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BEAM DIAGNOSTICS FOR SuperKEKB DAMPING RING IN PHASE-II OPERATION

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Abstract

The SuperKEKB damping ring (DR) commissioning started in February 2018, before main ring (MR) Phase-II operation. We constructed the DR in order to deliver a low-emittance positron beam. The design luminosity of SuperKEKB is 40 times larger than that of KEKB with high current and low emittance. A turn-by-turn beam position monitor (BPM), transverse feedback system, synchrotron radiation monitor (SRM), DCCT, loss monitor (LM) using ion chambers, bunch current monitor and tune meter have been installed for beam diagnostics at the DR. An overview of the instrumentation and its status will be presented.

INTRODUCTION

SuperKEKB [1] is an electron-positron collider and started construction towards 40 times luminosity as large as KEKB in 2011. The beam energies are 4GeV and 7GeV for positron rings (LER) and electronic ring (HER). 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 [2]. We installed the Belle-II detector and remodeled injection region of an accelerator for Phase-II operation. The beam commissioning was from March 2018 to July [3,4]. It is necessary to squeeze the vertical beam size to nm level at the collision point to achieve design luminosity. We build the damping ring (DR) in order to achieve a low-emittance positron beam [5,6]. The present parameters of DR are shown in Table 1. DR tuning was started prior to MR commissioning at the beginning of February 2018. We performed the tuning of injection from the injection line (LTR) to DR and DR to extraction line (RTL) in approximately one month [7]. The DR monitor system adjustment including timing system and feedback system was smoothly advanced.

The monitor system of DR follows a system of the MR as shown in Table 2 [8]. Two button electrodes of BPM are attached to the top and down of the ante-chamber of 24mm height in 83 quadrupole magnets. The visible light from a bending magnet downstream of the extraction line is used for a synchrotron radiation monitor. The ion chambers are attached on the wall to cover all the tunnels to monitor beam loss. We installed a monitor chamber and a kicker chamber for bunch feedback, and a DCCT chamber for beam current monitors just upstream of the injection point of DR.

Table 1: Damping Ring Parameters

Parameter		unit
Energy	1.1	GeV
No. of bunch trains/ bunches per train	2/2	
Circumference	135.5	m
Maximum stored current	12	mA
Damping time (h/v/z)	11.5/11.7/5.8	ms
Emittance(h/v)	29.2/1.5	nm
Energy spread	0.055	%
Bunch length	6.6	mm
Mom. compaction factor	0.01	
Cavity voltage	1.0	MV
RF frequency	509	MHz

Table 2: Beam Monitors in DR

System	Quantity
Beam position monitor	83
Synchrotron radiation monitor	1
Beam loss monitor	34
Transverse bunch by bunch feedback	1
DCCT	1
Bunch current monitor	1

BEAM POSITION MONITOR

A button electrode with a diameter of 6 mm has been developed for the beam position monitor (BPM). Two button electrodes are attached in one flange due to narrow space for their installation as shown in Fig. 1. The detection circuit is VME 18K11 L/R which incorporates a logarithm amplifier. The signals of BPM are sent to four control racks which accommodate VME racks near cable holes on the ground to reduce a cable loss. 20 or 21 signals are sent to one rack and the converted signals are sent to the central control room through network.

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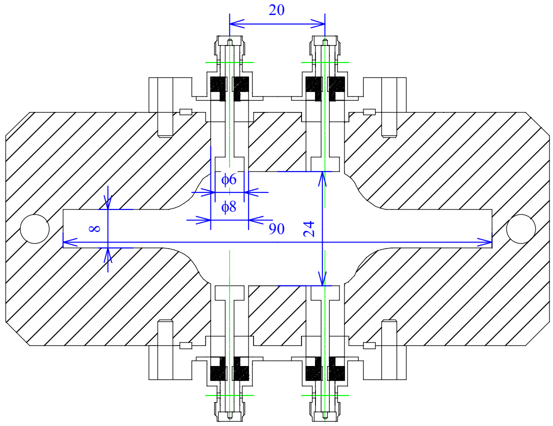

Figure 1: BPM chamber.

