MAGNET DESIGN OF THE PLS 2 GeV STORAGE RING

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Abstract

The Pohang Light Source (PLS) is designed to be a third generation electron storage ring producing high brightness VUV and X-ray radiation from wiggler and undulator insertion devices. The storage ring lattice has a 12 period TBA structure with a full energy linac injection system. This paper is concerned with magnets that form the storage ring lattice; dipoles, quadrupoles, sextupoles, and correctors. After a brief outline of the magnetic lattice, the major design parameters of these magnets are listed. Schematic diagrams and fabrication procedures for the magnets are presented.

Introduction

A 2 GeV storage ring for a powerful synchrotron radiation source has been being designed at the Pohang Accelerator Laboratory[1]. The magnetic lattice has a TBA structure with a 12 super-period. One cell consists of three identical bending magnets, twelve quadrupoles, four sextupoles, and ten dipole correction magnets. In addition, trimming coils are wound inside the bending magnets and inside the sextupoles, respectively, to create a horizontal steering dipole component and a skew quadrupole component.

The general shape of the storage ring magnets is designed to allow the synchrotron radiation beam lines to exit the ring from the outside radius. All the magnets are optimized for a 2 GeV operation and capable of 2.5 GeV operation. The magnetic field calculations have been made for each of these magnets using the two-dimensional Poisson group computer code. Mechanical deformation due to the magnetic force and the magnet weight itself is estimated using a FEA computer code. The designs will be verified by building a full-scale prototype and by measuring the magnetic field. Delivering of the prototype magnets will begin at the end of 1990.

Dipole magnets

The ring dipole is a straight magnet and a schematic diagram of it is shown in Fig. 1. The major parameters for this magnet are given in Table 1.

The magnet pole gap is 56 mm, which allows for the vacuum chamber size and some clearances. The pole width is determined from the vertical and horizontal beam clear region and the sagitta of the curved beam orbit. The shape of the pole edge is optimized to minimize the pole width, to keep the required field quality, and to avoid magnetic saturation at the pole. The width of the magnet return yoke is 210mm which allows an average 1.6 Tesla of magnetic flux density at the maximum excitation.

1.0mm-thick low carbon steel is used as the core material because of its high saturation induction and modest coercive force. The laminated sheets are punched with a precision of 25μ along the edge of the pole tips. Prior to stacking, the laminations are shuffled in order to provide the best uniformity of the magnetic characteristics. After stacking, the end plate is axially compressed with hydraulic presses at around 5Kg/mm^2. The

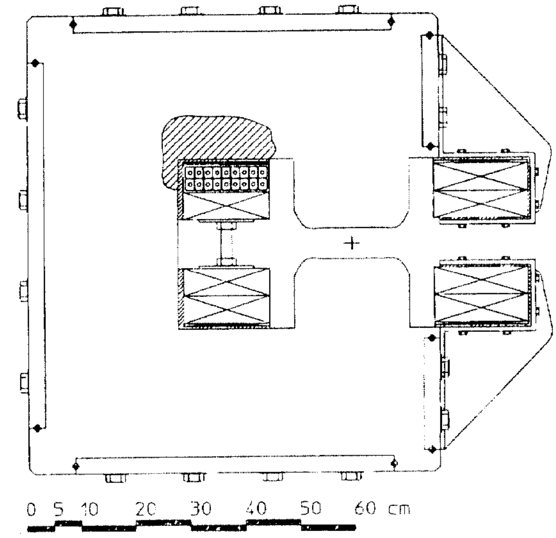

Fig. 1. End view and coil configuration of the storage ring dipole magnet and horizontal steering trim coil.

Table 1. The Parameter List of the Storage Ring Dipole at 2 GeV

Type	C-type, straight
Quantity of magnet [ea]	36
Bend Angle [degree]	10
Magnetic Flux Density [Tesla]	1.058(1.323)**
Effective Magnetic Length [cm]	110
Total Magnet Weight [Kg]	5200
Magnet Gap on Orbit [mm]	56
Good Field Width [mm]	±35
Good Field Height [mm]	±18
Ampere-Turns (efficiency = 98%)	48129(60160)**
Number of Turns	72
Current [A]	688(835)**
Voltage Drop/Magnet [V]; excluding lead wire	10.2(12.8)
Conductor Area [mm^2]	286.7
Current Density [A/mm^2]	2.40(2.91)**
Power Dissipation per Magnet [KW]	7.02(10.65)**
Field Uniformity $\Delta B/B_0$, apart from fringe-field	$\pm 2\times10^{-4}$

** Parentheses represent the parameters at 2.5 GeV.

side, top and bottom plates are tensioned, and then these plates are pinned to the end plates. Finally, these fixtures are joined with bolts and nuts. To prevent any core lamination movement, an epoxy filling is used between core lamination and supporting plates.

