BEAM DIAGNOSTICS OF SUPERKEKB DAMPING RING

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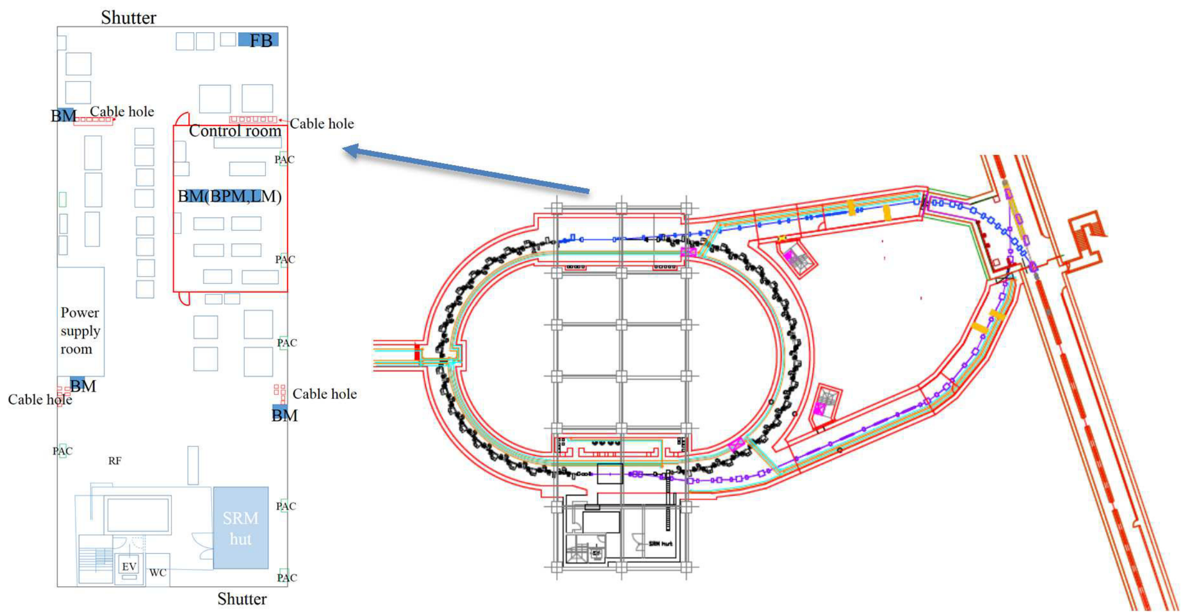

Figure 1: Layout of the SuperKEKB DR.

Abstract

The KEKB accelerator ceased operation in 2010, and is being upgraded to SuperKEKB. Adopting low emittance and high current beams, the design luminosity is set at 40 times larger than that of KEKB. We are constructing a damping ring (DR) in order to achieve a low-emittance positron beam for injection. Turn-by-turn beam position monitors (BPMs), a transverse feedback system, a synchrotron radiation monitor (SRM), a DCCT, loss monitors using ion chambers, a bunch current monitor and a tune meter will be installed for beam diagnostics at DR. An overview of the instrumentation of DR will be presented in this paper.

INTRODUCTION

The KEKB collider is being upgraded to SuperKEKB in order to improve the luminosity. The beam energy of the Low Energy Ring (LER) is 4 GeV for positrons, and that of the High Energy Ring is 7 GeV for electrons. The beam currents are 2.6 A in HER and 3.6 A in LER. LER injection system includes a 1.1 GeV DR [1,2]. Machine parameters of the SuperKEKB DR are shown in Table1. The construction of DR will be finished in Japanese FY 2013 and the first beam is expected in FY 2015.

