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SYNCHROTRON RADIATION MONITOR FOR SuperKEKB DAMPING RING IN PHASE-III OPERATION

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Abstract

The SuperKEKB damping ring (DR) was commissioned in March 2019, before main ring (MR) Phase-III operation. The design luminosity of SuperKEKB is 40 times higher than that of KEKB with high current and low emittance. We constructed the DR in order to deliver a low-emittance positron beam. A synchrotron radiation monitor (SRM) has been installed for beam diagnostics at the DR. A streak camera and a gated camera were used for measurement of the damping time and the beam size. This paper shows the design of DR SRM and the result of the measurement.

INTRODUCTION

SuperKEKB is an electron-positron collider and constructed in 2011 towards the luminosity of $8x10^{35}cm^{-2}s^{-1}$ that corresponds to 40 times higher luminosity as large as KEKB. The beam energies are 7 GeV and 4 GeV for the electron ring (HER) and the positron ring (LER), respectively. Phase-I was the test operation of the main ring (MR) for confirmation that there was no problem in accelerator from February 2016 through June [1]. We installed the Belle-II detector and remodelled injection region of an accelerator for Phase-II operation. The beam commissioning was from March 2018 to July [2]. It is necessary to squeeze the vertical beam size to nm level at the collision point to achieve the design luminosity. We built the damping ring (DR) in order to achieve a low-emittance positron beam and started the operation on February 2018[3,4]. Main design parameters of SuperKEKB MR and DR are shown in Table 1. Phase-III operation was done from March 11th to July 1st2019. We started the collision data acquisition and aimed at improving the luminosity by increasing the beam currents and squeezing the beam size by beam tuning [5]. DR system works smoothly, and we measured DR parameters using a synchrotron radiation monitor at Phase-III operation.

SYNCHROTRON RADIATION MONITOR OF DAMPING RING

Main parameters of the DR synchrotron radiation monitor (SRM) are shown in Table 2. SRM uses the light from a bending magnet with a bending radius of 3.14m [6]. The magnet is located just after beam extraction point of DR. The beryllium mirror which we used in KEKB was installed to 0.5m downstream of the magnet to extract the light. That is a water-cooled mirror and the power from the light is 3.0W for maximum current of Phase-III that corresponds to 1/10 of KEKB LER. We don't need to care about the deformation of the mirror. Four transfer mirrors are set in the pit under the tunnel floor to the SRM room which is in the same level as that of the tunnel as shown in Fig.1. The mirrors are remotely controlled by the pulse motors to adjust the light axis by using real synchrotron radiation after the beam operation was started. The adjustment time was short since the alignment was done by a laser light at the construction of the light path.

Table 1: Design Parameters of SuperKEKB

Parameter	LER	HER	DR	Unit
Energy	4.0	7.0	1.1	GeV
Maximum stored current	3.6	2.6	0.070	A
Circumference	3016.315		135.5	m
Crossing angle	83			mrad
Number of bunches	2500		4	
Bunch current	1.44	1.04		mA
Coupling	0.27	0.28		%
Damping time (h/v/z)			11.5/11.7/5.9	ms
Emittance(h/v)	3.2/8.64	4.6/12.9	29.2/1500	nm/pm
β^*_x/β^*_y	32/0.27	25/0.3		mm
Bunch length	6	5	7.85	mm
Beam-beam parameter ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity		$8x10^{35}$		$cm^{-2}s^{-1}$

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Table 2: DR SRM Parameters

Parameter		Unit
SR Opening Angle	3.47	mrad
Chamber Vertical Aperture	13.6	mrad
Chamber Horizontal Aperture	38.64	mrad
Bending Radius	3.15	m
Bending Angle	0.152	rad
Bending Length	0.4794	m
SR Power	12	W
Forward Spectral Angular Density of Flux	8.37×10^2	Photons/mr^2 /0.1%band width/nC

The light path is divided into two lines in the SRM room with a plane mirror; one for a streak camera to measure bunch length and the other for a gated camera to measure transverse beam size at the same time.

