REDUCTION OF SUDDEN BEAM LOSS IN SUPERKEKB

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Abstract

Sudden beam loss (SBL) is one of the major problems facing SuperKEKB, and various efforts have been made to solve it. SBL is a beam loss event in which a significant percentage of the beam current is lost in an instant. Beam loss begins within 10 microseconds, the equivalent of one revolution, and as a result, tens of percent of the total charge is lost in a few revolutions before the beam is aborted. In order to solve the problem, various monitors are being analyzed and new beam instrumentation devices are developed. Various circumstantial evidence suggests that removing the black stains caused by the vacuum sealant inside the vacuum chamber is likely to be effective in resolving the SBL. This paper explains, using various measurement results, how much SBL was reduced by cleaning the chamber as much as possible. We also report measurement results that may lead to the identification of the cause of SBL, though it has not been completely solved.

INTRODUCTION

SuperKEKB is a circular collider with the circumference of about 3 km. It consists of the 7GeV electron ring(HER) and the 4GeV positron ring(LER)[1]. SuperKEKB continues to hold the world record for luminosity, with the current record being 5.244 x $10^{34}cm^{-2}s^{-1}$ set on March 19, 2026. Further improvement in peak luminosity and accumulation of integrated luminosity are challenges for the SuperKEKB accelerator and the Belle II detector. Reducing sudden beam loss (SBL) will help to overcome the challenges. SBL became noticeable after the start of luminosity runs. It is a phenomenon in which a significant percentage of the beam current is suddenly lost in a few turns before the abort [2]. SBL causes damage to accelerator components, quenches of final focusing superconducting magnets (QCS) [3], and large background noise to the Belle-II detector. The total number of SBLs is overwhelmingly high in the LER, and the QCS quenches occur almost at the LER. Figure 1 shows an example of SBL event.

REDUCTION OF SBL

Since SBLs in the LER occur with vacuum pressure bursts and increase in beam size, we suspected an interaction between the dust and the beam [4]. Accordingly, we conducted a knocker study in which dusts were experimentally knocked down by striking the beam duct with a knocker. Since SBLs occurred when knocking on beam pipes with clearing electrodes installed on the upper wall of the chamber, and the number of SBLs decreased after many knocks, some beam pipes with electrodes suspected to be the source of the dusts were flipped. But the effect of flipping the beam pipe was inconclusive.

Subsequently, observation of the inside the beam pipes, where large number of vacuum pressure bursts occurred, revealed the presence of the black stains which were thought to be caused by vacuum sealant. After cleaning the stains, the number of SBLs decreased. Laboratory investigations revealed that the MO-type flanges used in SuperKEKB likely allowed the vacuum sealant to enter the beam pipe in case of an air leak. As a result, we speculate the SBL is generated by beam-dust interaction, and one of the dust sources is the vacuum sealant [5-7]. Since it was confirmed that the vacuum sealant, which had entered the beam pipe, was one of the main causes of SBL in the 2024 operation, during the 2025 shutdown vacuum team opened and cleaned all accessible beam pipes where the vacuum sealant was suspected to have been used. Figure 2 shows the inside the beam pipe where the black stains were found.

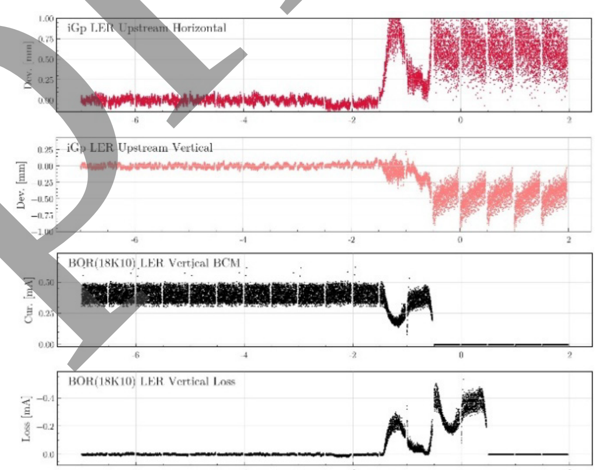

Figure 1: From top to bottom: Horizontal orbit, Vertical orbit, bunch current, and beam loss compared to the previous turn at the SBL abort.

