ABORT DIAGNOSTICS AND ANALYSIS DURING KEKB OPERATION

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Abstract

KEKB has stopped since June 2010 for upgrading the luminosity 40 times, i.e. SuperKEKB. During the operation of 11 years, a pair of controlled beam abort systems worked more than 10000 times to protect the hardware components of KEKB accelerator and the detector against the high intensity beams of high and low energy rings (HER and LER, respectively). Optimization of the abort trigger was necessary to balance efficient operation with the safety of the hardware. Therefore, we analyzed one-by-one all of the aborts, and continually adjusted the abort system. The diagnostic system was based on a high-sampling-rate data logger that recorded beam currents, RF signals and beam loss monitor signals. The beam oscillation signals, vacuum pressure and detector dose rate were also examined. This paper describes the typical abort causes, optimizations of abort levels, and abort statistics over approximately eight years after having arrived at high current operation.

INTRODUCTION

KEKB was an energy asymmetric electron positron collider dedicated to B meson physics. An electron ring of 8 GeV (HER) and a positron ring of 3.5 GeV (LER) were installed in a tunnel. The maximum achieved currents of the electron and positron rings were 1.35 A and 2.0 A respectively so far. When a large beam loss is expected, the beam should be quickly dumped in order to avoid the damage to the accelerator and the Belle detector components due to high current beams. A controlled beam abort system was installed for this purpose [1]. The system triggered more than 10000 aborts during the KEKB operation for eleven years. Optimization of the condition to issue the abort trigger was necessary to compromise between efficient operation and safety of the hardware. Therefore, we analyzed all of the aborts one by one, and continually adjusted the abort system.

SETUP OF ABORT MONITOR

The diagnostic system was based on a high-sampling-rate data logger that recorded beam currents, RF signals, signals from beam loss monitors and the Belle detector at the moment of the beam abort. In addition to the data stored in the data loggers, beam oscillation, vacuum pressure, the earthquake sensor and the dose rate of the Belle detector were also examined to analyze the beam abort.

Loss monitor signals of whole rings were collected at four local control rooms (LCRs), and were sent to the data loggers distributed in five LCRs where both loss monitor signals and RF cavity signals were obtained.

The signal flow of the data loggers is shown in Fig. 1. Logged data were beam current measured by a direct-current-current transformer (DCCT) [2], a part of loss monitor signals from PIN photo-diodes (PD) and ion chambers (ICs), signals from the RF cavities, i.e. cavity voltages and output of klystrons, the beam phase signal showing the deviation of the synchronous phase, the injection trigger timing and the Belle PD signal. Most PDs were fixed on the movable masks of each ring, and determined the ring in which the beam loss occurred. On the other hand, ICs were installed in the whole tunnel and covered the wide range in space, but could not distinguish the ring. These signals were useful to diagnose the cause of the beam abort since they had a strong correlation with the beam condition. The recorded data were sent to the KEKB central control room (CCR) via the KEK internal network then monitored by operators. The information was ready for inspection within a few minutes after the abort. The beam oscillation signals were obtained from the beam oscillation recorder (BOR) [3]. The signals were also ready within a few minutes after the abort. The BOR recorded the bunch-by-bunch beam position over 4000 turns immediately before the beam abort so as to detect vertical and horizontal beam oscillations.

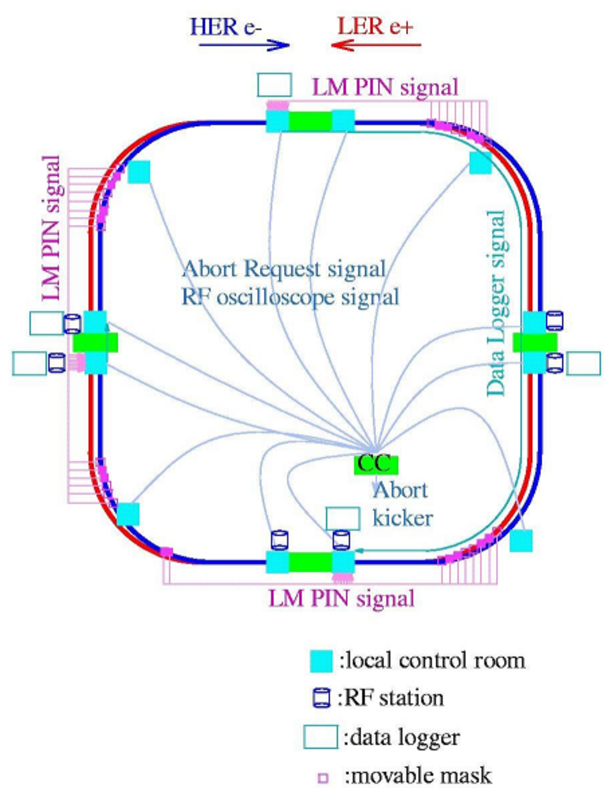

Figure 1: A signal flow of data loggers.

