DEVELOPMENT OF PULSED BENDING MAGNET FOR SIMULTANEOUS TOP-UP INJECTION TO KEKB AND PF RING

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Abstract

KEK B-factory (KEKB) linac is used to deliver beam to four rings, KEKB High Energy Ring (KEKB-HER), KEKB Low Energy Ring (KEKB-LER), Photon Ractory (PF) ring and Photon Factory Advanced Ring for Pulse X-rays (PF-AR). Simultaneous pulse-by-pulse multi energy injection to three rings (KEKB-HER, KEKB-LER, PF ring) is required, recently. We have developed a pulsed bending magnet for the top-up injection to PF ring. The stability of less than 1×10^{-3} is required. In this paper we describe the design of the pulsed bending magnet and the field measurement results.

INTRODUCTION

KEKB linac is a 600 m long electron linac and is used to deliver beam to four rings, KEKB-HER (e^-, 8 GeV), KEKB-LER (e^+, 3.5 GeV), PF (e^-, 2.5 GeV) and PF-AR (e^-, 6.5 GeV). KEKB rings are operated under the top-up injection mode and have occupied the current linac operation mostly.

Injector upgrade plan is required due to the following reasons. (1) It takes a few minutes to switch beam between four rings because DC magnets are needed to be initialized to change an injection mode. (2) Machine study for PF and PF-AR interrupts KEKB operation. (3) The top-up injection to PF is required, recently. Injector upgrade plan was performed in the three steps.

(Phase-I) A New beam transport line to PF was constructed at the linac end beam switch-yard in summer of 2005. The parameter settings of the magnets, rf phases and the timing are changed to the optimum condition for each ring.

(Phase-II) Simultaneous multi-energy top-up injection to two rings of KEKB-HER and PF was realized by replacing a DC magnet to pulsed magnet at the end of linac in 2008. The parameter settings of the other magnets isn't changed. Because PF needs 2.5 GeV electrons, the beam is accelerated to about 5 GeV and decelerated to 2.5 GeV by adjusting only the rf phases.

(Phase-III) Simultaneous pulse-by-pulse top-up injection to three rings (KEKB-HER,KEKB-LER and PF) is realized by using a Event Timing system [1]. To perform the fast switching between electrons and positrons, a positron target with a bypass hole are used and the beam orbit of electron beam is controlled by the pulsed steering magnets.

The pulsed bending magnet was developed for the top-up injection to PF ring in phase-II. The stability of less than 1×10^{-3} are required at any repetition frequency up to 25 Hz. The main parameters of the pulsed bend magnet are given in Table 1.

Table 1: Specifications for the pulsed bending magnet. () value is for the second magnet.

Max. beam energy	3 GeV
Deflection angle	114.4 mrad
Field strength @ 3 GeV	1.15 T
Magnet core length	990 (980) mm
Magnet core gap & width	30 x 155 mm
Coil turn	1
Max. PS peak current	32 kA
Peak current @ 3 GeV	28 kA
Pulse width	200 μsec
Pulse shape	half sine
Max. repetition	25 Hz
Effective current	1.4 kA
Stability	1×10^{-3} (p-p)
Peak force for coil	1.6 ton
Magnet resistance	1 mΩ
Magnet inductance	6.6 μH

MAGNET DESIGN

This magnet produces an 114 mrad deflection angle for a 2.5 GeV electron beam. Fig. 1 , 2 shows the picture of pulsed bending magnet and the cross section, respectively.

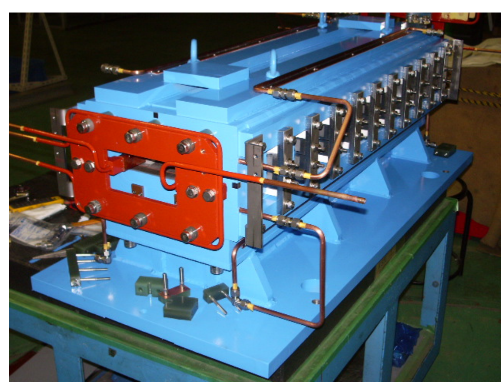

Figure 1: Picture of Pulsed bending magnet.

The magnet is made of the 0.35 mm thickness stamped silicon steel. The laminated core is welded with the 25 mm end stainless plates. The stainless plates have the slit structures not to become high temperature due to eddy currents and the water cooling pipe are attached to that. The copper plates of 5 mm thickness (10 mm for the second magnet), which are cooled by water are also sandwiched between the core and the stainless plates on both ends.

