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BEAM SIZE MEASUREMENT AT SBL IN SuperKEKB

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Abstract

Sudden beam loss (SBL) is one of the obstacles to improving the luminosity of SuperKEKB. SBL cause damage to collimators and other accelerator components, QCS quench, and large background to the Belle II detector. It also causes beam abort and prevents the accumulation of high currents. Therefore, it is an important issue to investigate and resolve the causes of SBL events. In order to investigate the causes of SBL events, we measured the beam profile at the moment of abort due to SBL using three different cameras and found that the beam size at SBL events was larger than at the moment of abort due to other causes. This paper summarizes the results of the size profile measurements made as part of the investigation into the cause of the SBL.

INTRODUCTION

The SuperKEKB accelerator is a collider of 7 GeV electrons (HER) and 4 GeV positrons (LER) with a circumference of 3 km. In 2024 operation, we achieved 5.1×10^{34} $cm^{-2}s^{-1}$ at lower beam current than KEKB [1]. One of the obstacles that must be overcome to increase the luminosity is sudden beam loss (SBL) [2-4]. SBL causes damage to accelerator components, final focusing super conducting magnets (QCS) [5] quenches, and large backgrounds to Belle-II detector. In particular, SBL has caused damage to the collimator head more than 10 times [6]. After various tests, it was found that the most likely candidate to cause SBL is dusts interacting with the beam, and that the dust was thought to come from the vacuum sealant used to prevent vacuum leaks. When the SBL occurred, measurements were characterized by a vacuum burst and an increase in the beam size.

SUDDEN BEAM LOSS

SBL is a type of beam loss where the circulating beam suddenly loses several tens of percent of its charge during two or three turns, as shown in Fig. 1. Just before the beam loss begins, the orbit appears to move, but the displacement is the order of 0.1 mm. The orbit displacement becomes order of 1 mm after the start of the beam loss. Beam loss occurs in the narrow aperture (collimator, IR) and the starting point of beam loss depends on the collimator setting. SBLs have occurred in both LER and HER, but the damage is more severe in LER because of the greater number of SBLs in LERs and the smaller number of collimators that protect interaction point in LER. Therefore, observations and countermeasure related to SBL in SuperKEKB are mainly made in LER. The measurements in this paper were also performed at LER. SuperKEKB is equipped with a fast beam abort system to dump the beam as soon as possible in an abnormal situation [7-9]. After aborting the beam, it is necessary to accumulate it again from 0 mA, so a large number of beam aborts hinder the gain in integral luminosity. Aborts caused by SBL are 16 % in LER and 1.4 % in HER, indicating that the impact is huge in LER. SBL can occur with both single beam and collision beam. SBL occurs both at β*=1 mm, 3 mm and detuned optics. SBLs occurred with different filling patterns of bunches which were combinations of 2 or 3-bucket spacing, but did not occur when the patterns were significantly different from them. For example, no SBLs were observed when the number of bunches was small though the machine was not operated for long periods of time in these patterns.

Furthermore, a notable feature is that the SBL frequency depends on beam current, and vacuum bursts were observed with the SBL mainly at the wiggler magnet section.

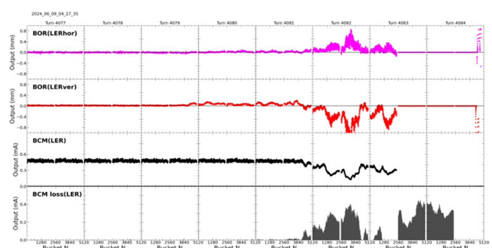

Figure 1: From top to bottom: horizontal orbit, vertical orbit, bunch current, and beam loss compared to the previous turn at the SBL abort.

