BEAM LOSS MONITOR AT SUPERKEKB

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Abstract

We will use beam loss monitors for protection of the hardware of SuperKEKB against unexpected sudden beam losses. The sensors are ion chambers and PIN photo-diodes. The loss monitor system provides an important trigger to the beam abort system. We can optimize the threshold of the abort trigger by checking the beam information at each abort event. This paper explains the overall system of the SuperKEKB beam loss monitors including the damping ring (DR).

INTRODUCTION

The KEKB collider is being upgraded to SuperKEKB in order to get higher 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 3.6A in LER. LER injection system includes a 1.1 GeV DR [1, 2]. The machine parameters of SuperKEKB are shown in Table 1. In order to get 40 times higher luminosity than that of KEKB, the beam currents will be increased 2 times higher than at KEKB and the beam size at the interaction point will be further squeezed with a large crossing angle. The first beam is expected in FY 2015.

Table 1: Machine Parameters of SuperKEKB

Parameter	LER	HER	DR	unit
Energy	4.0	7.0	1.1	GeV
Max. bunch charge	14.4	10.4	8	nC
No. of bunches	2500		4	
Circumference	3016		135.5	m
Max. stored current	3.6	2.6	0.07	A
Horizontal damping time	58	29	10.9	ms
x-y coupling	0.27	0.28	5	%
Emittance (h)	3.2	4.6	42.5	nm
Emittance (v)	8.64	12.9	3150	pm
Bunch length	6.0	5.0	6.53	mm
$\beta x^*/\beta y^*$	32/0.27	25/0.30		mm
Crossing angle	83			mrad
Luminosity	$8x10^{35}$			$cm^{-2}s^{-1}$
RF frequency	509			MHz

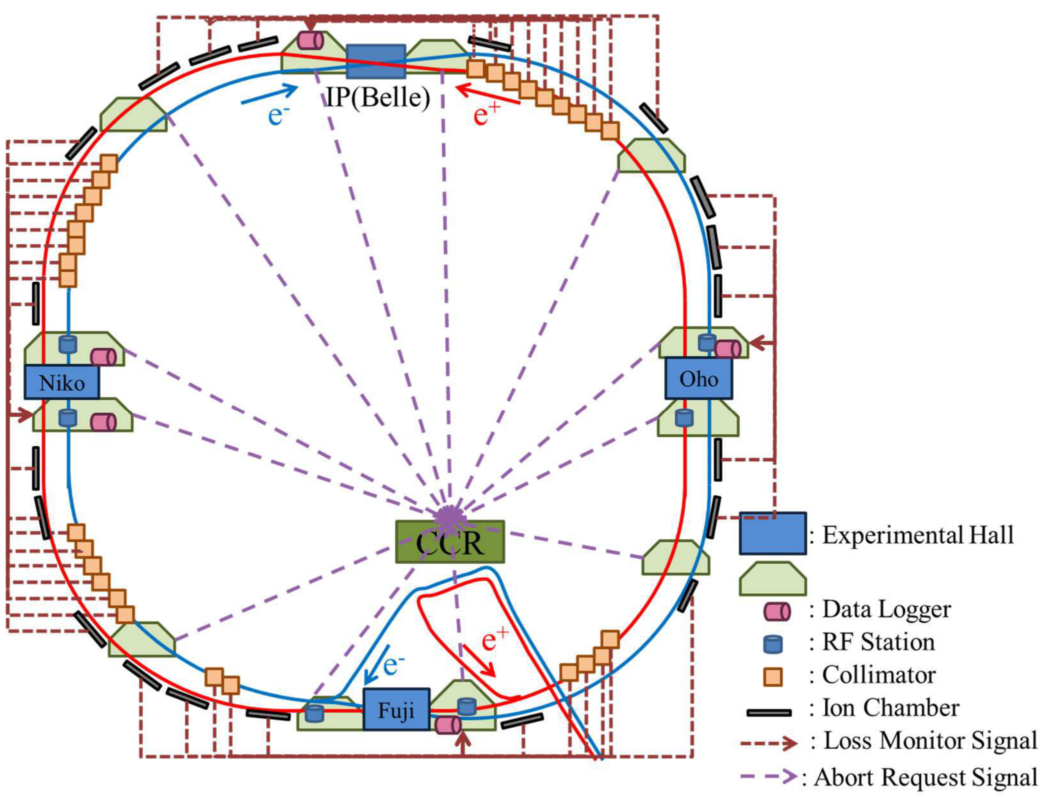

Figure 1: The overall system of the SuperKEKB beam loss monitor.