Table 1: Damping Ring Parameters

Parameter		unit
Energy	1.1	GeV
Maximum bunch charge	8	nC
No. of bunch trains/ bunches per train	2/2	
Circumference	135.5	m
Maximum stored current	70.8	mA
Horizontal damping time	10.9	ms
Injected-beam emittance	1700	nm
Equilibrium emittance(h/v)	41.4/2.07	nm
Maximum x-y coupling	5	%
Emittance at extraction(h/v)	42.5/3.15	nm
Energy band-width of injected beam	±1.5	%
Energy spread	0.055	%
Bunch length	6.53	mm
Momentum compaction factor	0.0141	
Cavity voltage for 1.5 % bucket-height	1.4	MV
RF frequency	509	MHz

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A DR vacuum chamber is an ante-chamber of 24mm height to reduce the beam instability which is caused by the coherent synchrotron radiation and light mask [3]. The beam monitors of DR are based on those of the main rings. Some of the KEKB monitors are re-used for DR. The system of the DR monitors is shown in Table 2. The layout of the DR monitors is shown in Fig. 1. There are 4 monitor stations near the cable holes from the tunnel to a DR power supply building. A few VME racks and NIM BINs for BPM signals are located there. Each station is connected through network and supplied with the RF (508.887MHz), revolution and bunch timing signals. FB and DCCT signals are sent to one of the stations. Loss monitor signals are collected at the control room and the SRM signal is collected and analysed in the SRM hut.

Table 2: Number of Beam Monitor in DR

System	Quantity
Beam position monitor (BPM)	83
Transverse bunch by bunch feedback (FB)	1
Synchrotron radiation monitor (SRM)	1
Loss Monitor	34
DCCT	1
Bunch current monitor	1

BEAM POSITION MONITOR

A button electrode with a diameter of 6 mm has been developed. Two button electrodes are attached in one flange due to narrow space for their installation as shown in Fig. 2. A detector of the BPM is a log-ratio (LR) detector accommodated in a VME 18K11 L/R detect circuit [4]. In DR, the beam usually stays in only 40ms in the ring, and the bunch distance changes in short time. Thus, we take turn-by-turn method to read 4 electrode signals at the same time. We take the data of 32k or 64k turns by turn-by-turn method and performs data handling in IOCs.

Figure 3 shows the mapping result which is calculated by the LR method based on the charge distribution using boundary element method. The input positions of charge distribution are changed by 1mm step in horizontal and vertical directions to $\pm$10mm. The beam position by the LR method are calculated as

$$x = k_x(\log V_A - \log V_B - \log V_C + \log V_D)$$
$$y = k_y(\log V_A + \log V_B - \log V_C - \log V_D), \quad (1)$$

where V_A, V_B, V_C and V_D are the signals from each electrode. Figure 4 (A) shows the horizontal beam position which is calculated by the LR method when the vertical beam position is fixed to 0, 2 and 5mm. Figure 4 (B) shows the vertical beam position when the horizontal position is fixed to 0, 2 and 5mm. The result does not greatly deviate from a linear approximation within about $\pm$5mm in both directions. While we use same type of BPM as that for the main rings (MRs) in a few place, the two button electrode is used in most place because of tight space for installation.

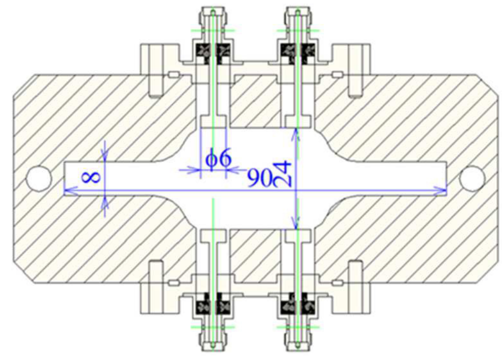

Figure 2: BPM monitor chamber.

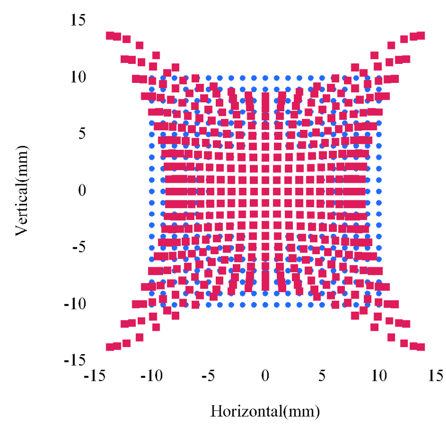

Figure 3: Mapping of beam position using the log-ratio method.

