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TEST-BENCH CALIBRATION SYSTEM OF STRIPLINE-TYPE BEAM-POSITION MONITORS FOR THE KEKB INJECTOR LINAC

T. SUWADA AND H. KOBAYASHI

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

Abstract

About 90 stripline-type beam-position monitors (BPMs) have been newly installed in the KEKB injector linac. These monitors reinforce the handling of beam orbits and measuring the amount of beam charge for single-bunch electrons and positrons which are injected to the KEKB rings. The design value of the beam-position resolution is expected to be less than 0.1mm. A new test-bench calibration system has been developed in order to calibrate them precisely. This report describes in detail the test-bench calibration system of the BPMs, its performance and some bench-test results.

1. Introduction

The KEKB injector linac[1] is required to supply certain amounts of electron beams($8\times10^9 e^-$/bunch) and positron beams($4\times10^9 e^+$/bunch) for the KEKB high-energy and low-energy rings[2], respectively. High-current primary electron beams($6\times10^{10} e^-$/bunch) are also required to produce certain amounts of positron beams. Therefore, it is important to be able to easily handle the orbits of the beams; especially, the beam positions and currents of the primary high-current electron beams must be controlled so as to suppress any beam blowup generated by large transverse wakefields. A beam-position monitor (BPM) system has been developed to perform this function since 1992. The goal of the beam-position measurement is to detect the charge center of gravity within a resolution of 0.1mm. The amount of beam current must be precisely controlled in order to keep the positron production and beam-injection rate to the KEKB rings higher, because a well-controlled operation of its injector is required so that an optimum operational condition can be reached with as short tuning time as possible, and also to keep it during a long-term operation period. A test-bench calibration system has been newly developed in order to obtain horizontal and vertical beam positions precisely. The beam positions are calculated from the four pickup voltages of the monitor by using the calibration coefficients measured in the bench calibration. All of the BPMs were installed in the injector linac after test-bench calibrations. In the following sections the hardware of the calibration system, the method and the calibration results are reported in detail.

2. Beam-Position Monitor

A conventional stripline-type BPM made of stainless steel (SUS304) was designed based on a $\pi/2$ rotational symmetry. A photograph of the BPM is shown in fig.1. 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[3]. 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 is variable within ±5 mm by a bellows connected to one side of the BPM. A quick-release flange coupling (EVAC NW40) is used at one end of the monitor for easy installation into the beam line.

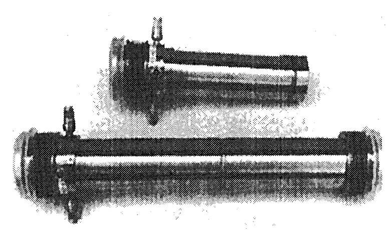

Fig.1. Photograph of the new beam-position monitors. The long BPM is directly mounted into a quadrupole magnet and the short one is fixed to one end of magnet poles.

3. Test-Bench System

Figure 2 shows a photograph of a new test bench for the BPM calibration. Two broadband transformers and a precise xy stage are placed on a 2-m-long girder. Their installation precision is less than 50 μm by fitting them with a liner, which is a precise reference plate fixed on the bench. The guirder's surface slant was measured by two balance levels and adjusted to within 0.1 mm/m. A BPM is mounted on a precise V-type block fixed on the xy stage at the girder center. The stage can move in a two-dimensional plane perpendicular to the girder surface by using a stepping motor controlled by a motor controller wihch communicates with a personal computer (PC) through GPIB. The precisions of the motor steps are 2μm/step and 1μm/step horizontally and vertically, respectively. Two broadband transformers to match the cable impedance (50Ω) to the characteristic impedance of the BPM are attached to both ends of it with bellows. A thin current-carrying wire (0.5mmϕ) is stretched by a weight of 5kg through the center of the monitor in order to simulate the beam. Leaving the wire and the matching sections fixed, the relative position between the monitor and the wire can be changed by driving the monitor precisely with the xy stage.