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The beam loss rates at SuperKEKB were simulated and predicted to be 10mA/s and 7.2mA/s at the LER and the HER, respectively [3]. They are 50 times higher than that of KEKB. The beam will be lost at the interaction region and collimators mainly. Beam loss monitors (BLMs) must protect the Belle II detector and the accelerator hardware components against unanticipated beam loss caused by beam instabilities. Typical beam loss rates at KEKB were 10 mA/ms and 10mA/μs in the case of BLM aborts caused by ion chambers and PIN photo-diode sensors, respectively. An example of a beam loss abort is shown in Fig.2. Since the dangerous beam loss rate which triggers the beam abort and could cause the hardware damages will be much larger than the expected beam loss rate at SuperKEKB, the abort system at KEKB will work at SuperKEKB even in large background due to the beam loss by adjusting a threshold level of the abort trigger. We decided to use the same beam loss monitor system as the KEKB system [4], which consists of ion chambers and PIN photo-diodes. The overall system of the BLM is shown in Fig. 1. BLM signals from the whole rings are collected at four local control rooms (LCRs). An interlock signal from each BLM generates a beam abort. The number of channels is approximately 200 in the tunnel. Table 2 shows the number of BLM in the main ring (MR) and DR. We use the data loggers which are installed at 5 LCRs in order to diagnose whether the abort is correctly requested by BLM and other sensors or not [5].

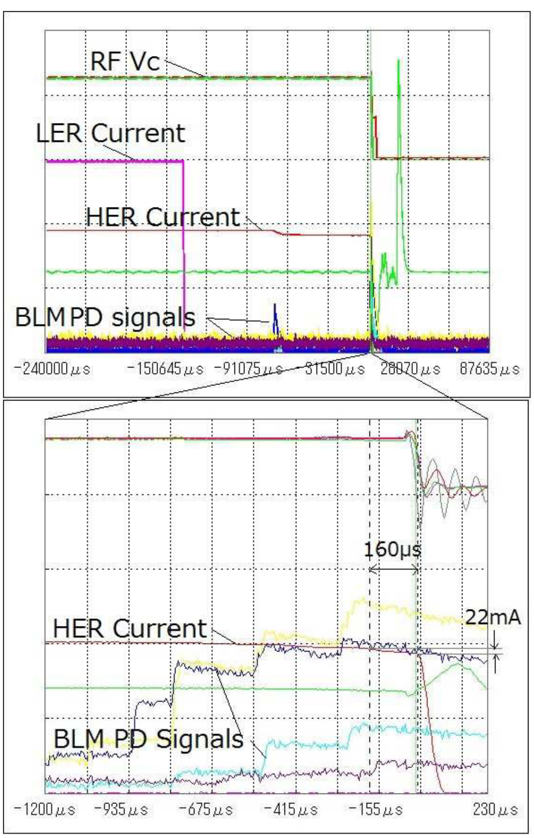

Figure 2: An example of a beam loss monitor abort at KEKB. HER beam loss was 22mA within 160μs. PIN photo-diodes generated an abort signal.

Table 2: Number of Beam Loss Monitors at SuperKEKB

Sensor	MR	DR
IC	105	40
PD	101	-
Optical fiber	-	optional

ION CHAMBER

The ion chambers (ICs) are reused sensors that were used for KEKB. The 5-m long chambers are mounted in cable racks on the outer wall along the tunnel. The IC is a Fujikura FC-20D co-axial cable. The inner and outer conductors are separated by an air gap. The high voltage at the outer conductor is 200V. The typical drift time over which a positive ion is collected at the inner conductor is 1 ms. The resulting current is sent to a readout electronics which include an integrator and an amplifier as shown in Fig. 3. Each module handles eight channels. The amplifier gain can be selected to be 1, 10 or 100. The RC time constant also can be selected to be 10, 100, 300 or 1000 ms. The IC is sensitive down to a loss of around 0.1mA/s. An interlock signal is generated and a beam abort is requested when the beam loss level exceeds a threshold that is set for each channel. The loss signal is buffered and sent to a 16-bit 64 channel ADC (DGX 18K14B) and logged at 1 Hz. The same signal is sent to a data logger with a higher sampling-rate just after any beam abort.