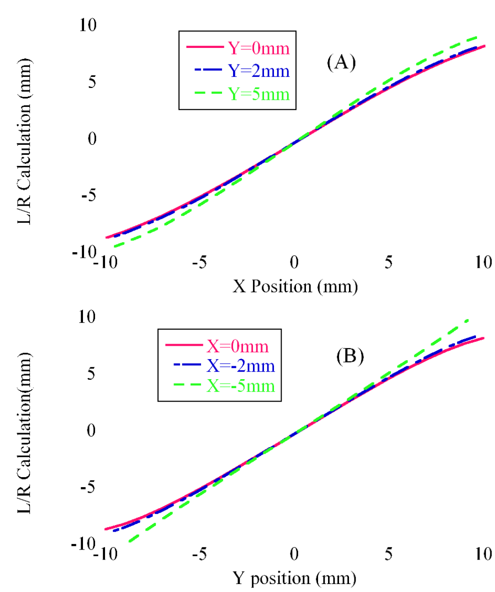

Figure 4: The beam position v.s. the result of the LR calculation method when we fixed a vertical position and changed the horizontal position (A) and when we fixed a horizontal position and changed the vertical position (B).

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SYNCHROTRON RADIATION MONITOR

We designed a SRM to measure a beam size [5]. Synchrotron light is extracted from a bending magnet with bending radius of 3.14m located near a straight section for beam extraction. The light is led to the SRM hut through a pit under a floor in a tunnel as shown in Fig. 5. Level of the SRM hut is same as that of the tunnel in order to make propagation distance of the light as short as possible (<10m). A horizontal and vertical beam sizes at a source point of the light are 380μm and 75μm respectively. A bunch length is longer than 6.5mm. The transverse beam size is measured by an interferometer and a gated camera, and the bunch length is measured by a streak camera.

Resolution of the beam size measurement depends on diffraction of the light. The opening height of the extraction chamber is 8mm at 590mm downstream from the light emission point. Diffraction patterns calculated by following Fraunhofer formula [6] are shown in Fig. 6(a),

$$F(x,y) = \left(\frac{\sin(2\pi ax/\lambda L)}{2\pi ax/\lambda L}\right)^2 \left(\frac{\sin(2\pi bx/\lambda L)}{2\pi bx/\lambda L}\right)^2, \quad (2)$$

where a and b are opening size of the x and y direction, L is the distance from emission point to extraction point of SR and λ is the wavelength. Figure 6 (b) shows the convolution of the quantum efficiency of the camera and the Fraunhofer diffraction pattern at λ = 200nm - 900nm. We get 12μm resolution by Gaussian fit of the convolution distribution. This is small enough in comparison with beam size. The longitudinal resolution is 1psec that is caused by the measurement accuracy of the streak camera.

The extraction mirror of SR is a Beryllium mirror which we used in KEKB. When the power to the mirror is too large, it may cause the deformation of the mirror [7]. Emission power per unit angle and the total radiation power from the magnet are calculated by the following expression [8],

$$\begin{pmatrix}\frac{d^2P_\sigma}{d^2\Omega}\\ \frac{d^2P_\pi}{d^2\Omega}\end{pmatrix} = \left[\frac{7}{64\pi}\frac{e^2}{\varepsilon_0}\frac{\gamma^5}{\rho}\frac{I}{e}\right]\frac{1}{(1+\gamma^2\psi^2)^{5/2}}\begin{pmatrix}1\\ \frac{5}{7}\frac{\gamma^2\psi^2}{1+\gamma^2\psi^2}\end{pmatrix}[W/rad^2] \quad (3)$$

$$\begin{pmatrix}P_\sigma\\ P_\pi\end{pmatrix} = \frac{2}{3}\frac{e^2}{4\pi\varepsilon_0}\frac{\gamma^4}{\rho^2}\frac{I}{e}l\begin{pmatrix}7/8\\ 1/8\end{pmatrix}[W] \quad (4)$$