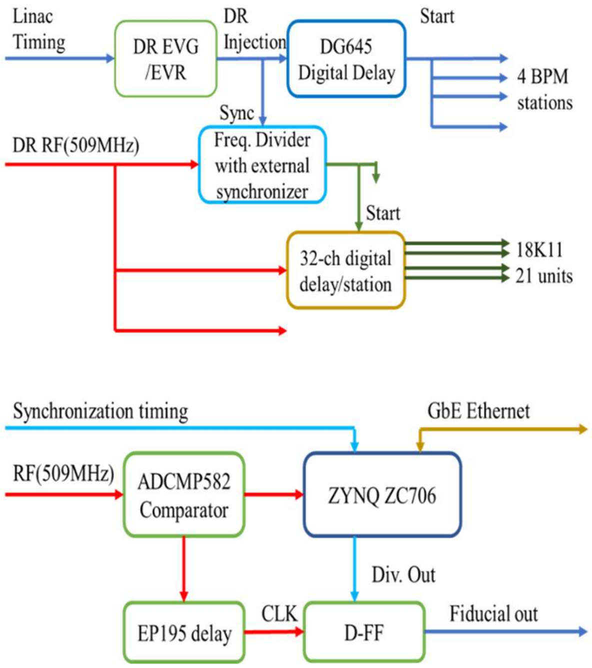

Figure 2: BPM timing.

It is necessary to set timing of 83 BPM signals so that the measurement is completed before the next turn to measure the turn-by-turn beam position. Four electrode signals of single BPM have to be measured within 4 ns. Figure 2 is the flow of the timing signal. We divide the injection timing synchronized with bunch timing to the signal which synchronized with DR revolution using frequency divider and transmit to BPM station with a measurement-start-timing. We measured cable length from each BPM rack to an electrode (about 30m) using TDR and calculated the delay by the distance from an injection point to the BPM position before DR operation. We set total delay of every channel individually by a 32ch digital delay. The total delay is below around 200ns [9]. In order to adjust timing at each control rack, we measured a beam signal from the most upstream BPM of each rack with an oscilloscope and set delay to the right timing which was measured at bench before the commissioning. As a result, it was able to confirm the first turn of the DR beam in several hours after the first injection of the DR.

For the confirmation of the installed position of each BPM block, we surveyed BPM block using FARO 3D-ARM [10] and obtained a result in Fig. 3. The measured result was put in EPICS record as an offset of BPM. After a startup, it was found that a BPM reported an abnormal position. This was because the assumed chamber shape was reversed in horizontal and vertical position. Other problems are not found on BPM system.

We estimated BPM resolution using the three BPM method. Vertical resolution is 2~3μm and horizontal resolution is 2~10μm as shown in Fig. 4.

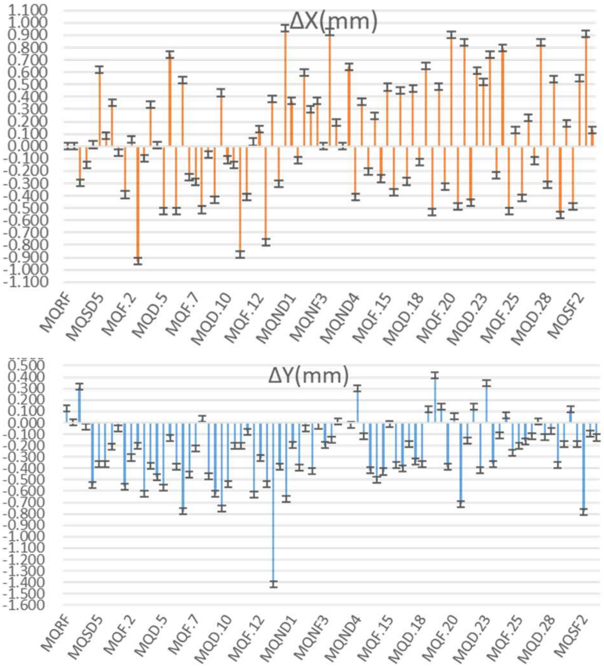

Figure 3 : BPM survey result.

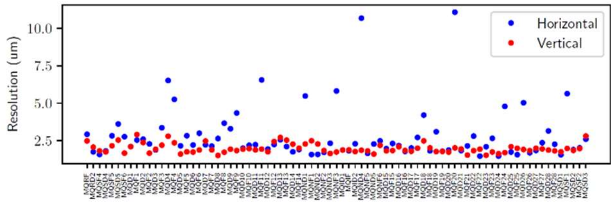

Figure 4: BPM resolution.

