BEAM LOSS AND ABORT DIAGNOSTICS DURING SuperKEKB PHASE-I OPERATION

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Abstract

Beam commissioning of SuperKEKB Phase-I started in Feb., 2016. In order to protect the hardware components of the accelerator against the Ampere class beams, the controlled beam abort system was installed Because of the higher beam intensity and shorter beam lifetime of SuperKEKB than that of KEKB, a beam abort monitor system was prepared aiming to monitor the machine operation and to diagnose the hardware components. The system collected the data of all aborts, totalling more than 1000 in this operation period, and we diagnosed not only the hardware performance but the tuning software by analysing the relations between beam current, loss monitor signals and RF cavity voltages. This paper will give the outline of the monitoring system, and will present typical examples of signal and diagnoses.

Table 1: Machine Parameters of SuperKEKB

Parameter	LER	HER	DR	unit
Energy	4.0	7.0	1.1	GeV
No. of bunches	2500		4	
Circumference	3016		135.5	m
Max. stored current	3.6	2.6	0.07	A
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
$\beta x/\beta y$ at IP	32/0.27	25/0.30		mm
Luminosity	$8\text{x}10^{35}$			$cm^{-2}s^{-1}$
RF frequency		509		MHz

INTRODUCTION

SuperKEKB [1] is an electron-positron collider with a design luminosity of $8\text{x}10^{35}$ $cm^{-2}s^{-1}$. The beam size at the interaction point (IP) will be squeezed to the nm level and the beam currents will be 2.6 A and 3.6 A for electrons and positrons, respectively, to achieve the design luminosity. The machine parameters of SuperKEKB are listed in Table 1.

High current beams may cause damage to sensitive detector and accelerator components. In KEKB, we had several problems and needed to improve the system each time. For example, an IP chamber was melted by strong synchrotron radiation, some collimators were damaged by high intensity beam, and imperfect beam dumps due to the wrong abort timing were observed. The collimators were upgraded and the abort system was improved using fast loss monitor and beam phase signal etc. It is important to check all accelerator systems before installation of the detector for higher current operation. We operated the accelerator without the Belle detector for five months in Phase-I.

ABORT AND ABORT MONITOR SYSTEM

In order to protect the hardware components of the detector and the accelerator against the high beam currents, we installed the controlled abort system. The abort monitor system was prepared also for diagnosing and optimizing the abort system.

Abort Kicker and Trigger System

The beam abort kicker is composed of a tapered vertical magnet, a horizontal magnet, a Lambertson DC septum magnet, and additional pulsed quadrupole magnets for LER and a sextupole magnet for HER to increase the beam cross-section to avoid damaging the extraction widow [2]. The dump duration corresponds to one revolution time, i.e. 10 μsec. The beam is distributed in every two RF buckets with an empty bucket space of 200 ns which covers build-up time of the abort kicker magnet. It is also required to synchronize the kicker timing with this abort gap for the protection of hardware. This abort trigger system collects four types of abort trigger requests [3].

1. Direct trigger from hardware components such as RF, vacuum, magnet and monitor.
2. Trigger from loss monitor.
3. Trigger from synchrotron oscillation phase.
4. Manual abort which is requested for machine stop and various studies.

The abort request signals from each hardware component are converted to optical signals and collected to VME modules in 12 local control rooms (LCR). The request signals from LCRs, software abort request signals, and manual abort request signals are collected in the central control room (CCR) and sent to the abort kicker within 20 μsec.

Abort Monitor System

Our monitoring system consists of four data loggers. The SuperKEKB ring circumference is 3 km with 12 LCRs as shown in Fig. 1. Loss monitor signals are collected at 4 LCRs, RF signals are collected at 6 LCRs and the data loggers are located in 4 LCRs. Collected signals include beam current measured by a DCCT, beam loss signals from PIN photo-diodes (PINs) and ion chambers (ICs), signals from the RF cavities, i.e. cavity voltages and output power of klystrons, the beam phase signal showing the deviation from the synchronous phase, the injection trigger timing and the abort request signal.