where I is beam current, e is the electric charge, ε_0 is the vacuum dielectric constant, ρ is radius of the bending magnet, and *l* is the orbital length. The result is shown in Fig. 7(a) when we calculate with DR parameters. The total power is 70.5W when the maximum current is injected to DR. The power to the extraction mirror is 17.9W. We can provide the mirror and mirror cooling system used in KEKB. Figure 7 (b) shows the spectral angular density of the flux in the DR SRM. It is 2.99E+5[photons/0.1%band width/nC] for a wavelength 550nm used for the measurement and the band width of 0.1% in DR. The measurement in DR is possible down to 0.1nC bunch which emits photons of the same level as that from 5nC bunch of KEKB LER.

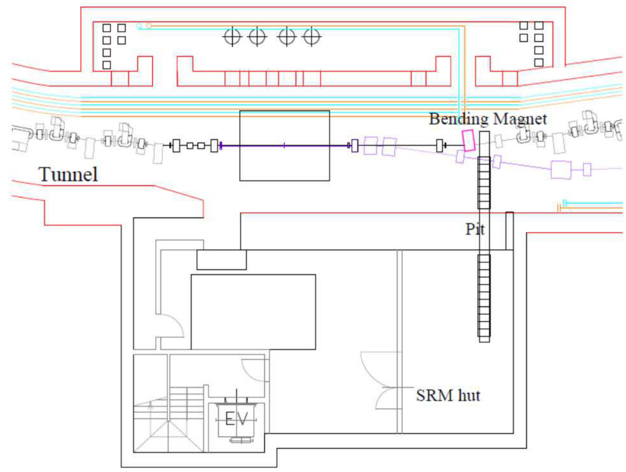

Figure 5: Layout of the DR SRM line.

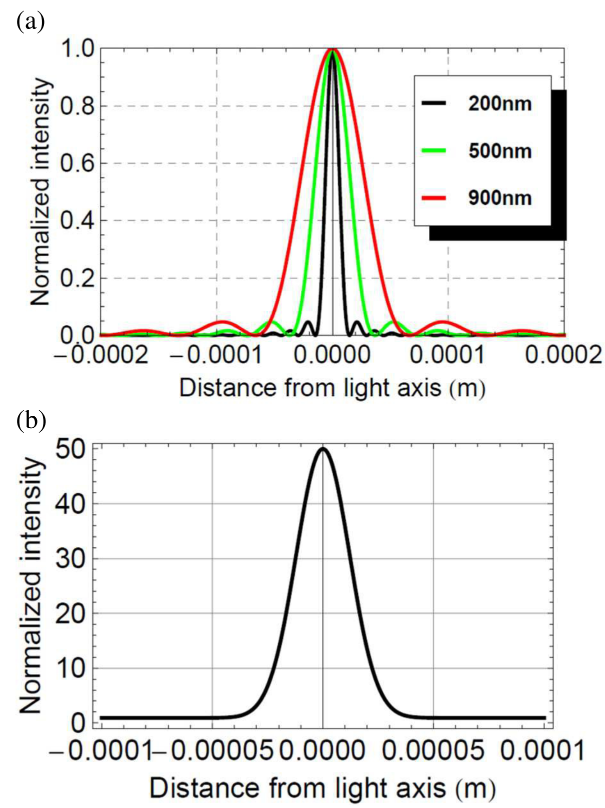

Figure 6: (a) A pattern of the Fraunhofer diffraction at the extraction mirror of the SR with λ = 200nm, 500nm and 900nm. (b) The convolution of the quantum efficiency of the camera and the Fraunhofer diffraction pattern of λ = 200nm - 900nm.

