Engineering Design of the PLS 2 GeV Storage Ring Dipole Magnet

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ABSTRACT

The Pohang Light Source is designed to be a 2 GeV third generation electron storage ring producing high brightness VUV and X-ray from the dipole magnets and insertion devices[1]. The storage ring has a TBA lattice structure with 12-period. The prototype dipole magnet is being built and will be delivered at the end of June this year. A magnetic measurements facility has been set up for characterization of the dipole magnet which includes hall probe field mapping and rotating coil harmonic analysis system.

INTRODUCTION

The storage ring lattice contains 12 dispersion-free straight sections, 10 of which are available for insertion devices. The other two sections are reserved for rf cavities and for injection, respectively. The insertion straights are connected by achromatic arcs, with matching between straights and arcs by quadrupole triplets. The achromatic bending system from one dispersion free section to the next is provided by three 10° bending magnets. Two pairs of triplet quadrupoles are located in the two dispersive straight sections which are between two dipole magnets. Chromaticity in the dispersive region of the lattice is corrected by the addition of sextupoles. Two pairs of sextupoles are used for this chromaticity correction and closed-orbit correction is carried out by nine horizontal and eight vertical correction magnets per cell. The local orbit steering system is composed of two pairs of vertical and horizontal correction magnets. A pair of these magnets located upstream of the straight section adjusts both position and angle of the beam in the insertion device. The downstream pair of magnets restores the beam to the circulating orbit. Magnets of the storage ring are optimized to 2 GeV operation and capable of 2.5 GeV operation. The magnetostatic calculations have been made using the two-dimensional POISSON group computer code. Mechanical deformations due to the magnetic force and the magnet weight itself are estimated using the ANSYS computer code.

MAGNET DESIGN

Table 1 shows the design parameters of the dipole magnet, and figures 1 and 2 show an assembly diagram of this magnet and a typical cross section of the magnet coils. The magnet is a C-type design with a laminated steel core and water-cooled coils of square, hollow copper conductor. The height of the magnet pole gap is 56mm, which takes into account the vacuum chamber size and some clearances. The pole width of the magnet is determined from the width of the beam stay clear region in the magnet and the sagitta of the curved beam orbit.

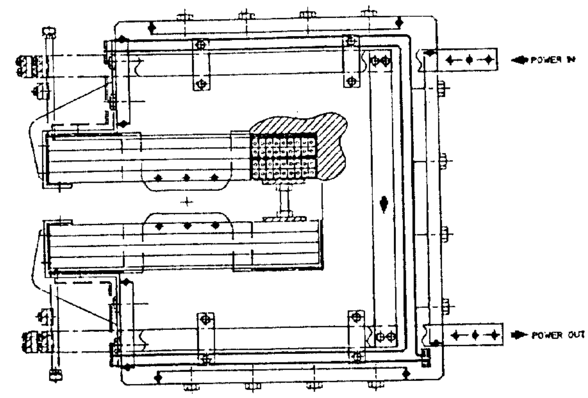


Figure 1. Side view and coil configuration of the storage ring dipole magnet.

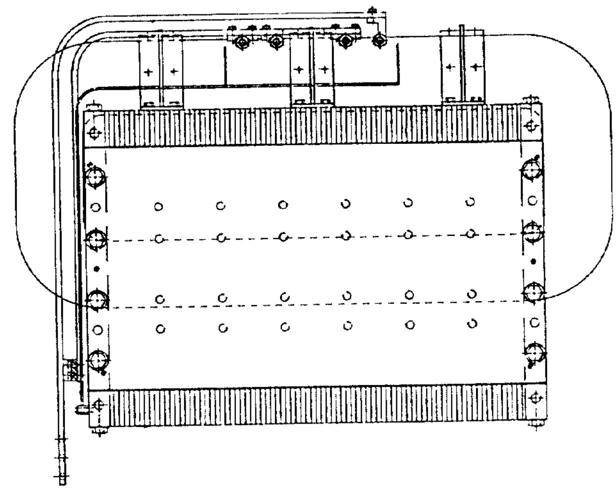
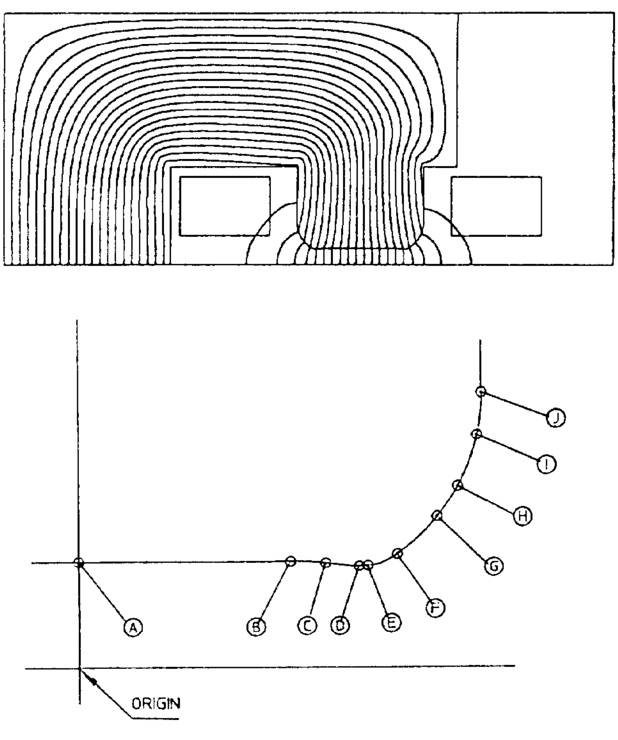