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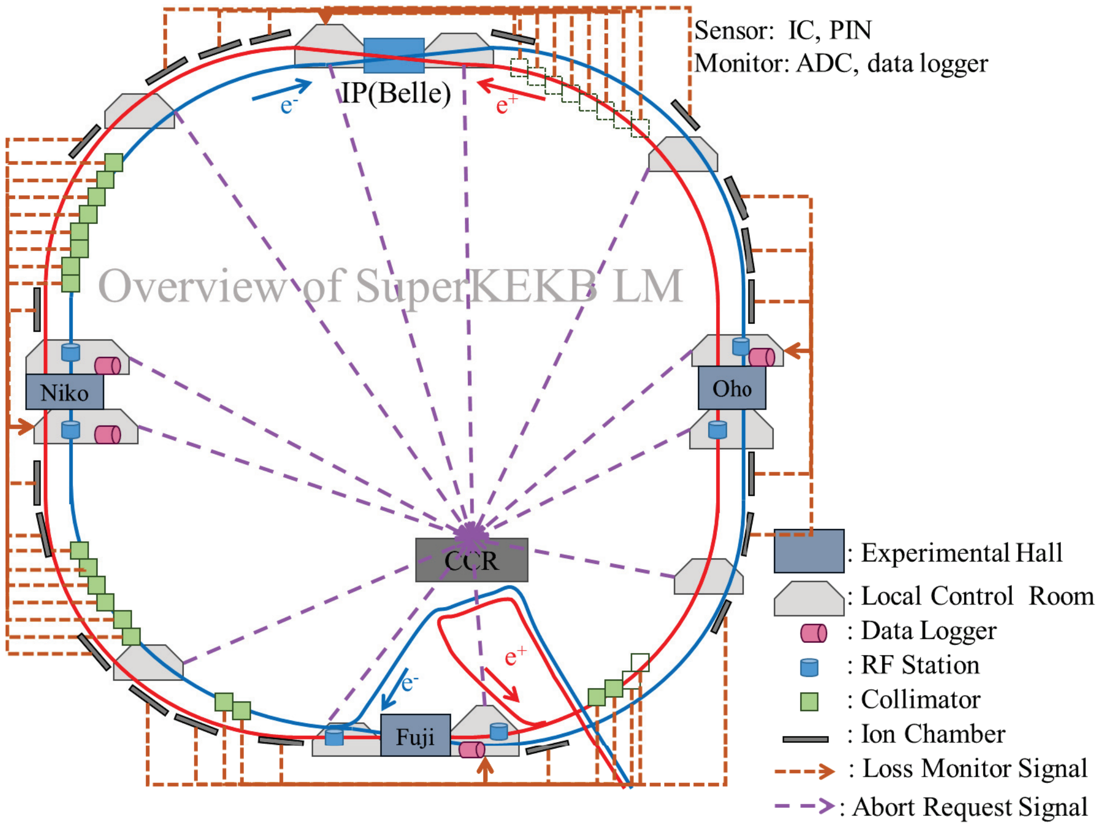

Figure 1: Overview of beam loss monitor and abort monitor system at SuperKEKB phase I.

The logging time is from 300 ms to 600 ms for every abort with a sampling time of 1 µs to 5 s, which depends on the type of logging apparatus. The recorded data is sent to the CCR via the KEKB control network and monitored by the operators.

DATA ANALYSIS

The beam commissioning started in Feb. 2016. Both injection and abort system tuning were done at the beginning of commissioning. The total number of events collected by four data loggers after March was more than 5000. The number of beam aborts was about 1500 and about 95% of the aborts were recorded. The other 5% were missed due to too-short intervals of successive manual aborts in the kicker timing studies. The manual abort data was the reference of each signal response time as shown in Fig. 2. The beam current is measured by DCCT and the signal has a delay of 45 µs which depends on the distance from DCCT to LCR, and has a decay slope of 90 µs. This is the normal behaviour of the DCCT signal when the beam is normally aborted at the correct timing. If the decay time and the slope differ from this example, we consider the abort abnormal. We analysed all abort data to find the causes. The results will be described for three types of abort triggers separately: the hardware trigger, the loss monitor trigger and the beam phase trigger.

