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FAST TRIGGER SYSTEM FOR BEAM ABORT SYSTEM IN SuperKEKB

H. Ikeda†,[1], T. Mimashi[1], S. Nakamura[1], T. Oki[1], S. Sasaki, High Energy Accelerator Research Organization (KEK), Tsukuba, Japan
[1]also at SOKENDAI, Tsukuba, Japan

Abstract

In order to protect the hardware components of the detector and accelerator from sudden beam loss of high beam currents, the fast beam abort system is developed in the SuperKEKB. The previous abort system was not fast enough for sudden beam loss that caused QCS quench, and it gave a damage to the collimator and the Belle-II detector. A fast abort system is required to preventing such damage. The abort system consists of several sensors that generate interlock signal (the loss monitor, dose in the Bell-II detector, and the magnet failure etc.), optical cable system to transfer the interlock signal to central control room (CCR), the abort trigger signal generation system and the abort kicker. To reduce total time, we reduce transmission time from local control room to CCR by changing signal cable route. Since the interlock signal produced by magnet power supply was slow, we modified the magnet power supply. For more quick generation of abort trigger signal, we increased number of the abort gap. By these improvements, an average abort time is reduced from 31μsec to 25μsec. This improvement looks small, but it brought preventing the serious radiation damage to many hardware components. Detail of the system and result is presented in this paper.

INTRODUCTION

SuperKEK is a collider of 7GeV electrons and 4GeV positrons. KEKB was upgraded from 2011 over 5 years in order to increase the luminosity and started commissioning in 2018 after the test operation [1 - 3]. SuperKEKB is increasing the beam current and squeezing the beam size in order to obtain high luminosity. Superconducting quadrupole magnets (QCS) are installed in the interaction region (IR) in order to squeeze β^*. At present, the luminosity is increased more than twice the luminosity of KEKB, by gradually reducing β, and gradually increasing the current value [4].

Accelerator and detector hardware has been upgraded and more precise handling is required for operation. In order to increase the beam current while protecting the equipment, it is necessary to strive for beam stability and abort the unstable beam as soon as possible.

ABORT 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 window [5, 6]. It takes one revolution, i.e. 10μsec to completely extract the storage beam from the ring. The beam is distributed every 2-4 RF buckets in the ring and 200 ns is empty to cover the build-up time of the abort kicker magnet field as shown in Fig. 1. We call 200ns no beam period in the beam train "Abort Gap".

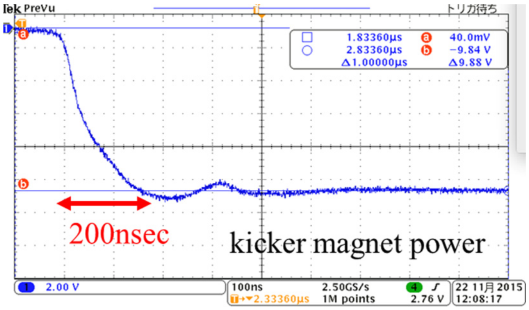

Figure 1: Abort kicker magnet power.

ABORT TRIGGER

The abort trigger system collects several types of abort trigger requests as shown in Fig. 2. First type is direct trigger from hardware components such as RF, vacuum, magnet and monitor. For example, the RF group monitors the cavity voltage, klystron power, synchrotron oscillation phase and so on. The vacuum group monitors the vacuum pressure and temperature of the chamber in the ring. The magnet group uses the comparator current of power supply.

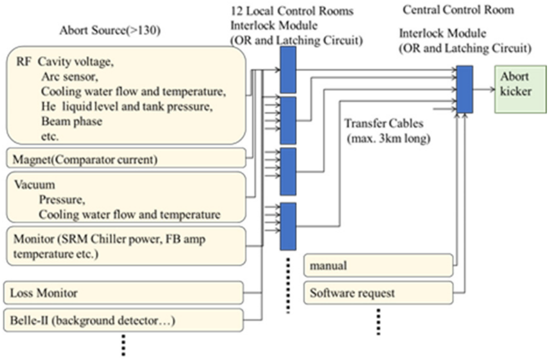

Figure 2: Abort trigger flow.

The second trigger type is as follows. Beam loss monitor is the main abort trigger to protect the hardware of the accelerator and detector [7]. We are using the ion chambers (ICs) and PIN photo-diodes (PINs) as beam loss monitor sensor. ICs are installed in various places in the tunnel to detect beam loss in a wide area, and PINs are installed mainly in the downstream of the collimator where the aperture is narrow.