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TYPICAL ABORT EXAMPLES

Manual Abort

A manual abort is a beam abort triggered manually by switches by operators. An example of the signals at the manual abort in HER is shown in Fig. 2 (a). The DCCT signal shows delay of 40 μs and decay in 90 μs in spite of the beam being aborted in 10 μs, i.e. one turn. This is a normal behaviour of the DCCT signal when the beam is aborted in one turn. If the decay time and the decay slope differed from this example, the abort was judged abnormal and the data logger information was analyzed to determine the cause of the beam abort.

(a) (b) (c)

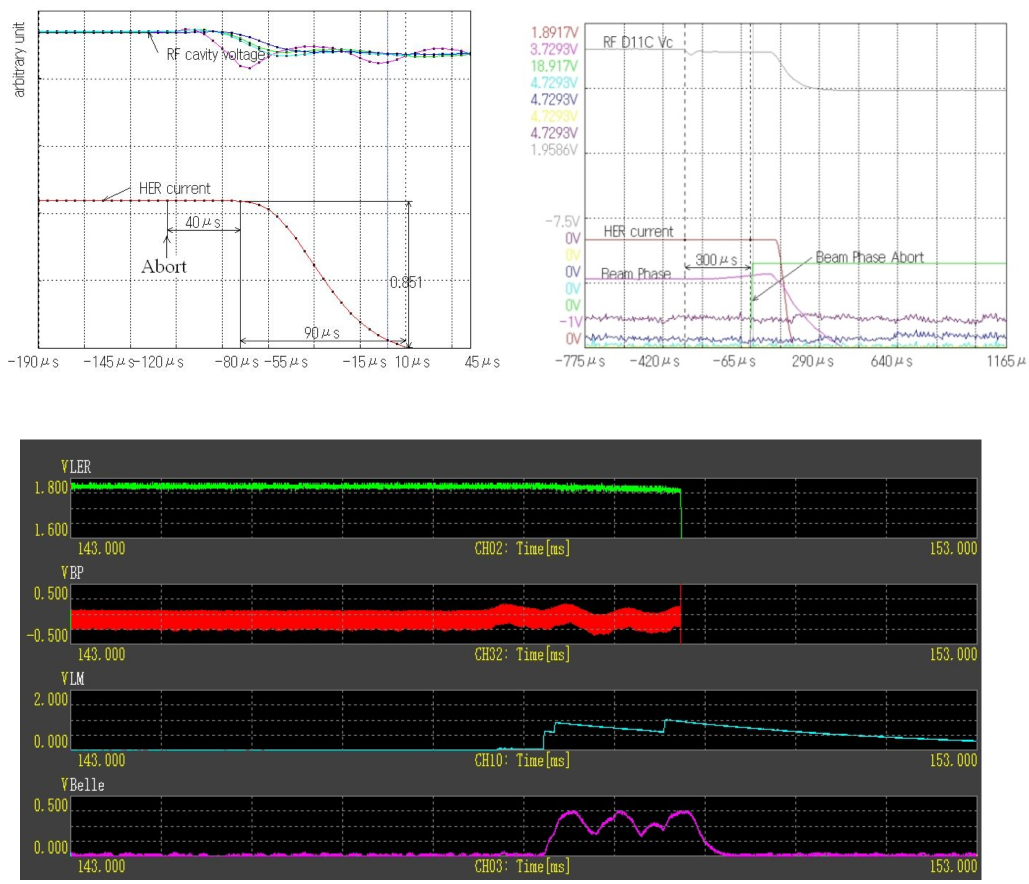

Figure 2: Examples of logged signals at a moment of (a) a manual beam abort, (b) a beam phase abort caused by RF voltage down and (c) a beam loss abort caused by vacuum problem. Signals in (c) are the LER beam current, the beam phase, the loss monitor PD and the Belle PD from top to bottom.

Beam Loss Abort

The beam aborts were categorized as the beam loss aborts, when the loss of the beam current was observed before RF cavity trips. About a half of the beam aborts were the beam loss aborts. In most cases the signal of the PD at a movable mask was also detected. The PD signal was useful to identify the location of the beam loss when the beam loss happened at a movable mask. The PD information was analyzed together with the data of BOR to identify the cause of the beam loss. The analyzed result was used to improve the operation parameters of KEKB.