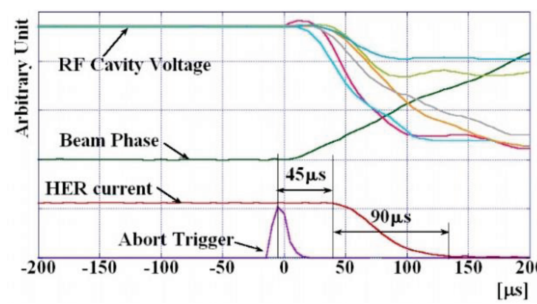

Figure 2: Manual abort.

Hardware Abort

Each hardware component has its own interlock signal for abort request. Since abort request signals of the magnet and vacuum systems are relatively slow, the beam condition worsens before the abort kicker is fired. As a result, the beam is aborted by the beam loss monitor trigger or the beam phase abort trigger. The RF system has many interlock signals to avoid hardware damage and beam instability. Figure 3 describes an example what happened when an abort was requested by an RF component. In this case, we found one RF cavity voltage (Vc) was down at 3 ms before the abort trigger. As a result of analysis, we understood that at first a piezo frequency tuner was broken, resulting in the cavity frequency becoming detuned. As a result, the Vc of the cavity was reduced to 80 % of the desired voltage, which was the abort trigger level set to protect the cavity.

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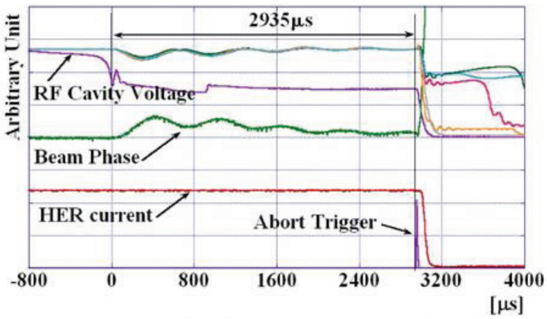

Figure 3: RF hardware abort.

Loss Monitor Abort

A loss monitor system of ion chambers and PIN photo-diodes was prepared to protect the accelerator hardware against unexpected sudden beam losses. Most PINs were fixed on the collimators of each ring, and identified the ring in which the beam loss occurred. On the other hand, ICs were installed in the whole tunnel and covered a wide range in space, but could not distinguish the ring [4]. Some examples of the abort caused by beam loss will be shown.

Two-Ring Abort Figure 4 is an example where both rings abort, but not at the same time. HER beam loss is observed 2.5ms before the HER abort trigger signal, while the LER abort is requested before that. We found the LER abort trigger came from the RF fast arc sensor, and understood that the noise of HER beam loss was detected by the LER RF sensors since the beam was lost at the LER RF section. After that, the HER beam was aborted by LM PIN request. Therefore, we adjusted the LM interlock level to avoid such a fake LER abort.

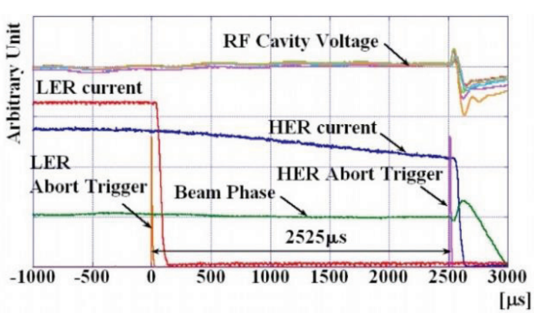

Figure 4: Loss monitor abort caused by HER beam loss.

Injection Timing Problem We found that some LM aborts happened at the end or start of injection. In order to check the relation between injection timing and abort timing, each timing signal was sent to the abort monitor logger. Injection timings are sent to injection kickers installed upstream and downstream of an injection point, and a septum magnet installed near the injection point, respectively. The upstream injection kicker was found not to receive the final injection trigger as shown in Fig. 5. As a result, the stored beam was kicked only by the downstream kicker, and the beam was lost at that time. This problem was caused by injection trigger system software, and was fixed after understanding the reason.

