Design of Beam Position Monitor System for KEKB

N.Akasaka, M.Arinaga, S.Hiramatsu, T.Ieiri, H.Ishii, K.Mori, T.Obina,
T.Shintake, and M.Tejima, KEK,Tsukuba,JAPAN

Abstract

The KEKB Beam Position Monitor(BPM) system will have about 900 BPMs, each of which is installed near every quadrupole magnet in the ring. The BPM data will not only be used for correcting closed orbit distortion and optimizing the operation of the ring, but also used for analyzing the alignment and strength errors of magnetic components. This requires the BPM system to have good stability and high precision. Therefore, we adopted slow method measuring the average beam position during many turns. Since a multi-bunch(5000), high-current beam(LER 2.6A, HER 1.1A) will be stored at KEKB, special attention must be paid to the design of the pickup electrode, transmission line, switches and front-end electronics. This paper describes the design of a BPM system for KEKB.

1 BPM block

Important design considerations for the KEKB BPM block are as follows:

- Reduce the pickup beam power by using electrodes with a small diameter,
- Transfer the beam power safely through a tough feed-through with sufficient mechanical strength and power capacity,
- Suppress the higher-order mode resonance in the electrode assembly,
- Minimize mechanical deformation of the unit to improve the measurement precision,
- Assemble the unit with reliable brazing processes,
- Support the unit firmly and precisely with respect to the adjacent quadrupole.

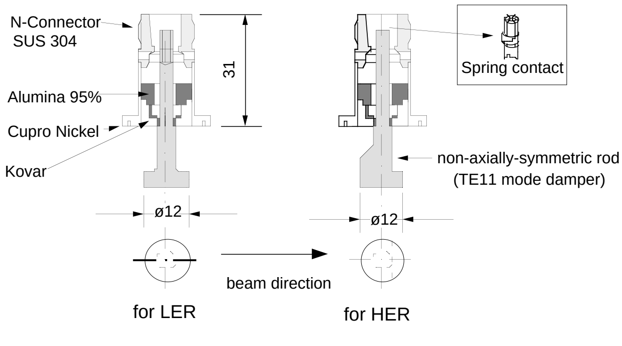

Figure: 1 BPM electrodes for KEKB.

Figure 1 shows the dimension of the pickup electrodes in the low energy ring (LER) and in the high energy ring(HER). 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(ø4mm), together with a spring contact, is employed.

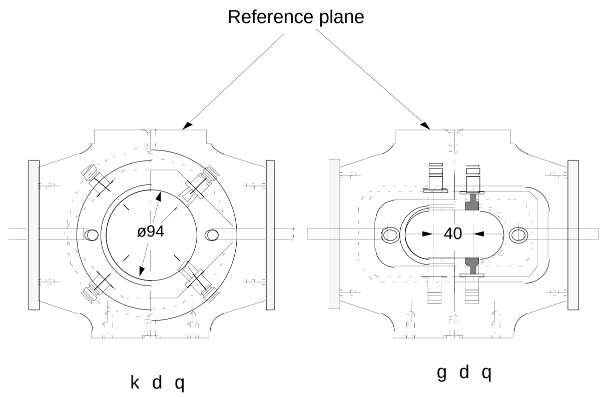

Figure: 2 BPM blocks for KEKB

The KEKB vacuum chamber is made of a copper material 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, as shown in Figure 2. Two stainless steel frames are brazed to the block, in order to prevent deformation. 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 the frame also serves as a reference plane for the decision of mechanical and electrical offset of the BPM.

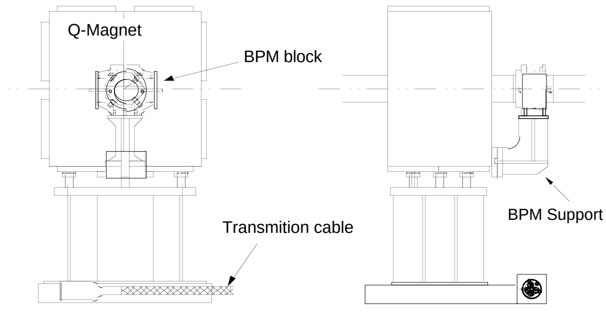

Figure: 3 Support of the BPM block

All BPMs will be tested at a calibration bench where the electrical center of the BPM will be identified with a high degree of accuracy by using a movable antenna.