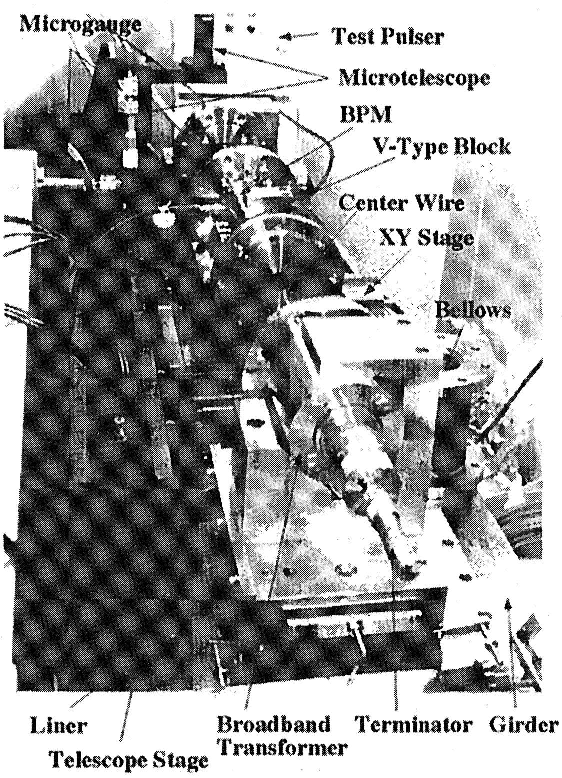

Fig.2. Photograph of the test bench for the BPM calibration.

The absolute position of the BPM center is set so that the horizontal and vertical reference lines, wihch are marked on the surface of the BPM, correspond to the wire center. This can be performed by human eyes viewing these reference lines and the wire position using two microtelescopes in both the horizontal and vertical direction. This two-telescope system is also mounted so as to fit the liner reference plate. The setting error of the BPM center is estimated to be within 50 μm. One input of the transformers is driven by a high-voltage test pulser (Kentech SPS/V/L) with a pulse width of 1ns in FWHM. The other is terminated by 50 Ω in order to reject any reflection pulses. The four signals of the BPM are picked up through 50Ω SMA feedthroughs and are transmitted to a digital oscilloscope (Tektronics TDS684A) with a sampling rate of 5GHz/sec by coaxial cables 5m long.

3. Calibration Method

All of the BPMs have been calibrated by "mapping", in which four output voltages picked up from the monitor are measured at 121 wire positions changed in the horizontal and vertical directions like a lattice around the BPM center. The step length and region was set to be 1 mm and ±5 mm, respectively. At each wire position the pickup voltages are measured 50 times and the average value and the error are stored together with the wire positions on the hard disk. The data-taking time for a BPM is about 2 hours under this condition. The calibration coefficients of the map function relate the wire positions to the pulse-height information obtained from four pickups. The horizontal (x) and vertical (y) beam positions are represented by the map functions up to a third-order polynomial, as follows:

$$x = \sum_{i,j=0}^{3} a_{ij} (\Delta_x / \Sigma_x)^i (\Delta_y / \Sigma_y)^j,$$

$$y = \sum_{i,j=0}^{3} b_{ij} (\Delta_x / \Sigma_x)^i (\Delta_y / \Sigma_y)^j,$$

$$Q = G \sum_{k=1}^{4} g_k V_k.$$

Here,

$$\Delta_x = g_1 V_1 - g_3 V_3,\ \Sigma_x = g_1 V_1 + g_3 V_3,$$
$$\Delta_y = g_2 V_2 - g_4 V_4,\ \Sigma_y = g_2 V_2 + g_4 V_4,$$

where a_{ij} and b_{ij} are the coefficients of the map functions, which are derived by fitting the map data to the map functions by using a least-squares fitting procedure; V_1 and V_3 (V_2 and V_4) are the horizontal (vertical)-pickup voltages, and g_k (k=1-4) the gain correction factors. Q is the beam charge, which is calculated by summing the four-pickup voltages, and G is a conversion factor used to calculate the beam charge, which can be measured by wall-current minitors[4]. The gain correction factors (g_k), which correct any signal-gain unbalance caused by attenuation losses of the cables and any difference in the coupling strength between the cables and the oscilloscope, were measured by fast test pulses with a width of 500ps. These parameters (a_{ij}, b_{ij}, g_k, and G) for each BPM are stored in the PC and are also summarized in a host computer as a calibration table.

4. Calibration Results

The map functions have finally been obtained after corrections concerning a gain unbalance for four channels of the oscilloscope and for the cable losses. The maximum gain unbalance of 3% was corrected. Figure 3 shows a typical example of the mapping. The horizontal and vertical solid lines show equipotential lines of (Δ_x/Σ_x) and (Δ_y/Σ_y), respectively. No large distortion of the mapping has appeared within a mapping region of ± 5mm. The wire step region was chosen so that the difference in the wire position calculated from the map function to the set position is less than 30 μm. Furthermore, for a larger region of mapping, the position difference is not very good, even when using higher order map functions, because the distortion of the mapping is larger near to the electrodes.

