THE EFFECT OF THE SOLENOID FIELD IN QUADRUPOLE MAGNETS ON THE ELECTRON CLOUD INSTABILITY IN THE KEKB LER

H. Fukuma#, J. W. Flanagan, T. Kawamoto, T. Morimoto,
K. Oide, M. Tobiyama, KEK, Tsukuba, Japan
F. Zimmermann, CERN, Geneva, Switzerland

Abstract

Solenoids made of flat cables were installed in 88 quadrupole magnets in the KEKB LER to study their effect on the electron cloud instability (ECI), especially the blow-up of the vertical beam size. The strength of the solenoid field was 17 Gauss. No clear effect of the solenoids was observed in the sidebands of the vertical dipole oscillation, the vertical beam size or the luminosity.

INTRODUCTION

The KEK B-factory (KEKB) is an asymmetric energy collider which is operated to study the physics of B mesons [1]. A blow-up of a vertical beam size has been observed since the beginning of the operation in the KEKB LER. The blow-up is explained by the strong head-tail instability caused by electron clouds [2]. The blow-up is largely mitigated by a solenoid field applied to vacuum chambers in the drift spaces. However it is still observed when the average bunch separation is reduced to 3.27 rf buckets or shorter [3]. A question is where the remaining electron clouds are.

The electron clouds may accumulate in a quadrupole field because the magnetic field vanishes at the centre of the magnet. A simple model of the strong head-tail instability caused by the electron clouds [2] shows that the instability appears if the condition

$$\int_{circumference} \rho(s) \cdot ds > \frac{2\gamma\nu_s}{\pi r_e \beta_y} \qquad (1)$$

is satisfied, where ρ is the density of the electron clouds, γ the relativistic factor, ν_s the synchrotron tune, β_y the average vertical beta function, r_e the classical electron radius and s the orbit length. Since the total length of quadrupoles in the LER is 218 m, which is 7.2% of the circumference, the strong head-tail instability would occur if the average density of the electron clouds in the quadrupoles is larger than $7.4\ 10^{12}\ m^{-3}$, assuming that the remaining electron clouds are mainly in the quadrupoles. And if the weak solenoid field can affect the electron clouds in the quadrupoles its effect on the strong head-tail instability would be observed.

To investigate the above possibility, a solenoid made of a flat cable was developed and installed in many arc quadrupoles of the LER.

SOLENOID SYSTEM

Since disassembling and re-assembling the quadrupoles to wind a solenoid would need much manpower and time, a non-halogen flat cable ECO-OKIFLEX-SN4, which is supplied by Oki Electric Cable Co., Ltd., was used to make the solenoid. The flat cable was attached to connectors so that wires form a loop. As the gap between the vacuum chamber and the poles of the quadrupole is less than about 2 mm, we used a flat cable whose thickness is about 1 mm. Measured temperature rise at 2 A was 18 ºC on the cable and 33ºC on the connectors. The field strength of the solenoid was limited to 17 Gauss due to the temperature rise of the solenoid. Table 1 shows parameters of the solenoid. Figure 1 shows a picture of a piece of the solenoid. The solenoid may be used not only in the quadrupole but also at any place where the winding of conventional solenoids is difficult. Hereafter we refer to the solenoids as Q-solenoids.

Table 1: Parameters of a solenoid

Thickness with an insulator (mm)	0.98
Wire pitch (mm)	1.27
Length (mm)	400
Resistance with connectors (ohm)	5
Current (A)	2
Field strength at 2 A (Gauss)	17

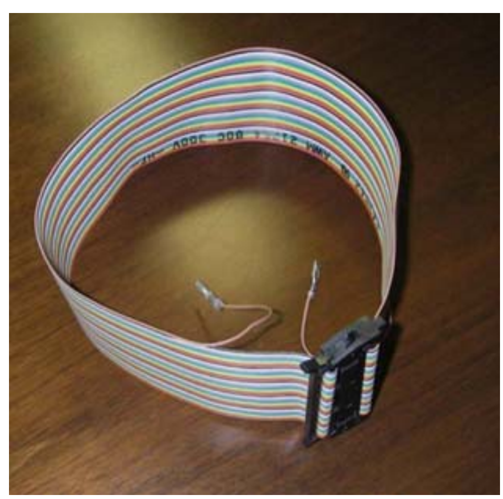

Figure 1: A solenoid made of a flat cable.