Some beam loss aborts were caused by the beam oscillation. For example, when the LER beam was aborted, the HER beam sometimes remained alone in the ring. Then an instability of the HER beam accompanied by the horizontal oscillation was occurred, probably because the damping effect by the beam collision was lost. As a result the HER beam was also aborted. It depended on beam condition and parameters of the bunch feedback system. Figure 3 (a) and (b) show the statistics of the aborts caused by the beam loss. The ratio of the beam loss aborts without the oscillations to the whole of beam loss aborts increased in the latter period of the KEKB operation. When no oscillation was found despite of a large beam loss, we often found the tune was shifted.

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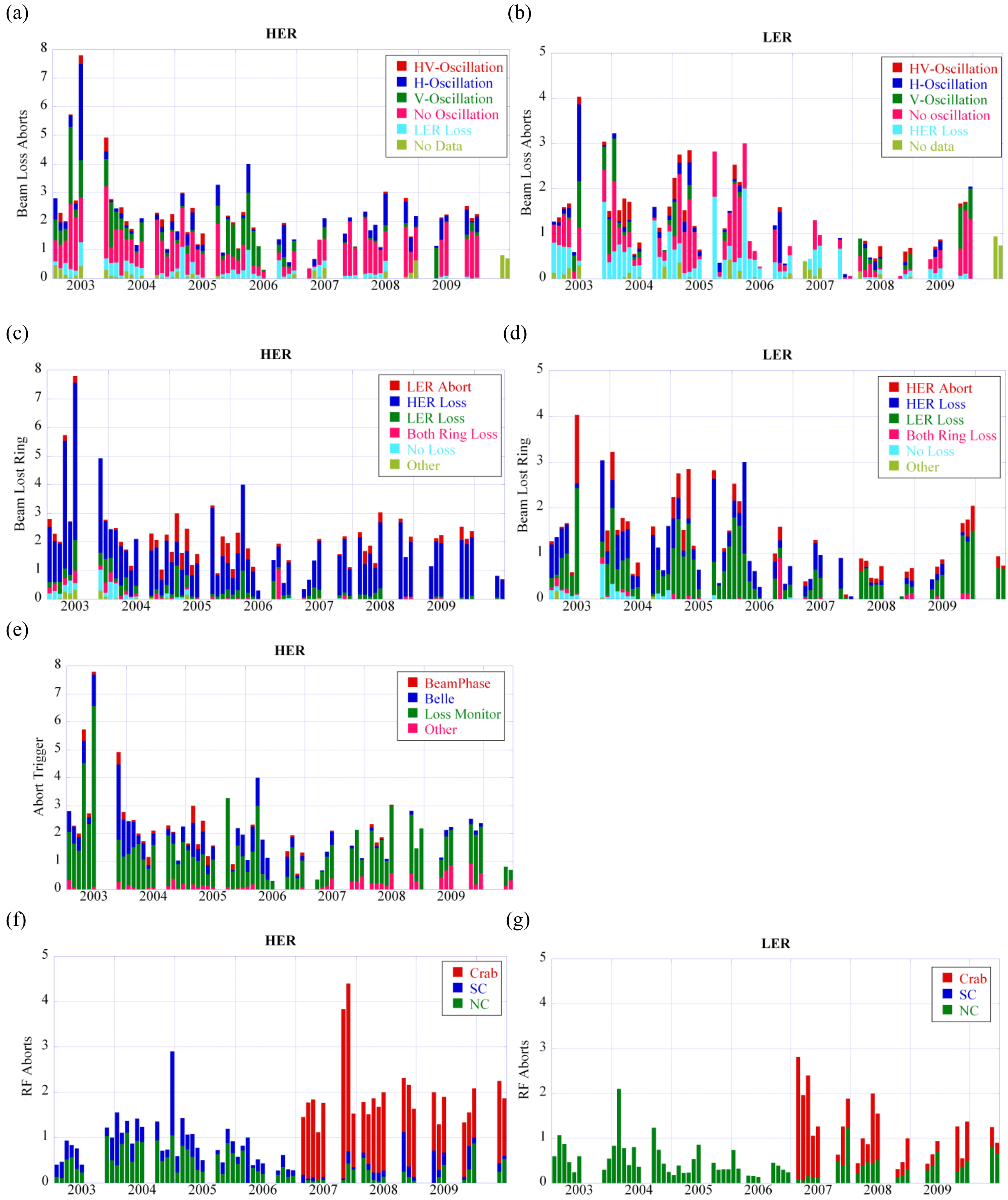

Figure 3: Cause of beam loss in HER (a) and LER (b), status of beam loss and the abort when HER (c) or LER (d) was aborted, signals which requested the abort of HER (e) and aborts triggered by the RF of HER (f) and LER (g).