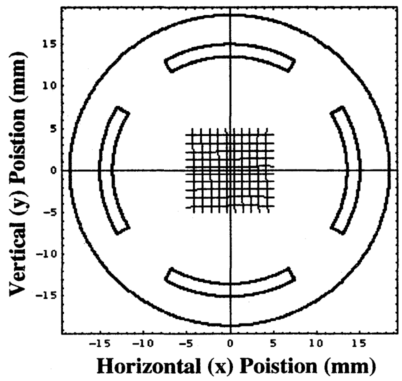

Fig.3. Typical example of a mapping result.

The lowest-order coefficients (a_{00} and b_{00}) of the map functions give the offset values of the BPM center. This means that the mechanical center of the BPM does not correspond to the electrical center, which is mainly caused by mechanical distortions of the electrodes, an impedance mismatch of the pickups and a setting error of the monitor. Figure 4 shows a scatter plot of the horizontal offsets versus the vertical ones. Almost all the offset values are concentrated within ±0.2 mm for both directions.

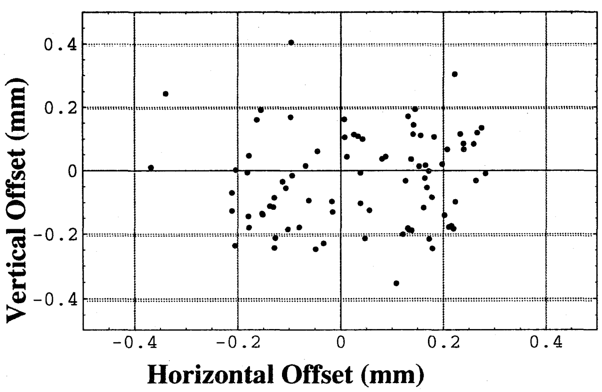

Fig.4. Horizontal- and vertical-offset plot measured by the bench calibration.

The sensitivities (S_b) of the BPM are generally formulated using the beam positions and the output voltages, as follows:

$$x=S_b\frac{V_1-V_3}{V_1+V_3},\ y=S_b\frac{V_2-V_4}{V_2+V_4}.$$

The 1st-order coefficients (a_{10} and b_{01}) of the map functions approximately give the sensitivity if the beam displacement is not very large around the BPM center. In such a case the sensitivity obeys the following formula under an approximation where the gap length between the electrode and the inner surface of the BPM is almost zero[5]:

$$S_b=\frac{R\Delta\phi}{2\sin\Delta\phi},$$

where R (=18.5 mm) is the inner radius of the BPM and $2\Delta\phi$ is the opening angle of the electrode. Figure 5 shows a scatter plot of the horizontal 1st-order coefficients versus the vertical ones. The calculated sensitivity is 9.69 mm; however, the measured ones are around 8.68 mm. The reason for the disagreement of about 10% is that the gap length and the thickness of the electrode are finite under the real BPM geometry. Here, if an effective radius (R_{eff}) is calculated using the above formula, the radius is about 16.6 mm; this length approximately gives the center position between the electrode and the inner radius of the BPM. This effect surely shows the real electrode geometry. In any case, we need a more precise BPM model in order to derive this disagreement[6]. In the figure, we can see several points apart from main distribution region ($8.6<S_b<8.7$). The reason is not very clear, and is now under investigation.

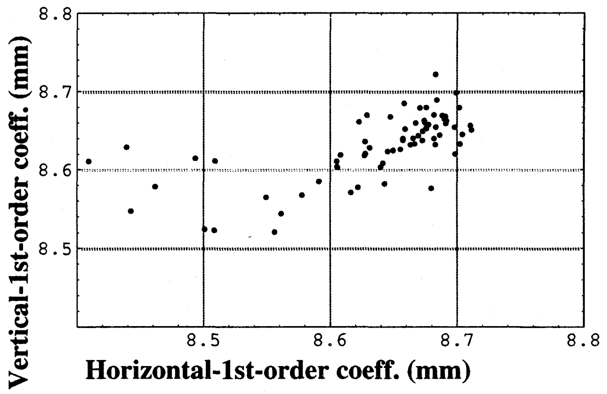

Fig.5. Horizontal and vertical 1st-order coefficient plot measured by the bench calibration.

5. Summary

A precise BPM calibration system using a PC has newly been developed for the KEKB injector linac, and after calibration all of the BPMs have been installed in the linac beam line. The horizontal and vertical offset values of the BPMs are within about ±0.2 mm. The 1st-order calibration coefficients are around about 8.68 mm. Since they do not correspond to the simple BPM model, we need a more accurate model by taking into account of the finite gap length between the electrode and the inner surface of the BPM.

References

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