〔P8-25〕

Beam-Based Alignment of Beam-Position Monitors for the KEKB Injector Linac

T. SUWADA AND N. AKASAKA

Accelerator Laboratory
KEK, High Energy Accelerator Research Organization
1-1 Oho, Tsukuba, Ibaraki, 305-0801 Japan

Abstract

Absolute center-position measurement of alomost all of the beam-position monitors (BPMs) was performed by using electron beams. The root-mean-square center position of the BPMs deviating from the magnetic-field center of quadrupole magnets were 0.3 and 0.3 mm in the horizontal and vertical directions to the beam axis, respectively. This report describes the method and the beam test for the beam-based alignment of the BPMs are described in detail.

1. Introduction

The KEKB injector linac[1] is required to supply certain amounts of single-bunch electron beams (8×10^9 e^-/bunch) and positron beams (4×10^9 e^+/bunch) for the KEKB high-energy and low-energy rings[2], respectively. High-current primary electron beams ($6\times 10^{10}e^-$/bunch) are also required to produce certain amounts of positron beams. It is, thus, important to keep the orbits of the beams stable; especially, the beam positions and charges of the primary high-current electron beams must be well controlled in order to suppress any beam blowup generated by large transverse wake-fields. A beam-position monitor (BPM) system was newly installed in the beam line, and has been working well since 1997. Since then, several kinds of the performance measurement have been done using electron beams. The first is the position resolution measurement on the basis of a three-BPM method [3], and the second is the absolute center-position measurement with respect to the magnetic field-center of quadrupole (Q) magnets. All of the BPMs were installed into the beam line after the test-bench calibration [4], which corrected signal gain unbalance for four pickups of a BPM mainly due to the mechanical alignment errors of the electrodes. However, because of the alignment error in the installation, the absolute center position of the BPMs are somewhat still ambiguous within the mechanical installation errors. The mechanical installation errors are mainly due to the alignment error in mounting a BPM on an entrance face of a pole piece of a Q magnet, and the difference between the mechanical center and the magnetic-field center of the Q magnet. Thus, these errors cause wrong absolute beam-position readings, and furthermore, do not keep any beam orbits stable. Thus, the absolute center positions of almost all of the BPMs have been measured using electron beams (beam-based alignment). In the following sections, the mechanical design of the BPM and the mounting method into the beam line, the principle of the beam-based alignment, and the beam tests are reported.

2. Beam-Position Monitor

A BPM system including the hardware and software has been already reported elsewhere [3] in detail. Here, only the mechanical design and mounting method for the BPM are briefly summarized. A conventional stripline-type BPM made of stainless steel (SUS304) was designed on the basis of $\pi/2$ rotational symmetry. A photograph of the BPM is shown in fig.1.

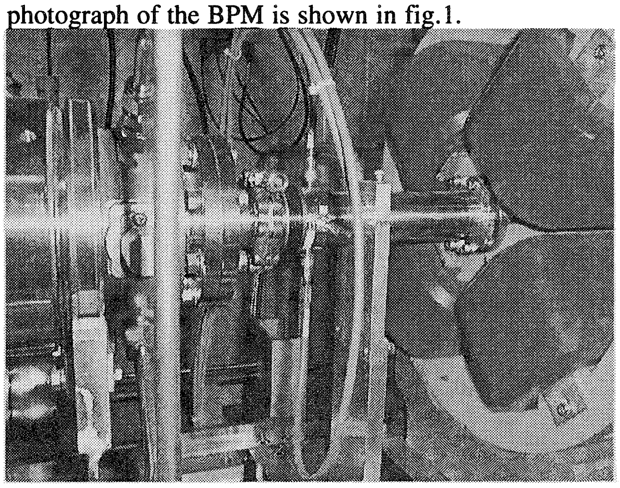


Fig.1. Photograph of an installed BPM.

