MAGNET SYSTEM FOR PLS-II PROJECT*

D.E.Kim†, K.H.Park, H.G.Lee, H.S.Han, Y.G.Jung, H.S.Suh,
Pohang Accelerator Laboratory, POSTECH, Pohang, Korea

Abstract

Pohang Accelerator Laboratory (PAL) is planning to upgrade the Pohang Light Source (PLS) which is a 3rd generation light source operating since 1995. The key features of the upgrade are, decrease of the beam emittance to 5.6 nm, increasing the beam energy to 3.0 GeV, additional shorter straight sections for more insertion devices. Because the PLS-II should use practically same circumference preserving the shielding wall structure of the existing PLS, the lattice space is squeezed to the limit to secure the additional space for the insertion devices. This requirements forces heavy use of the combined function magnet. All dipoles are replaced to gradient magnet, and all sextupoles have horizontal corrector winding, vertical corrector winding, skew quadrupole windings. In this report, the design features and engineering efforts for the PLS-II magnet systems are reported.

OVERVIEW

The magnet system of PLS-II consists of 24 gradient magnets, 96 quardupoles, and 144 sextupole magnets which has additional windings for horizontal corrector, vertical correctors, and skew quadrupole excitations. For injection system, 4 pulsed kicker magnet and a septum magnet is needed.

The major changes from the PLS design can be listed as follows:

- The combined function gradient magnet is adopted to save the lattice space for an additional short straight seciton per each superperiod. Also the dipole field is pushed to the limit to make it shorter with smallest possible 34 mm vertical gap. The number of dipole magnet is reduced from 36 to 24 and the magnetic length is increased from 1.1 m to 1.8m.
- Also all 70 combined function horizontal/vertical correctors are removed and the corrector function is incoperated with the sextupole magnets like ALBA [1]and SPEAR3 [2]. The number of sextupole magnets are changed from 48 magnets with 2 families to 144 magnets with 12 families. 120 new combined sextupole magnets will be needed.
- The existing PLS quadrupole will be mostly recycled. In PLS, we had 6 familes of quadrupoles with 24 magnets per each family (Q1 to Q6). Q1, Q2, Q3 were wired in pair across the straight sections and Q4, Q5, Q6 were connected in series for the whole 24 magnets for each family. In PLS-II, we have 4 families of quadrupoles which will be powered in series with addtional trim winding for maximum operational flexibility. Therefore, as far as possible, quadrupole magnets will be recycled with newly designed additional trim coil. For PLS-II, the maximum required field gradient is 22 T/m compared to design limit of 18 T/m for the PLS. Magnetic analysis showed that the existing quadrupoles can be operated at 22 T/m with small changes in the higher order harmonic contents.
- The kicker magnets for the injection will be mostly recylced. The space for injection straight will be readjusted to accomodate the increased septum length, and the increased kicker separation. The septum magnet will be redesigned with smaller gap and smaller leakage field which is essential for top-up operation.

The details of the magnet system for PLS-II will be detailed in the following section.

COMBINED FUNCTION DIPOLE

A lot of smaller rings are adopting combined function dipole magnets to reduce the lattice space [1] [2] [3]. Since PLS-II should utilize the existing radiation shielding wall, the storge circumference is nearly identical with PLS. To squeeze the lattice space for the additional short straight section, the space between the magnets is minimized. And the use of combined function dipole is very essential to save lattice space.

The combined function dipole magnet (also called gradient magnet) has a dipole field combined with the focusing quadrupole field. With builtin quadrupole field, the number of quadrupole magnets can be reduced. In PLS-II, the gap at the center of the magnet is 34 mm which is very small compared to the previous 58 mm. The central field is increased significantly to 1.4544 T compared to the previous 1.32 T at 2.5 GeV. This dipole field is superposed with the focusing field gradient of 4.0028 T/m. And for PLS-II DBA lattice, there are only 24 bending magnets and each bending magnet should bend 15 degrees compared to the previous 10 degree bending for TBA. The effective magnetic length of the gradient magnet is increased to 1.800 m. The major parameters of the gradient magnet is summarized in Table 1.

There are a few limitations related to the design of the gradient magnet.

