TUP002

Development of Bunch Position Monitors to observe Sudden Beam Loss of SuperKEKB Rings

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Abstract

In the SuperKEKB rings, we have encountered extremely fast beam losses occurring primarily within one to two turns in some parts of the bunch train. Such sudden beam loss induced severe failure in the vertical collimator heads, quenches on the superconducting final quadru-poles, and damage on the Belle II detector in some cases. It is essential to investigate the cause and take counter-measures. This paper presents the phenomena clarified by the bunch current and position monitor of the bunch feedback system. The upgrade plan for the existing monitor, and recently developed simple monitors installed in the suspected area is also introduced.

Introduction

SuperKEKB collider

Need to increase peak luminosity
around 10^{35}/cm^2/s by the end of FY2024
around 2.4x10^{35}/cm^2/s by FY2026

During luminosity runs

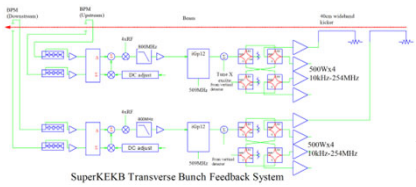
Encountered so-called sudden beam loss (SBL) events
Both LER and HER.
Losses some part of bunch train within one or two turns
Seems have some threshold value on bunch current (~0.65 mA/bunch in LER)

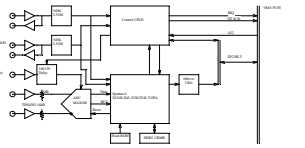
SBL damages

Heads of vertical collimators, quenches QCSs, cause huge background to Belle-II detector---
Limit the luminosity (due to lower bunch current!)

	HER	LER
Energy (GeV)	7	4
Circumference (m)	3016	
Maximum beam current (achieved, mA)	1099	1321
Max. bunch current (achieved, mA)	1	1.5
Bunch length (mm)	5	6
RF frequency (MHz)	508.886	
Harmonic number	5120	
Typical synchrotron tune	0.028	0.024
Momentum compaction factor	4.5e-4	3.2e-4
Longitudinal radiation damping time (ms)	29	23
Natural horizontal emittance (nm)	4.6	3.2
Peak luminosity (achieved, cm^{-2} s^{-1})	4.7x10^{34}	
Bunch current monitor	1	1
Bunch oscillation recorder	3	3

Monitors to measure the sudden beam loss(BOR/BCM)

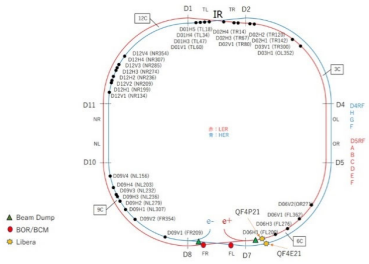




18k10 bunch current/bunch oscillation recorder

- 8-bit fast ADC with 509MHz RF clock
- Spartan6 FPGA with SRAM daughter card
- 6U 2W VME card
- 5120 bunches x 4k turns of memory
- Normally triggered by quick intensity drop of DCCT
- X, Y, longitudinal and Bunch current /per ring

Beam loss monitor system, beam collimators

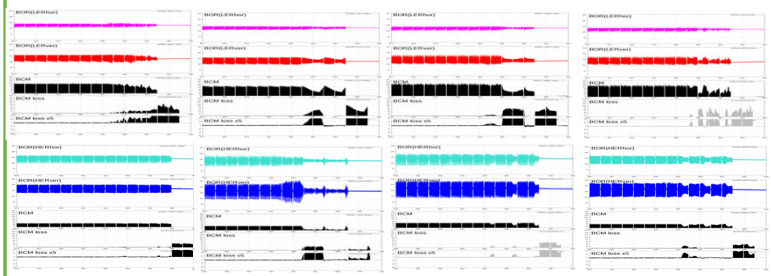


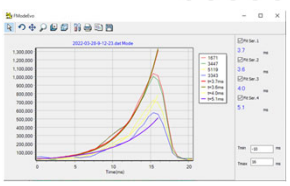
- Ion chambers (around the ring):slow
- PIN-photodiodes (around beam collimators):fast
- Scintillators (Belle-II, collimators):Ultra-fast
- Diamond sensors (Belle-II)
- Optical fibers (collimator, injection point)

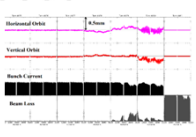
- Beam abort request from loss monitors:
  - Convert the signal to optical signal in the local control rooms, then transferred to CCR.
  - Synchronize the timing with the 2xfrev to adjust the abort gap in the bunch train (two abort gaps in one revolution), then initiate beam abort.
  - Response time : 5-30 us (0.5-3 turns).

Example of sudden beam loss (SBL) event

Automatic data transfer to NAS (EPICS device support)
20MB– 5 sec /board (mostly within VME transfer time)
After data transfer, off-line code on Linux server summarizes the loss data on Web.







The orbit has slightly changed just one turn before the loss but the amount of change was small, the order of 0.1mm at the FB monitor.