#hitoshi.fukuma@kek.jp

Figure 2: A solenoid installed in a quadrupole magnet.

Eight pieces of the Q-solenoid were installed per quadrupole. The Q-solenoids were installed in 88 quadrupoles in arc sections among a total of 461 quadrupoles in the LER. The strength of the quadrupoles is typically 5 T/m. The Q-solenoids were located near the entrance of each arc because wiring work of DC cables there was easiest. Fig. 2 shows a Q-solenoid installed in a quadrupole.

EXPERIMENT

Measurement in single beam

Since observations show that the blow-up is accompanied by vertical sidebands [4], the sidebands of the vertical dipole oscillation were measured turning-on or -off the Q-solenoids using a single positron beam. The dipole oscillation of each bunch was recorded by the BOR (Bunch oscillation Recorder [5]). At the same time the vertical beam size was measured by the interferometer. Fill patterns were 8/50/2 or 4/80/3, where a/b/c means bunch trains / bunches in a train / a bunch separation in units of rf buckets.

The beam parameters were set to slightly different values from those in the colliding beam operation to avoid the poor injection rate, the dipole oscillation by the

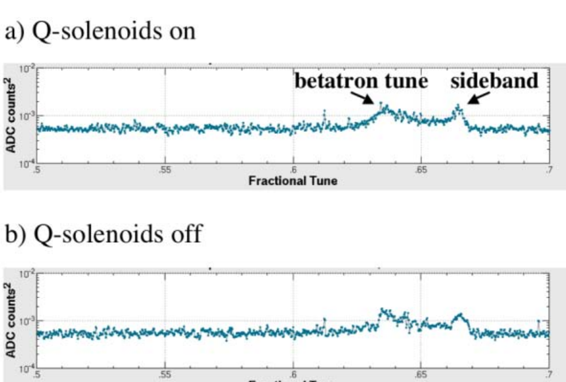

Figure 3: Power spectrum of the vertical dipole oscillation with or without Q-solenoids.

coupled bunch instability and the beam size blow-up by the coupling resonance in the single beam operation. The horizontal and vertical betatron tunes were 45.522 and 43.624 respectively. The horizontal chromaticity was 2.1 and the vertical chromaticity was 6.5. The vertical feedback gain was -14.6dB which was larger than that in the colliding beam operation by 4 dB. The rf voltage was 8 MV which corresponded to a synchrotron tune of 0.024.

The sideband peak was obtained from a Fourier power spectrum of the dipole oscillation of each bunch. The results in the bunch separation of two rf buckets are shown below. Fig. 3 shows the averaged spectra of all

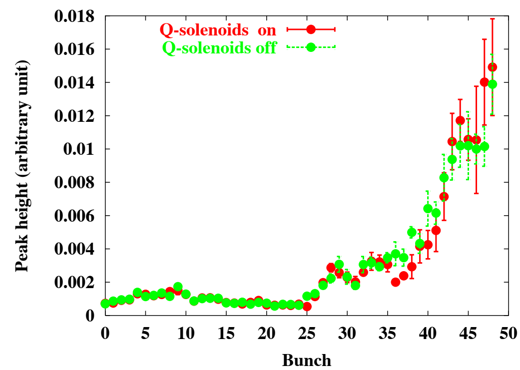

Figure 4: Peak height of vertical sidebands along the train with or without Q-solenoids.

bunch at the bunch current of 1.1 mA. Fig. 4 shows the peak height of the sidebands along the train at the bunch current of 1.1 mA. There is no clear difference in the peak position and the height of the sidebands with or without the Q-solenoid field.

