OBSERVATIONS AND CURES OF ELECTRON-CLOUD EFFECTS AT THE KEKB LOW ENERGY RING

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Abstract

The luminosity of the KEKB B-Factory is currently limited by a single-beam blowup at the low-energy positron ring (LER). Its major characteristics are well-consistent with single-bunch head-tail instability caused by the photoelectron cloud (Zimmermann and Ohmi[1]). There remain, however, a few strange observations which are not expected from the model.

1 SINGLE BEAM BLOWUP IN LER

The single-beam blowup at LER was first observed in March 1999[2] using an interferometer for the synchrotron light[3]. The vertical beam size scaled at the interaction point is typically 2 μm at a low current, and starts to blowup around 350 mA for a long train of bunches with 4-bucket spacing. Here “long train” means a single train to fill the 90% of the ring, devoting the remaining 10% as the gap for the abort kicker. In the case of 4-bucket spacing, which has been used as a standard pattern for a physics run, a train consists of 1150 bunches. One bucket spacing is 2 ns. The vertical size reaches about 6 μm at 600 mA when no cure is made by the permanent or solenoid magnets.

The blowup is characterized as:

- A single-beam effect.
- No dipole oscillation is seen when the chromaticity is enough positive ($\xi_x \gtrsim 3$).
- No synchrotron motion is observed.
- No dependence on the betatron tunes nor other parameters of the lattice.
- The threshold of the blowup scales by the (bunch intensity)/(bunch spacing).
- The beam size after the threshold scales by (bunch intensity)^2/(bunch spacing), at least during the injection.
- No dependence on the vacuum pressure. An artificial pressure rise by a factor 100 to 1000 did not change the beam size at all.
- No dependence on the excitation of wiggler, at least at the injection.
- A weak dependence on the chromaticity was observed, A higher chromaticity ($\xi_y \sim 12$) reduced the blowup by 30% from $\xi_y \sim 3$.

It has been also noticed since April 1999 that the observed beam size at injection is smaller than that at storage. Figure 1 is a typical beam size measured by the interferometer at injection, storage, and collision. The single-beam beam size shows a hysteresis curve against the stored current.

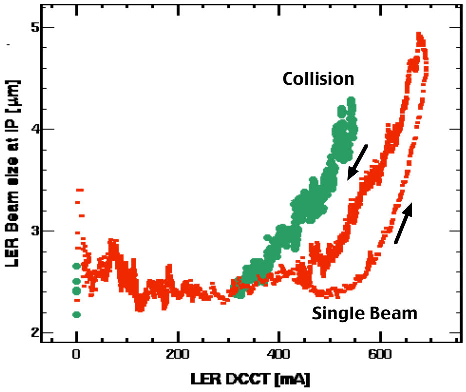

Figure 1: A typical vertical beam size, measured by the interferometer, versus the LER DC current. Traces correspond to injection (up arrow), storage (down arrow), and collision, respectively. This data was taken in November 2000 with solenoid field. This was a long train (1150 bunches) with 4 bucket spacing (8 ns).

The characteristics of the blowup listed above (except the hysteresis) is consistent with the single-bunch head-tail instability caused by the photoelectron cloud. More observations also confirm the model[4]:

- The blowup starts after about 6 bunches at the head of a short train (typically 60 bunches with 4 bucket spacing, 2 trains in a ring with about 4 μs spacing). See Fig. 2.
- The effect disappears with a gap of about 24 buckets, at least for a short train without the solenoid.
- The magnitude of the blowup of a bunch depends on the charge of the bunch. It was confirmed unsing a gated camera, by changing the charge of a witness bunch keeping the intensity of the rest of the train unchanged.
- The vertical betatron tune of each bunch increases along a train similar to the vertical size. The magnitude ($\Delta\nu_y \sim 0.01$) agrees with the result of the simulation[5].
- The amount of the photoelectrons in the vacuum chamber was measured by a photo-electron monitor. It is proportional to the beam current and its amount and the energy spectrum are consistent with the simulation[6].
- The C-Yoke and the solenoid magnet were effective on improving the threshold. The most clear example of the solenoid is shown in Fig. 3 for a short train at injection.