The total length (195mm) was chosen to make the stripline length (132.5mm) as long as possible so that it can be installed into limited spaces in the new beam line of the linac. The angular width of the electrode, viewed from the center position of the BPM, is 60 degrees in order to avoid any strong electromagnetic coupling between the neighboring electrodes [5]. The inner radius of the vacuum pipe (13.6 mm) and the electrode width comprise a 50Ω transmission line. A 50Ω SMA-vacuum-feedthrough is connected to the upstream side of each electrode, while the downstream ends are short-circuited to a pipe in order to simplify the mechanical manufacturing. The total length of the pipe is variable within ±5 mm by a bellows connected with one side of the BPM. A quick-release flange coupling (EVAC NW40) is used at both ends of the monitor for easy installation into the beam line. The mechanical alignment of the BPM (see fig.2) is performed as follows: The first is that a dummy vacuum chamber connected with the BPM is inserted inside a Q magnet, and the second is that after adjusting the rotation of the BPM by using a level set perpendicular to the beam axis within an error of 0.5 mm/m, and one end of the BPM is fixed on an entrance face of a pole piece for the Q magnet, and the last is that the mechanical center of the BPM is fixed to be 300 mm high from a surface of an accelerator girder by a support table.

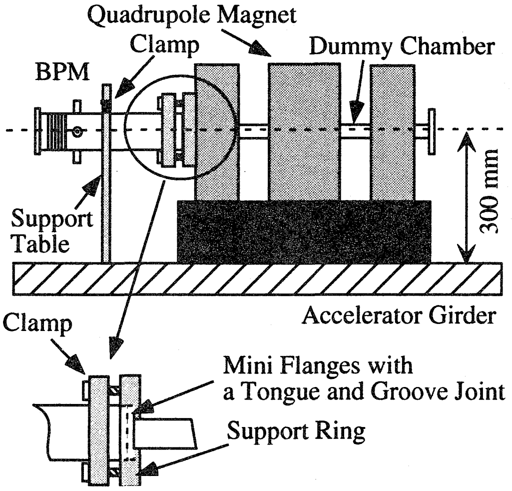


Fig.2. Schematic drawing of an installation of a BPM. One side of the BPM is mounted on an entrance face of a Q-magnet pole through a support ring with a tongue and groove joint. One end of the BPM is connected with a dummy chamber with mini flanges.

3. Method of Beam-Based Alignment

In the linac, most of the Q magnets are grouped as doublets or triplets. The BPMs are installed just before almost all groups of Q magnets. The magnetic-field center positions of the Q magnet were obtained as the reading of the nearest BPM. Three BPMs are basically used in this measurement, as shown in fig.3.

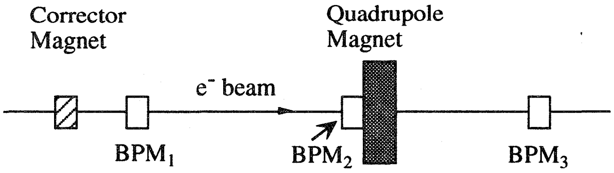


Fig.3. Typical configuration on the measurement for the absolute center positions of a BPM.

The horizontal (or vertical) beam positions (x_1, x_2 and x_3) are measured while changing the field strength (k) of the Q magnet and the corrector magnet. The BPM_2 is just before the Q magnet being tested. The upstream corrector magnet before the BPM_1 is used because it is essential that the transfer matrix from, to the BPM_3 is constant during the measurement. The reading of the last BPM can be expressed as

$$x_3 = a_1x_1 + a_2x_2 + a_3k + a_4kx_2 + a_5, \tag{1}$$

where a_n are the fitting parameters. If the beam passes through the magnetic-field center of the Q magnet, x_3 does not depend on k:

$$\frac{\partial x_3}{\partial k} = a_3 + a_4x_2 = 0, \tag{2}$$

which leads to an offset (Δx_q) of the Q magnet relative to the BPM:

$$x_2 = -\frac{a_3}{a_4} \equiv \Delta x_q. \tag{3}$$

Thus, a_3 is a parameter, which is proportional to the offset between the origin of the BPM and the magnetic-field center of the Q magnet. The term a_1x_1 in Eq. (1), which is related to the BPM_1, allows a reliable measurement, even if the beam fluctuates at the upstream section. For triplet Q magnets, the strength of the two defocusing magnets, which are connected in series, are changed in the vertical measurement, whereas the focusing magnet in the middle is fixed, and on the other hand, the strength of the focusing magnet is changed in the horizontal measurement, whereas the defocusing magnets are fixed.

4. Beam Experiment

The beam experiment has been performed using single-bunch electron beams for the BPMs at sectors A, B, C and 1, and using multi-bunch electron beams for other BPMs at sectors 2-5. There was no reason for the use of two kinds of electron beams because we did not have enough beam time for the use of single-bunch electron beams. High-current single-bunch electron beams can be generated by the new pre-injector [6], which comprises two subharmonic bunchers, a prebuncher and a buncher. The electron gun can generate a beam charge of about 18 nC/pulse with a pulse width of 4 μs and a repetition rate of 50 Hz. Relatively low beam charge of 1~2 nC/bunch for single-bunch electron beams were chosen in the beam test in order to avoid any beam blowup due to the wake-fields. The beams were stably accelerated from the outlet of the buncher until the end of sector 1 without any observational beam loss. The beam energies were about 500 MeV and 4 GeV at the end of sectors A and 1, respectively. The longitudinal width of the beams was about 10 ps in a full width at half maximum measured by an optical transition-radiation monitor after tuning of the pre-injector. The beam test was performed under the condition of a repetition rate of 5 Hz. On the other hand, multi-bunch electron beams are injection beams well tuned for the Photon Factory Ring. The beam charge was about 200 pC/pulse and its pulse width was about 1 ns in a full width at half maximum. One data-taking cycle for a meaurement is as follows: The first is that a rough scan is performed in order to choose a corrector magnet (or a set of corrector magnets) paired with a tested BPM, in which the scanning condition is that the beam-charge loss does not exceed 30% of the beam charge, and at that time the regions of field variation for the corrector and the Q magnet are decided; the second is that for a set value of the corrector magnet the position readings of three BPMs are performed by changing a Q field (Q-scan procedure). Eight data points are measured in one Q-scan procedure, and four Q-scan procedures are repeated by changing the field of the corrector magnet. Thus, 32 data points in total for a measurement are taken under a condition less than the beam-charge loss of 30 % during the three BPMs.

5. Experimental Results

Figure 4 shows a typical example of a Q-scan result for a BPM in the vertical direction. The abscissa shows the position displacement for the tested BPM (SP564), and the ordinate indicates the differentiation of the position displacement (SP583) just after the tested BPM with respect to the variation of the field strength of the Q magnet, where SP564 and SP583 correspond to BPM_2 and BPM_3 described in section 3, respectively. The zero-cross point of the fitted line which is derived from a method of least-squares, gives the absolute center position of the tested BPM. Figures 5 (a) and (b) show the measured center positions of almost all of the BPMs along the beam line in the horizontal and vertical directions, respectively. The mean values and standard deviations were 0.0 and 0.3 mm in the horizontal direction, and those were 0.0 and 0.3 mm in the vertical direction, respectively. A consistency check for the difference of the frequency responce of the BPM due to the use of the two kinds of the beam was performed by using a BPM in sector 1. Any difference was not found within the measured error. The measured standard deviations are larger than those expected from the mechanical precision or the resolution of the BPM. The reason is not yet understood.

6. Conclusions

Absolute center-position measurement of almost all of the BPMs were performed usnig electron beams at the KEKB injector linac. The root-mean-square center positions of the BPMs deviating from the magnetic-field centers of the Q magnets were 0.3 and 0.3 mm in the horizontal and vertical directions to the beam axis, respectively.