BEAM SIZE MEASUREMENT

We decided to measure the beam size when the SBL-induced abort occurred. The setup of SuperKEKB visible light monitor consists of an extraction mirror, optical window, transfer mirrors and optical system. An extraction mirror of visible light is made of thick polycrystalline diamond [10, 11]. It is possible to obtain a sufficient amount of light for beam profile measurement for each bunch. Extraction chamber is set up to downstream 23 m of the source bending magnet. At the downstream of the chamber, five mirrors are used to relay light to the above ground SRM hat about 30 m downstream. An optical system for beam measurement, a gated camera, streak camera etc. are installed in the SRM hat on the ground.

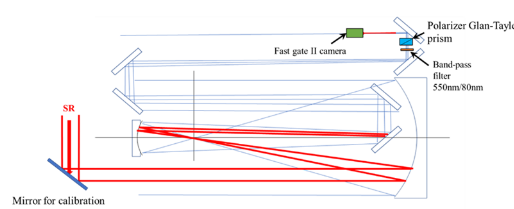

Figure 2: Gregorian objective for observation of injection beam f = 7028 mm.

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At the first, to confirm the beam profile when SBL occurred, measurements were performed using a gated camera. Figure 2 is an incident optical system for gated camera. Object system which designed for corona graph is used to measure the injection beam [12]. When the abort trigger signal sends to the abort kicker, it also sends the signal to the SRM hat. By using an abort trigger, it is possible to measure the profile of part of the final turn. The gate width is set to 100 ns, which corresponds to about 20 bunches. Data was also collected simultaneously using a streak camera to confirm the beam size for each bunch. The streak camera can measure the transverse beam size at the same time as the bunch length. This time we adjusted the optical axis to measure the vertical beam size. For reference, Fig. 3 shows the beam orbit, the bunch current, and the beam profile when the abort trigger is manually activated.

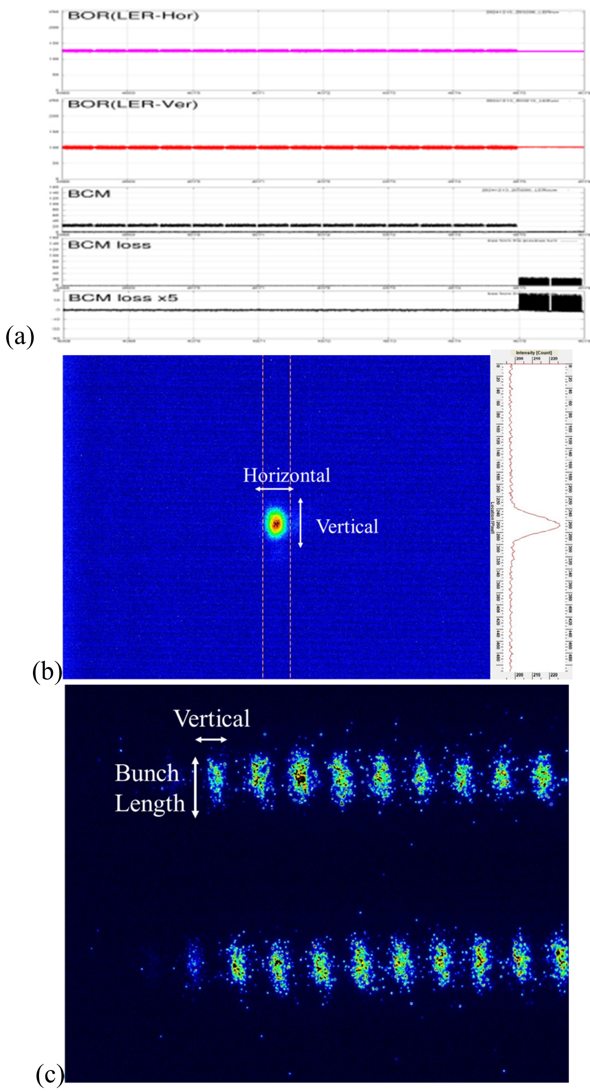

Figure 3: (a) Beam orbit and bunch current and beam profile measured with (b) gated camera and (c) streak camera at the moment of manual abort. The horizontal direction of the streak camera measurement corresponds to the vertical beam size.

