Magnetic Field Measurements of the 2.0 GeV PLS Storage Ring Magnets*

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Abstract

The Pohang Light Source (PLS) at Pohang Accelerator Laboratory was designed to be a third generation electron storage ring producing high-brightness VUV and X-ray radiation from bending magnets and insertion devices. A Triple bend Achromat (TBA) lattice structure with 12 super-periods was employed for the storage ring. All magnets were delivered at the end of 1993. Magnetic field mesurement and installation were completed in March, 1994.

1. INTRODUCTION

PLS storage ring magnets are composed of 36 dipoles, 144 quadrupoles, 48 sextupoles, and 70 combined horizontal and vertical correctors. Two trim coils are installed in each pole of the dipole magnet to kick 2-mrad of the 2-GeV electron beam. There are six different types of quadrupole magnets; Q_1 through Q_6. Sextupoles have also additional trim coils for horizontal and vertical orbit corrections, and for skew quadrupoles. All magnets are asymmetrical C-type to make fabrication easy , to allow easy extraction of the synchrotron radiation, and to accommodate the vacuum chamber. Prior to fix the magnet designs, five different types of prototype magnets were built and tested such as dipole, two quadrupoles (Q_1, Q_2), sextupole, and corrector. Magnet core was laminated type and core steel was specially developed at Pohang Steel Company. Magnet fabrication was carried out by a local company, Hyundai Heavy Industries.

2. DESIGN PARAMETERS OF THE MAGNETS

The main design parameters of the magnets are listed in Tables 1 - 4. Magnetostatic caculations were carried out usig POISSON and TOSCA group computer codes. The shapes of the magnet end along beam direction were decided by the method of trial and error for each type of prototypes.

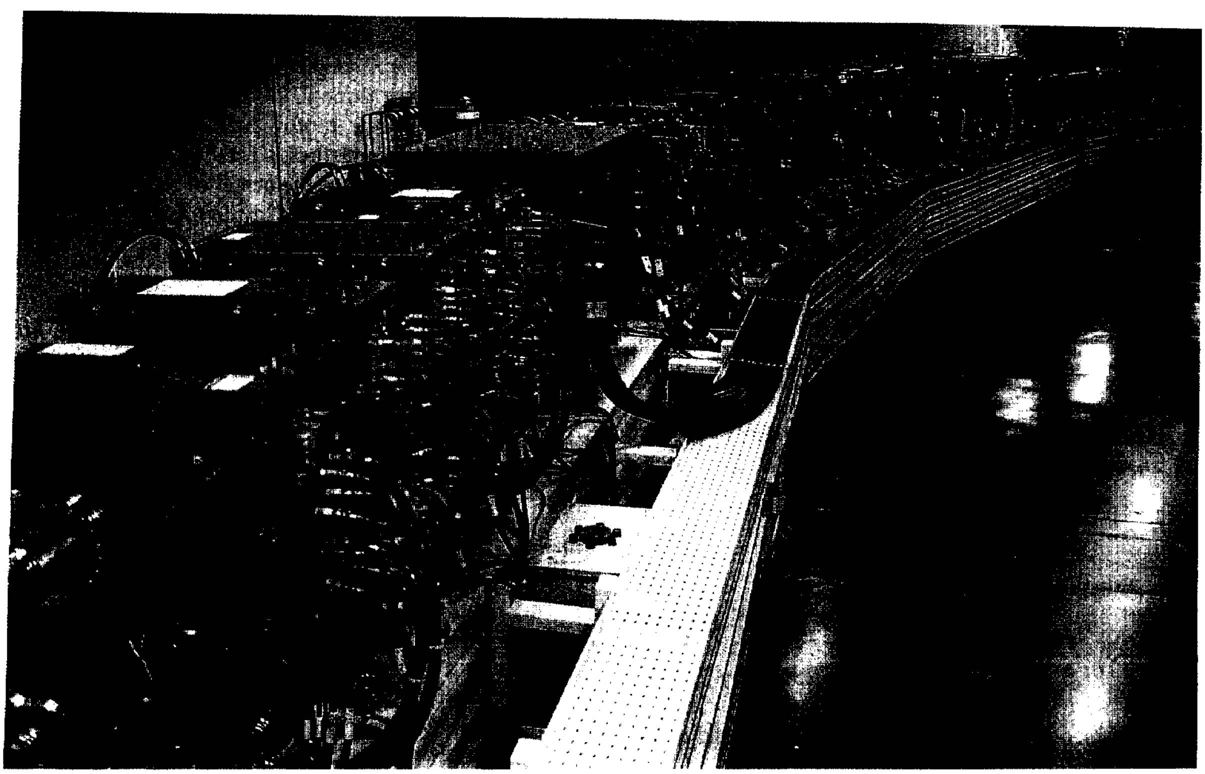

Fig. 1. Magnet assembly of one super-period of the storage ring.

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Table 1. Major Parameters of the Dipole

Type	C-type, straight
Bend angle (degree)	10.
Magnetic flux density at 2.0 GeV (T)	1.058
Trim winding (T)	0.75
Gap height (mm)	56.
Magnetic length (mm)	1100.
Horizontal good field width (mm)	± 30.
Vertical good field width (mm)	± 18.
Magnetic field error tolerance	$\pm 1.0 \times 10^{-3}$.