The coil for the dipole magnets is constructed of two flat pancakes on each pole. Each coil is composed of 9 turns of 2 layers of a 20.9mm x 15.65mm hollow copper conductor with a 7mm diameter cooling channel. The coil is to be wound from the bottom layer to the top layer without joints. The coil is insulated with 1 layer of 0.08mm thick and 20mm wide polyester tape, half

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wrapped, followed by 1 layer of 0.13mm thick and 20mm wide Dacron tape, half wrapped. Wound coils are "ground wrapped" with 1 layer of 0.25 mm thick and 20 mm wide fiberglass tape, half wrapped. Finally, the wound coils are impregnated with epoxy resin in a vacuum chamber.

Magnet assembly and field measurements are carried out at the factory in order to obtain the required magnetic field qualities. Prior to installing the magnets, field measurements are again performed to confirm the magnetic field quality.

Quadrupole Magnets

There are six different types of quadrupoles used in the storage ring, namely, Q_1, Q_2, Q_3, Q_4, Q_5 and Q_6. The major parameters for these magnets are given in Table 2, and a cross section of magnets is shown in Fig. 2.

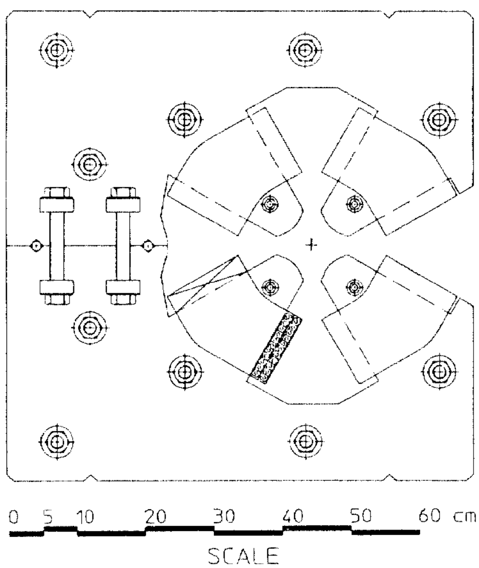

Fig. 2. End view and coil configuration of the storage ring quadrupole, Q_4, magnet.

Table 2. The Major Parameter List of the Storage Ring Quadrupole Magnets at Maximum Excitation

Descriptions	Q_1/Q_6	Q_2/Q_5	Q_3/Q_4
Type		C-type, straight	
Quantity of Magnet [ea]	24/24	24/24	24/24
Maximum Field Gradient [T/m]	18.0	18.0	18.0
Magnetic Length [cm]	24	52	38
Total Magnet Weight [Kg]	718/721	1448/1450	1167/1170
Good Field Radius [mm]	32	32	32
Magnet Aperture Radius [mm]	37	37	37
Ampere-Turns per Pole (efficiency = 98%)	10005	10005	10005
Number of Turns per Pole	76/22	76/22	76/22
Current [A]	132/455	132/455	132/455
Voltage Drop per Magnet [V]; excluding lead wire	33.8/10.0	56.8/16.3	46.7/13.9
Conductor Area [mm^2]	7.51/60.5	17.51/60.5	17.51/60.5
Current Density [A/mm^2]	7.54/7.52	7.54/7.52	7.54/7.52
Power Dissipation/Magnet [KW]	4.46/4.56	7.50/7.42	6.17/6.32
Field Uniformity $\Delta G/G_0$, apart from fringe-field	$\pm 5\times10^{-4}$	$\pm 5\times10^{-4}$	$\pm 5\times10^{-4}$

The pole shape of the ring quadrupole is conformally mapped from a dipole magnet which satisfies the required field quality. The cores of these quadrupoles consist of two separate sections, identical except that there are three different lengths; 0.52m, 0.38m, and 0.24m. Each laminated sheet is made from the same material as the dipole. The bore diameter is 74mm. The sorting and flipping of the laminations is also performed as described for the dipole magnet. Each laminated sheet is stacked using a fixture containing a precision reference surface, and the laminations are compressed in each stacking step. After stacking, the fixture bars which go through the core are compressed.

