OBSERVATION OF VERTICAL BEAM BLOW-UP IN KEKB LOW ENERGY RING

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Abstract

This paper describes an experimental study of the enlargement of the vertical beam size observed in single beam operation at the KEKB LER.

1 INTRODUCTION

A blow-up of the vertical beam size is observed in the KEKB positron ring (LER)[1]. The beam size as a function of beam current starts to increase at a threshold beam current and is almost doubled at 300 mA under typical operating conditions. Thus the blow-up is one of the most serious problems limiting the luminosity of KEKB.

The main characteristics of the blow-up observed in early operation period are summarized as: 1) the blow-up is a single beam and a multi-bunch effect; 2) the blow-up has a threshold intensity which is determined roughly by (bunch current)/(bunch spacing); 3) no dipole oscillation has been observed when the vertical chromaticity is high (5 to 8), though the chromaticity is as low as 2 and the bunch feedback system is turned off, a vertical dipole oscillation is excited; 4) the blow-up is almost independent of betatron tunes; 5) the blow-up does not depend on the positions of the vertical masks, which are among the main impedance sources; 6) the blow-up does not depend on the vacuum pressure, especially for hydrogen, in the arc; 7) the blow-up does not depend on the excitation of the wigglers; and 8) no blow-up is observed in the horizontal plane.

A model to explain the blow-up is proposed by two of the authors, F. Zimmermann and K. Ohmi [2]. In their model the blow-up is explained as a single-bunch instability of a positron bunch due to a large number of electrons generated by photoemission or secondary emission. The instability will occur only in multi-bunch operation since the electron cloud is built up by the successive passage of the bunches. The coherent dipole oscillation of positrons along the bunch caused by the “wake” force due to the electron cloud appears as either weak or strong head-tail instability. A beam-size blow-up will be observed as a result of the head-tail oscillation of the instability. In this model the strength of the instability depends on the electron cloud density near the beam.

2 EXPERIMENT

Several experiments were performed to examine the model. In most experiments, so-called “C-Yoke” magnets (C-Yokes) were installed in the ring. They were attached to the outside of the vacuum chambers to confine the electrons to the vicinity of the chamber walls. A C-Yoke consists of two permanent magnets and a C-shaped iron yoke. The magnets are attached every 10 cm along the drift space between ring magnets. Initially the C-Yokes were installed only on the outer circumference of the ring and covered a 7-m long drift space downstream of every bending magnet in the arc. Then C-Yokes were added to cover about 50% of the drift space of the whole arc and were attached both on the inward and outward sides of the ring so as to generate a quadrupole field. The polarity of the magnets along the chamber was reversed every 20 cm to reduce the effects on the beam optics. The peak vertical magnetic field was 250 G at the chamber wall.

The multi-bunch feedback was turned on in all experiments to suppress dipole oscillations.

2.1 Formation of electron cloud

The average beam size at various bunch spacings was measured by the interferometer[3] as a function of beam current. As shown in Figure 1, without C-yokes the threshold intensity scaled as I_b/s_b, namely the charge density of the beam, where I_b and s_b are the bunch current and the bunch spacing respectively. With C-yokes the beam size scaled as $I_b/s_b\ I_b$. In models of the single bunch instability due to the electron cloud, the growth rate is proportional to $\rho\ I_b^a$ where ρ is the density of the electron cloud and a is a number depending on models[2,7]. The

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observation is consistent with this picture if the density of the cloud is proportional to that of the beam ("partial neutralization"). The reason why the scaling changed before and after the installation of C-Yokes is not understood yet. C-Yokes may change the shape of "wake" function due to the electron cloud.

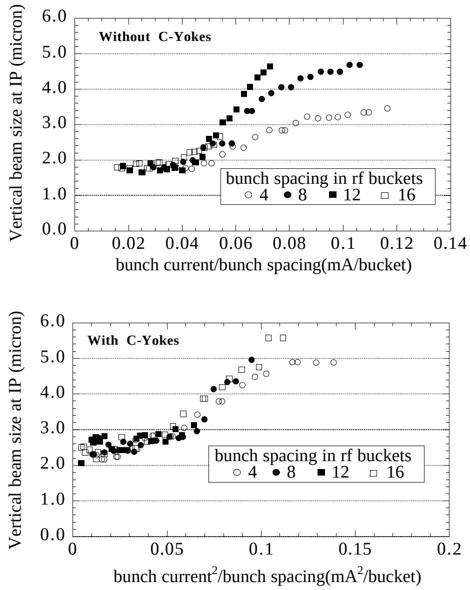

Figure 1: Blow-up of beam size in various bunch spacing with and without C-Yokes.