Table 2. Major Parameters of the Quadrupole

Type	Two pieces of yoke, C-type, asymmetrical
Maximum field gradient (T/m)	18.
Pole inscribed radius (mm)	36.
Magntic length (mm) Q_1, Q_6	24.
Magntic length (mm) Q_2, Q_5	35.
Magntic length (mm) Q_3, Q_4	53.
Good field radius (mm)	30.
Q_1, Q_2, Q_3 ;	Independent power supplies
Q_4, Q_5, Q_6 ;	One power supply for each type
Magnetic field error tolerance	$\pm 1.0 \times 10^{-3}$.

Table 3. Major Parameters of the Sextupole

Type	Three pieces of yoke, C-type, asymmetrical
Maximum 2-nd field gradient (T/m^2)	320.
Pole inscribed radius (mm)	39.
Magntic length (mm) SD SF	20.
Maximum vertical steering field (T)	0.07
Maximum horizontal steering field (T)	0.07
Maximum skew quadrupole field gradient (T/m)	1.0
Good field radius (mm)	30.
SD, SF;	One power supply for each type
Magnetic field error tolerance	$\pm 1.0 \times 10^{-3}$.

Table 4. Major Parameters of the Corrector

Type	C-type, asymmetrical
Gap height (mm)	120.
Magntic length (mm)	230.
Maximum vertical steering field (T)	0.06
Maximum horizontal steering field (T)	0.06

3. MGNETIC FIELD MEASUREMENTS FOR STORAGE RING MAGNETS

3.1 Facility

A magnet measurement facility that meet the measurement requirements for the storage ring DC magnets has been designed, proposed and accepted to build a prototype system. The PLS Magnet Measurement Facility (MMF) consists of two Faraday cages, four magnet power supplies, two auxiliary racks, four stands, one 20 Ton over-head crane, and two utility panels for water and power distribution.

MMF data aquisition system (DAS) is located inside of the Faraday cage to shield electromagnetic interference from enviroment. The DAS system is based on the control rack and IBM PC compatible 386 system with several plug-in boards for data processing and system control. The installed plug-in boards in the system computer are an EGA board, an I/O control board, a GPIB board from metrabyte Co., the DT 2823 16 Bit A/D converter board from Data Translation Co., the DDA 06 Digital I/O board from Metrabyte Co., and PC23 3-axis stepping motor indexer from Compumotor Co..

On the control rack, six home-made boards and three equipments are installed: Attenuator/Matching board, Integrator board, Preamplifier board, Search Coil Configuration Selection board, Reley Control board, Interface board, one digital votmeter, one oscilloscope, and one function generator. The control rack selects measurement configuration, integrates and preconditions the measured signals for the DT 2823 and DDA 06 boards, and interfaces other peripheral equipments.

Two types of sensors are used; the rotating coils and the Hall probes. The rotating coils measure the multipole content from the magnetic field and evaluate the integrated field quality of the magnet. The Hall probes measure a reference field for the rotating coil measurement and give a global field profile for each of the dipole magnet by field mapping. The Hall probes are mounted on a 24" x 4" x 60" X-Y-Z stage for the dipole field mapping. The X-Y-Z stage is controlled by the system computer and three Compumotor microstepping motors. The positioning accuracy of the X-Y-Z stage is 2.5μ/cm. The rotating coil has two separate windings on a same plane. The location of each winding is determined such that the fundamental component signal is bucked out when the response of each winding is substracted together, while leaving the higher order multipole reponses unaffected. The rotating coils are mounted on the magnet and rotated by a microstepping motor through a vibration decoupling universal joint. The stepping motor has 12800/revolution step revolution, and is mounted on a rotating coil stage which can align the center of motor to the center of rotating coil. In order to monitor the angular position of the rotating coil, an encoder is mounted on the axis of motor.

3.2 Magnetic Field Measurement results

Using the PLS MMF data aquisition system, all PLS storage ring magnets were measured and installed. The Magnetic field qualites of these magnets are listed in Table 5 and 6. Some details of the magnetic field measurments of each type of magnets are shown in below:

Dipole

The most important parameter for the dipole magnet measurement is $\int B d\ell$ along the beam trajectories. $\int B d\ell$ along the beam trajectories can be measured with a curved integral coil or with a Hall probe which is mounted on the X-Y-Z stage. A straight integral rotating coil was used for this measurement. Themeasured field integrals were corrected by calculation and were confirmed by the Hall probe mapping for some magnets. Multipole fields were measured with the rotating coil. A rotating coil with two loops of coil is needed for multipole analysis. The outer loop measures the fundamental component, and inner and the outer loops together measure the higher order multipole components while bucking out the fundamental component.

The core excitation properties are measured at the pole center with a Hall probe and a Gaussmeter. Before taking data, the magnet current is cycled three times from 0 to 1000 Amperes to condition any hysteresis effects. Then the magnetic fields are measured at each excitation current. Two sets of data are taken; one while ramping the current up and another while ramping the current down. The measured core efficiency with magnet current was shown in figure 2. The efficiency at 2GeV (660A) is 99.4%.

