STUDY ON THE PLS INJECTION KICKER MAGNET AND MODULATOR

S. H. Nam, S. H. Jeong, and J. H. Suh

PAL/POSTECH, Pohang 790-784, Kyung-Buk, S. Korea

Abstract

The PLS injects 2.0 GeV electron beams from Linac to storage ring (SR). After storing the current to 170 mA, the beam energy is ramped up to 2.5 GeV in the PLS SR before providing the beam to users. In the PLS SR injection section, there are four kicker magnets and one kicker modulator. Peak current for each magnet is about 12 kA for 2.0 GeV injection that corresponds to 21 mm bump. Analytical, simulation, experimental studies of the kicker magnet show good field uniformity. An usable peak current range of the kicker system is also studied for future upgrade. The kicker magnet and modulator has been operated for 35,800 hours as of August 2001 since its installation..

1 INTRODUCTION

The 2 GeV full energy electron beam from the linac is transported through a beam transfer line (BTL) to the storage ring. The injector linac is located under ground and the storage ring is positioned on ground. A septum magnet deflects the electron beam on the same level as the stored beam in the SR. The injected beam from the BTL into the storage ring is then placed within the storage ring beam dynamic aperture by kicker magnets. In Fig. 1, a concept of the bumped beam orbit is presented. A thin septum magnet wall separates the injected beam. Total four kicker magnets are used to disturb the normal storage ring beam orbit, to move the orbit closer to the septum magnet wall and also bring the injected beam within the storage ring beam dynamic
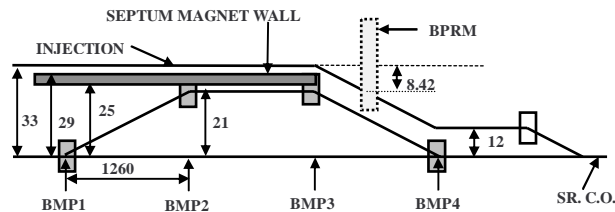
aperture [1]..

. Fig. 1. Bumped beam orbit. Units are in mm.

INJECTION: Injected beam path, SR C.O.: Storage ring center orbit, BPRM: Beam profile screen monitor (During injection, the screen is removed.), BMP1, BMP2, BMP3, BMP4: Kicker magnets (1.324 kG peak field), SEPTUM MAGNET: Indicates septum magnet wall (11 kG peak field)

2 KICKER MAGNET

Table 1. Specification of the kicker magnet

Parameter	Specification
Beam Energy	2.0 GeV
Bending Field (@ 8.4 kA per magnet)	0.1324 T
Max. Relative Field Deviation	0.5 %
Max. Time Jitter between Magnets	6 ns
Number of Turns per Pole	1 turn
Resistance of Magnet @40 ℃	8.28 mΩ
Inductance of Magnet	0.867 μH

Major parameters of the kicker magnet at 2 GeV SR operation are given in the table 1 [2]. Only one kicker magnet modulator is used to drive the four kicker magnets, to give balanced current for all four magnets and also have precise timing between magnet currents. Specification of the kicker magnet modulator is ~6 μs pulse width, 30 kV maximum voltage, ~24.06 kA peak current, 266 MW maximum power and 10 Hz repetition rate. It can bump 2.0 GeV electron beam to the maximum of 21 mm [1].
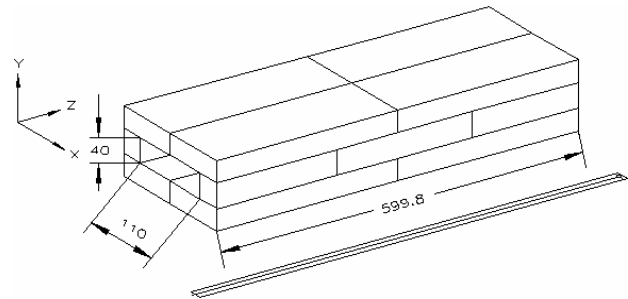

Fig. 2. Ferrite structure of kicker magnet

Table 2. Specification of MN80C ferrite core

Parameter	Specification
Initial Permeability	2400
Maximum Permeability	6000 typ.
Maximum Flux Density	4800 gauss min.
Remanent Flux Density	2000 gauss max.
Coercive Force	0.23 oersted max.
Cure Temperature @40	230 ℃ typ.
DC Volume Resistivity	200 Ω-cm typ.