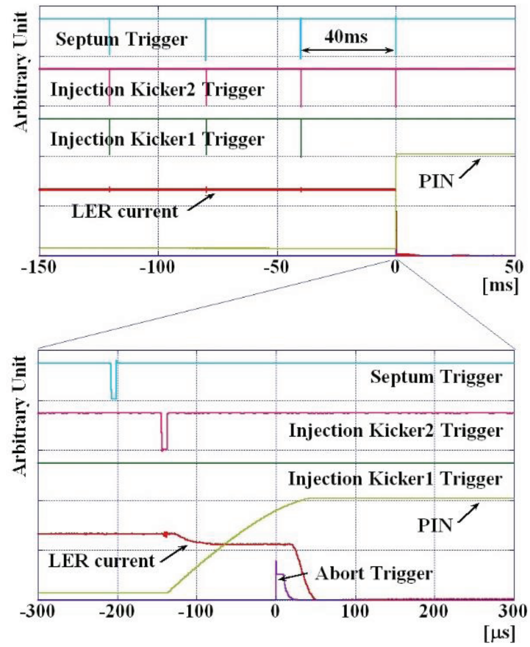

Figure 5: Beam loss that synchronized for injection timing.

Vacuum Problem As beam currents increased, loss monitor aborts with beam phase oscillation increased. Figure 6 describes that the beam phase starts to oscillate and the beam loss occurs with PIN signal. We investigated the reason and found vacuum pressure spikes taking place somewhere in this type of beam loss. It was supposed that the vacuum spike was caused by dust trapping, leading to beam oscillation. Finally the beam was lost at a narrow aperture of the ring. Even if vacuum bursts happened anywhere, the position of the beam loss did not change. The PINs which requested the abort were located downstream of the injection point in this case. The PINs located on collimators were able to make abort requests after we adjusted collimators to protect the beam pipes elsewhere. This type abort is expected to be reduced after further vacuum scrubbing.

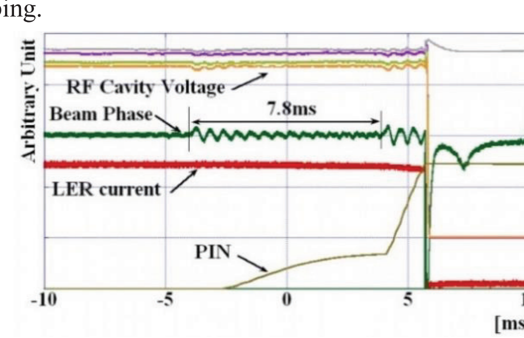

Figure 6: Loss monitor abort with beam phase oscillation.

Beam Phase Abort

Because of the strong interaction between accelerated beam and RF cavities, the cavities tripped whenever high current beam was lost. On the other hand, when one of the cavities tripped, the coherent synchrotron motion of the beam occurred and caused beam loss. The synchronous

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phase between the beam oscillation and the reference RF phase were monitored, and the beam phase (BP) abort trigger was introduced when the phase difference reached a threshold level. If the LM does not detect beam loss, the BP starts oscillation due to the change of the RF voltage, and results in a BP abort.

RF Quench When a BP abort was requested as shown in Fig.7, at first we checked whether RF signals were normal or not. Vc of an RF cavity jumped up during a quench, and the klystron power increased gradually over 75 ms. Finally, the power reached to the interlock level, and turned off. As a result, the BP rose up then reached the threshold level. This BP abort request is fast enough to protect the RF cavity.