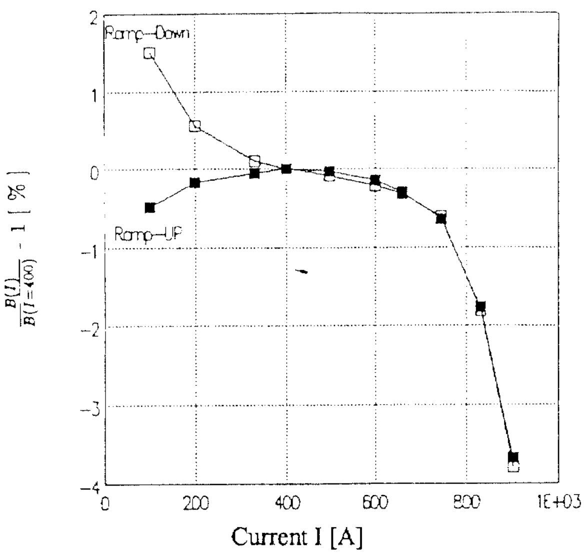

Fig. 2 Difference in normalized B versus excitation current: Measured at the gap center, and normalized at I = 400A.

Quadrupole

For the quadrupole magnets, the most important parameter for the dipole magnet are the integrated magnetic field gradient, ∫ B'$d\ell$, and the location of the field-zero-point, i.e., the magnetic axis. Two types of the rorating coils were used to measure the fundamental field integral and the multipole filed of the quadrupole magnets. Since the quadrupoles of the PLS storage ring are all C-type, such asymmetrical geometry can produce spurious magnetic mutipoles. However, all multipole errors can be controlled by rotation and/or translation of two core pieces of magnet, and by shimming of the magnet end to introduce compensating perturbation errors. Prior to magnet measurement, the magnet core pieces are assembled and disassembled for five times to insure the reproducibility of the magnetic field qualities. With this process, the multipole errors do not changed more than 10% and the magnetic center shift is less than 5 μm.

The measured magnet efficiency was greater than 99.5% at full excitation.

Sextupole

The C-shaped combined function sextupoles have three pieces of core and four separate winding; sextupole, horizontal correction, vertical correction, and skew quadrupole windings. Multipole field corrections, repeatbility test, and determination of magnetic axis were followed the same method as those of quadrupole.

Corrector

Magnetic field of the correctors was measured the same rotating coil as that of sextupole with differnt electronic settings.

Table 5. Average Fundamental Field Integrals and Transfer Errors of Each Type of Magnets

Type	Quantity of magnets	∫ B$d\ell$ average	Standard deviation
Dipole	36	1.192 (Tm)	1.88×10^{-4}
Q_1	24	0.023 (T)	5.60×10^{-4}
Q_2	24	0.161 (T)	3.23×10^{-4}
Q_3	24	0.116 (T)	5.35×10^{-4}
Q_4	24	0.101 (T)	3.95×10^{-4}
Q_5	24	0.195 (T)	4.73×10^{-4}
Q_6	24	0.037 (T)	5.55×10^{-4}
SF	24	0.0138 (T/m)	5.87×10^{-4}
SD	24	0.0199 (T/m)	5.87×10^{-4}
H_C	70	0.0133 (Tm)	7.48×10^{-4}
V_C	70	0.0134 (Tm)	8.63×10^{-4}

Table 6. Multipole Errors for Each Type of Magnets

Type		Multipole tolerence	Average multipole	Standard deviation
Dipole	n=2	1.74×10^{-4}	1.04×10^{-4}	2.07×10^{-5}
	n=3	4.50×10^{-4}	1.17×10^{-4}	1.33×10^{-5}
	n=4	3.00×10^{-4}	1.80×10^{-4}	8.72×10^{-6}
	n=5	6.00×10^{-4}	1.11×10^{-4}	9.89×10^{-5}
Q_2	n=3	9.90×10^{-4}	2.91×10^{-4}	6.45×10^{-5}
	n=4	3.40×10^{-4}	2.54×10^{-4}	7.95×10^{-5}
	n=5	5.60×10^{-4}	1.74×10^{-4}	1.58×10^{-5}
	n=6	2.00×10^{-3}	4.12×10^{-5}	1.33×10^{-5}
SF	n=4	1.50×10^{-3}	8.10×10^{-4}	3.39×10^{-4}
	n=5	1.25×10^{-3}	5.36×10^{-4}	1.43×10^{-4}
H_V	n=2	1.00×10^{-2}	4.48×10^{-3}	2.56×10^{-4}
	n=3	1.30×10^{-2}	6.82×10^{-3}	7.95×10^{-4}
	n=4	8.80×10^{-3}	3.21×10^{-3}	1.83×10^{-4}

4. SUMMARY

In PLS storage ring, 36 dipoles, 144 quadrupoles, 48 sextupoles, and 70 correctors were fabricated, measured and installed at the end of March 1994.

5. REFERENCES

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