A refractive optical system was tried with a band pass filter as the incident optical system at the Phase-II operation, however the size measurement of a single bunch was difficult due to limit light quantity. Therefor the system was rearranged with reflective optical system at the beginning of Phase-III. Now we can use the incident light of all wavelength without band pass filter. As a result, the size measurement of single bunch was available at the normal operation current (2.5mA/bunch).

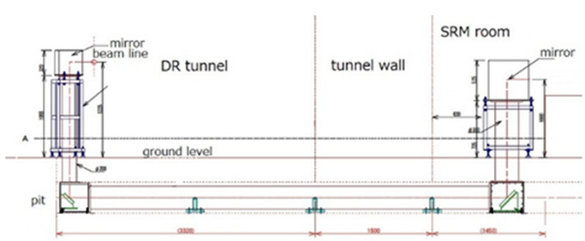

Figure 1: Layout of the DR SRM line.

SIZE CALIBRATION

The size has been calibrated by the following methods to convert the image of the camera into the beam size.

A frequency synthesizer and a semiconductor laser pulse light source (508.88MHz, pulse width about 50ps) were used to produce a pulse at regular intervals for the time range calibration of the streak camera. As the time axis of streak camera are changed to four ranges, the input pulse was changed with each range and measured. The results are shown in Table 3. As the time range 2 is mainly used for the real bunch length measurement, the difference of a design value and the actual value is -0.6%. It is 0.042mm for a bunch length of 7mm and is small enough.

Real beam was used for the calibration of the gated camera. A local bump (a horizontal direction: -3.5mm - 2mm, a vertical direction: -3mm - 3.5mm) was set at a light emission point and the change of the beam position was measured on the gate camera image plane. The conversion coefficients from the number of the pixels to beam size [mm] was derived by the data. An example of the local bump is shown in Fig. 2. A green line shows a bump orbit. Figure 3 shows the calibration results of horizontal (h) and vertical (v) direction.

Table 3: Streak Camera Calibration Result

Time range	Design value[pixels]	Measured value[pixels]	Difference
4	1122.94	1138	1.3%
3	802.1	800.7	-0.2%
2	398	395.7	-0.6%
1	105.5	109.9	4.0%

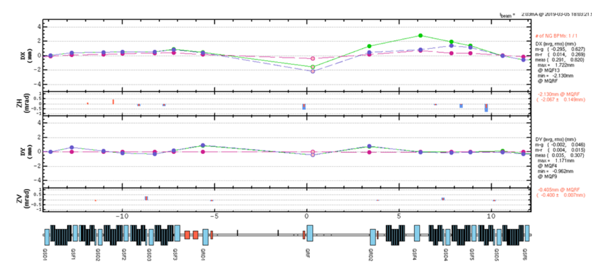

Figure 2: An example of local bump for a calibration.

BEAM SIZE MEASUREMENT

The result of the simulation of the bunch shape from upstream linac shows deformation in the longitudinal (z) direction just after the injection to DR, and it is damped during the accumulation in DR and approaches Gaussian shape [7]. An example of bunch shape measured by the streak camera is shown in Fig.4. The longitudinal and transverse shape gradually damped and closed to Gaussian shape 20ms after injection. The bunch shape of the vertical (v) and the horizontal (h) direction was also measured by the gated camera. The bunch shape was damped after repeating the growth and shrinkage at the first 10 turns.

The results after the injection to DR using the streak camera and the gated camera are shown in Fig. 5. The Fitted damping times of z, h and v direction were 5.1ms±1.17ms, 9.9ms±0.93ms and 11.5ms±0.29ms, respectively and these results showed near values with theoretical values 5.9ms, 11.7ms and 11.5ms which are calculated from design optics.