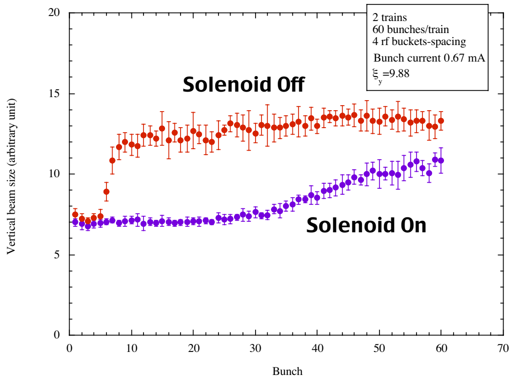

Figure 2: Bunch-by-bunch vertical beam sizes, measured by a gated camera. The horizontal axis is the bunch number from the head of a train (4 bucket spacing, short train).

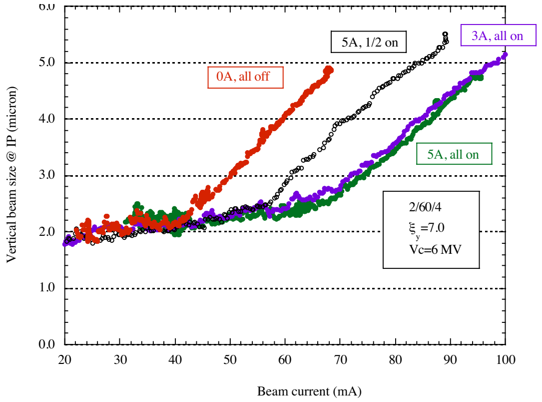

Figure 3: Effect of the solenoid was clear for a short train (2 trains/ring, 4 bucket spacing, 60 bunches each, the spacing between the trains was about 4 μs). The solenoid was wound for 800 m in total in the straight sections (1800 m) of the arc (2200 m), including inside of dipole correctors. The magnetic field is 45 Gauss at the center of the chamber. These data were taken by the interferometer during injection.

2 WHAT ARE NOT EXPLAINED BY THE MODEL

Since the Zimmermann-Ohmi model has explained many aspects of the blowup, it is confirmed that the single-bunch head-tail instability due to photoelectron cloud exists in LER. Now the question is whether it is the only effect causing the blowup or not. We have already mentioned the hysteresis of the beam size between the injection and storage as shown in Fig. 1, which is not expected from the model.

2.1 Hysteresis

The hysteresis can be interpreted as a time delay of the beam size from the beam current; the beam size continues to blowup after the injection stops. The peak of the beam size delays from the peak of the beam current by 30 to 150 seconds. Figure 4 shows the delay for various samples with different peak currents on different dates. One may suspect that the delay or the hysteresis is really happening on the beam, or due to instrumentation such as the heating of the mirror for the synchrotron light. Although we have to admit that there should exist some contribution from the mirror, it is also difficult to solve all hysteresis by the deformation of the mirror. The hysteresis appears even at very low current (30 mA), while the deformation becomes severe only at current higher than 300 mA. While the deformation may give opposite effect on the beam size depending on the position of the light on the mirror, the hysteresis always appears in the same way. The measured temperature of the mirror does not correspond to the beam size. For example, the beam size at the storage becomes equal to the injection at 450 mA in Fig. 1, while the temperature of the mirror was still higher than the injection period. We have not yet identified the cause of the hysteresis. The vacuum pressures at various locations in the ring also show a hysteresis, but the delay time for the pressure was much smaller than the beam size's[7].

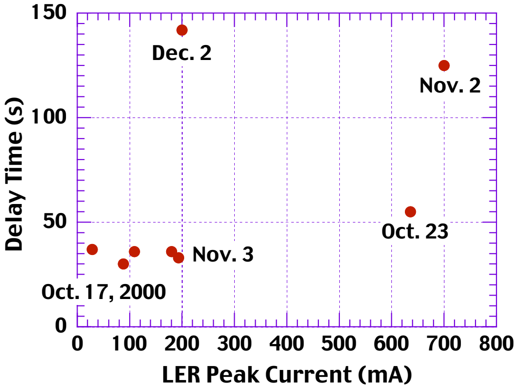

Figure 4: The delay time of the peak of the beam size after the stop of the injection for various beam currents and dates. The bunch current was nearly same for all cases.

2.2 Others

There are other observations not expected from the model:

- With the solenoid field, the beam size starts to blowup slowly after 30 bunches along a train, in the case of a short train. It is not expected by the simulation.
- The beam size at collision, which is mainly determined by the single-beam effect as shown later, blows up from the head in the case of a long train. For a short train, the head of a train shows smaller size.
- For a long train, the effect of a gap (hole) looks weaker. For a colliding long train, a gap of 1000 buckets did not improve the size of the head of the train.
- The bunch-by-bunch luminosity does not show a clear dependence on the bunches. This is quite different from the case of PEP-II.