References

[1] I. Sato, *et al.*, KEK Report 95-18 (1996).

[2] S. Kurokawa, *et al.*, KEK Report 90-24 (1991).

[3] T. Suwada, *et al.*, *AIP Conf. Procs.* 451, 1998, p.340.

[4] T. Suwada, *et al.*, *Procs. the 23rd Linear Acc. Meeting in Japan*, KEK, Tsukuba, 1998, p.175.

[5] T. Suwada, *Procs. the 10th Symp. on Acc. Sci. and Tech.*, Hitachinaka, 1995, p.269.

[6] S. Ohsawa, *et al.*, *Procs. the XVIII Int. LINAC Conf. (LINAC'96)*, CERN, Geneva, Switzerland, 1996, p.815.

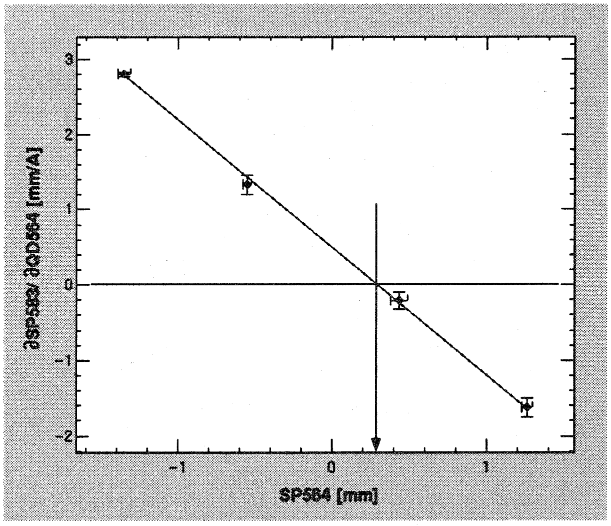
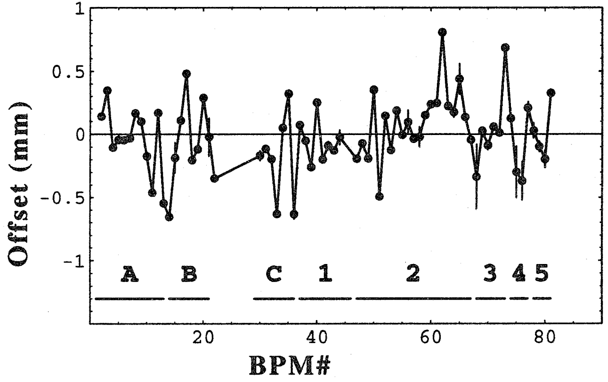
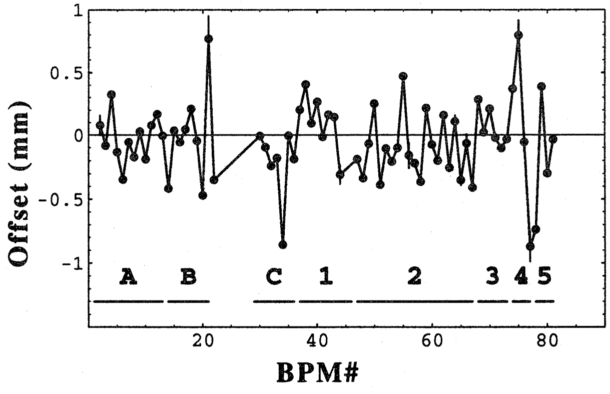


Fig.4. Typical example of a Q-scan result in the vertical direction.

(a) Horizontal



(b) Vertical



Figures 5 (a) and (b) show the variations of the measured center positions for all the BPMs in the horizontal and vertial diretion, respectively. In the figures, sector names are indicated with several lines with A, B, C, 1, 2, 3, 4 and 5, in which each line covers the region of its sector.