Sometimes the LER beam loss triggered the HER abort and verse versa. We call this event a wrong abort. The PIN PDs could identify the ring where the beam loss occurred, thus did not generate the wrong abort. RF

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signals did not generate the wrong abort, too. On the other hand the ICs and the Belle PDs could not identify the ring where the beam loss occurred because the sensors reacted in both HER and LER beam loss. They could generate the wrong abort. To improve this situation Belle group introduced a logic that checked which ring was being injected when the beam loss at Belle happened, then judged which ring should be aborted. Another improvement came from RF arc sensors which were PIN PDs located at RF cavities. Figure 3 (d) shows the status of the beam loss when the beam loss abort was requested to LER. "HER abort" means the LER beam was lost after the HER abort, probably because the LER beam become unstable. "HER Loss", "LER Loss" and "Both Ring Loss" mean that the beam loss was observed by DCCT at HER, LER and both rings, respectively. The wrong abort corresponds to "HER Loss" because the LER beam was aborted although the beam loss was observed in HER. Figure 3 (e) shows which sensors requested the abort of HER. The “other” in (e) was issued almost by the RF arc sensors. The number of the wrong aborts in LER decreased as the “other” abort requests in (e) increased. This correlation appeared after the installation of the crab cavities. We suppose that the wrong aborts in LER decreased because the RF arc sensors near the crab cavities could identify the ring where the beam loss occurred. Probably the extensive beam loss which caused the IC abort was avoided, since the loss was detected first by the arc sensors and then the right ring was aborted.

Figure 2 (c) shows another example of the beam loss abort in which no beam oscillation was observed. The tunes were stable. The beam phase (BP) started to swing before the beam loss happened and also before the loss monitor PD signals and the Belle PD signal appeared. This type of the abort was found in Feb. 2005. It was found that some bellows were troubled. The pressure and temperature near the bellows were higher than usual. By fixing the vacuum problem, the abort ceased. This type of abort happened again in 2006 as shown in Fig. 4. The vacuum troubles were also found again in this case.

The number of the beam loss aborts decreased in 2004 after the continuous injection started to keep the beam current at fixed level.

RF Abort

Because of the strong interaction between an accelerated beam and RF cavities, the cavities tripped easily whenever the beam lost. On the other hand, when one of the cavities tripped, the coherent synchrotron motion of the beam occurred and gave a strong radiation to the Belle detector. Figure 2 (b) shows an example of logged signals at the beam phase abort caused by an RF trip. The BP signal starts to rise in response to the RF trip. On the other hand, when the beam loss happens earlier than the RF trip, the BP starts to swing downward because the RF can't compensate the loss of the beam induced field immediately. In both cases, the induced synchrotron oscillation causes a large beam loss which could lead damages of hardware components. In order to avoid this situation, the BP was used as an abort trigger [4]. The trigger level of the BP abort was set to one degree in HER and five degrees in LER. We also installed a fast cavity voltage monitor in each RF station. Figure 3 (f) and (g) show the rate of RF aborts. While the HER was equipped with both superconducting cavities (SC) and normal conducting cavities (NC) [5], the LER was equipped with only NCs. The rate of the abort was similar in both types of cavities.

Crab Abort

Two crab cavities were installed in 2007 to improve luminosity [6]. Since the beam current was limited in first several months after starting the crab operation in order to tune the crab cavities, the breakdown of the crab cavities did not affect the beam. However the beam was manually aborted to recover the cavity voltage after the breakdown. In the early period of the operation the breakdown of the LER crab cavity occurred frequently. The breakdown caused the beam loss at a few hundred mA of the beam current. The luminosity was improved after the operation of the crab cavities became stable and the number of the aborts caused by the crab cavities decreased.

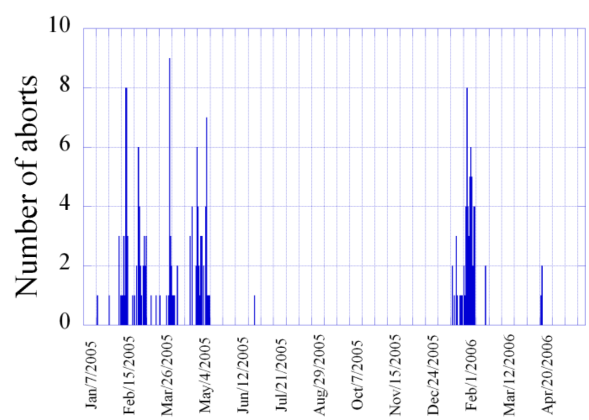

Figure 4: The number of beam loss aborts caused by vacuum troubles.