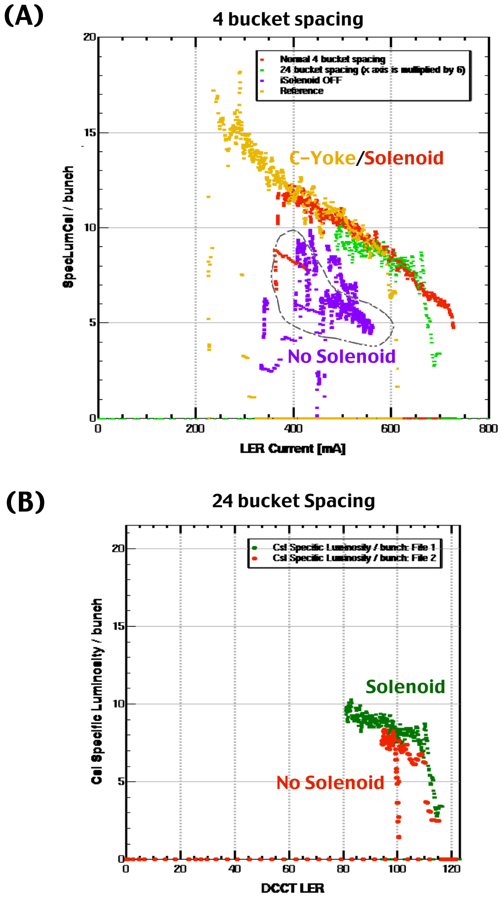

Figure 5: The specific luminosity per bunch as a function of the LER total current. (A) The effect to suppress the electron-cloud by the permanent magnet(“C-Yoke”) and the solenoid was clear for long trains with 4 bucket spacing. (B) In the case of 24 bucket spacing, the difference becomes small to verify that the other effects of the solenoid was insignificant.

3 THE LUMINOSITY

Figure 5 shows the specific luminosity per bunch versus the LER beam current for the cases with/without the permanent magnets and the solenoids. It clearly shows the effect of the permanent magnet(“C-Yoke”) and the solenoid on suppressing the electron cloud. Though this is a clear verification of the electron-cloud effect, there remains a big question: (1) why the specific luminosity still depends on the LER current, and (2) why the effects of the C-Yoke and the solenoid are equal. These questions become more mysterious when we look at the case for shorter bunch spacings in Fig. 6.

While in the case of “1100” pattern, the bunch current was reduced to a half of the 4-bucket spacing for a given total current, the specific luminosity per bunch (i.e., the beam size) is equal to that of the 4 bucket spacing. It is also true for the 3 bucket spacing. This indicates that the blowup due to the beam-beam effect is less significant compared to the blowup due to the single beam effect. The beam size at collision is determined only by the total current of LER. It was also confirmed that the specific luminosity per bunch was basically consistent with the beam size measured by the interferometer during collision, such as Fig. 1, as long as the collision tuning was good enough. It is easy to lose the specific luminosity by bad tunings, so the comparison must be done for the best data of each case.

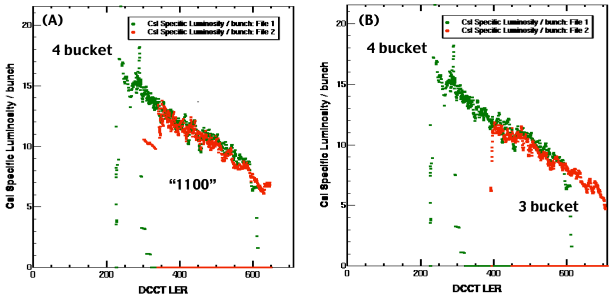

Figure 6: Comparison of the specific luminosity per bunch as a function of the LER total current. (A) 4 bucket spacing and “1100” pattern (the first two buckets are filled in every 4 bucket), and (B) 4 bucket spacing and 3 bucket spacing. The numbers of bunches were 1150, 1560, and 2300 for 4 and 3 bucket spacings, and “1100”, respectively.

The data for the specific luminosity may suggest that there is another cause of the beam blowup in LER beside the Zimmermann-Ohmi effect. We have not yet identified the reason for the second effect at all now. Since the collision has been done at nearly one operating point in the betatron tune space, the dependence of the second effect on the betatron tunes has not been studied yet. The second effect might be caused by the electron cloud, for instance in the bending magnets or wigglers, but also can be anything else with the equal possibility at this moment.

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