Figure 4 shows the instantaneous beam profile of the SBL measured with the same setup as in Fig. 3. From Fig. 4(a), it can be seen that a significant proportion of the bunch current is rapidly lost 1.5 turns before the abort. Figure 4(b) shows the beam profile measured with the gated camera, which shows that it is significantly broader in the vertical direction compared to the manual abort in Fig. 3. This corresponds to the profile of the integral of approximately 20 bunches. In order to compare the size of each bunch, measurements taken with a streak camera are shown in Fig. 4(c), but it can be seen that the profile is blurred because the bunch size is too large.

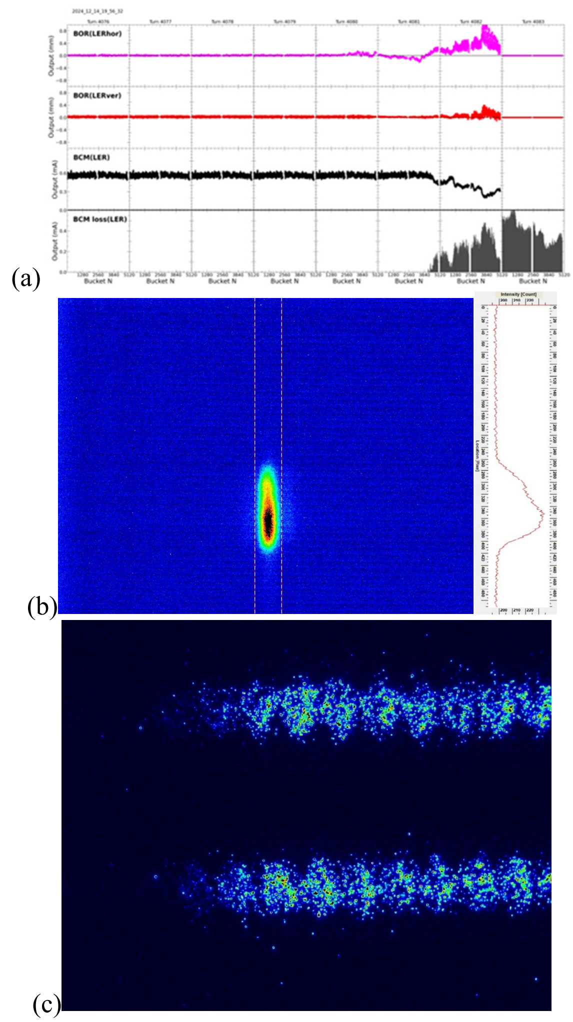

Figure 4: An example of SBL. (a) Beam orbit and beam loss per bunch. (b) Beam profile measured with a gated camera. (c) Bunch length vs vertical beam size per bunch measured with a streak camera.

We also measured the beam size at each turn using a CMOS camera, an example of which is shown in Fig. 5 [13]. This is an example of a sudden beam loss 1.5 turns before the abort that is similar with Fig. 4. The gated camera shows an increase in beam size in the final turn, and the CMOS camera shows that the beam size in the previous turns did not increase.

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(a) (b) (c)

