

Beam Position Monitor System for KEKB

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Abstract

The Beam Position Monitor (BPM) System for KEKB is now under construction. The system was designed to be able to measure closed orbit with a high accuracy less than $1\ \mu\text{m}$ within a few seconds. In order to fit to various modes of the multi-bunch operation, we chose a pickup frequency of 1.018 GHz of a beam signal, twice the accelerating RF frequency.

Since the system must measure closed orbit for a multi-bunch (5000), high-current beam (low energy ring LER 2.6A, high energy ring HER 1.1A), we paid attention to improve it about the following, the pickup electrode, the transmission line, the switch, the front-end electronics and the BPM support. This paper describes the system requirements, the design result of the system, and the laboratory test.

1 Introduction

The design of Beam Position Monitor System for KEKB[1] was based on some precious experience in the BPM for TRISTAN[2], such as a multipacting discharge phenomena in the button electrodes, the increase phenomenon of contact resistance at the center conductor of the electrode connector, radiation damage of transmission cable, trouble of the coaxial switch by the life. Moreover the measurement time of the Closed Orbit Distortion (COD) was too long (over 90 seconds). The BPM heads (451 BPMs for LER, 442 BPMs for HER) will be installed in almost all quadrupole magnets. Furthermore, for beam orbit feedback of the collision point, two BPM heads will be installed at the point of QCS magnets, too. Since the system is required to measure the beam position with a high accuracy better than $10\ \mu\text{m}$ in a short time within a few seconds, we adopted basically same slow method as the TRISTAN BPM system which measures the average position for the several thousand turns with signal processing circuits as many as possible.

To measure beam position of turn by turn, fast signal processing circuit will be also installed in each of 20 local control rooms[3]. The slow system and the fast system will share a beam signal from the same BPM head.

In addition to the above, there are some development, such as coaxial switches made by semi-conductor with long life, VXI (VME-bus Extensions for Instrumentation) standard module for high-speed processing of the data and Poly-Ethere-Ethere-Ketone (PEEK) semi-rigid cable with radiation resistance.

2 BPM block

Since the pickup electrode of BPM is exposed a high current beam field, we paid special attention. To realize sufficient mechanical strength and to withstand the expected transmission power, an N-type feed-through with a modified center conductor having a large diameter ($\phi 4\text{mm}$), together with a spring contact, is employed. To reduce the pickup

power, we adopted a small diameter ($\phi 12\text{mm}$) of the electrode. Figure 1 shows two types of pickup electrodes in the LER and in the HER.

Close attention was paid to both of resonance higher order mode (TE₁₁) at the button and trapped mode in the ceramic seal[4]. To avoid the growth of coupled bunch instabilities in the HER, we adopted the cross section shapes of the feed-through and the rod electrode which may be made non-axially-symmetric. Heating problems of the ceramic seal was solved by optimizing size of the one.

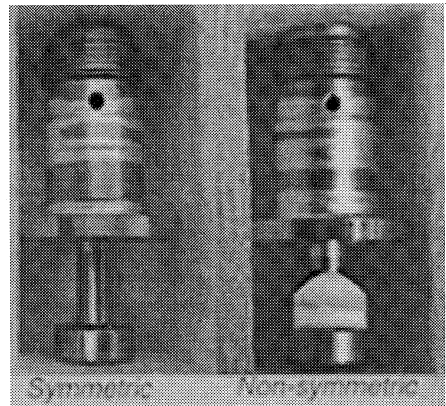


Figure 1: Electrodes for BPM.

The KEKB vacuum chamber is made of copper to withstand a high peak heat load, and to shield radiation from the beam. Therefore, the BPM block is also made from a solid piece of copper. Four feed-throughs with electrodes are brazed onto the block. Two stainless steel frames are brazed to the block, in order to prevent deformation. Four-hundred-thirty-two BPM blocks for LER arc sections and fifty-two ones for RF sections have already finished manufacture. And four-hundred-eight ones for HER arc sections and twenty-six LER local correction area are being manufactured at present. And we are designing two kinds of BPM block for beam injection chamber in others. Figure 2 shows the BPM blocks for the LER arc and the HER arc.

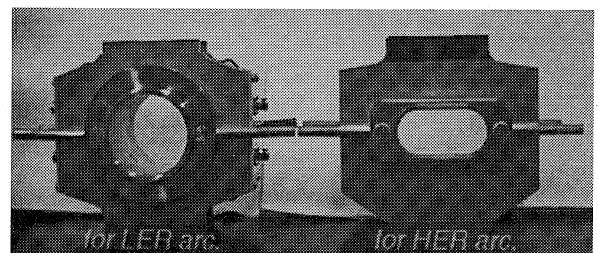


Figure 2: BPM blocks for KEKB

The completed BPM assembly is supported firmly and precisely at the end of a quadrupole magnet, as shown in

Figure 3. The flat surface of two frames also serves as a reference plane for the measurement of mechanical and electrical offset of the BPM. After installation, the BPM positions relative to the quadrupole magnets will be measured within several tens of a μm , and the data will be used to correct the measured beam position data.