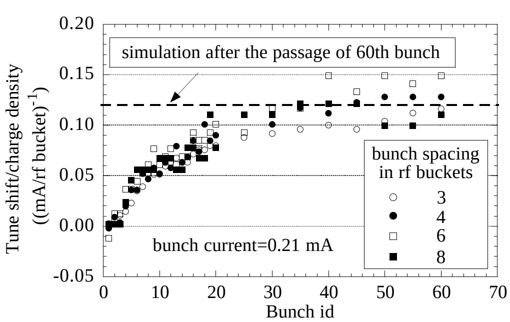

Figure 2: Vertical betatron tune shift along the train for four different bunch spacings of 3, 4, 6 and 8 rf buckets. The tune shift is normalized by the charge density of the beam (I_b/s_b).

To obtain information on the cloud build up the vertical betatron tune of each bunch was measured along the train by a gated tune meter. As shown in Fig. 2, 1) the tune increases along the train and almost saturates at about 20th bunch, 2) the tune shift is almost proportional to the charge density of the beam, and 3) (saturated tune shift) / (charge density) is about 0.12. These observations are consistent with a simulation[2,4,6] for a field free region though many C-Yokes were installed at the time of the measurement. An example of the simulation is shown in Fig. 3.

Another indication of the build up of the cloud is the observation of the vertical beam size by fast gated camera[5]. The data shows that the size gradually increases along the train, and then almost saturates (See Fig. 7).

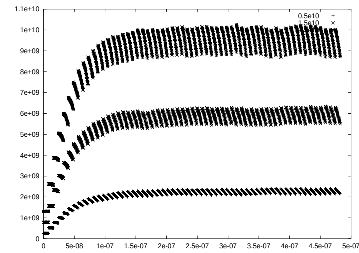

Figure 3: Build up of the electron cloud (total charge per meter) as a function of time in sec for three different bunch populations. The bunch spacing is 4 rf buckets[4].

To measure the decay length of the blow-up a test bunch was injected immediately after a train. The beam size of the test bunch was measured as a function of the train-to-bunch spacing. The data show that the decay length of the blow-up is about 12 rf buckets when the bunch spacing of the train is 4 rf buckets. Furthermore the beam size of two trains with a train-to-train gap was measured to observe the build up or decay of the cloud over two trains. As shown in Fig. 4 while the beam size of the first train started to blow-up at the 7th bunch, in the second train the 2nd bunch already showed a sizable blow-up which can be interpreted to mean that the density of the cloud generated

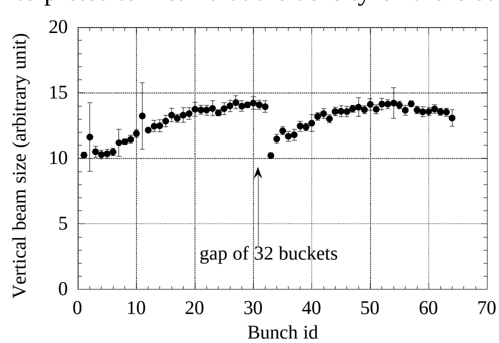

Figure 4: Beam size over two trains measured by the fast gated camera. Train-to-train gap which is not shown in the figure, is 32 rf buckets.

by the preceding train is quickly reestablished in the second train. Fig. 5 shows the simulation results with and without magnetic field. Again, the above measurements are consistent with the simulation for a field free region, though C-Yokes were attached for these measurements.

Fig. 6 shows the blow-up before and after the first installation of the C-Yokes. Though the blow-up was improved for a spacing of 12 rf buckets, the improvement for a spacing of 4 rf buckets was not remarkable. Also there was not much improvement after the second installation of the C-Yokes although the simulation shows that the density of the electron cloud decreases by a factor 10 with the quadrupole C-Yoke configuration as compared to the field free case[6].