Figure 2. Top view of the storage ring dipole magnet.

The magnetic field requirement at 2 GeV is 1.058 Tesla, however, it has been designed to operate at magnetic fields up to 1.323 Tesla at 98% efficiency. This higher field of the magnet provides for a capability of 2.5 GeV operation in the future machine upgrade. Extensive POISSION magnetostatic computer runs were made in designing the core. The shape of the pole tip is optimized to minimize the pole base width, to keep the required field quality, and to avoid magnetic saturation at the core. The width of the pole base is 220mm which allows average 1.60 Tesla of the magnetic flux density at the maximum field excitation. The results of two dimensional calculations of this geometry of the core, showing the systemetic and the asymmetric effects of the core on the magnetic fields,

Table 1. The Parameter List of the Storage Ring Dipole Magnet at 2.0 GeV and Auxiliary Coils

Description	Dipole	Trim Winding
Type	C-type, Straight	
Quantity of magnet	36 [ea]	72 [ea]
Bend angle	10 °	2.0 [m-rad]
Flux density	1.058 [T]	121 [gauss]
Effective magnetic length	110 [cm]	
Magnet gap on orbit	56 [mm]	
Good field width	±30 [mm]	
Good field height	±18 [mm]	
Magnet weight	5160 [Kg]	
Ampere-turns [A-T]	47680	547
No. of turns	72	112
Current [A]	662.2	4.88
Current density [A/mm²]	3.07	0.53
Voltage drop per magnet [V]	13.03	3.5
Power loss per Magnet	8.63 [KW]	17 [W]
Water circuits per magnet	2	
Water flow rate per magnet at 4.22 Kg/cm² pressure drop	2.9 [l/min.]	
Water temperature rise	22 °C	
Field uniformity (ΔB1/B1)	1×10^{-3}	



Point	Coordinates		Point	Coordinates	
	X (mm)	Y (mm)		X (mm)	Y (mm)
A	0.000	28.000	F	82.962	30.000
B	55.045	28.057	G	93.468	39.845
C	64.206	27.611	H	98.788	47.854
D	72.971	26.762	I	103.791	66.097
E	75.275	26.888	J	105.000	72.500

Figure 3. Flux lines and pole profile of a laminated steel sheet.

are summarized in Table 2 and shown in figure 3. The relative field harmonics at the beam stay clear region are about 10^{-6} to 10^{-5}, as shown in Table 2. The n-th harmonic coefficient is denoted as a_n.

Table 2. Harmonic Coefficients of the Magnetic Field at 1.058 and 1.323 Tesla

n	a_n at 2.0 GeV	a_n at 2.5 GeV
1	1.0000E+00	1.0000E+00
2	4.1932E-06	7.7626E-06
3	2.0853E-05	-8.6546E-06
4	9.4374E-06	1.5117E-05
5	1.0096E-05	5.5109E-06
6	6.2898E-06	6.2988E-06
7	-1.0549E-05	1.1338E-05

The field harmonics for several excitations do not change very much [2]. The yoke ends along the beam path have 40mm x 45° chamfer to provide a smooth transition, thus minimizing saturation at the ends and reducing the multipole components. The magnetic field calculations at the ends of magnet are carried out by slicing the magnet end, thus obtaining three dimensional magnetic fields. The field calculation of twenty different cross sections for the magnet ends is performed using the program POISSON. Transverse distributions of the integrated field for three excitations are shown in figure 4.