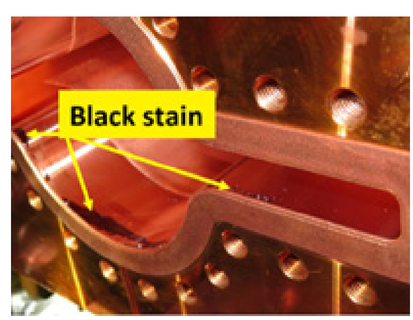

Figure 2: Black stains were observed inside the beam pipe.

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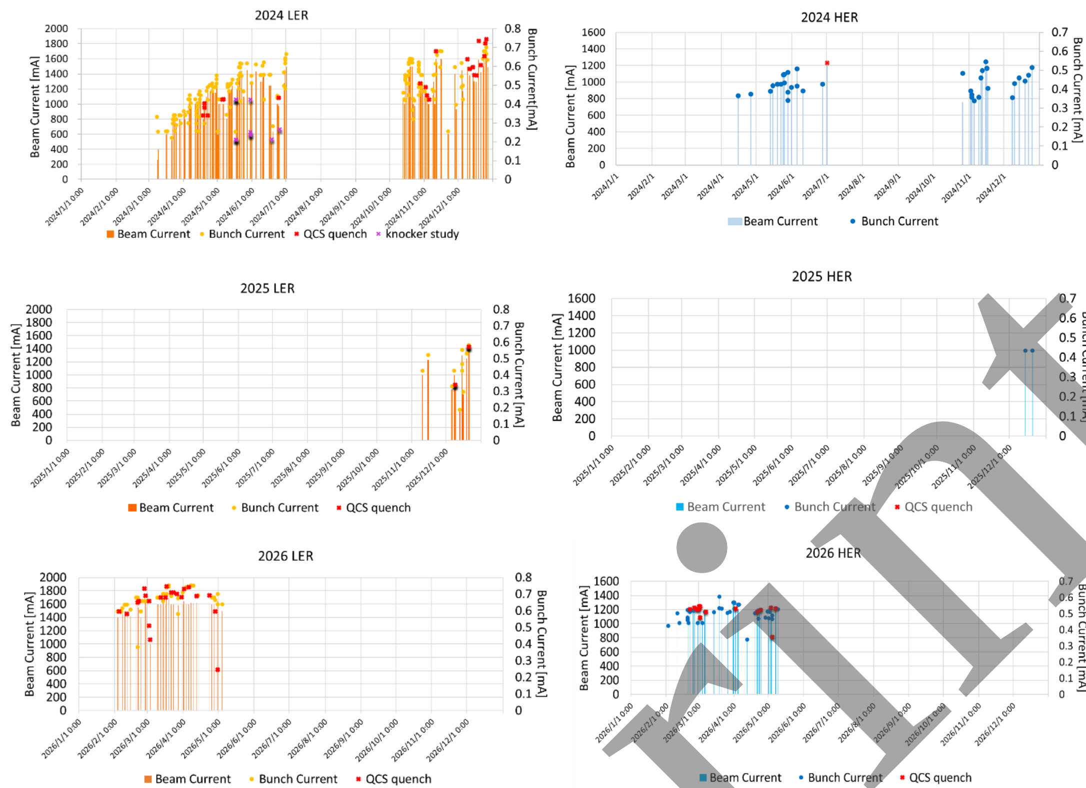

Figure 3: Beam current and bunch currents when SBL occurs at LER (left) and HER (right) in 2024～2026.