2.2 Single bunch characteristics of the blow-up

To prove the single bunch nature of the blow-up a test bunch was injected immediately behind a train. The beam size of the test bunch was measured at several bunch cur-

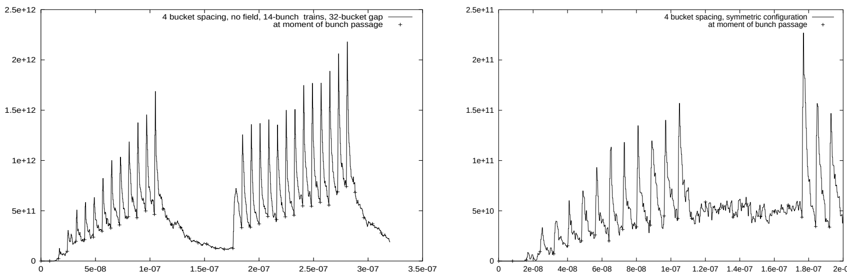

Figure 5: Simulated electron density near the beam per cubic meter as a function of time in sec. Left: without magnetic field, right : with quadrupole magnetic field[6].

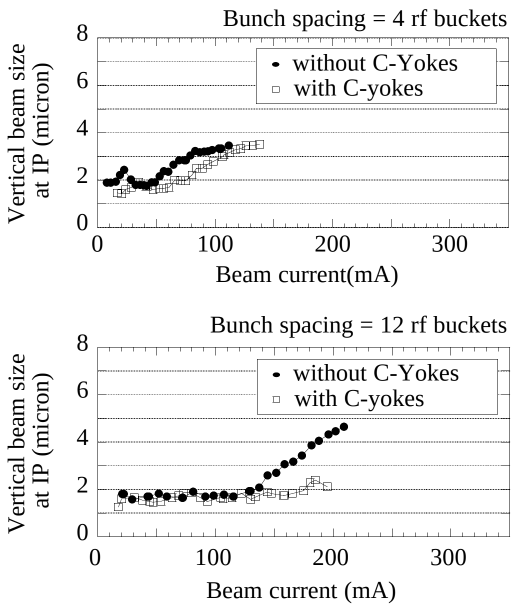

Figure 6: The blow-up before and after the first installation of the C-Yokes. The ring was filled with 4 trains each of which contained 60 bunches.

rents of the test bunch. The bunch current for all other bunches was kept constant. The results showed that the beam size of the test bunch increased when its bunch current increased, which demonstrates that the blow-up is a single bunch effect.

The effect of the vertical chromaticity on the blow-up was measured by the fast gated camera. If the blow-up is caused by the head-tail instability it should be sensitive to the chromaticity. Fig. 7 shows that the blow-up along the train became weaker when the chromaticity was increased. The effect was confirmed by the interferometer. Observed beam size dependence on the chromaticity could be consistent with either strong or weak head-tail instability[2,7]. This question requires further studies.

3 SUMMARY

The blow-up of the vertical beam size observed in KEKB LER is a single bunch effect only appearing in multi-bunch operation as predicted by the F. Z. and K.O. model.

The blow-up was weakened at high vertical chromaticity, which could be consistent with either strong or weak head-tail instability.

The increase of vertical betatron tune and beam size along the train, the decay time of the blow-up and the measurement of the beam size over two trains are consistent with the simulated build up of the density of the electron cloud for a field free region, though a large number of C-Yokes were attached on the chambers during the measurement. The reason why the C-Yokes are not very effective is not clear yet. Recently, a nonlinear pressure rise, which is suspected to arise from multipacting, was observed in the straight sections and in the drift spaces without C-Yokes in the arc. Thus, a large number of electrons in the remaining field-free chambers may be responsible for the persistent blow up.

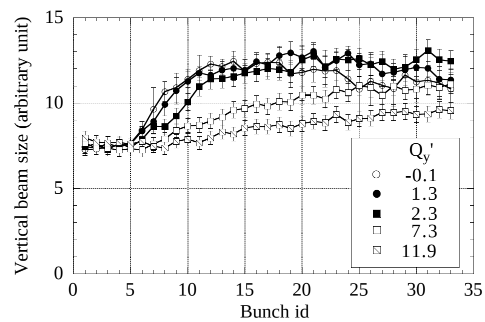

Figure 7: Beam size along the train observed by the fast gated camera in various chromaticities. Diffraction effect is not corrected.

At present there is no clear experimental evidence against the F. Z. and K.O. model in which the blow-up is caused by a single bunch instability due to the electron cloud.

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