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† hitomi.ikeda@kek.jp

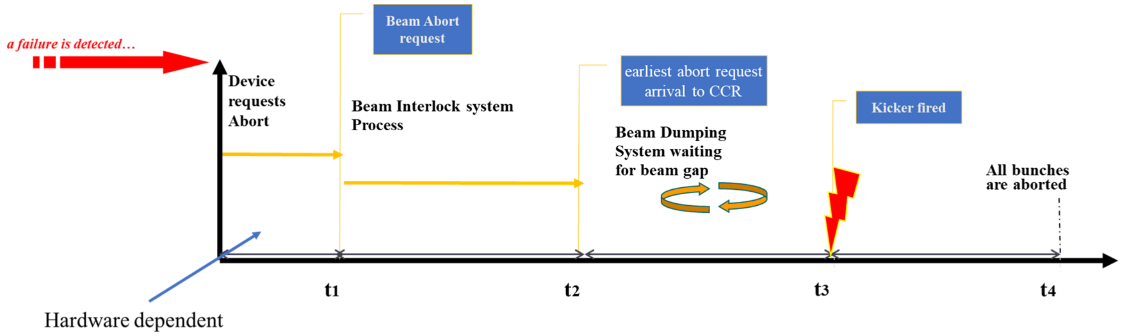

Figure 3: Time delay of the abort trigger. flow.

Signals that don't need to be as fast as hardwire trigger are aborts via software and 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) [8]. 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.

Figure 3 shows the flow of time from the signal output from each trigger source to the charging of the abort kicker and kicking all the beams out of the ring. t1 is the delay time to initiate interlock signal which depend on the sensors and readout electronics of each hardware. t2-t1 is the time to summarize the abort request on the beam abort system. Input signals at each LCR are sent to CCR. The time delay depends on the optical cable length from LCR to CCR. t3-t2 is the synchronization time of the abort request signal with revolution in FPGA. It is required to synchronize the abort kicker timing with the abort gap for the protection of hardware. After the synchronization, cable delay from CCR to kicker power supply (400m), time for Thyratron to turn on and rise time for the kicker (200ns) are needed.

HUGE BEAM LOSS

Beam loss is the most common cause of SuperKEKB beam abort. There are several reasons of beam loss, and they are mainly divided into two categories caused by beam injection or stored beam. If beam loss is caused by an injected beam, the beam loss can be suppressed by the upstream beam adjustment and injection tuning. In addition, since the injected beam has a smaller amount of charge than the stored beam, it causes less damage to the hardware. Especially if the high stored beam current is lost, it may cause serious damage to the hardware.

In SuperKEKB, a large beam loss of unknown reason suddenly occurred. This beam loss currently looks to occur suddenly without precursors such as increased beam size or beam oscillation. This sudden beam loss can damage the Belle-II detector or cause a quench of the QCS. Closing the collimator which protects the detector and QCS, also damage at the collimator head [9].

The fast beam abort is very important when beam loss occurs along with investigating the cause of beam loss.

SPEEDING UP THE TRIGGER TIME

The trigger time has been reviewed for quick beam abort and made efforts to minimize the delay time.

Each hardware can shorten t1 by making the detection time as fast as possible.

Especially for QCS, which may cause quenching, the detection time of the quench detector was shortened from 10ms to 2ms. QCS power supply module is developed to take out abort signal directly from FPGA without conventional PLC when a failure is inside a power supply as shown in Fig. 4.

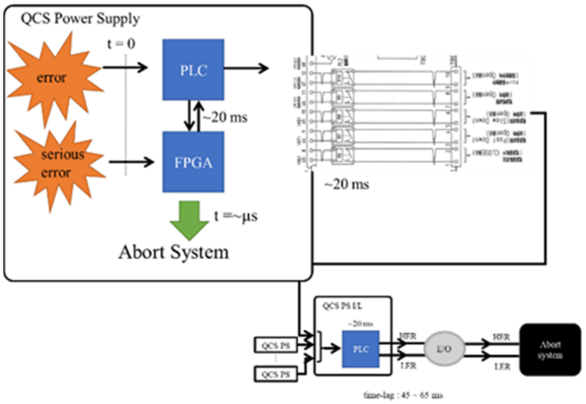

Figure 4: Magnet power supply interlock signal.