Figure 3 shows the Beam current and bunch currents when SBL occurred at the LER and the HER from 2024 to 2026. Although the operation of 2025 was short, from November 5th to December 22nd, the decrease in the number of SBLs is clear, and it is certain that cleaning the beam pipes was very effective in reducing the number of SBLs. While beam pipe cleaning reduced the number of SBLs, those issues were not completely resolved. During operations in 2025, pressure bursts and signals from nearby clearing electrodes were sometimes observed when an SBL occurred in the LER. During the subsequent winter shutdown, inspections were conducted inside the bellows in which the pressure burst had occurred in that vicinity and four bellows were replaced. In the bellows in the D11 section, discoloration was observed at the comb structure as shown in Fig.4, but we did not find the vacuum sealant. In the other places where the pressure burst occurred, no abnormality was found in the bellows, but they were replaced as a precaution. Subsequently, the number of SBLs accompanied by pressure bursts in this area decreased, but they did not disappear completely.

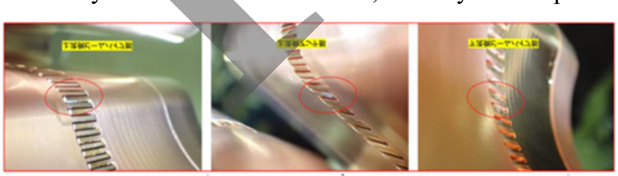

Figure 4: The discoloration was observed at the comb structure inside the D11 bellows.

OTHER SBL

Replacing the suspected bellows reduced the number of SBLs accompanied by vacuum bursts and electrode signals, but as shown in Fig. 3, SBLs are still occurring. Figure 5 shows the beam current dependence of the number of SBLs. Since 2026, operation has been carried out at relatively high currents in order to stably accumulate integrated luminosity. Accordingly, the number of SBLs has increased. While we have addressed the areas identified by pressure burst and electrode signals, identifying the source and cause of the current SBL problem is becoming increasingly difficult. Pressure bursts often occur near the collimators, making it difficult to determine whether the burst is a result of or caused by the SBL In particular, the number of SBLs has increased even in the HER, where it was previously low.

Figure 6 shows the number of aborts caused by beam loss in 2026. It can be seen that the HER has many small beam losses that are not visible to the naked eye in the bunch current monitor plot, in addition to SBL. In the HER, pressure bursts associated with SBL are less frequent, making it more difficult to determine the cause than in the LER.

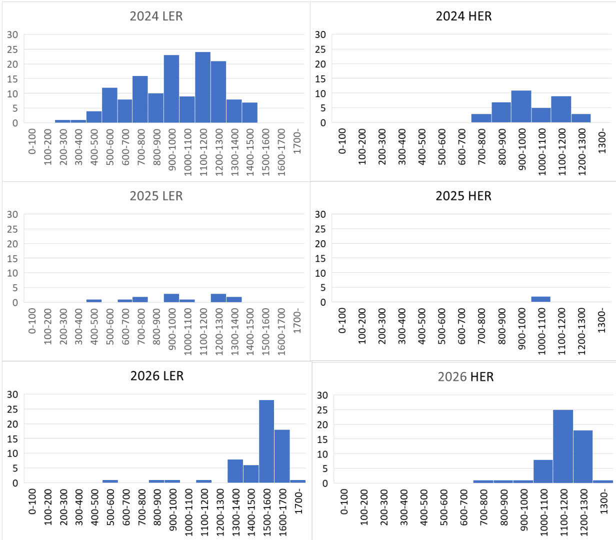

Figure 5: The beam current dependence of the number of SBLs each year.

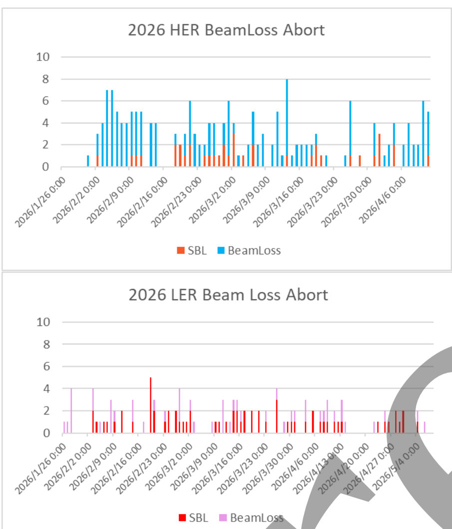

Figure 6: Number of aborts caused by beam loss which include SBL for HER and LER.