Core material of the kicker magnet is ferrite MN80C that is provided from Ceramic Magnetics, and the structure is appeared in Fig. 2. As shown in the figure, upper and lower

cores are consisted of 4 blocks each. The size of each block is 80x30x299.9 mm. Left and right side cores are consisted of 3 blocks each, and the each block size is 30x40x299.9 mm. Main specifications of the core material are given in Table 2 [3].
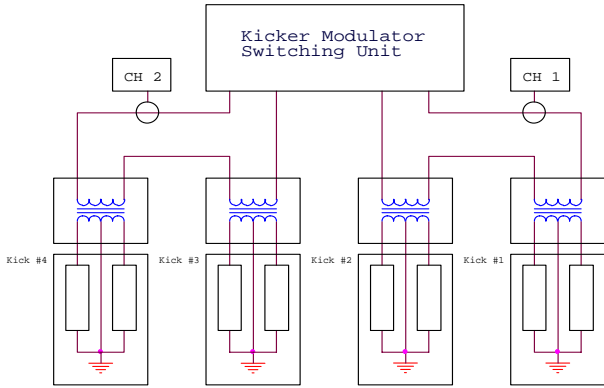

Fig. 3. Cable connection diagram of the kicker system. CH1 and CH2 indicate current transformers.

The cable connection diagram of the kicker magnets is shown in Fig. 3. Kicker magnets 1 and 2 and magnets 3 and 4 are connected in series. These two serially connected magnets are connected in parallel at the kicker modulator. The kicker magnets 1 and 2 are positioned at the up-stream side and the kicker magnets 3 and 4 are positioned at the down-stream side. There is a pulse transformer between the modulator and the magnet as shown in Fig. 3. The pulse transformer turn ratio is 1:2, and the secondary has a center tap so that equal but apposite direction current can flow for each side of the magnet conductors. Peak currents of each channel (CH1 and CH2 in Fig. 3) are in greater than 95 % balance.

3 MEASUREMENT AND ANALYSIS RESULTS OF THE KICKER MAGNETIC FIELD

Peak current of the kicker magnet has the following relationship with the peak magnetic field:

$$I = \oint H \bullet dl \approx \frac{B_0 g}{\mu_0} + \frac{B_{fe} L_{fe}}{\mu_0 \mu_r} \qquad (1)$$

where B_o is the peak field, g is the air gap height of the kicker magnet (g=40 mm), B_{fe} is the magnetic flux density in the core, L_{fe} is the average pass length through the core, and μ_r is the relative permeability of the core. Since the magnet is designed such that no significant saturation effects occur, implying that

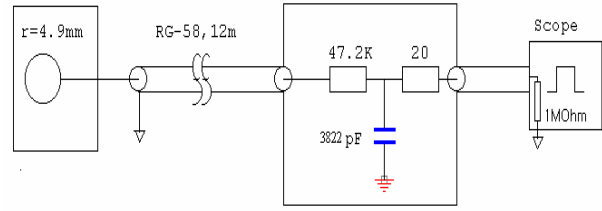$$B_o g \gg \frac{B_{fe} L_{fe}}{\mu_r} \qquad (2)$$

Fig. 4. A B-dot probe with an integrator

Therefore, the second term of Eq. (1) can be neglected, and the peak current can be approximated as

$$I = \frac{B_o g}{\mu_o} \qquad (3)$$

Fig. 4 shows a B-dot probe setup that is used to measure the magnetic field in the kicker magnet air gap. The probe sensor is an one-turn loop with 9.8-mm diameter, made with 0.6-mm thick enamel wire. The output voltage of the probe, V_o, has the following relationship with the peak field of the kicker magnet:

$$V_o = \frac{A B_o}{T_I} \qquad (4)$$

where A is the area of the probe sensor, and T_I is the RC time constant of the integrator. The sensitivity of the probe is calculated as 0.042 mV/Gauss from Eq. (4). The measured sensitivity is 0.035 mV/Gauss. The difference is mainly from the position angle and the uniformity of the one-turn loop.
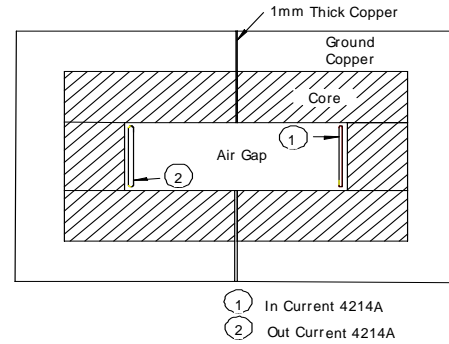

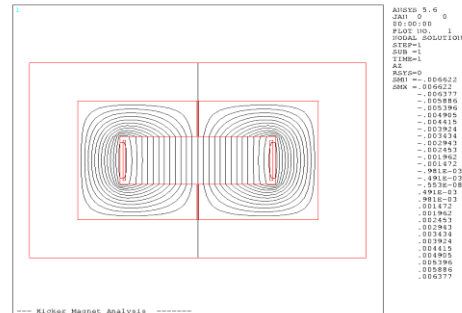Fig. 5(a). Setup for ANSYS simulation

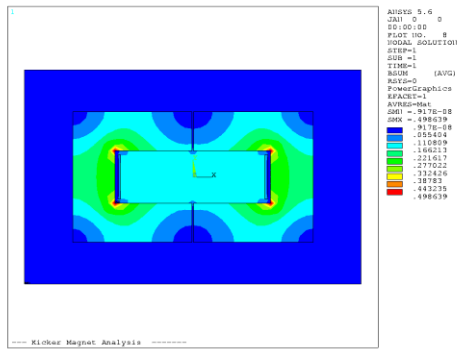Fig. 5(b). Simulation result: 2-dimension flux line plot