Fig. 5 shows the vertical beam size measured by the interferometer. The size at the synchrotron radiation monitor is translated into that at the interaction point

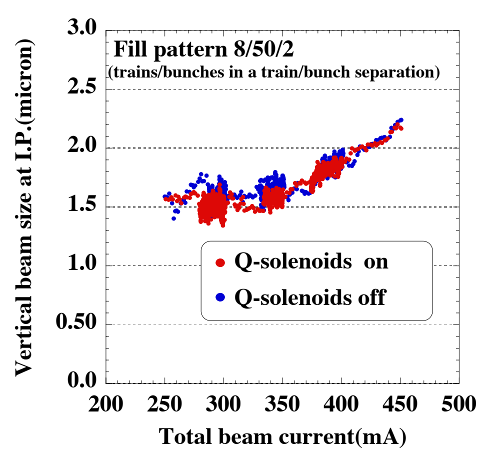

Figure 5: Vertical beam size at I.P. as a function of a total beam current with or without Q-solenoids.

(I.P.). Behaviors of the beam size are almost the same with or without the Q-solenoid field.

Similarly, no clear difference was observed in the data of the sideband and the vertical beam size in the bunch separation of three rf buckets with or without the Q-solenoid field.

Effect on the luminosity

The Q-solenoids were turned on or off during a physics run to observe their effect on the luminosity. The average bunch separation was 3.06 rf buckets. The beam current and the number of bunches in the LER were 1750 mA and 1585 respectively. No improvement of the specific luminosity was found when turning on the Q-solenoids. In 2006 KEKB has been operated with the use of the Q-solenoids for about four months. No improvement of the specific luminosity was found.

SIMULATIONS

Simulations by ECLOUD [6] and CLOUDLAND [7] were carried out to understand the results of the experiment. Fig. 6 shows the simulated line density and the central density of the electrons in a quadrupole of 5 T/m by ECLOUD. The bunch current is 1.28 mA. The maximum secondary emission yield is 1.5 at a primary-electron energy of 200 eV. The Hilleret model of secondary emission and elastic electron reflection is used [8]. The simulation shows that the central density without the solenoid field is less than 10^{12} m^{-3} which will be not enough to cause the instability according to the criterion of Eq. 1. The solenoid field of less than 600 G has no effect on the central density of the electrons. The simulation in which the quadrupole field is reduced to 0.1 T/m shows that in this case a solenoid of 60 or 600 G would be effective in reducing the electron density.

The effect of the solenoid field on the electron density was qualitatively consistent with the simulations by CLOUDLAND.

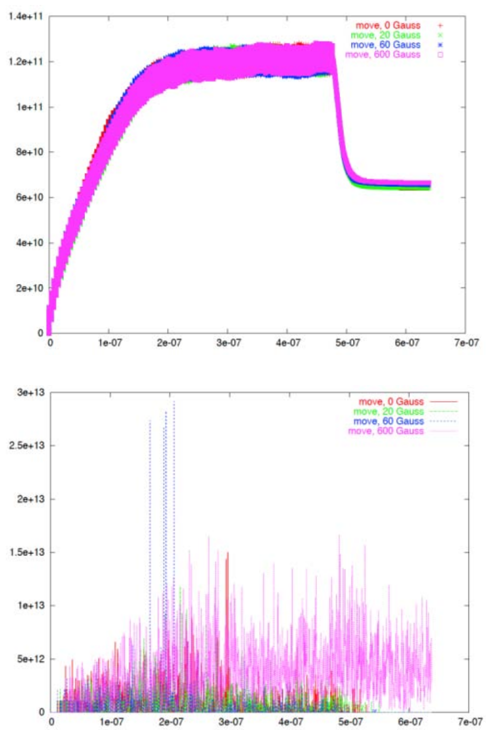

Figure 6: Simulated electron cloud density as a function of time in sec at four different solenoid strengths (0, 20, 60 and 600 G) by ECLOUD. Top: the electron line density in units of m^{-1}, bottom: the central electron density in units of m^{-3}. Bunch separation is 2 rf buckets. The strength of a quadrupole is 5 T/m.

DISCUSSION

The experimental result where no clear effect of the Q-solenoids was found is not inconsistent with the simulation which shows that the central electron density in the quadrupole will not be enough to cause the blow-up. Another possibility being consistent with the experimental result is that a stronger magnetic field, of the same order of magnitude as the pole-tip field in the quadrupole, may be required to clear the electrons [9]. In this case electrons may accumulate in the quadrupoles possibly up to the threshold level of the instability. The direct measurement of the electrons by an electron monitor will give a clearer answer on the role of the electrons in the quadrupole field. Further simulations are also necessary to study the above-mentioned possibility.

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