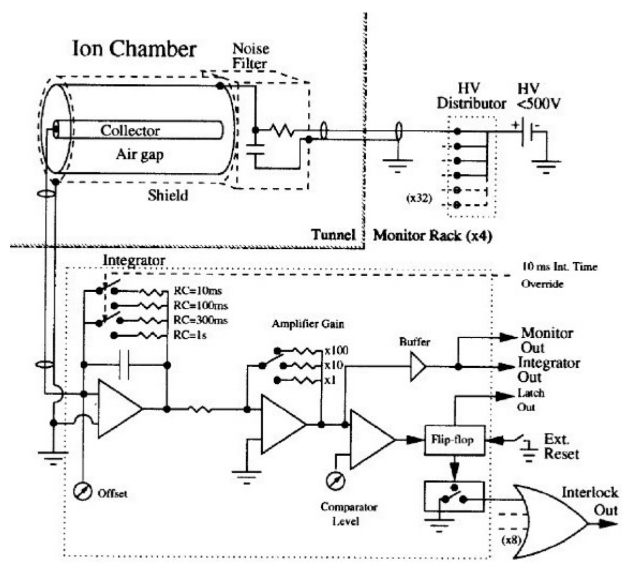

Figure 3: Block diagram of the readout electronics for the ion chambers [4].

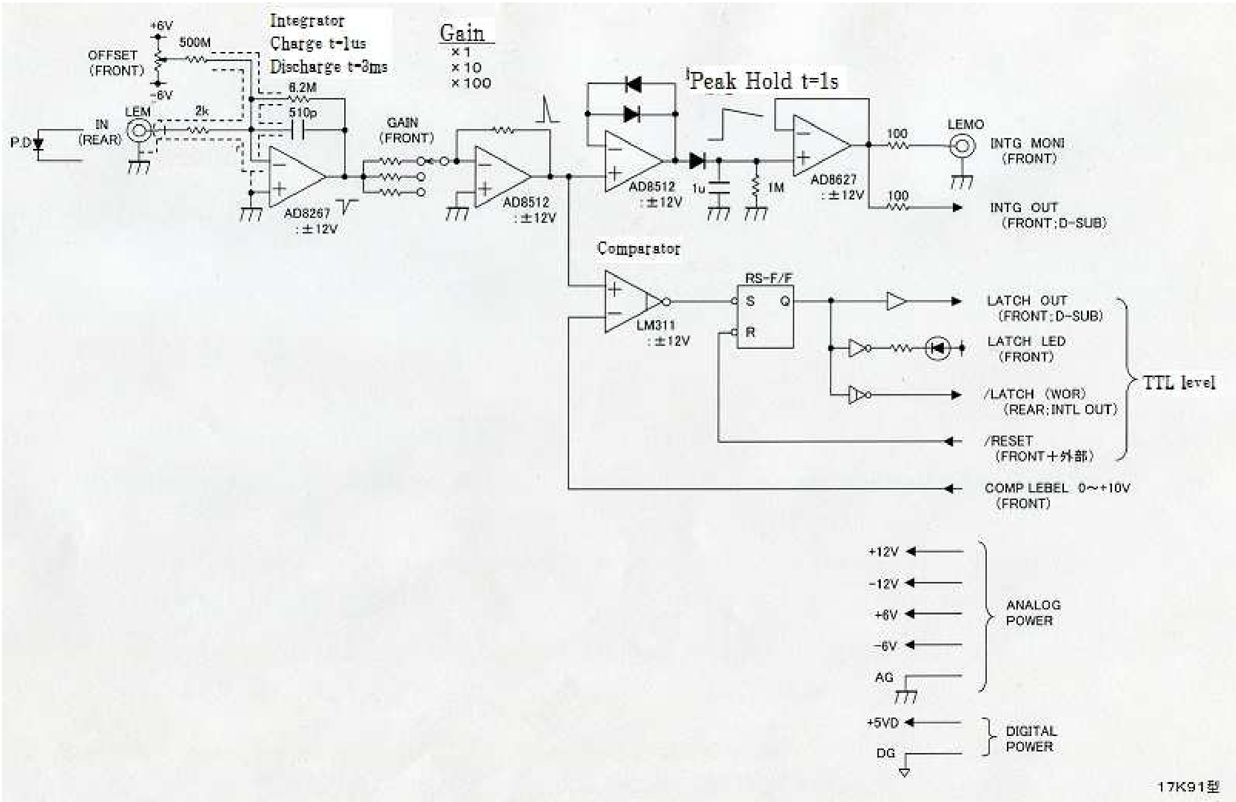

Figure 4: Block diagram of the readout electronics for the PIN photo-diodes.