Fig. 6. 2-dimension magnetic flux density distribution

Magnetic field of the kicker magnet is simulated to compare with the calculated and measured field results. Simulation setup is shown in Fig. 5(a). Fig. 5(b), and 6 shows the ANSYS magnetic field simulation results. Fig. 5(a) shows the 2 dimensional flux line diagram, and each line corresponds to an equivalent strength of magnetization. Fig. 6 shows the 2 dimensional distribution of magnetic flux density. From the figures 5(a) and 6, we can realize uniform flux line distribution in the magnet air gap. Fig. 7 shows the simulated and measured x-axis magnetic field profile of the kicker magnet. The peak current used for the results is 8.4 kA per magnet, or 4.2 kA per each conductor of the magnet. The distance '0' in the figure indicates center of the air gap. The field measurement position is 220 mm in z-axis while the x-axis position varies. The measured field at the center of the air gap is about 0.1325 Tesla while the simulated and the designed values are 0.1246 Tesla and 0.1324 Tesla, respectively. The measured field is more close to the design value while the simulated one has about 6% difference from the design value. The measured field shows more uniformity than the simulation result.
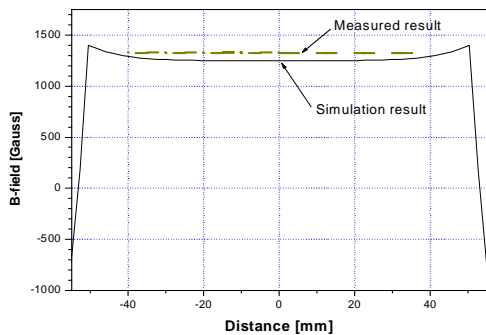

Fig. 7. x-axis spatial magnetic field distribution in kicker magnet (Z=220 mm)

All measured field within the measured range of ±40 mm from the magnet center is within 0.5% deviation, and the simulated field shows the same deviation within ±25mm. Fig. 8 shows a measured z-axis magnetic field profile at the center of the magnet. It also shows good uniformity of the z-axis field. Saturation current of the magnet is also measured as 12 kA total, or 6 kA per each

conductor. Fig. 9 shows the bump distance as a function of the kicker current. The bump distance in Fig. 9 is measured at the BPRM in Fig. 1. The bump distance of 8.6 mm corresponds to 21 mm actual bump. The kicker current in Fig. 10 is the total current. For each magnet, a half of the total current is supplied. The measured result shows a good linearity and the bump distance as designed.
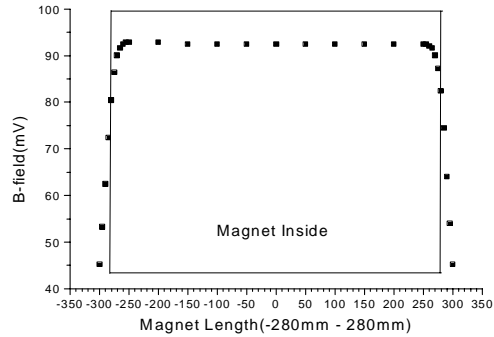

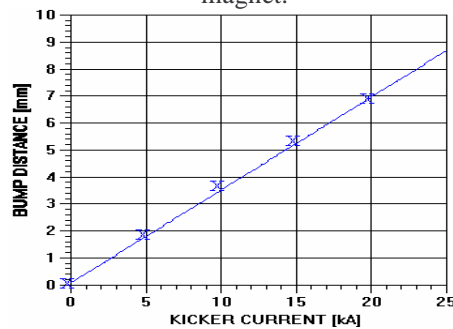Fig. 8. z-axis spatial field distribution in the kicker magnet.

Fig. 9. Bump distance variation as a function of the total kicker current. The bump distance is measured at the BPRM in Fig. 1.

4 CONCLUSION

Four kicker magnets in the PLS SR bumps maximum 21 mm at 2 GeV. Designed, simulated, and measured results of the kicker magnetic field strength and distribution are compared and show good agreement. Total operation time of the kicker magnet modulator and the magnet is over 35,800 hours as of August 2001, and the system is in stable operation without significant failures.

REFERENCES

[1] S. H. Nam, S. H. Jeong, "Kicker Magnet Modulator in the 2-GeV Pohang Light Source," IEEE Trans. Plasma Science, 28, 5, Oct. 2000, pp1386-1391.

[2] John Milburn and Namsoo Shin, "Injection system parameter list," PAL Engineering Note IN-007, July 1992.

[3] John Milburn, "Model bump magnet design parameters," PAL Engineering Note IN-002, June 1992.