During 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.

Since the 1 GHz component of the signal (i.e. 2nd harmonic of the RF frequency) will be used for beam position measurement, it is not necessary to be concerned about the VSWR over a wide frequency range. However, to avoid the growth of coupled bunch instabilities and heating problems of the ceramic seal, close attention was paid to the resonance impedance of the BPM electrode and the feed-through structure. One of the most harmful resonance modes against beam stability is the TE110 mode, which is expected in the 7.3~7.9GHz frequency range. Our calculations indicate that the coupling impedance of the TE110 mode may be sufficiently low , so that the beam instability due to this mode may not be a concern in the LER. But in the HER the total impedance of all BPMs due to this resonant mode has attained 8kΩ, which is over the acceptable limit(7.1kΩ). The HER BPM has been designed to use the cross section shapes of the feed-through and the rod electrode which may be made non-axially-symmetric to suppress the TE11 mode within the structure. As for the other resonance modes which may be trapped inside the feed-through structure, it is planned to optimize the size of the ceramic seal, thereby shifting the resonance frequency off the RF harmonics as shown in Figure 4.

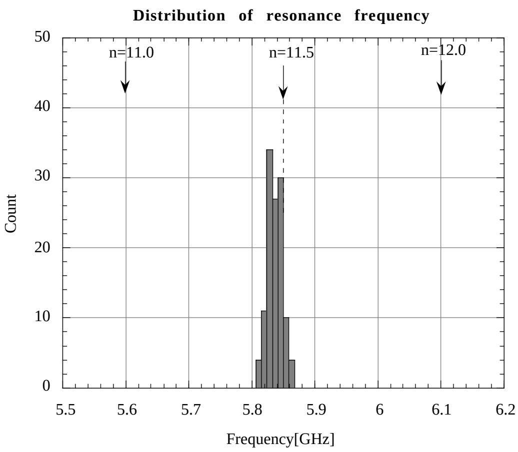

Figure: 4 Distribution of resonance frequency in the BPM feed-through.

2 Signal processing method

The following performance requirements have been given to the BPM read-out system design:

- The position resolution should be better than 10μm,
- The COD measurement must be completed within a short time of ~1 second,
- The system must function for a beam current range of 10mA~2.6A.

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 an 1GHz component a higher harmonic of the revolution frequency. With narrow band signal processing and by using a common detector, measurement errors reduced and the precision improved.

The expected position resolution and the measurable range of the beam signal have been estimated. The calculation assumed that the geometrical sensitivity coefficient K of typically 26 mm, and it includes the effects of the thermal noise of the detection circuit, including the signal cable. Figure 5 shows the expected position resolution as function of the beam current for a varying frequency band-width Δf. The resolution improves in proportion to the beam current, and to the inverse of the square root of the band width. From this study, the bandwidth has been chosen to be Δf =100Hz, so that the resolution, including the thermal noises, would be better than 10μm at the beam current of 10mA. In the case of the single bunch operation, the bandwidth must be significantly decreased, because the transient signal amplitude limits the dynamic range, and it becomes difficult to keep the noise figure small. Optimization for the single bunch measurement is now under consideration.

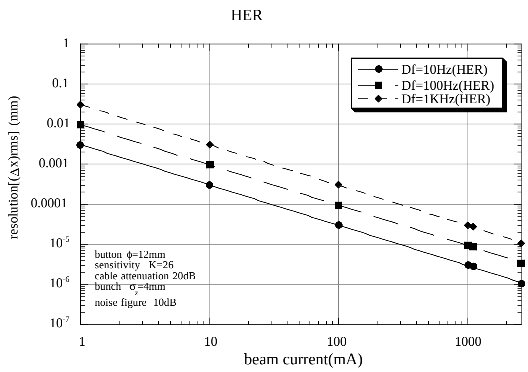

Figure: 5 Expected position resolution determined by the thermal noise.