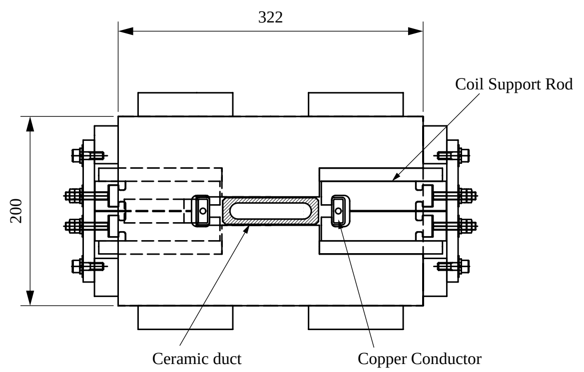

Figure 2: Cross section of the pulsed bending magnet.

Because the Lorentz force for the conductor is so large, the conductor must be fixed firmly for transverse direction and can move longitudinally due to the thermal expansion of the copper conductor. A coil support rods, which are made of silicon nitride ceramics (Si_3N_4, NGK Co. Ltd. EC-141) are used for this purpose as shown in Fig. 2. This is the method applied in KEKB septum [3]. A silicon nitride have good shock resistance as compared to the other ceramics. The rods shape was optimized by using ANSYS [4]. The hard lock nuts [5] are used to fix the ceramic rods not to loosen the screws by a shock. While one side of conductor is longitudinally fixed to the end plates, the other side isn't fixed.

The ceramic vacuum chamber, whose ceramic size is 27 mm (height) x 99 mm (width) x 1.2 m (length) can pass through the magnet core gap. However, the end flanges of chamber cannot be sufficient small to pass through it. Thus a demountable flange is used [2]. The inside wall of the ceramic duct is coated by Titanium, which thickness is about 20∼50 nm in order to avoid the ceramic surface to charge up. The temperature rise of the ceramic by the eddy current is less than 10 ℃.

POWER SUPPLY

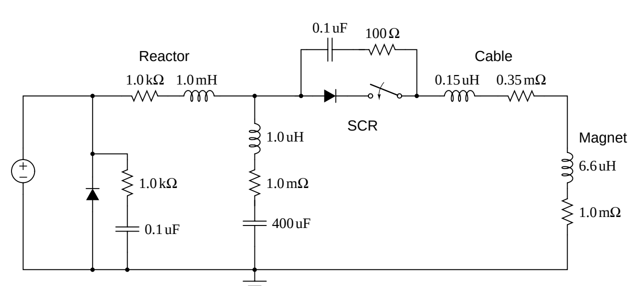

Figure 3: Simplified electrical circuit of power supply.

The half-sine wave field pulse with duration of 200 μs and repetition rates of 25 Hz will be generated by a pulsed circuit based on LC resonant discharge. Fig. 3 shows the simplified electrical circuit of power supply.

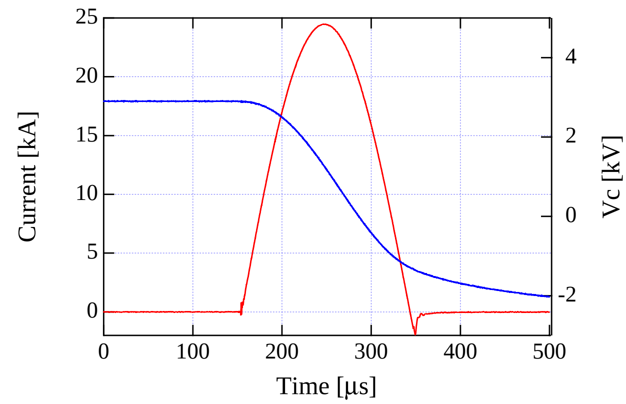

Figure 4: The pulse shape of the magnet current and the voltage of main capacitor.

The voltage of the main capacitors are precisely charged by the inverter power supply (5 kV, 20 kA). The voltage stability of less than 0.1 % (p-p) is required for a stable beam injection. The stored energy in the capacitor is switched by 24 thyristor modules (4 parallel and 6 series, Mitsubishi electric Co. Ltd. FT1000A-50) to the magnet inductance. The transmission of the power pulse from the power supply to the magnet is supplied by 40 parallel coaxial cables. The power pulse is used to re-charge the capacitor through a diode which is connected to the main capacitor in parallel. The pulse shape of the magnet current and the voltage of the main capacitor is shown in Fig. 4.

FIELD MEASUREMENTS

The magnetic field strength is measured by the short pick up coil (ϕ5 mm, 4 turn) and the long pick up coil (1 mm in width and 1.5 m in length).

Fig. 5 shows the measured field distribution as a function of longitudinal position. The drops of the field at the coil support rods are observed and the magnitude of the drop depends on the horizontal position. Fig. 6 shows the homogeneity in the required region (x=± 40 mm) is about 0.45 %.

Stability measurements

Fig. 7 shows the normalized charged voltage of the main capacitor and the normalized magnetic field strength, respectively. These are measured at the current of 24 kA at the repetition of 25 Hz. Both of the charged voltage of the main capacitor and the magnetic field strength are about 0.1 % decreased in one second from the beginning. The voltage is almost constant after that and the pulse-by-pulse stability is about 3×10^{-4} (p-p) in one hour. On the other hand, although the charged voltage are almost constant, the magnetic field strength is quickly decreased to 99.8 % of the first pulse in a few minutes.