- Since the effective magnetic length is long compared to the bending radius, the sagitta of the orbit is very

* Work supported by POSCO and MEST of Korea
† dekim@postech.ac.kr

Table 1: Parameters of the Combined Function Gradient Magnet

Parameters	Value
Number of Magnets (EA)	24
Bend Angle (rad)	0.2618
Magnetic Length (Along the arc) (m)	1.800
Central Field (Tesla)	1.4555
Nominal Gradient (T/m)	4.0028
Bending Radius (m)	6.8755
Field Integral (Tesla m)	2.6198
Gap at the Center (mm)	34.0
Yoke length (m)	1.7660
Magnetic Efficiency	0.95
Ampere Turns (kA)	41.42
Power per Magnet (kW)	16.4
Total Power (24 magnets) (kW)	393
Conductor size(X/Y) (mm)	11.8/10.3
Cooling Hole Size (mm)	6.0
Number of Turns	48
Number of Pancakes/Pole	4
Nominal Current (A)	863.6
Current Density (A/mm^2)	4.67
Voltage Drop/magnet (V)	19.0
Resistance (mOhm/magnet)	43.9
Inductance (mH/magnet)	30.0
Number of cooling channel	4
Coolant Flow Rate (liters/min)	10.7
Coolant Velocity (m/sec)	1.58
Coolant Temperature Rise (K)	21.9
Coolant Pressure Drop (kPa)	700.0

large. Half sagitta reaches 29.4 mm. If we make the core of the magnet straight, we need to increase the pole width to include the half sagitta which results in a bulky, and heavy magnet. To avoid this problem, the pole should be curved following the trajectory. Manufacturing wise, this approach might be challenging but it will be more compact and cost effective magnet.

- Using one lamination for the core is more cost effective and accurate. But the thickness of the coil pancake is limited to the minimum opening in the gap region. In our case, the center gap is 34 mm and the minimum opening is 27.8 mm. Therefore, the thickness of a pancake should be less than 27.8 mm for the coil assembly.

- Another restriction is the very small longitudinal clearance between the gradient magnet and the adjacent sextupole magnet. The clearnace between the iron yoke is 120 mm and the coils from both magnets should not extrude more than this. This severely restricts the coil width, and result in a high aspect ratio coil. The coil consists of 4 layers of 26.28 mm thick identical pancake. This is barely enough for assembly. And the coil extends only 79.83 mm from the end of the core.

A simple 2D FEM anslysis is carried out using a pole contour which is conformal mapped from the SPEAR3 pole profile. The flux shape is shown in Fig. 1. The 2D multipole contents are well within the physics requirements. However, there is a possiblity of end saturation and end effects which may results in worse higher harmonic content and higher saturation. A full 3D analysis will be done to assess these effects.

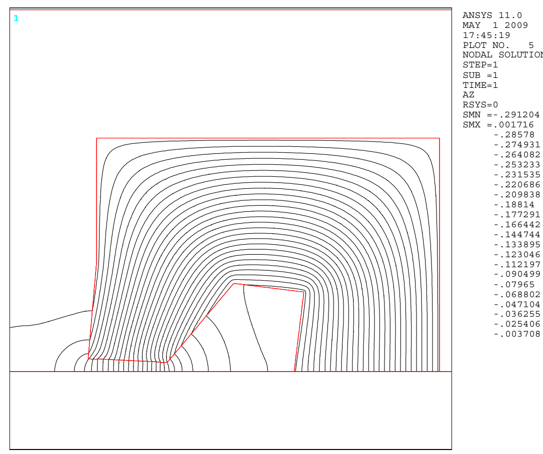

Figure 1: Flux shape in the gradient magnet.

QUADRUPOLE MAGNETS

There are four different types of quadrupoles used in the PLS-II, designated as Q1, Q2, Q3, Q4. All 4 type has same cross section and have effective length of 0.24m, 0.35 m, 0.42m and 0.24 m respectively. The major parameters of the longest quadrupole Q3 are summarized in Table 2.

The quadrupole magnets of the PLS will be mostly recycled for PLS-II. However, there are a few required changes which are listed below.

- For PLS, Q1, Q2, Q3 magnets were powered in pairs, and Q4, Q5, Q6 were powerd in series of 24 magnets to save power supply costs. To save the power supply cost, all quadrupole magnet series will be powered in series in PLS-II. Howevery, to achieve more flexbility for the operation, all quadrupoles will have auxiliary independent winding.