3 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 100m long). A 20 cm long radiation-resistant cable, such as a PEEK (poly-ether-ether-keton) insulation cable, will be 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 will be manageable by the radiation resistant cable.

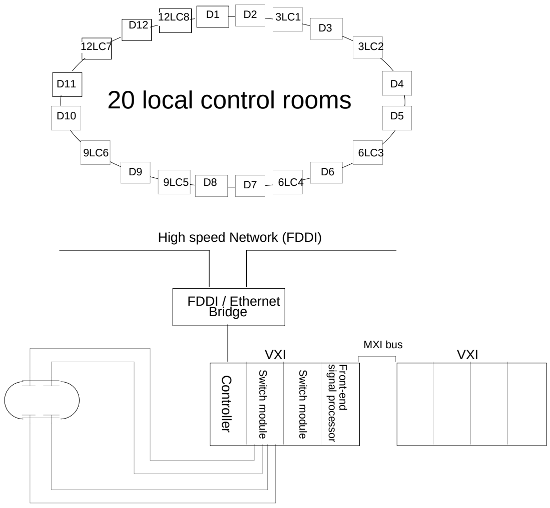

Figure 6 Schematic of the BPM system.

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 10μm. 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. Two types of RF switches are currently under consideration: a PIN diode switch and a mercury switch. In the on/off test of 5×10^6~1.4×10^7 switching, 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 <10μm.

The signal detection circuit consists of a super-heterodyne circuit, a 16 bits ADC and Digital Signal Processor(DSP). Figure 7 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 (~99.9KHz).

The super-heterodyne circuit converts a pickup frequency into a 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 16 bit 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 ~1μm in the position measurement for the 10mA beam current with Δf=100Hz at the HER. The digital data will be sent to a VXI bus (VME-bus Extensions for Instrumentation) mainframe in each local control room, where they are transformed into beam position data. Each VXI station will be linked to a workstation through a local area network.

The shortest possible measurement time is determined by the sum of the switching time of the RF switch (~ 4×2ms), the response time of the front-end processor (~ 4×100ms). Each front-end signal processor has an individual A/D converter to minimize the conversion time and the data acquisition time. If each BPM signal is managed by an individual front-end processor, a short data acquisition time of ~0.6s is expected, thus satisfying the ultimate performance requirement described earlier. In the early stage of operation, signals from the BPMs will be multiplexed to a common circuit to reduce the system cost. For example, if 4 BPMs share a common circuit, the measuring time will be ~3sec. However, since the signals from all BPM electrodes are delivered through separate cables, the signal processing time will be shortened by incrementally adding circuits in the electronics house.

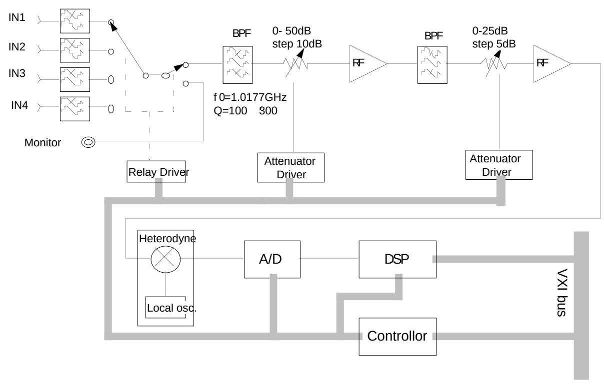

Figure 7 Block diagram of the front-end signal processor.

REFERENCES

[1] 'Damped Button Electrode for B-Factory BPM System', by T.Obina, T.Shintake, Y.H.Chin and N.Akasaka, in proceedings of the 1995 IEEE Particle Accelerator Conference , Dallas, Texas, U.S.A./KEK Preprint 95-41.

[2] 'The Present Status of the KEKB Project', by S.Kurokawa, in proceedings of the same coference.

[3] 'KEKB B-Factory Design Report', KEK Report 95-7 August 1995.

[4] 'BEAM POSITION MONITOR SYSTEM OF TRISTAN MAIN RING, in proceedings of the 6th symposium on Accelerator Science and Technology, Tokyo, Japan, 1987.