SYNCROTRON RADIATION MONITOR

The synchrotron radiation monitor (SRM) uses the light from a bending magnet with bending radius of 3.14m. The magnet is located just after beam extraction point of DR. The beryllium mirror is installed to 0.5m downstream of the magnet to extract the light. 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. A streak camera and a gated camera are prepared for bunch length and transverse beam size measurement. The visible light was confirmed in the SRM room when the beam got longer lifetime and beam current became higher enough. The optical axis was adjusted to each camera.

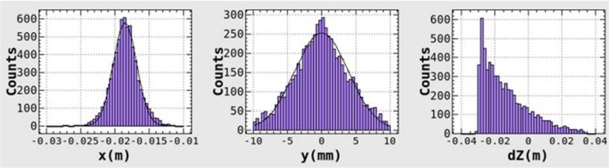

Figure 5: Bunch shape just after injection by a simulation.

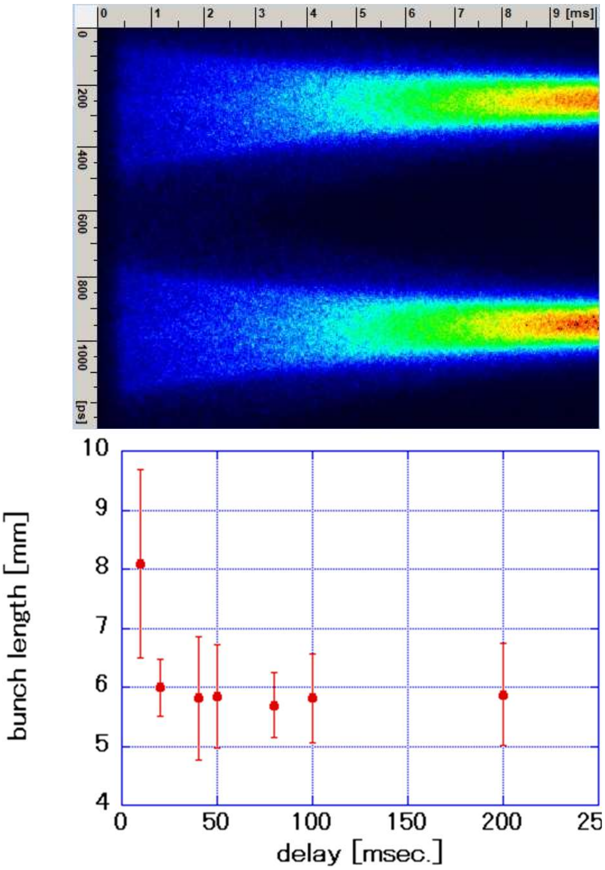

Figure 6: Measured bunch length after injection.

The bunch shape is distorted longitudinally just after injection according to a simulation as shown in Fig. 5. It is damped during accumulation and approaches Gaussian. Figure 6 shows that the bunch length gradually damped after injection and became 6.5mm of the design value in 20ms. As the measurement accuracy of the streak camera is 1ps, the measurement accuracy of the bunch length of 6.5mm is approximately 5%. Figure 7 shows the transverse beam size measured with a gated camera. As the calibration of absolute value is not applied yet, there is an offset, but it is obvious that the size is almost damped after 50ms. We will calibrate the beam size in Phase-III and then compare it with the size measured by the wire scanner in RTL.

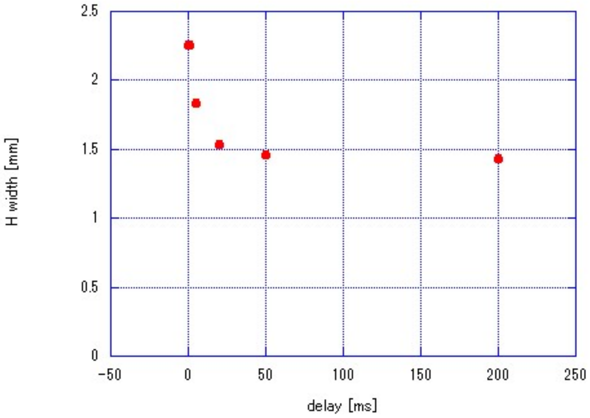

Figure 7: Measured horizontal beam size after injection.

