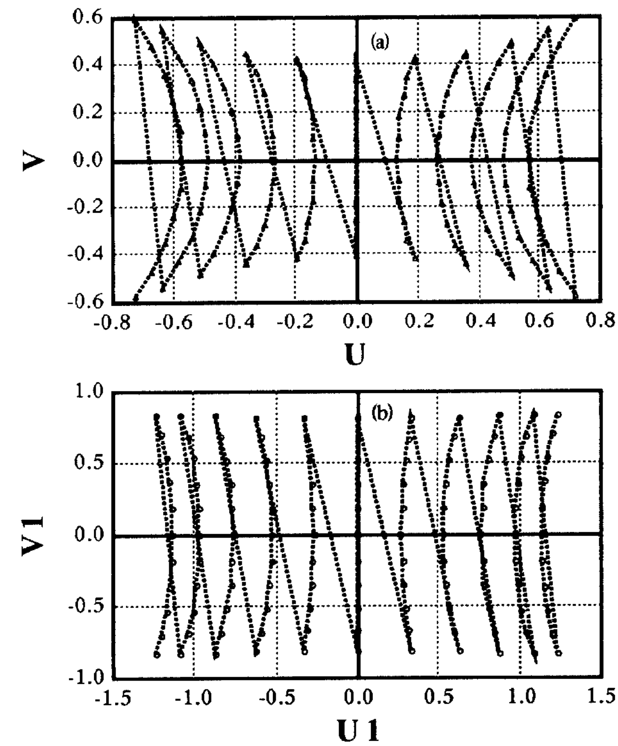

Fig. 9 Calculated response of the SOR-RING's BPM
(a) : (U,V)-map, (b) : (U1,V1)-map

We also made the measurement of the electric offset with the method of S-parameters [4]. These measured results are summarized in Table II.

Table II. Measured center-offset of test BPM

ΔXa [mm]	ΔXe[mm]	ΔXs[mm]
0.064	0.087	0.081

ΔYa[mm]	ΔYe[mm]	ΔYs[mm]
0.077	0.203	0.198

subscript a: antenna offset , e: electric offset(RF antenna)
s: electric offset (S-parameters)

B. BPM's for SOR-RING

Before installing the BPM's in SOR-RING, we took the data of sensitivities and offsets for all BPM's in the same way as for the test BPM's. It was found from the calibration data that the beam center position is well estimated with a fifth order polynomial of (U,V) or (U1,V1). At present, however, we make use of the (U,V)-coordinates to calculate the beam position (x, y), though the sensitivity map for (U,V)-coordinates is more deformed than for (U1,V1)-coordinates. The coefficients of the polynomials for all BPM's were stored on the BPM computer thereby to calculate the beam position. For example, the polynomials, x and y at a BPM, are written as,

$$
\begin{aligned}
x = & -0.078 + 14.17U - 0.24V + 0.09U^2 + 0.09V^2 - 0.26UV \\
& + 4.97U^3 + 1.06V^3 + 0.53U^2V - 19.69UV^2 \\
& - 0.21U^4 + 0.24U^3V - 0.14U^2V^2 - 0.08UV^3 + 0.13V^4 \\
& + 10.45U^5 - 0.16U^4V + 12.35U^3V^2 - 0.68U^2V^3 - 8.59UV^4 - 4.68V^5,
\end{aligned}
$$

$$
\begin{aligned}
y = & \ 0.14 - 0.22U + 19.45V - 0.12U^2 + 0.44V^2 + 0.02UV \\
& - 0.19U^3 + 9.3V^3 - 15.64U^2V + 0.63UV^2 \\
& - 0.01U^4 - 0.08U^3V + 0.13U^2V^2 + 0.18UV^3 - 3.41V^4 \\
& + 0.57U^5 + 7.13U^4V - 0.86U^3V^2 - 4.04U^2V^3 - 1.18UV^4 - 3.66V^5.
\end{aligned}
$$

C. BEM Calculation

We developed a two-dimensional computer code using the method of BEM. Then we calculated the response of BPM to the beam for both C-type and SOR-type. The calculated results are shown in Fig. 8 for C-type BPM and in Fig. 9 for SOR-type BPM. For C-type, both measured and calculated maps of sensitivity are alike in shape but slightly differ in scale. For SOR-type, they largely differ in the vertical direction. The discrepancy between measured and calculated results has not been solved yet; it is probably because the RF-antenna used in the measurement can not generate a field as truly two-dimensional as a relativistic beam does. However, this discrepancy is almost irrelevant to the center offset of BPM.

Acknowledgments

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