THE PULSED QUADRUPOLE MAGNET FOR KEKB LOW ENERGY RING*

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Abstract

In order to correct the tune shift generated by photoelectrons in the KEKB positron ring, the pulsed quadrupole magnet was designed and installed. The magnet is excited every revolution and correct the tune shift for the first 700nsec at the head of train. It has been successfully operated.

INTRODUCTION

The KEKB is an asymmetric electron-positron collider. The accelerator consists of a 3.5 GeV positron storage ring (LER) and an 8GeV electron ring (HER) [1]. The maximum current stored in each ring is 2000mA in LER and 1401mA in HER.

Motivation

The synchrotron light from the positron beam strikes the wall of vacuum chamber and generates the photoelectrons. Since the sign of the charge is opposite to the beam, it gives a strong effect to the beam in LER.

To remove the effect from electron cloud, many solenoids are implemented only in the positron ring. Even with the solenoid field, still the beam is affected from electron cloud. The electron cloud gives the focusing force to the positron beam. Because of the beam abort gap*, the density of electron cloud is not uniform. It is lower just after the abort gap. Specifically the focusing force is weaker and betatron tune is lower at the head of train. This is remarkable in the vertical plane. Figure 1 shows the betatron tune shift along the bunch train at 750mA and 1400mA beam current respectively. [2] With the 1400mA beam current, the betatron tune is 0.012 lower in vertical and the 0.001 lower in horizontal at the head of train. This tune shift is observed first 2μsec in vertical, and 100nsec in horizontal. The installed pulsed quadrupole magnet gives an extra focusing force to the beam at the first 700nsec out of the 10μsec revolution period to compensate for these tune shift. Although it depends on the operation condition, sometimes luminosity is higher near the resonance line in the tune diagram. When we get closed to the resonance line from higher tunes, the head of the train reaches to the resonant line first, and the beam is lost. Figure 2 shows the situation that the beam was lost at the head of train. Before installing the pulsed quadrupole magnet, the extra bunches are added at the train head to make more electron cloud that gives focusing force, but it was not enough. The pulsed magnet makes the tune spread small in the train and it becomes possible to approach closer to the resonance line without losing the beam of the train head. It can be easily switched from vertical focusing to horizontal focusing by changing the cable connection.

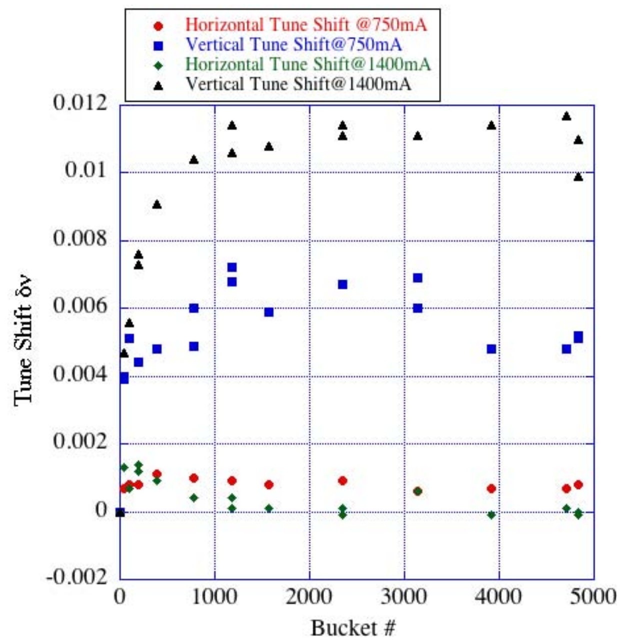

Figure 1: The betatron tune shift along the train. It was measured at the beam current of 1400mA and 750mA at the KEKB positron ring

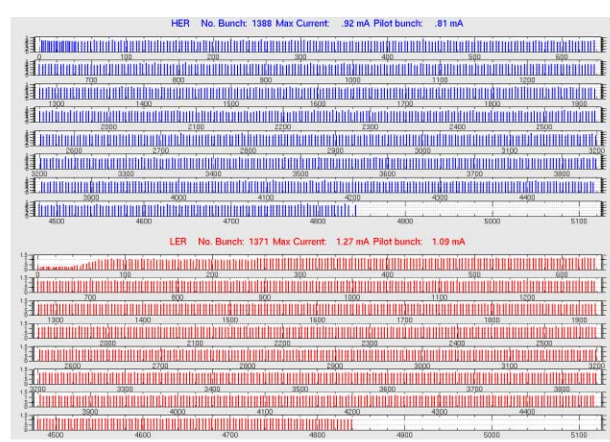

Figure 2: The bunch current monitor of HER and LER.