We introduced the injection veto system to PIN beam loss monitor for collimator to set lower threshold and the abort trigger can be issued quickly. Moreover, in order to shorten the time of t2-t1 as much as possible, the signal path of the loss monitor was changed. Detect the beam loss by the detector near CCR and send by shorter cable. As shown by Fig. 5, the loss monitor signal are collected in four CCRs on the ring, and generate the trigger signal which is sent to the CCR. The signal from the loss monitor installed at the downstream of one collimator that frequently issues abort triggers, used to be sent to the LCR near OHO. Instead of OHO, by sending it to the LCR near FUJI which is near the CCR, the abort trigger can be sent out earlier.

In order to shorten t3-t2, we minimized delay to synchronize to the abort gap. We removed unnecessary fixed delays and increased the abort gap in the beam train from one to two. In other words, the waiting time of the abort gap can be shortened from 10µs to 5µs at the maximum.

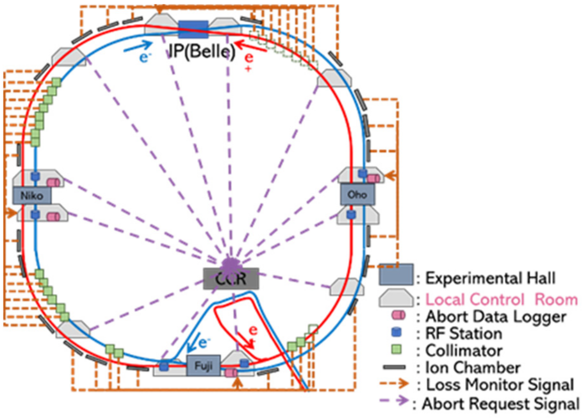

Figure 5: Loss monitor signal flow.

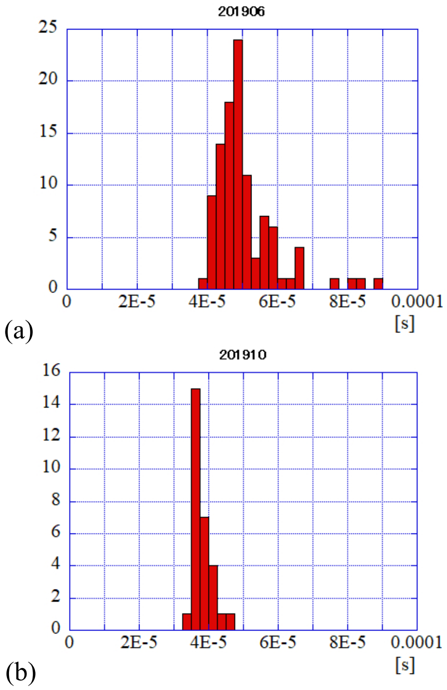

Figure 6: Time difference between first abort trigger and the loss monitor just after the abort dump with (a) original timing and (b) after improvement.

By accumulating these efforts, the abort delay, which took 21 to 37 µs, can be shortened to 17 to 30 µs. The actual abort trigger time is not a fixed value as it varies depending on the location of the sensor and other conditions. In order to know whether the abort shortening was successful, the difference between the trigger that first issued the abort and the trigger signal of the loss monitor behind the abort dump was plotted in Fig. 6. Since the loss monitor behind the dump detects the aborted beam and issues a trigger, it is possible to measure the time difference between when the beam loss actually occurs and the trigger is issued until the beam is discarded. The fastest value before improvement is 33.5µs, and after that it is 39.9µs. Considering the time from the reaction of the loss monitor behind the dump to the release of the abort trigger, it can be considered that the actual abort trigger delay has changed from 31µs to 25µs. It is almost in agreement with the expected calculated value.

CONCLUSION

A controlled beam abort system has been installed in SuperKEKB from the beginning of commissioning. However, sudden huge beam loss causes problems such as damage to the collimator and QCS quenching. In order to reduce these problems as much as possible, we reviewed the time taken for the abort trigger. As a result of reducing the time required in the abort system as much as possible, the delay time, which took 21 to 39 µs at the beginning of commissioning, was reduced to 17 to 30 µs. As for the measurement result, the average of 31µs is shortened to 25µs. Since the revolution is 10µs, it is concluded that we succeeded in reducing it as much as possible as a trigger system for the current abort system.

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