DESIGN OF MAGNETS FOR PAL-XFEL

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Abstract

Pohang Accelerator Laboratory (PAL) is starting the X-ray Free Electron Laser of 10 GeV from 2011. PAL-XFEL has the hard X-ray and soft X-ray branches. This accelerator contains several kinds of magnets such as dipole magnets, quadrupole magnets, kicker magnets, and so on. In this presentation, we describe the preliminary design and the classification of the magnets.

INTRODUCTION

The PAL-XFEL is a 0.1-nm hard X-ray FEL project starting from 2011. Two FEL beamlines, one hard X-ray (HX1) and one soft X-ray (SX1) will be prepared in the first phase. The flexibility of beam control for these two lines will be done by the switching system of a kicker and a septum magnet at 3 GeV point.

This facility for the first phase contains 484 electro-magnets. The magnets are composed of dipole magnets, quadrupole magnets, corrector magnets, kicker magnets, and septum magnet. They are used for the bunch compressors, acceleration section, diagnostic section, beam switch line, beam transport line, undulator hall, and dump section, and so on.

The lattice requirements called for a lot of different types of magnets, many efforts have been dedicated to reduce the total number of the magnet families. We are designing all magnets on our own physically and mechanically, and will search for the domestic and foreign manufacturers.

Corrector magnet and septum magnet are left out of this presentation because they are not determined exactly yet.

Table 1: Summary of Magnets for HX1 and SX1

Magnet	Number of magnet
Dipole	35
Quadrupole	222
Corrector	222
Kicker	3
Septum	1
Sum	484

DIPOLE MAGNET

The dipole magnets for the HX1 and SX1 are classified into four kinds according to the effective magnetic length and the maximum magnetic field.

They are used in the bunch compressor, linac tunnel, BTL, undulator hall, and dump. All dipole magnets have pole gap of 30 mm.

Table 2: Four kinds of Dipole Magnets for HX1 and SX1

Family name	Effective length [m]	Max. field [T]	Magnet number
D3	0.3	0.8	7
D8	0.8	0.9	15
D10A	1.0	0.8	7
D10B	1.0	1.2	6
Sum			35

D8 dipole magnet for the bunch compressors was designed preliminary. The main parameters are listed in Table 3, and the magnetic profile is shown in Fig. 1.

Table 3: Main Parameters of D8 Dipole Magnet

Parameter	Value
Number of magnets	15
Max. field	0.9 T
Max. current	109 A
Pole gap	30.0 mm
Effective length	800 mm
Core length	753 mm
Number of turns	100
Coil size (hollow)	6.5x 6.5 (ϕ4) mm
Cooling system	water
Temperature rise ΔT	22 deg
Field uniformity (ΔB/B)	< 3E-4 (at x=±30mm)

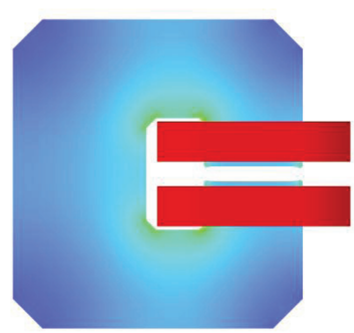

Figure 1: Cross section of dipole magnet (D8) and the field profile.

ISBN 978-3-95450-123-6

The coil size is determined in order that the cooling water velocity is lower than 2 m/s to avoid erosion and vibrations safely. But we have to pay special attention to the temperature rise for magnets of the undulator hall.

QUDRUPOLE MAGNET

The quadrupole magnets are classified into 12 kinds according to the aperture diameter, effective length, and maximum gradient. The results of the classification are listed in Table 4. The purpose for these quadrupoles is focusing, steering, and aligning in various positions.

Table 4: 12 kinds of Quadrupole Magnets

Family name	Aperture diameter [mm]	Effective length [m]	Max. gradient [T/m]	Magnet number
Q12-10	12	0.1	20	15
Q12-20	12	0.2	25	27
Q22-15A	22	0.15	30	8
Q22-15B	22	0.15	15	60
Q22-20	22	0.2	20	16
Q22-30	22	0.3	20	37
Q22-50	22	0.5	25	21
Q30-10	30	0.1	10	6
Q30-15	30	0.15	10	17
Q36-30	36	0.3	25	7
Q44-30	44	0.3	15	4
Q80-50	80	0.5	15	4

A quadrupole magnet (Q22-20) used for the beam compressor and emittance measurement unit was designed preliminary. The main parameters are listed in Table 5. And the magnetic distribution is shown in Fig. 2.

Table 5: Main Parameters of Quadrupole Magnet (Q22-20)

Parameter	Value
Number of magnets	16
Max. field gradient	20 T/m
Max. current	12.3 A
Aperture diameter	22.0 mm
Effective length	200 mm
Pole width	26 mm
Return yoke thickness	26 mm
Number of turns	80
Coil size	3.2x2.0 mm
Cooling coil size	6.5x6.5 (ϕ3) mm
Cooling system	Indirect water
Temperature rise ΔT	7 deg
Power	70 W
Whole magnet width	220 mm
Harmonics (∫An/∫A2)	< 5E-4 (n=6,10, 14)

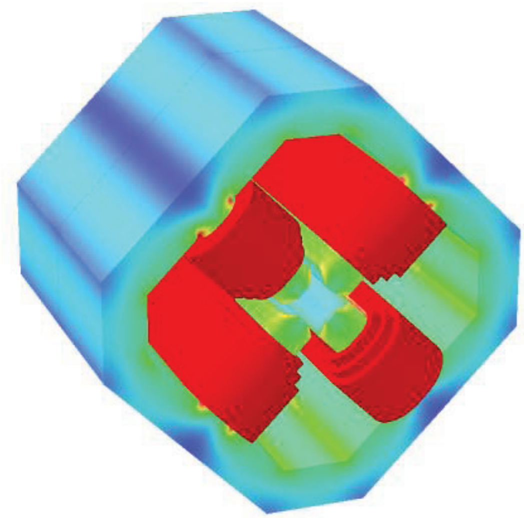

Figure 2: Magnetic distribution of quad (Q22-20).