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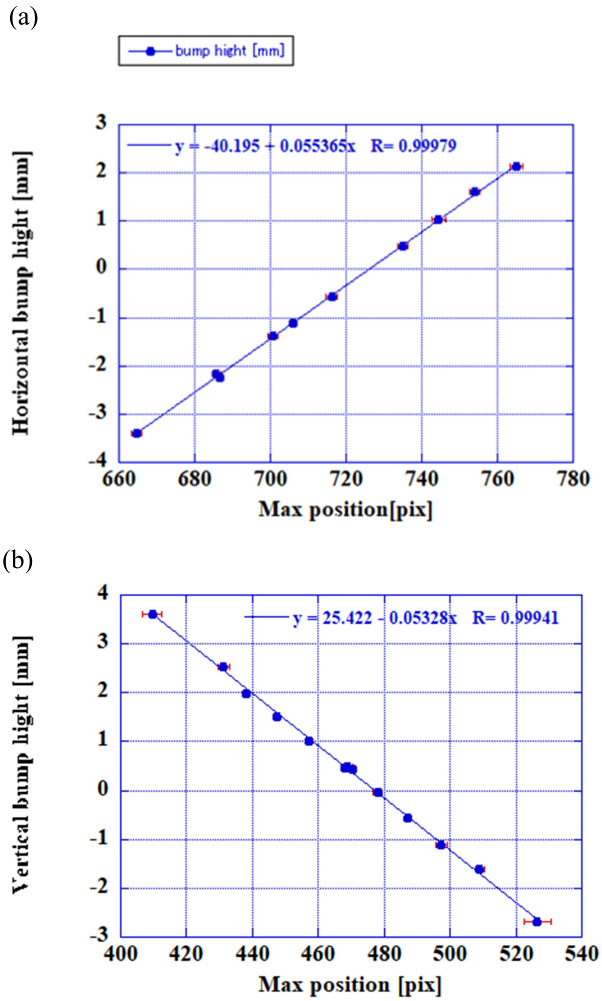

Figure 3: Calibration of beam size measurement by the gated camera for (a)horizontal and (b)vertical direction.

CONCLUSION

The dumping ring of SuperKEKB was constructed to get lower emittance of the positron beam and operated without a big problem. The synchrotron radiation monitor was re-arranged with reflective optical system for bunch by bunch measurement at Phase-III commissioning. The beam size and the damping time of DR were measured by using a streak camera and a gated camera. The expected damping time and a measured value of each direction is consistent. Measured bunch length is also consistent with calculated value from current optics. These results show that the DR works as expected to make beam size small.