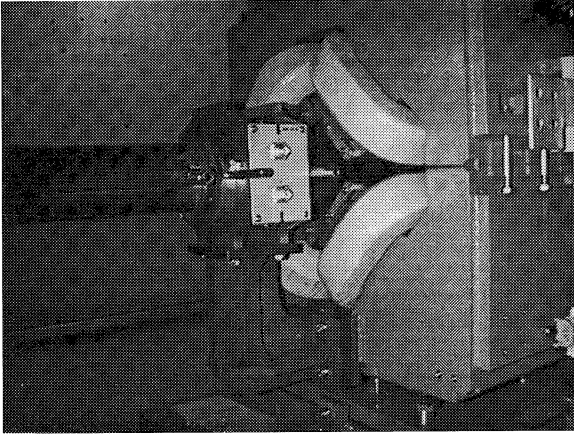


Figure 3: Support of the BPM block.

3 Calibration

Before welding the BPM-head to the beam pipe, all BPMs will be calibrated at a test bench (Figure 4) where the electrical center of the BPM is identified with a high degree of accuracy by using a movable antenna (1.018GHz CW signal). The measurement is made at the 273 mesh points in the central area of $\pm 10\text{mm}$ (horizontal) \times $\pm 6\text{mm}$ (vertical) with 1 mm step. Setting of a BPM block, movement of antenna probe and data taking are automatically controlled by a micro-computer.

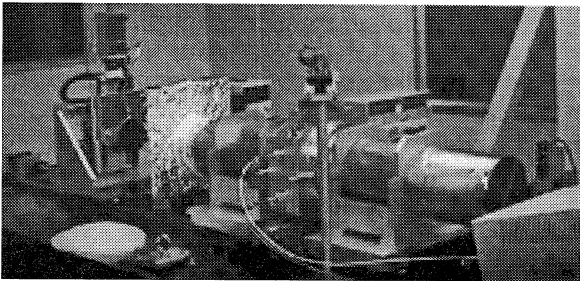


Figure 4: Test bench for BPM calibration.

We set an antenna at the position (X,Y) and measure the four electrode outputs (A,B,C,D), and then obtain the normalized quantities (H,V) by

$$H = \frac{A - B - C + D}{A + B + C + D}, \quad V = \frac{A - B - C + D}{A + B + C + D}.$$

Next, the mapping data are fitted by least-square method to third order polynomials of

$$X = \sum \{k_x(i,j) \cdot H^i \cdot V^j\}, \quad Y = \sum \{k_y(i,j) \cdot H^i \cdot V^j\}$$

where $0 \leq i, j \leq 3$, $0 \leq i+j \leq 3$. In these expression, $k_x(0,0)$ and $k_y(0,0)$ gives the deviation of the electrical center from

the geometrical one, and $k_x(1,0)$ and $k_y(0,1)$ are reciprocals of sensitivity of BPM in the x and y direction, respectively.

As another method of calibration, a practical model for output signals of BPM electrodes was proposed to define a geometric monitor center by assuming that each electrode has its ideal position-response function. We can give a precise definition of geometrical center of KEKB BPM[5].

4 Signal processing method

The following performance requirements have been given to the BPM read-out system design; such as the position resolution better than $10\mu\text{m}$, the COD measuring time within a short time of ~ 1 second and beam current range of $10\text{mA} \sim 2.6\text{A}$.

In order to satisfy these requirements, we have adopted basically the same signal processing method as that of the TRISTAN Main Ring BPM read-out system. Four beam signals from each pickup unit are detected with a common detection circuit, which detects a higher harmonic component of the revolution frequency.

The signal detection circuit consists of a super-heterodyne circuit, a 16 bits ADC and Digital Signal Processor (DSP). Figure 5 shows a block diagram of the front-end electronics. In order to measure beams with any multi-bunch configurations, a pickup frequency of 1.018GHz has been chosen. This corresponds to twice the accelerating RF frequency, and the 10240'th harmonic of the revolution frequency ($\sim 99.9\text{KHz}$).

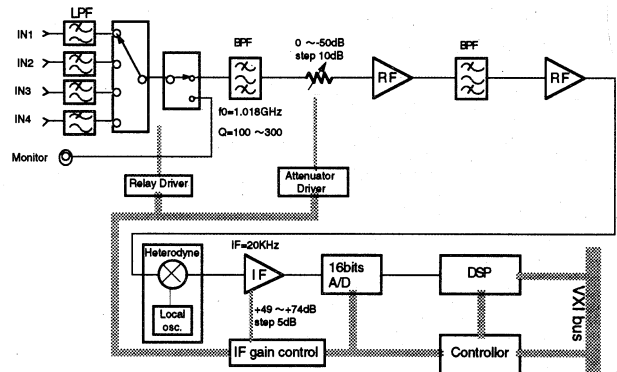


Figure 5: Block diagram of the front-end signal processor.