No energy change just before the loss (Libera turn-by-turn)
No significant beam size change in the X-ray size monitor
Vacuum pressure burst at collimator section

Normal CBI: Growth time >50 turns

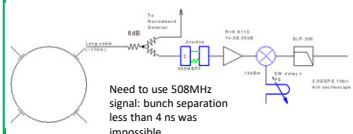
Known characteristics of SBL up to now

- Some parts of the bunch train were lost in one or two turns without growth of oscillation : completely different from the normal coupled-bunch instabilities.
- There appears to be a bunch current threshold (~0.65 mA/bunch) for the occurrence of SBL. The correlation with the total beam current appears to be rather weaker.
- Beam loss mainly starts around D6V1 collimator where the effective vertical gap was the narrowest in the ring. There exist some SBL events which started D2V1 collimator when we occasionally operated the vertical gap of D6V1 larger due to the damaged heads of the collimator.
- The BOR data have shown no significant beam ex-cursion just before the SBL. It is strongly suspected that there were a strong kicking source between the Fuji-straight section and D6 arc section where first beam loss occurred.

Upgrade plan for the existing bunch position monitors

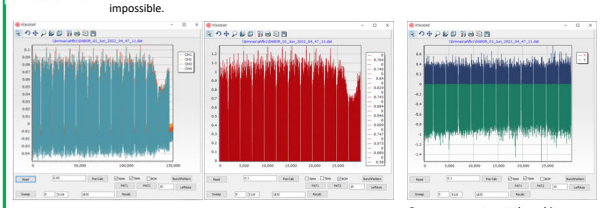
- In our transverse bunch feedback system, we have constructed two independent feedback loops: betatron phase advance roughly 60-90 deg at the monitor position.
- Use block ram (inside FPGA) to trigger/record the SBL: we could reconstruct the phase space information of the bunches just before SBL. (could record only 96 turns but should enough for SBL)
- Use the same beam loss trigger signal as BOR to trigger data acquisition to the BRAM of IGp12.
- EPICS sequencer to transfer the data from iGp12 to NAS.

Simplified (and cheap) bunch oscillation/intensity monitor



Need to use 508MHz signal: bunch separation less than 4 ns was impossible.

Significant leak of LO signal had disturbed the narrowband detector!

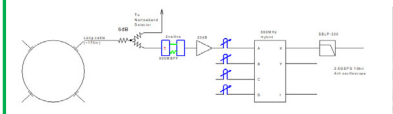


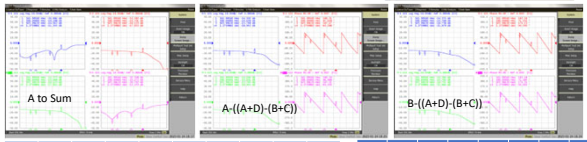
Analog subtraction of the signal using special hybrid circuit should be needed!

Raw intensity signal

Bunch intensity data behaves similarly to those obtained from BCM.

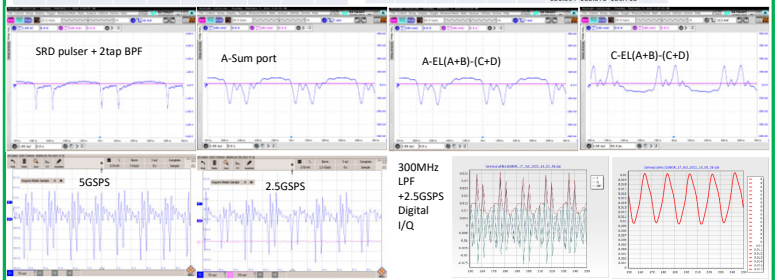
Poor accuracy to get the orbit. (due to Insufficient resolution).





	341.995	500	926	1270	Ref341	Ref500	Ref926	Ref1270
A-AZ	-18.827	-111.36	-12.637	122	0	0	0	0
B-AZ	163.16	71.352	171.13	-54.593	181.987	182.712	183.767	-176.593
C-AZ	160.21	67.028	167.47	-63.286	-181.987	-182.712	-183.767	176.593
D-AZ	-18.146	-110.66	-8.8046	121.83	-0.681	-0.7	-3.8324	0.17

	341.995	500	926	1270	Ref341	Ref500	Ref926	Ref1270
A-EL	161.98	69.183	168.42	-85.545	0	0	0	0
B-EL	161.9	68.669	165.35	-86.057	-0.08	-0.514	-3.07	-0.512
C-EL	-20.027	-113.99	-16.333	92.436	182.007	183.173	184.753	177.981
D-EL	-19.884	-114.19	-18.298	95.308	181.864	183.373	186.718	180.853



Another simple (robust) way to overcome the difficulty: Prepare better oscilloscope which have capability to sample all 4 channels with the sample rate of 5GSPS: We have purchased it..

The EPICS device support using socket connection, and the EPICS sequencer to transfer the data from the oscilloscope to NAS has been ready.

Summary

To investigate the cause of the sudden beam loss observed in SuperKEKB rings, we are preparing several kind of post-mortem bunch position monitors which record the behavior of individual bunch positions and intensities over several turns just before the SBL event. For the rough bunch position and intensity detection around the suspected location in the ring, simplified bunch oscillation recorder based on the hybrid circuit and the digital oscilloscope. The required parameter on the cutoff frequency of the LPF and digital filter are also checked and are ready to test with the real beam.

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