- The maximum field gradient for PLS was 18 Tesla/m. For PLS-II, we need maximum 22 Tesla/m field gradient. To check the multipole contents at this level of excitation, a simple 2D FEM anslysis is carried out. Neglecting the C-shape structure, only one pole is simulated. The flux shape is shown in Fig. 2. The 2D ideal multipole contents are well within the physics requirements. However, there is a possiblity of end saturation which may results in worse higher harmonic content.

The existing quadrupoles will be measured with 22 T/m excitation to check the field quality in near future.

Table 2: Major Parameters of the Longest Quadrupole Magnet Q3

Parameters	Value
Magnet ID	Q3
Number of Magnets (EA)	24
Magnetic Length (m)	0.530
Max. Field Gradient (T/m)	22.0
Aperture Radius (mm)	36
Core length (mm)	494
Ampere Turns per pole (kA)	11.37
Magnetic Efficiency	0.99
Number of Turns	16
Current Density (A/mm^2)	10.8
Conductor size (X/Y) (mm)	9.5/9.5
Cooling Hole Diameter (mm)	5.5
Power/magnet (kA)	13.6
Nominal Current (A)	710.5
Voltage Drop/magnet (V)	19.2
Resistance/magnet (mOhm)	27.0
Inductance/magnet (mH)	5.70
Number of cooling channel	4
Coolant Flow Rate (liters/min)	16.0
Coolant Velocity (m/sec)	2.80
Coolant Temperature Rise (K)	12.2
Coolant Pressure Drop (kPa)	700.0

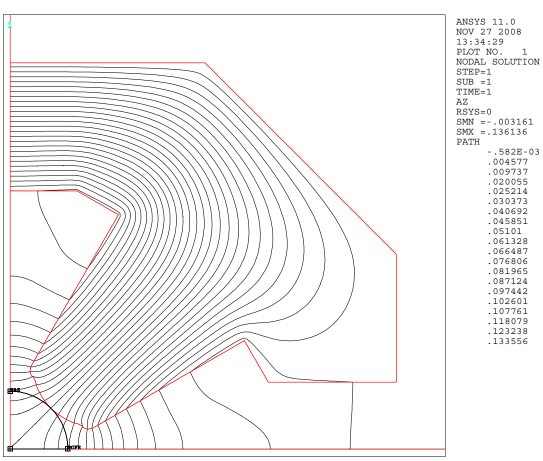

Figure 2: Flux distribution in the quadrupole magnet.

PLS-II SEXTUPOLE MAGNETS AND LAMBERTSON SEPTUM MAGNET

There were two different types of sextupole magnets in PLS, each series is powered in series. In PLS-II, there are 6 types of sextupoles and 2 sextupoles from each types are used for each super-period resulting in 144 sextupole magnets. Among the existing 48 PLS sextupole magnets, 24 magnets will be recycled without modifications. The other 120 sextupoles will be manfactured with same core cross section geometry with existing one. The maximum 2nd derivative field of the PLS sextupole was 320 Tesla/m^2. For PLS-II, we need maximum 550 Tesla/m^2 2nd derivative field. The power supplies will be replaced to accomodate increased current. The coil temperature rise is still well within 20 K. And there are three kinds of effective magnetic length, which are 0.200 m , 0.150 m, and 0.100 m.

In addition to its primary function as the sextupoles, these magnets should also operate as horizontal and vertical correctors, and skew quadrupole magnets. The maximum kick angle for 3.0 GeV ranges 1.33 mrad for 0.2 m long sextupole , and 0.66 mrad for 0.1 m long one.

For injection system, the existing PLS injection scheme [4] will be used with needed upgrades. The most important upgrade will be development of low leakage Lambertson septum magnet. The leakage field from the V-notch into the stored beam area will be optimized using an insert made of high permeability 2.5 % silicon steel (Carpenter Silicon Core Iron B-FM annealed at 1066 ^{o} C inside the 1010 steel yoke [5].

SUMMARY

The status of the PLS-II magnet system is briefly summarized. Major changes will be adoption of the gradient magnet for dipole magnet and increased field gradient strength for the quadrupole magnets.

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