* For the beam abort kicker pulse rise time, 500nsec abort gap, where no beam can be filled, is reserved.

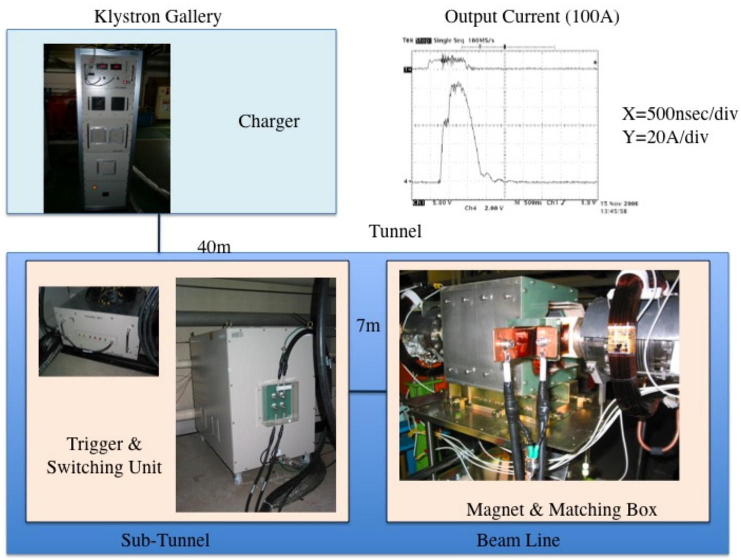

Figure 3: The schimatic diagram of the pulsed quadrupole magnet system.

PULSED MAGNET SYSTEM

Table 1 shows the specification of the system. The pulsed magnet repetition rate is the revolution frequency of the ring (100kHz). Output current waveform is a half sinusoid and the pulse width is 1.5μsec. The output current rises during the abort gap, and the magnetic field become maximum at the head of train. The maximum tune shift is almost 0.005. Output current peak is 100A. The maximum field gradient is 0.075 T/m.

Table 1: System Specification

Parameter name	Value
Tune Shift δv (Vertical)	0.005
Field gradient dBy/dx (T/m)	0.075
Ferrite core length (mm)	250
Bore Radius (mm)	58
Length of ceramic (mm)	420
Ti coating thickness (μm)	6
Coil inductance(μH)	5-6
βy @ Pulsed magnet (m)	30
βx @ Pulsed magnet (m)	6
Peak current (A)	100
Output current waveform	Half sinusoid
Pulse width (μsec)	1.5
Repetition rate (kHz)	100

Magnet and ceramic chamber

The pulsed quadrupole magnet is installed at the Fuji straight section. The amplitude of vertical beta function is 30m and 6m at horizontal. As shown in Figure 1, the horizontal tune shift is much smaller than that of the vertical, the magnet was implemented at the place where the amplitude of the vertical beta function is larger than that of horizontal. The magnet core was made from Ferrite (TDK PE14E). The loss in the ferrite core was estimated to 2.3W at the 100kHz, 100A operation, which is small enough. The coil of the quadrupoles magnet is a 2 turns 2 parallels and inductance of the coil is almost 5 μH. Figure 4 shows the ferrite core of the magnet. Flatness of dBy/dx can be controlled by the width of the pole. The error of field gradient was designed to be less than $2.2*10^{-3}$ in the magnetic aperture of 30mm. Figure 4 also shows the water-cooling ceramic chamber used for the magnet [3]. Main contribution of the heating loss at the chamber comes from the beam image current. The heating loss due to eddy current caused by the quadrupole magnetic field is estimated to be 17 W.

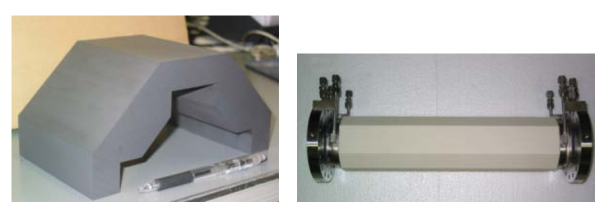

Figure 4: Ferrite core of the pulsed quadrupole magnet and the water-cooling ceramic chamber

Power supply system

The most difficult point of this system is the design of power supply. We have to supply relatively large current (100A) at the very high repletion rate (100kHz). The selection of switching device is the key of the system. The field-effect-transistor (FET) was chosen as high repetition and high voltage switching device. Total 24 FETs, 8 series and 3 parallels, were used. Figure 3 shows the schematic diagram of the power supply system. The power supply consists of three parts. The DC charging power supply and control parts are implemented in the klystron gallery which is accessible during an accelerator operation.