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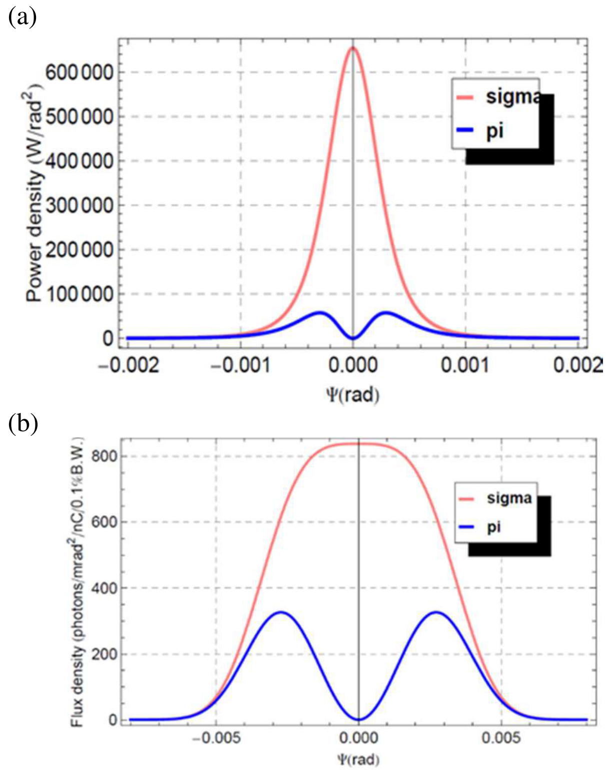

Figure 7: σ component and π component of (a) the emission power density and (b) spectral angular density of flux [photons/s/rad2/0.1%band width/A] from the bending magnet.

BEAM LOSS MONITOR

The DR LM is not used for an interlock signal giving a beam abort. It is used for commissioning, injection tuning and monitoring in routine operation. The maximum beam current is 70mA which corresponds to 8nCx4bunch accumulation. As for the injection efficiency of DR, the normal beam loss is estimated to be 2.5% near the injection point and 2.7% in all other arc sections. Alternatively, around 20% of loss is expected in a collimator part. It is necessary to have enough sensitivity when loss more than expected happens.

Ion chambers which are shown in Fig.8 are reused sensors that are used for KEKB linac. It is a 9 m FC-20D co-axial cable. The inner and outer conductors are separated by an air gap. A positive potential of 200V is applied to the outer conductor to collect the electrons. The positive ion is collected to the inner collector with typical drift time of 1 ms. The IC will be mounted on the cable rack or magnet in the DR and LTR/RTL tunnel. Read-out electronics consist of an integrator and an amplifier. The amplifier gain is selected to 1, 10 and 100. The IC is sensitive down to the loss of around 0.1mA/s. DR beam loss is expected to be smaller than loss in MR. The read-out gain will be adjusted based on simulation. The signal is sent to ADC which is developed for the DR and MR LM and logged in SuperKEKB logging system. Pin photo-diodes and optical fibers are also installed to check the beam loss situation in detail as backup.

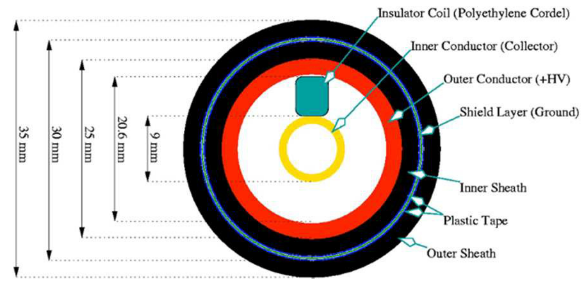

Figure 8: Ion chamber for the beam loss monitor.

OTHER MONITORS

Bunch feedback system is installed to damp the residual bunch oscillation at injection and extraction. The detector uses 2GHz detection as same as that of MR. A digital filter is the iGp with firmware matched with DR. Power amps (250W x 4) are spares of KEKB.

A DCCT for beam current measurement is reuse of KEKB with modification of the detection circuit.

A data logger is prepared for the temperature monitoring of FB system and at SRM stations.

A bunch current monitor and a tune meter are in the R&D stage.

SUMMARY

The preparation of the beam monitors of the SuperKEKB DR is in progress for a start-up in 2015. The installation schedule is very tight because the power supply building is completed in 2014 spring.

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