The coil pancakes of the Q_1, Q_2 and Q_3 magnets are constructed of four layers of a hollow copper conductor (5mm square with 3mm hole) which is insulated with 0.13mm thick and 20mm wide Dacron tape, half wrapped. Each layer consists of 18 turns, and four layers of coils are ground wrapped with 0.25mm thick and 20mm wide fiberglass tape, half wrapped. The pancakes of Q_4, Q_5, and Q_6 magnets are constructed of two layers of a hollow copper conductor. Coil of each layer is wound 11 turns using a 9mm square hollow copper conductor with a 5mm diameter cooling channel. Coil winding and vacuum impregnation are similar to those for the dipole.

After the coil pancakes are installed on each half yoke, the top and bottom halves are joined with two tie bars. The two halves are aligned by means of a dowel pin in two V grooves so that in the magnetic circuit there is no joint which could contribute to magnetic field errors.

Sextupole Magnets

The PLS sextupole magnet is shown in Fig. 3. and its major parameters are listed in Table 3. In addition to its primary function as a sextupole, two auxiliary coils located at the 6 and 12 o'clock poles of the sextupole provide an excitation of a skew quadrupole component to control vertical beam size[2].

The bore diameter is 82mm, which provides clearance between the neck of the vacuum chamber and the two adjacent poles. The magnet yokes are constructed of three pieces of core. The same material described in previous sections is used for the cores. Core stacking and assembly are done with fixtures similar to those for the quadrupole.

Coil pancakes are constructed from a 8mm square copper

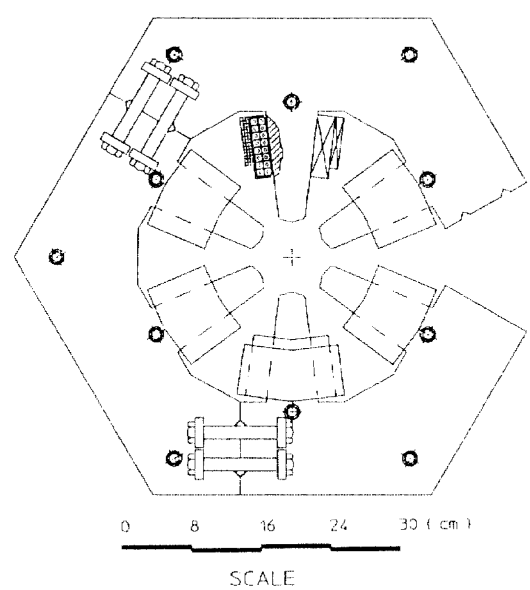

Fig. 3. End view and coil configuration of the storage ring sextupole magnet.

conductor with a 3.5mm cooling channel. Coil winding of a pancake consists of 9 turns of the inner layer and 8 turns of the outer layer. The skew quadrupole component is created by two auxiliary coils that are located at the 6 and 12 o'clock poles of the sextupole. The major parameters at the maximum excitation are given in Table 3.

Table 3. The Parameter List of the Storage Ring Sextupole Magnet and Skew Quadrupole Excitation Coils at Maximum Excitation

Descriptions	SD/SF	Auxiliary Coil
Type	C-type, straight	
Quantity of Magnet [ea]	24/24	4
Maximum Field Gradient	-450/450[T/m^2]	0.61[T/m]
Magnetic Length [m]	0.22	-
Total Magnet Weight [Kg]	403	11
Good Field Radius [mm]	32	32
Magnet Aperture Radius [mm]	41	41
Ampere-Turns/Pole(efficiency = 98%)	4198	888
Number of Turns per Pole	17	72
Current [A]	247	12.33
Voltage Drop per Magnet [V]; excluding lead wire	6.28	3.41
Conductor Area [mm^2]	46.31	9
Current Density [A/mm^2]	5.33	1.37
Power Dissipation/Magnet [KW]	1.55	0.042
Field Uniformity $\Delta K/K_0$, apart from fringe-field	$\pm 1 \times 10^{-3}$	-

Corrector Magnets

Four types of correction schemes are used for vertical and/or horizontal beam movements. Vertical fields for horizontal orbit corrections are provided by auxiliary coils in the main dipole magnets and by separated small dipole magnets as shown in Fig. 1 and Fig. 4-(a), respectively. Horizontal fields for vertical beam steering are provided where bellows are installed in the vacuum chamber. Finally, dual function correction magnets are installed in the straight section of the vacuum chamber. The major parameter for the auxiliary coils and the other correction magnets are summarized in Table 4.