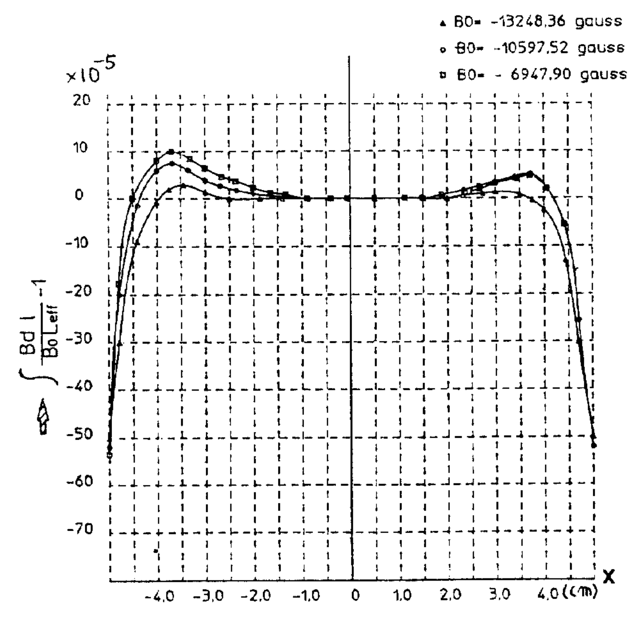


Figure 4. Integrated field profiles of three different excitations, 0.695, 1.058 and 1.323 Tesla.

The laminated core is assembled with an external fixture which remains integral with the laminations after assembly. This method facilitates the precision assembly, compression and support of the core laminations without the cost of special assembly fixtures.

CORE

The core is a laminated structure using 1.0mm ultra low carbon steel which is custom-made produced by POSCO. The thickness variation across the lamination is ±3 μm and the carbon content is less than 50 ppm. The hardness of the lamination is 55 ± 3 in Rockwell B scale. The magnetic induction at 100 Oe is 1.9 Tesla and the coercive force is 1.7 Oe after magnetic excitation up to 100 Oe [3,4]. The production sequence for these steel sheets is as follows:

-elaboration of ultra low carbon steel in 100 ton LD converter,
-continuous casting to produce 18 ton slabs,
-heat treatment for homogenization
-hot rolling to coils, 2.5mm thick and 950mm wide,
-pickling in an acidic bath,
-cold rolling to 1.00mm thickness
-heat treatment in the mixed gas of nitrogen and hydrogen atmosphere at 780 °C for grain growth
-oiling for 12-month corrosion free storage
-flattening and shearing to sheets of 770mm x 850mm and packing to sea-transport criteria in three ton palettes.

Punching was performed with an 800 ton hydraulic press at 20 °C. The burr height is less than 12 μm and the standard deviation of the pole profile from the ideal contour along the edge of the pole tip is 20 μm.

The external structure of the core is composed of two end plates, 50mm thick, and five side plates, 30mm thick, as shown in figure 1. This structure can be used for stacking, compressing, and supporting the laminations. Core alignment bars which are mounted on a precision granite surface table are bolted to the precision machined edges of the core support plates. Using the end plates and side plates, core stacking is carried out with the above fixture. After core stacking the lamination sheets are pressed with a small hydraulic press at the four corners of one end plate. All frame plates are pinned together in this position, and the end plates are also bolted to the side support plates. Since laminations are symmetrical about their horizontal centerline, they are periodically flipped about the centerline to minimize top to bottom symmetry errors caused by non-uniform lamination materials.

COILS

The coils for the dipole magnet are constructed of two flat pancakes on each pole. The coils are fabricated from 16mm square with 7mm diameter cooling channel, OFHC copper conductor. Each pancake is composed of 9-turns of 2-layers and is wound from the bottom layer to the top layer without joints. The bare conductor is insulated with polyester tape, 0.08mm thick and 20mm wide. And then, Dacron tape, 0.13mm thick and 20mm wide, is wound on the conductor. The insulated coils are wound using a two axis winding machine. After completion of winding, the coils are removed from the winding form and "ground wrapped" with 1-layer of 0.25mm thick and 20mm wide fiberglass tape, half wrapped. Fiberglass is chosen for the ground wrapping since it becomes transparent after the epoxy impregnation, thereby allowing for the detection and filling of trapped air bubbles which could contribute to electrical shorts. After the coils are wound and tested, the coils are epoxy encapsulated in a vacuum tight mold. Finally, curing of the epoxy is proceeded in an electric oven. In addition, the auxiliary coils are wound inside of each pole to create a horizontal steering dipole component for the local correction.

ACKNOWLEGEMENTS

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