CONVENTIONAL MAGNETS DESIGN FOR THE CANDLE STORAGE RING

V. Khachatryan#, A.Petrosyan, CANDLE, Yerevan, 375040, Armenia

Abstract

The lattice of 216m long CANDLE storage ring (16 Double Bend Achromat cells) will contain 32 gradient dipole magnets, 80 quadrupole magnets of three types and two types of 64 sextupole magnets. Magnetic as well as mechanical design of those magnets has been performed relying on extensive world experience. Computer simulations and large volume of computations have been carried out to design magnets that conform to strict requirements.

INTRODUCTION

CANLE storage ring gradient dipole magnets serve as bending magnets (bending angle is 11.25° per magnet) and replace substantial part of integrated strength of the vertical focusing quadrupole magnets allowing to gain space for the installation of insertion devises and finally they are source of synchrotron radiation. Three types of quadrupole magnets have the same cross section. The same approach is applied in the design of the two types of sextupole magnets that differ each from other only by their lengths. That reduces the number of types of laminations from which magnet cores are assembled simplifying fabrication process and lowering production costs.

Field simulation was performed using 2D code POISSON (Version 6.15) [2]. 3D simulation of the quadrupole magnets was performed using RADIA code [3] that enables one to investigate magnet end field and define appropriate shape and size of magnet pole ends.

GRADIENT DIPOLE MAGNETS

The main parameters of gradient dipole magnets are shown in the Table 1.

Table 1: Gradient Dipole Magnet Parameters

Bending angle [Degree]	11.25
Field at pole center [Tesla]	1.35
Magnet Length [mm]	1450
Orbit Arc Length [mm]	1452.3
Orbit Arc half sagitta [mm]	17.81
Bending Radius [m]	7.3967
Quadrupole Strength [m^{-2}]	-0.
Field Gradient at center [T/m]	-3.3
Horiz. Region with $\Delta B/B \leq 5\times10^{-4}$ [mm]	±48
Excitation Current [Ampere-Turns]	24120

The construction is like to that of the SPEAR3 gradient dipoles but with reduced gaps at pole center from 50 mm to 44 mm [4]. C-shape of magnet yoke allows synchrotron radiation produced by bended beam in dipole to exit the ring thus making them the most straightforward source of the synchrotron radiation. That gap provides enough room for vacuum camera and coil assembly (Figure 1). Magnet yoke is curved and will be assembled from one-piece magnetic steel laminations with 0.5 mm thickness.

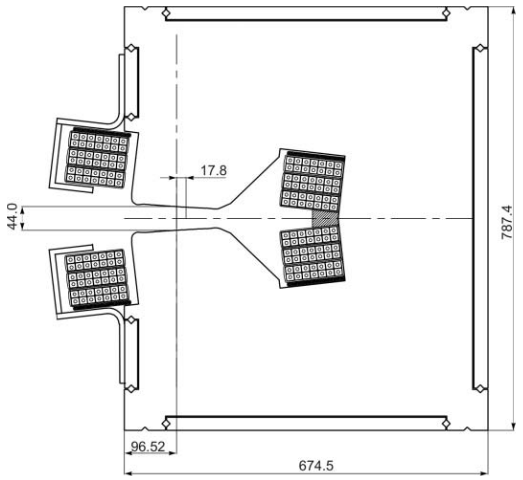

Figure 1: Gradient dipole magnet cross section. Excitation coils' positions are shown.

QUADRUPOLE MAGNETS FOR THE CANDLE STORAGE RING

Storage ring lattice contain three types of quadrupole magnets that have the same cross section and will be assembled from the same type of laminations.

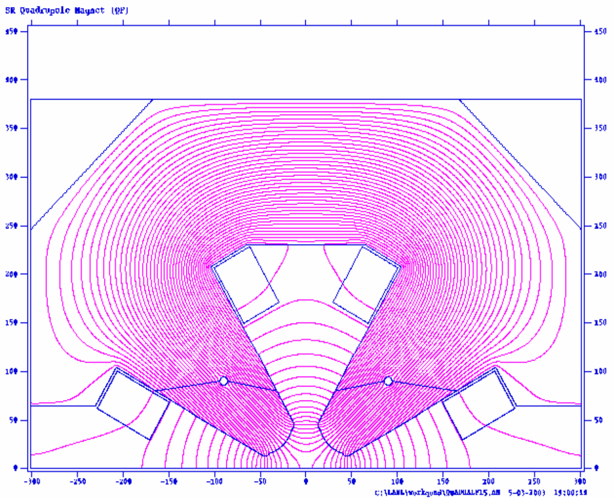

Figure 2: Storage ring quadrupole field lines.

#khachatryan@asls.candle.am

Figure 2 shows quadrupole magnet field lines calculated by POISSON while Table 2 lists magnets principal parameters. In Table 2, QF stands for horizontal focusing, QD-vertical focusing, QFC-central focusing quadrupole magnets.

Table 2: Quadrupole Magnet Parameters.