One of the key factors in determining the cause of the LER SBL was the increase in beam size during the SBL occurrence. Measurements using three types of cameras—a gate camera, a streak camera, and a CMOS camera—appeared to show an increase in the vertical beam size in each bunch. The observed increase in beam size and the occurrence of pressure burst at specific locations suggested interaction between the dust and the beam [8]. Therefore, we decided to measure the beam size during abort in the HER as well. When the abort trigger signal is sent to the abort kicker, the signal is also sent to the synchrotron radiation monitor (SRM) hut. Because the distance to the SRM hut is longer than the distance from the central control room generating the trigger to the kicker, it is not possible to measure the entire beam train immediately before the abort. However, by using the abort trigger, it is possible to measure beam profile in a part of the final turn. The gate width is set to 100 ns, which corresponds to approximately 20 bunches. Measurements using the streak camera have shown that the abort trigger measures the position at 3 microseconds before the end of final turn. Figure 7 shows the vertical beam size for SBL and other aborts. The vertical beam size at one SBL abort is larger than at others, but this is not the case for all SBL aborts, and even when it is larger, the difference is not very significant. Simultaneously, the beam orbit was measured using the Bunch Oscillating Monitor (BOR) and the bunch current was measured using the Bunch Current Monitor (BCM). The results are shown in Fig. 8. The HER often exhibits a larger orbit displacement compared to the LER during SBL. The apparent beam size spread is due to the superposition of only 20 bunches. It is therefore independent of orbit displacement. At this point, the relationship between beam size increase and SBL remains unclear. Occasionally, orbit oscillations and rapid changes of tune are observed in the HER. This may suggest that there are causes of HER SBL other than dust as seen in LER.

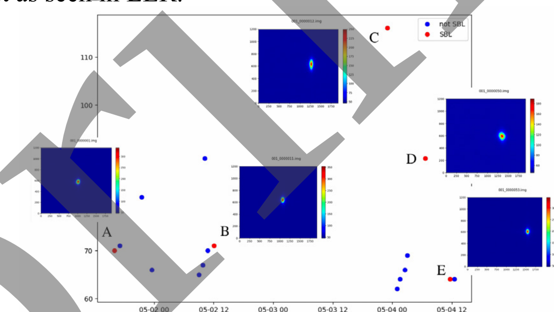

Figure 7: Vertical beam size for SBL and other aborts.

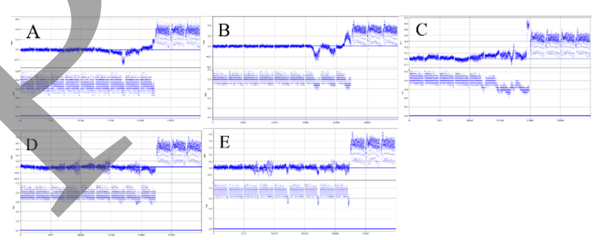

Figure 8: The beam orbit and the bunch current, for the SBL events A through E of Fig.7.

CONCLUSION

During operation in 2024, dusts from the vacuum sealant were suspected to be the main cause of SBLs. The vacuum team thoroughly cleaned the vacuum ducts, and the number of SBL occurrences dramatically decreased during operation in 2025. Even during SBL occurrences in 2025, pressure bursts were observed, and signals were sometimes detected simultaneously at nearby clearing electrodes. Some bellows in that area showed damage and discoloration and were replaced during the winter shutdown period. In 2026, pressure bursts associated with SBLs were often concentrated in the collimator region, making it difficult to determine whether SBLs were the cause or effect. HER SBLs and QCS quenching are increasing with increasing beam current. Investigation into the causes of SBL is also underway at the HER.

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