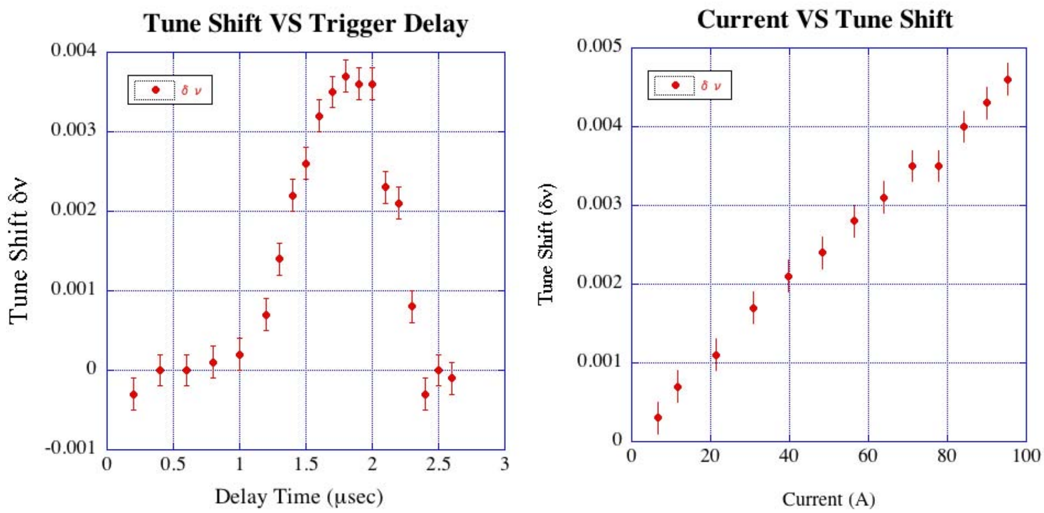

Figure 5: Vertical tune shift as a function trigger timing and magnet current.

The FET switch and a main capacitor are located at the sub-tunnel, which are approximately 40 m from the charger and 7 m from the pulsed quadrupole magnets. The matching impedance is placed under the pulsed quadrupole magnet to adjust the output current waveform not to have an undershoot. Since the main capacitor is located inside the tunnel, the large current passes is localised. It minimized the noise from the magnet.

OPERATION AT THE KEKB LER

Beam based alignment has been done first. Pulsing the magnet, observing the orbit and the bump orbit was adjusted to pass the beam at the center of the magnet.
The trigger timing was determined as follows. We filled only one bunch, then pulsing the magnet. Measuring the tune shift, the timing of trigger signal is changed step by step. Figure 6 shows betatron tune shift at each trigger timing. Trigger timing was set to maximise the field at the head of the train. Figure 7 shows tune shift as a function of magnet current under vertical focusing configuration.

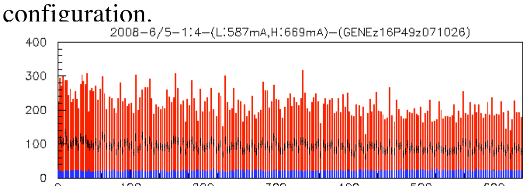

Figure 6 Bunch by bunch luminosity monitored by ZDLM (Zero Degree Luminosity Monitor)

Since the extra focusing force is added, the beta function is also distorted. The distortion of the beta function at the collision point can be written as

$$\Delta\beta(s_0) = -\frac{\beta(s_0)}{2\sin(2\pi\nu)}\beta(s_1)\Delta K(s_1)\cos[2(\Phi(s_1)-\Phi(s_0))-2\pi\nu]$$

Since KEKB is operated near the half integer tune, the distortion is not small. The effect of the distortion to the luminosity and injection rate was investigated. Figure 6 shows the bunch-by-bunch luminosity monitored by Zero-Degree Luminosity Monitor (ZDLM) at νx=45.515 νy=43.587. The leading first 350 bunches are supposed to have some affection from the distortion, but no serious luminosity drop was observed. Beam injection ratio is also observed, and there is no effect on the injection.

CONCLUSION

The pulsed quadrupole magnet is installed in the KEKB positron ring. The magnet successfully corrected tune shift caused by electron cloud not to lose the beam at the head of train.

ACKNOWLEDGEMENTS

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