PIN PHOTO-DIODE

Collimators are installed in the beam line in order to protect the BelleII detector from lost particles. The number of collimators is 13 and 16 for the LER and the HER, respectively. High current beam can damage the collimator itself when the beam orbit changes rapidly. PIN photo-diodes (PDs) with high speed and high radiant sensitivity (BPW34) are used as sensors for the BLM since the interlock signal from an IC is not fast enough to protect the collimator. The cross section of the PD is 2.65mm$\times$ 2.65mm. Two PDs are put in an aluminium box and insulated by Kapton tape. We put 4 boxes around a collimator to detect beam loss in all directions. The rise time of the PD is 60 μs, which is determined by the capacitance of the signal cable (30 nF for a 400 m cable) and an input resistor of 2 kΩ. The readout electronics are shown in Fig. 4. The peak hold circuit is for logging the signal by ADC and the comparator is for the interlock signal. The interlock signal is generated within a few turns after beam loss happened. The PD signal can protect the hardware from a localized rapid beam loss, and it is possible to distinguish in which ring the beam loss happened. We will install PDs in several locations where we expect localized beam loss, including collimator sections as shown in Fig. 5. The signal flow after the readout module is the same as for the IC signal.

Figure 5: Examples of PIN photo-diodes which are put (a) on the collimator and (b) near bellows at KEKB.

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LOGGER SYSTEM

The abort diagnostic system is based on a high-sampling-rate data logger that records BLM and other signals at the moment of beam abort [5]. Data loggers are located in five LCRs where BLM signals and RF cavity signals are collected. The logged time period is 600 ms and 300 ms. The sampling intervals are 5 µs and 1µs for the two logging times, respectively. Beam intensity, signals from the RF cavities, beam phase showing deviation of synchronous phase, and injection trigger timing signals are logged along with BLM signals. These fast signals are useful to diagnose the cause of the beam abort. The recorded data are sent to the central control room (CCR) via the KEK internal network. The information is ready for inspection within a few minutes after the abort. By analysing the data, the reason for beam loss and the beam abort are identified.

DAMPING RING

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. Regarding the injection efficiency of the 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. It is necessary to have enough sensitivity when greater than the expected loss occurs.

ICs are reused sensors that were used at the KEKB linac. They are 9 m long FC-20D co-axial cables. The cross section of the DR IC is shown in Fig. 6. This is similar to the MR IC. The IC will be mounted on the cable rack or the magnet. A readout electronics consists of an integrator and an amplifier, same as for the MR IC. The amplifier gain can be selected to be 1, 10,100 or 1000. The signal caused by beam loss at DR is expected to be smaller than that of the MR, since the DR beam current and beam energy are smaller.

Signal level of the IC was simulated by the electromagnetic shower code EGS5 [6]. In the simulation a beam chamber was assumed to be a rectangle with aluminium walls of 6 mm thick. Two iron blocks with 5 cm thick separated by 30 cm along the beam axis were placed around the chamber to simulate magnets. The IC with an aluminium conductor of 1.8 mm thick, 5 m long and with a shape of a square of 22.5 mm on a side was placed 1 m apart from the beam axis horizontally and vertically. Positrons of 1.1 GeV horizontally hit a side of the chamber wall. The code counted the number of electrons, positrons and photons that entered the IC. The number of the ions created in the IC was calculated from the stopping power and the mass attenuation coefficient in the air. The ionization constant for the air was assumed to be 34 eV. The result shows that 2.7×10^5 ions are created for 1×10^5 incident electrons. This means 1.1×10^8 lost positrons, that is 0.2 % of the maximum bunch population, gives output voltage of the ion chamber of 0.1 V assuming that the gain of 100 and the capacitance of the integrator of 47 nF.

The planned setup has enough sensitivity. The signal is sent to ADC which is the same as that used for the MR LM, and logged by the SuperKEKB logging system. PIN photo-diodes and optical fibers also will be installed to check the beam loss situation in detail as backups.

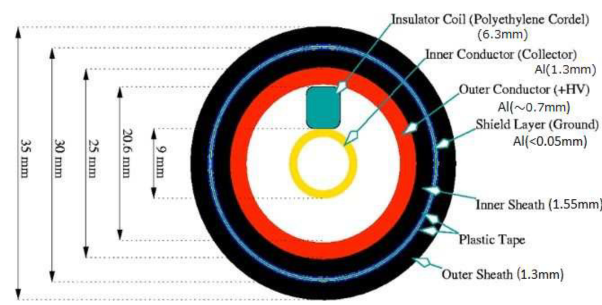

Figure 6: Cross section of the Ion Chamber.

CONCLUSION

Preparation of the BLM of the SuperKEKB is in progress for a start-up in FY 2015. The BLM system is based on the KEKB BLM system. Most of the sensors and the readout electronics are re-use from KEKB. The number of MR channels is increased, and electronics are partially modified for the DR.

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