The multipole components were calculated according to this equation, $B = \Sigma\{An \sin(n\varphi) + Bn \cos(n\varphi)\}$.

Indirect cooling system for the quad (Q22-20) was adopted in the limited space around coils. Figure 3 shows the cross section of the coil and the temperature profile.

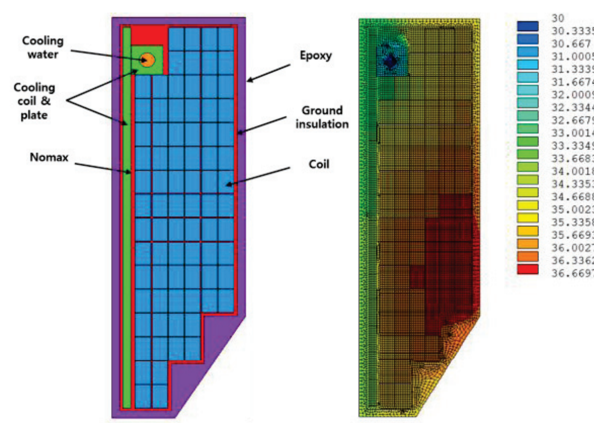

Figure 3: Cross section of quad (Q22-20) coil and the temperature distribution.

SLOW KICKER MAGNET

A kicker and a septum are used for switching to soft X-ray FEL line. Electron beam is kicked vertically with the kick angle of 0.7 mrad at the kicker and then switched out horizontally at the septum where the vertical beam offset is 9.0 mm. 6 quads are necessary for kick and matching to the dog-leg line.

We designed the kicker magnet preliminarily by using OPERA/ELEKTRA code [1]. The main parameters of the kicker are listed in Table 6, and the ferrite core and coil size are depicted in Fig. 4. The magnetic field profile is shown in Fig. 5. We simulated this kicker by using the BH table of a ferrite (CMD10) from A Thomas & Skinner Company.

ISBN 978-3-95450-123-6

Table 6: Main Parameters of Ferrite Kicker Magnet

Parameter	Value
Electron energy	3.0 GeV
Kick angle	0.7 mrad
Pulse width	4 μsec
Repetition rate	60 Hz
Peak current	330 A
Magnetic field	140 G
Inductance	1.9 μH
Resistance of coil	2.6 mΩ
Core material	Ferrite (CMD10)
Gap height	30 mm
Gap width	100 mm
Return core thickness	24 mm
Core length	491 mm
Effective length	500 mm
Field uniformity	< 4E-4 (x= ±10mm)
Coil cross-section	3x28 mm
Number of turns	1
Cooling system	air

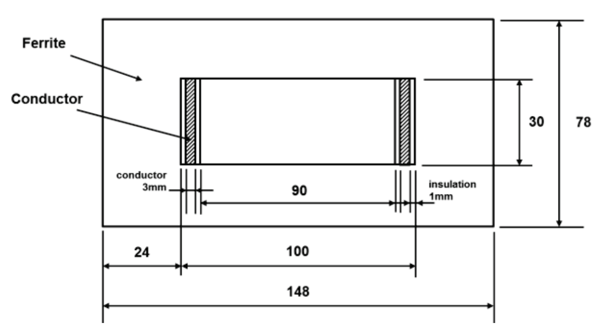

Figure 4: Core and coil size of kicker magnet.

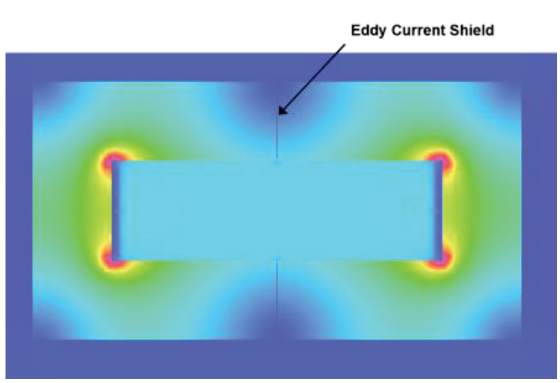

Figure 5: Magnetic field profile of the kicker magnet.

The magnetic field uniformity depends on the eddy current shield thickness as well as the return core thickness and the aperture size. Table 7 shows the field uniformity according to the shield thickness.

Table 7: Field Uniformity on Shield Thickness Variation

Shield thickness	Field uniformity (ΔB/B) at x=10mm
0.3 mm	3.7E-4
0.5 mm	5.0E-4
1.0 mm	9.3E-4

At the second phase, we are considering the strip-line kicker or the resonant cavity as a bunch by bunch switching system (fast kicker) for two bunch operation. The bunch separation is limited by how fast the kicker kicks out the second bunch [2].

REFERENCES

[1] Vector Fields Software, http://www.cobham.com/
[2] PAL XFEL Lattice Internal Report6, Heung Sik Kang, 2012.

ISBN 978-3-95450-123-6