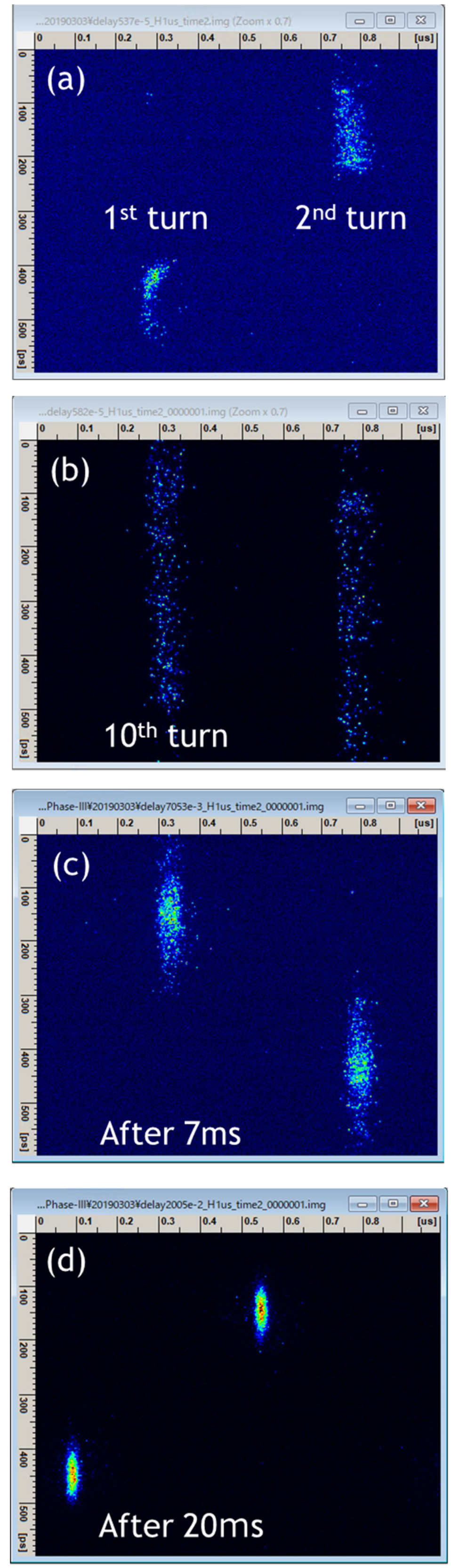

Figure 4: Longitudinal beam distribution measured by the streak camera (a)just after injection, (b)10 turn after injection, (c) 7 ms after injection and (d) 20ms after injection.

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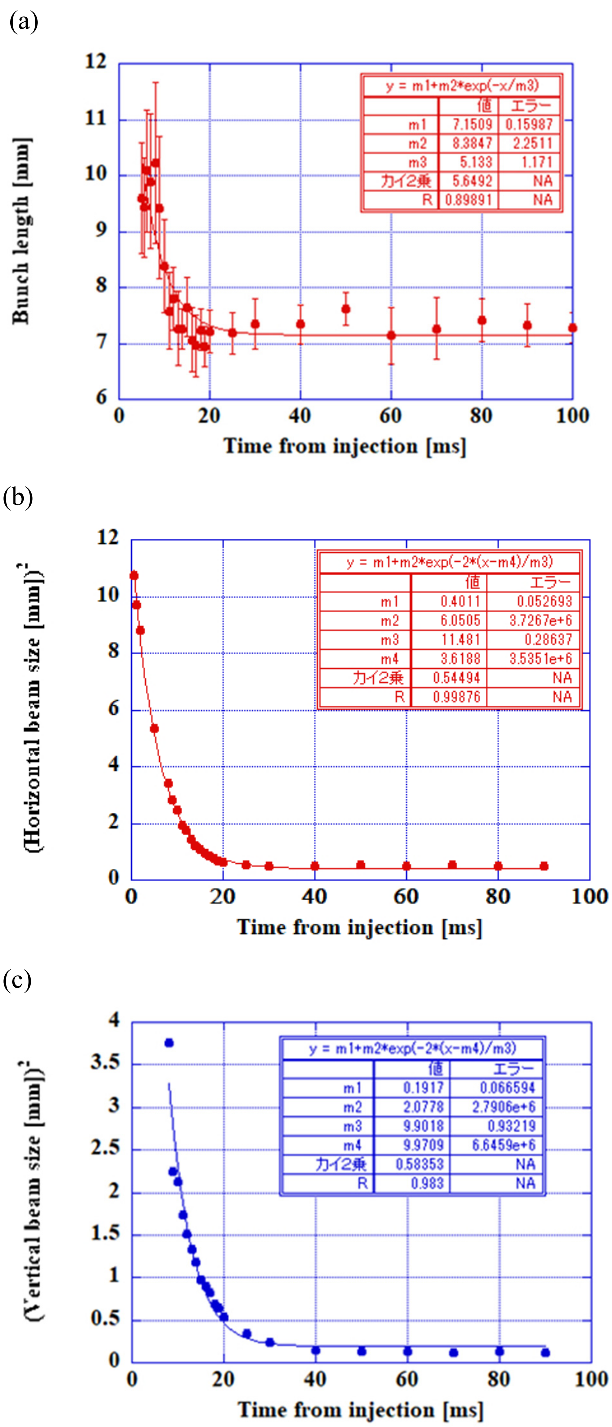

Figure 5: Measured beam size of (a)longitudinal, (b)horizontal and (c)vertical after injection.

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