STATISTICS

The statistics of the beam abort, which are categorized by analyzing the information of the data loggers and other monitors, is shown in Fig. 5. It shows the number of aborts per day averaged over one month during eight years operation of KEKB with high beam current. The manual aborts issued by operators are not included. From the figure, we see that there are two major origins of the beam abort; the RF trouble and the beam loss. Since the coupling between the beam and RF cavities are strong, it is important to clearly classify the cause of the abort in order to improve machine performance. The fractions of the RF and beam loss aborts in all number of aborts were 30% and 60%, respectively, before the crab cavity installation. The ratio of the crab cavity abort was higher than the other RF cavity aborts, but the sum of all aborts were not changed after the installation of the crab cavities since the beam current at the crab operation was lower than that before the crab operation. There are many other aborts due to earthquakes, troubles of vacuum system and magnet power supplies and so on, though the fraction of these aborts was small. The number of the aborts did not strongly depend on the beam current as shown in Fig. 5 (c) and was reduced by optimization of the abort condition. The number of HER and LER aborts was 3.7/day and 2.3/day respectively. The total number of the aborts was about 6000 and 4000 in HER and LER, respectively.

CONCLUSION

A controlled beam abort system was installed in KEKB to protect the hardware components from the loss of high current beams. In order to make clear the real reason of each abort, various signals such as the PIN PD beam loss monitors and the status signals of the RF system were collected by the data logger system and analyzed to identify the cause of the beam loss and the beam abort. The results showed the real situation of the accelerator hardware and gave us a lot of hints not only to protect the hardware but also to optimize the operation parameters. As a result, we could suppress the unnecessary beam aborts and improve the luminosity.

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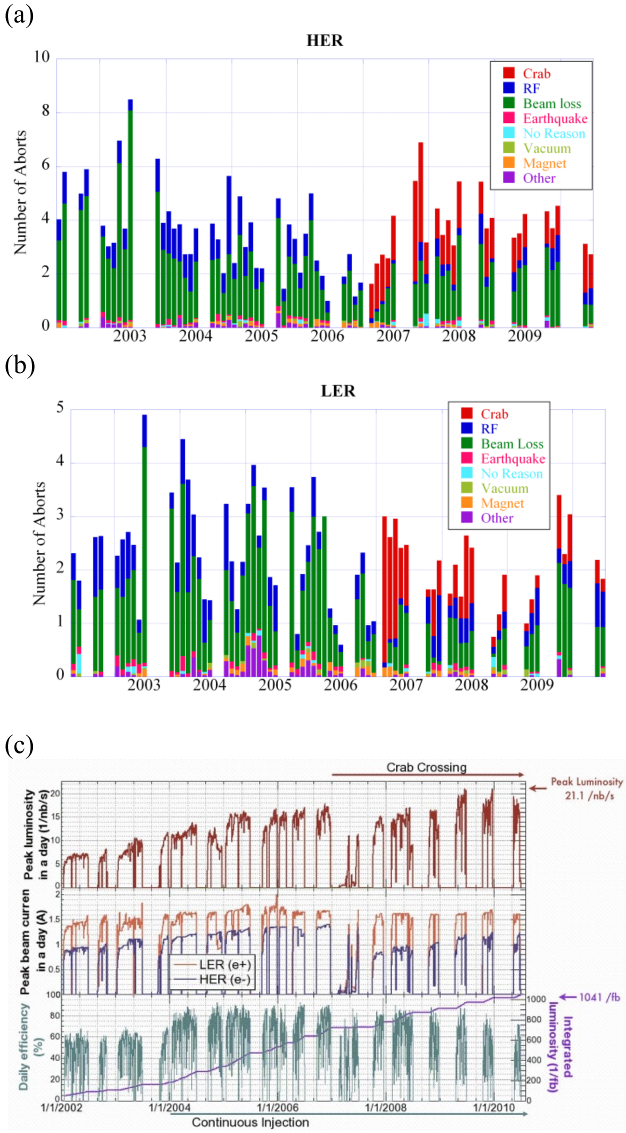

Figure 5: Statistics of the beam abort for last eight years of KEKB operation in HER (a) and LER (b). (c) History of the beam current and the luminosity of KEKB.

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