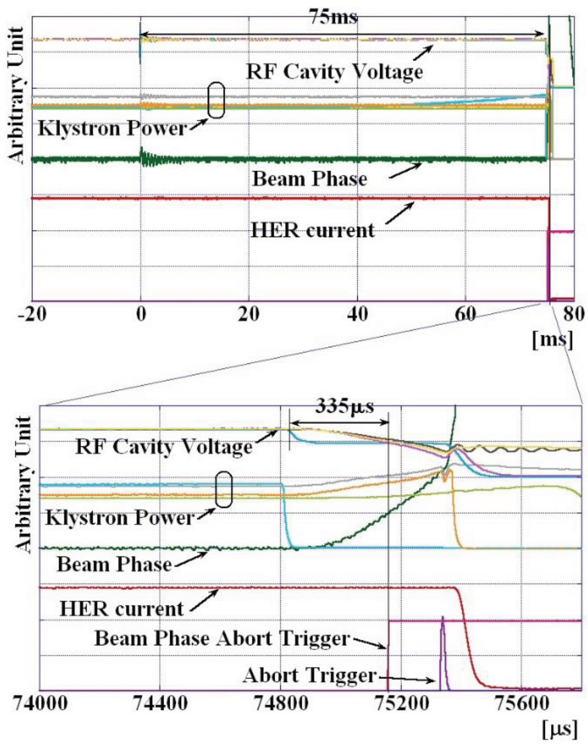

Figure 7: Beam phase abort caused by RF down.

Earthquake Figure 8 describes another type of BP abort. The abnormal behaviour of a cavity was found at 2.5 ms before the BP abort request, and the Vc dropped 0.5 ms afterwards. The BP signal starts to rise in response to the RF drop, and the PINs signals jumped up at the same time as the abort. It means something caused the vibration of hardware components including RF cavities. At that time, we sensed an earthquake and concluded the earthquake is the source of the abort.

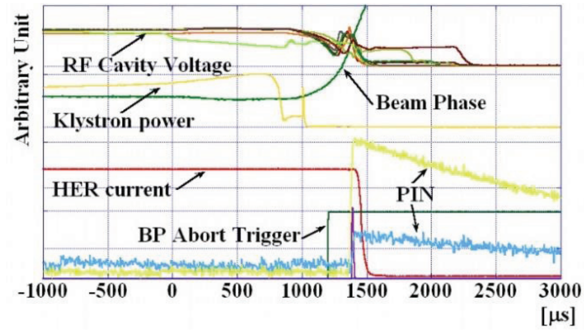

Figure 8: BP abort caused by earthquake.

CONCLUSION

We diagnosed more than 1500 aborts during Phase I operation up to 1 A, and classified them by the abort causes. Figure 9 shows the monthly statistics. Many manual aborts were required to find the optimum kicker timing for the various kicker magnet voltage and optics. Other studies for beam instability measurement, beam size measurement, detector background measurement, and others also required manual aborts. The rather large number of RF aborts in May and June was due to problems with a frequency tuner and insufficient HOM dumping. Aborts caused by beam loss accompanied by vacuum spikes occurred at higher current operation. The beams were correctly dumped by the abort system after optimizing the abort trigger timing. The abort system of the LER will be improved by adding a pulsed quadrupole magnet to increase the beam size at the extraction window before Phase II commissioning.

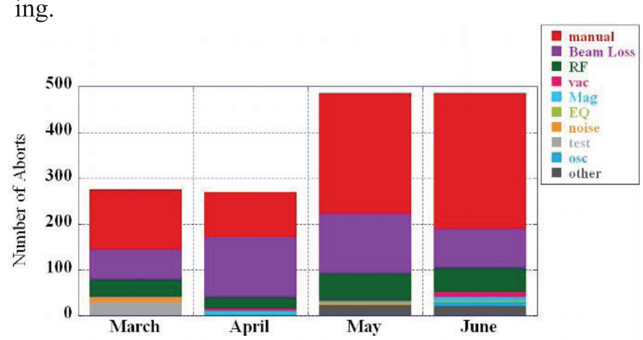

Figure 9: Abort statistics.

REFERENCES

[1] Y. Ohnishi *et al.*, “Accelerator Design at SuperKEKB”, *Prog. Theor. Exp. Phys.*, 2013, 03A011.

[2] T. Mimashi *et al.*, “SuperKEKB Beam Abort System”, *IPAC2014*, Dresden, Germany, MOPRO023.

[3] S. Sasaki *et al.*, “Upgrade of Abort Trigger System for SuperKEKB”, *ICALEPCS2015*, Melbourne, Australia, MOPGF141.

[4] H. Ikeda *et al.*, “Beam Loss Monitor at SuperKEKB”, *IBIC2014*, Monterey, CA, USA, TIPD22.

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