Polyester coated 3mm square solid copper wire is used for the trim coil winding in the main dipole magnets. The trim coil is

Table 4. The Parameter List of the Storage Ring Correction Magnets

Descriptions	Trim coil	Hori. C. Mag.	Vert. C. Mag.	H./V. Corr. Mag.
Quantity of magnet [ea]	36	48	48	24
Maximum Field [T]	0.022	0.076	0.05	0.06/0.06
Magnetic Length [cm]	110	14	16	16
Magnet Gap [mm]	56	58	160	120***
Ampere-Turns	1000	3508	6366	9072/9072
Number of Turns	90	300	644	920/920
Current [A]	11.1	11.7	9.9	9.9/9.9
Voltage Drop/Magnet [V]; excluding lead wire	6.74	5.20	6.10	10.1/10.1
Conductor Area [mm^2]	9	9	9	9/9
Current Density [A/mm^2]	1.23	1.30	1.10	1.1/1.1
Power Dissip./magnet [W]	75	53	60	193

***Magnet gap denotes the width between coils.

assembled with adjacent main dipole coil before potting, and is impregnated with epoxy resin in a vacuum chamber.

The magnet yoke of the horizontal correction magnets is constructed from 0.5mm silicon steel laminations coated with a C-5 insulating film and is of a C-configuration to allow installation around the vacuum chamber. The pole gap, 58mm, can accommodate the steering coil and the vacuum chamber.

The vertical steering magnets are shown in Fig. 4-(b). The magnet yoke is made of solid iron and coil is wound around the bottom of the magnet yoke.

As shown in Fig. 4-(c), the vertical and horizontal correction magnets produce both horizontal and vertical fields with coils wrapped around the window frame laminated sheet yoke. The yoke is constructed from 0.5 mm silicon steel which is used in the horizontal correction magnets.

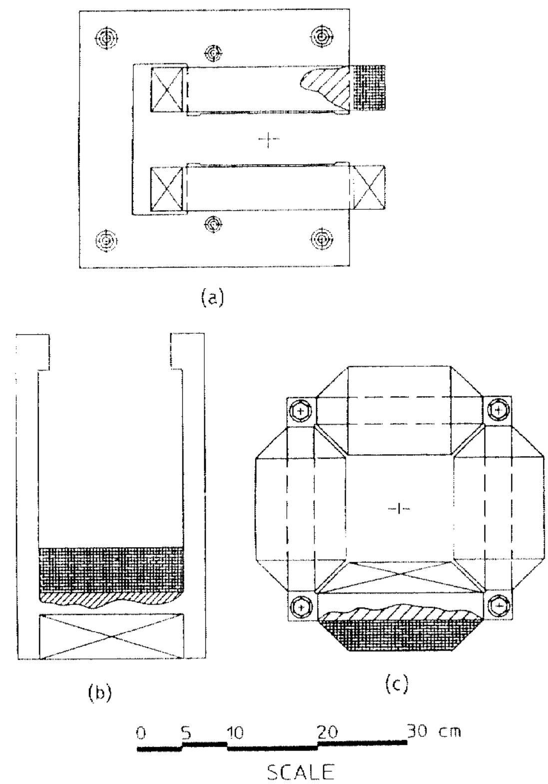

Fig. 4. End view and coil configuration of the storage ring (a) horizontal correction, (b) vertical correction, and (c) horizontal and vertical correction magnets.

References

[1] Pohang Accelerator Laboratory, Conceptual Design Report of Pohang Light Source, POSTECH press, 1990.

[2] K. Halbach, "First Order Perturbation Effects in Iron-Dominated Two-Dimensional Symmetrical Multipoles", Nucl. Inst. and Methods, vol. 74, pp. 147- 163, 1969.