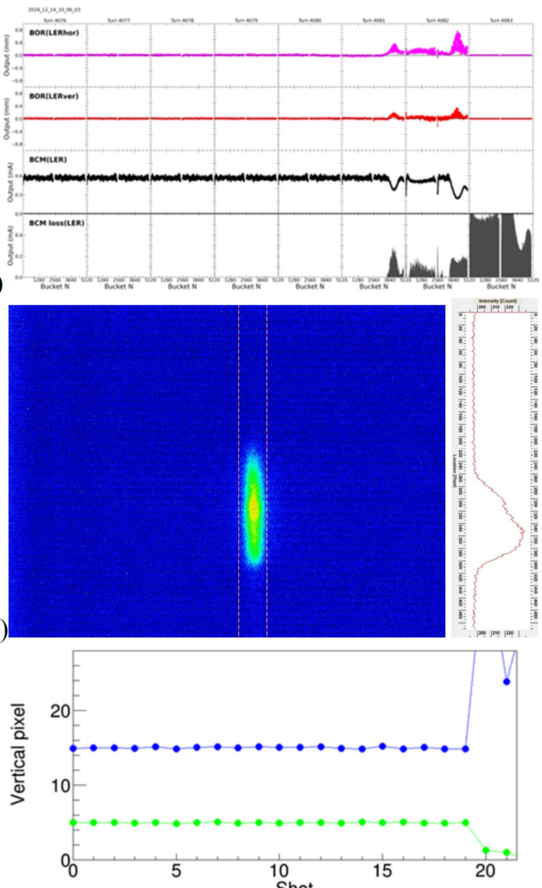

Figure 5: An example of SBL. (a) Beam orbit and beam loss per bunch. (b) Beam profile measured with a gated camera. (c) Beam size per turn measured with a CMOS camera.

Since orbit fluctuations are also observed when beam loss occurs, the bunch oscillation recorder (BOR) was used to measure the orbit fluctuations as well as the beam size [14]. Since the profile measurement with the gated camera is an integration of many bunches, the orbit fluctuations and beam size were compared to check whether orbit fluctuations for each bunch were reflected in the beam size or not. The upper graph in Fig. 6 shows the beam size measured by the gated camera, and the lower graph shows the difference between the maximum and minimum values of the trajectory for each bunch measured by the BOR. A calibration was performed to estimate the transverse scale of the gated camera. The most upstream mirror of Fig. 2 was placed on a cross roller stage equipped with a micro-meter and moved horizontally by ± 15 mm to measure the position on the screen. This corresponds to moving the beam virtually. At the SBL event shown in the blue circle, both the orbit fluctuation and the beam size increase and the beam size increase is larger than the beam orbit change. 239 LER SBLs occurred in 2024, and the beam size varied from event to event, which is thought to depend on the beam conditions and the location and size of the pressure bursts that accompanied the SBL.

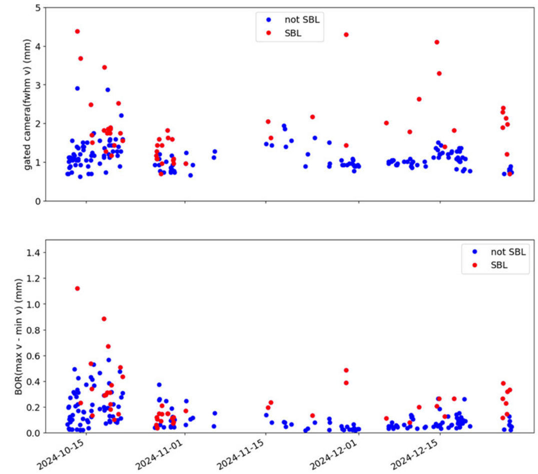

Figure 6: (top) The beam size measured by the gated camera, and (bottom) the difference between the maximum and minimum values of the orbit for each bunch measured by the BOR.

CONCLUSION

At SuperKEKB, it is urgent to find out the cause of the SBL. Various measurements were carried out at the timing of SBL, and the key to identifying the cause was the increase in beam size during the SBL. Measurements using three types of cameras - a gated camera, a streak camera, and a CMOS camera - showed that the vertical beam size appeared to be increasing for each bunch. Since the increase in beam size and the occurrence of pressure bursts in specific locations were observed, an interaction between dust and the beam was suspected.

Based on these results, we knocked on the vacuum chamber to artificially cause dust to fall, and we were able to reproduce SBLs. When we opened the area where vacuum bursts frequently occurred, we found black stain that was thought to be caused by the vacuum sealant. When this stain was removed, the number of SBLs decreased. Cleaning of the chamber and investigation into the mechanism leading to the SBL through dust beam interaction are currently underway [15].

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