BEAM LOSS MONITOR

The purpose of the beam loss monitor (LM) is to prevent the damage of the hardware against unstable injected beam by stopping injection trigger. The sensors are ion chambers which are 9 m FC-20D co-axial cables and attached on the tunnel wall. The signals are sent to 8 channel integrators. An interlock level is adjusted by integration time (0.1,0.3,1ms) and gain (1,10,100,1,000). We can monitor the signal at each position in real time which helps injection tuning.

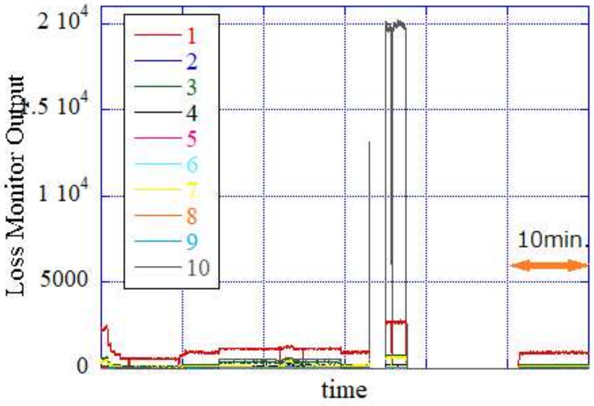

Figure 8: Loss monitor signals at the moment of the alarm from the radiation monitor.

There was an event that the radiation monitor which we attached to the SRM room issued an alarm in DR commissioning. Irradiation of neutron 15μSv/h and gamma ray 12μSv/h lasted several minutes, and it did not have any problem for a radiation management area at the time. Since it was an unexpected event, we checked the situation and found that 25Hz injection had continued with high bunch current although the high voltage of extraction septum magnet had been off. As a result, the radiation level rose in the SRM room which is near to beam extraction region. The LM signal by the side of septum (which is shown in Fig. 8 No.10) showed 20 times larger value than normal level. Nevertheless, injection continued in six minutes because the level was lower than an interlock level. We made an interlock level severe after this event and added an 1m ion chamber to the direct down stream of both sides of septum to refine interlock system.

BEAM CURRENT MONITOR

We use the detection circuit of MR which was modified to DR and a DCCT core which is reuse of MR as a beam current monitor. It is able to measure the current up to 200mA and the resolution is 30μA. The measurement rate is 5ksps. We always monitor the beam current as shown in Fig. 9. Current limit for the safety interlock is set to 17mA by software and injection is stopped if the current exceeds the limit level. A hardware current limiter will be constructed before Phase-III operation. We found the current level showed minus value after offset subtraction. This problem was caused by reverse installation of the chamber. The sign is reversed by software.

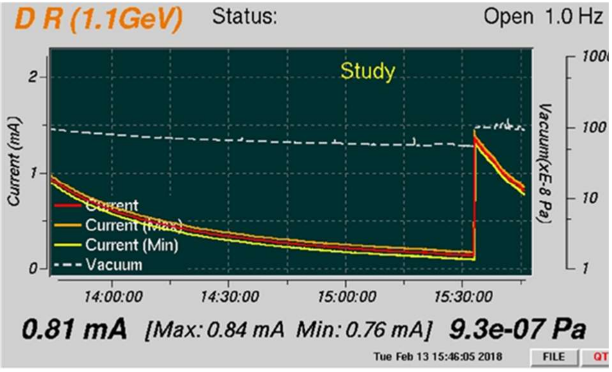

Figure 9: Beam current measurement by DCCT.

BUNCH FEEDBACK SYSTEM

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. Four electrodes of 40cm in length which oriented 45 degree each other are used for a kicker. We adjusted the phase shift of iGp12 processors for both horizontal and vertical planes and successfully excited betatron oscillation with stable amplitude using single-bunch PLL excitation function of iGp12.

As the bunch current monitor, the detection circuit that is same as that of MR and VME board (Digitex 18K10) which changed over the internal firmware are used. Injection is stopped if the bunch current exceeds the limit level for safety.

The tracking generator output of the spectrum analyzer is down converted and drives beam. The electrode output is observed directly with the spectrum analyzer for betatron tune measurement. The measurement system is working well.

CONCLUSION

All the monitor systems of SuperKEKB DR were installed on schedule and finished initial tuning. We performed timing adjustment, phase adjustment, optical axis adjustment after DR injection started. System works smoothly after some alterations. We have plan to construct the beam current limiter, calibrate a gain of BPM, calibrate SRM and optimize the interlock level of LM before the high beam current operation at the Phase-III commissioning.

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