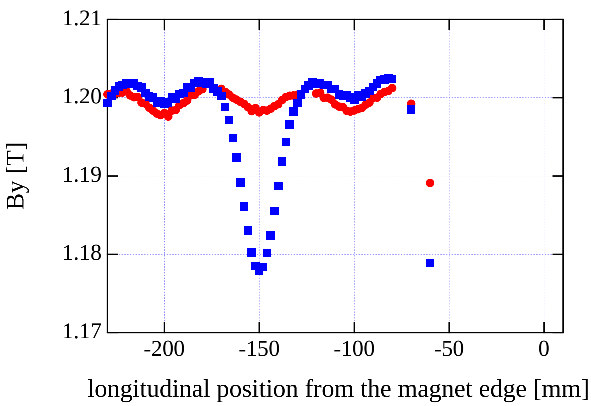

Figure 5: Measured field distribution along longitudinal direction from the magnet edge. The filled circle and the filled box show the longitudinal distribution at x=0 mm and x=45 mm, respectively.

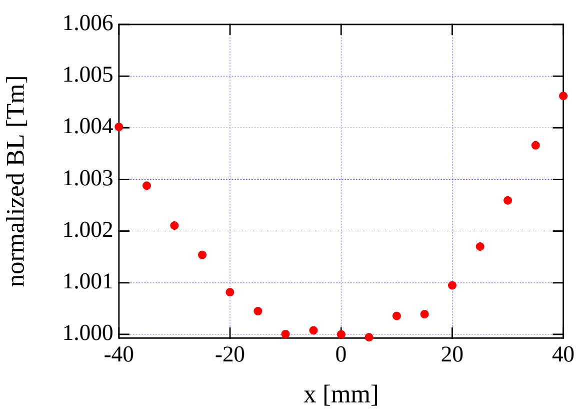

Figure 6: Measured distribution of the longitudinal integrated field as a function of horizontal position.

Temperature rise of the end plates

The power consumption by the eddy currents is estimated about 370 W at the end plates by using Opera-3d ELEKTRA-TR [6]. Temperature of magnet is measured by the fiber optics temperature monitor. The temperature rise of the end plates is about 60 and 25 ℃ for the first magnet and the second magnet, respectively. The difference between the first and the second magnet is the thickness of the copper plates and the cooling pipe position. The cooling pipe position for the second magnet is closer to the magnet gap.

CONCLUSION

We have developed a pulsed bending magnet for top-up injection for PF ring. It works well. However, the charged voltage drift of 0.1 % and the drift of the magnetic field of 0.23 % were observed in the begining. It seems that the decrease of magnetic field is due to the increase of the resistance in the main circuit by the temperature rise of thyristor

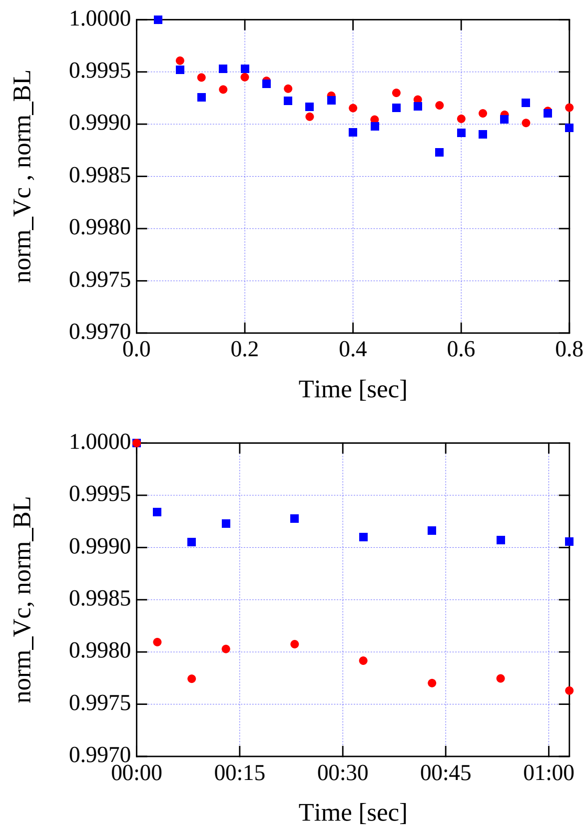

Figure 7: the pulse-by-pulse stability in the beginning and in the long term, respectively. The filled box and the filed circle show the normalized voltage of main capacitor and the normalized magnetic field strength on each graph, respectively.

modules and cables. The reason why the charged voltage go down in one second is not well understood. The further improvement is required.

The operation of the pulse-by-pulse multi energy acceleration has started in KEKB linac and the simultaneous top-up injection to three rings was succeeded on Apr. 2009. This scheme is used in the normal operation now.

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