The super-heterodyne circuit converts a pickup frequency into an intermediate frequency (IF=20KHz). To obtain good linearity in a wide signal dynamic range, the rectifier stage such as a synchronous detector is removed out. The IF signal is digitized directly by the ADC with 100kHz sampling rate, and the frequency spectrum is calculated by a DSP with the 2048 points FFT (Fast Fourier Transformation) to obtain the required signal which appears at the spectrum peak. The DSP has a data average function to increase the S/N ratio. The effective S/N ratio will reach 92dB which corresponds to the resolution of less than $1\mu\text{m}$ (rms) in the position measurement for the 10mA beam at the HER.

We tested the position resolution by using prototype of the signal processing module. We inputted to the module four signals that the source signal (1.018 GHz) was distributed by a RF divider circuit and measured the test data repeatedly many times. Then the inputted signal level was -60 dBm, the sampling conditions was changed as follows:

the FFT measurements of 128, 512, 2048 points and the average of 128, 32, 8 measurements. As a result of the test, we confirmed the performance of S/N ratio within 92dB and measuring time less than one second per a BPM as shown in Table 1.

Table 1: Resolution & Measuring time

FFT points* Average.	S/N ratio [dB]	Resolution [μ m]rms	Measuring time[sec]
128*1	71.6 \pm 0.1	4.5	0.007
512*1	77.7 \pm 0.1	2.2	0.027
2048*1	83.4 \pm 0.1	1.2	0.110
128*128	92.2 \pm 2.0	0.4	0.820
512*32	91.9 \pm 0.8	0.5	0.839
2048*8	91.7 \pm 0.2	0.5	0.867

In the early stage of KEKB operation, we will install 240 front-end signal processing modules and 480 RF switching modules. Therefore four BPMs of the LER and the HER will be multiplexed to a common circuit and we can measure the closed orbits of two rings within a few seconds.

5 Layout of the BPM system

A schematic layout of the Beam Position Monitor system is shown in Figure 6. The electronics units are distributed in 20 local control buildings around the ring. The beam signal from the four pickup electrodes for each BPM are transmitted through independent coaxial cables (the average length is 80 m long).

A 20 cm long radiation-resistant PEEK insulation cable is used between the pickup electrode and the signal transmission cable to overcome possible damage due to radiation. The expected radiation dose at the BPM connector is 7.3×10^5 (9.1×10^7) rad/year for the LER(HER). This radiation level is manageable by the radiation resistant cable. The results of the irradiation experiment proved that PEEK insulation cable withstand 1 Grad of γ -ray irradiation.

At the input of the detection circuits the signals are selected by RF switches. The effects of the cable impedance variation during a period of several days have been evaluated for signal cables of the TRISTAN BPMs. It has been found that the equivalent shift of the measured beam position due to such effects is less than 10μ m. Since the frequent measurement of the beam orbit is expected at KEKB, the use of mechanical RF switch was abandoned at the early stage of the design studies. We considered two types of RF switches: a PIN diode switch and a mercury switch. The result of the on/off switching test, the measured fluctuation of the insertion loss was less than 1×10^{-4} for both types of switches. This contact fluctuation translates into a measurement error of $<10\mu$ m. We chose a PIN diode switch after all, as it was good characteristic as compared with a mercury switch.

After installation of the BPM system, we will also calibrate each gain ratio of all BPMS about signal transmitting from a BPM head to a front-end circuit, such as a loss factor of a long cable and a attenuation of constant of low pass filter and RF switch, using a specially designed 4-fold reference signal distributor.

The digital data calculated by signal front end processor is sent to a VXI bus of mainframe in each local control room, where they are transformed into beam position data. Each VXI station is linked directly to VME-bus of IOC(Input / Output Controller) of EPICS which is the control system for the KEKB [6], by the high-speed Multisystem eXtension Interface bus(MXI). The IOC and UNIX work station for the operator's consoles are connected through a high-speed network, such as FDDI.

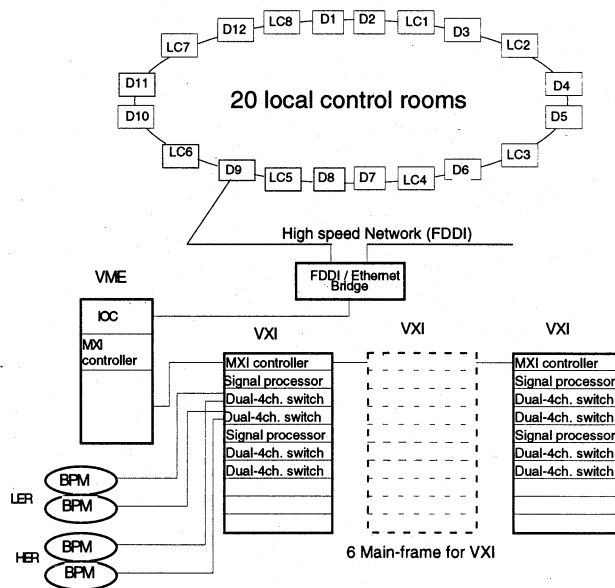


Figure 6: Schematic of the BPM system.

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