	QF	**QD**	**QFC**
Number of Magnets	32	32	16
Magnetic Length [mm]	380	160	500
Field Gradient [T/m]	16.5	12.9	17
Inscribed Radius [mm]	35	35	35
Pole Tip Field [T]	0.58	0.45	0.6
Ampere-turns per Pole	8157	6377	8404
Good Field Region [mm]	± 25		
Gradient Uniformity in good field region	$\Delta B'/B' \le 5\times10^{-4}$		
Constraints on Multipoles	$\left(\int B_n dl/\int B_2 dl\right)\Big\vert_{r=25mm} \le 5\times10^{-4}$		

3D SIMULATION OF THE QUADRUPOLE MAGNETS

Some minor simplifications and an appropriate usage of spatial symmetries are necessary while creating 3D RADIA model of the magnet. The main purpose of those 3D simulations is the study of the magnet end fields and development of necessary chamfering algorithms.

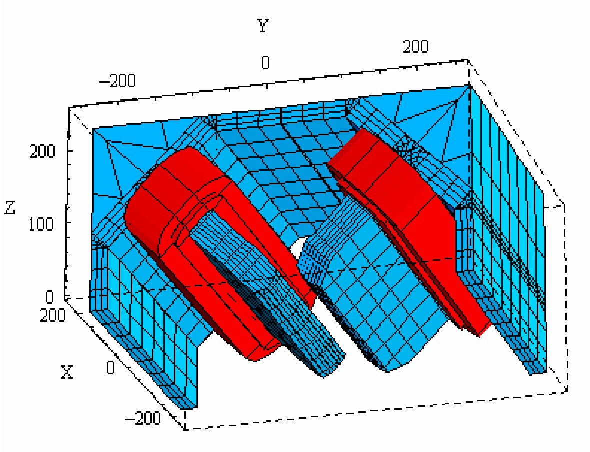

Figure 3: 3D model of upper half part of quadrupole magnet for RADIA simulations. The figure is drawn using MATEMATICA [5] graphics utilities.

The number of spatial components of the magnet model should be as low as possible to reduce calculation time and required computer memory while subdivisions should be small enough to get stabile solution. Subdivision lines must be either parallel or normal to field lines. A model that conforms those requirements has been created (Fig. 3).

Dependence of integral field (field gradient integrated along the line parallel to magnet axis) has been investigated.

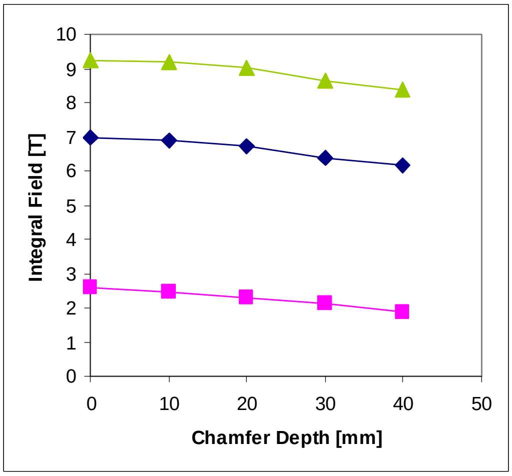

Figure 4: Dependence of the integral Field at 1 mm from the magnet axis on the 45° chamfer depths for the three types of quadrupole magnets (QFC-triangles, QF-diamonds and QD-squarees).

Figure 5 gives the distribution of the field along the magnet axis inside of magnet and beyond the magnet end In the result of RADIA calculations 45° chamfer depths for all three types of the quadrupole magnets was found (Table 3).

Table 3: Chamfer depths for the quadrupole magnets.

	QF	QD	QFC
Magnetic length [mm]	380	160	500
Gradient x Length [T]	6.27	2.064	8.5
Chamfer depth [mm]	35.4	32.6	35.9

One cannot have detailed description of pole face fine structure in the RADIA model and get reasonable low calculation time. Therefore RADIA modelling should be complementary to simulation applying another well established magnet simulation tool. We used 2D POISSON as the main tool while studied magnet end fields by the means of 3D RADIA.

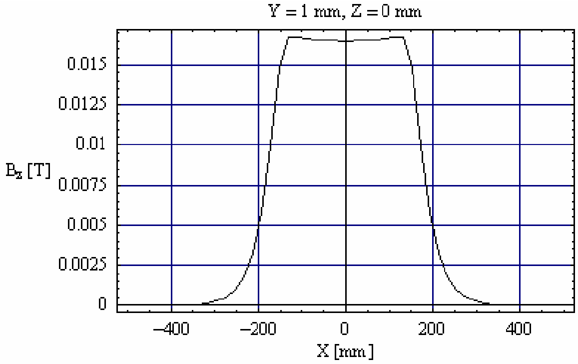

Figure 5: Vertical field induction along the axis parallel to magnet axis and at the distance of 1 mm.

0-7803-8859-3/05/$20.00 ©2005 IEEE

SEXTUPOLE MAGNETS

CANDLE storage ring sextupole magnets are 2 types. Both of them have the same cross section and different lengths. Vertical Focusing (SD) magnets have strength –35.11 m^{-3} and length 25 cm, while horizontal focusing magnets (SF) have strength 29.7 m^{-3} and length 21 cm.

Geometrical parameters of CANDLE storage ring sextupole magnets are similar to those of SPEAR 3 sextupoles but due to different focusing parameters required excitation currents are different. Table 4 presents the main parameters of sextupole magnets.

Table 4: Sextupole magnets main parameters

	SD	SF
Number of Magnets per period	2	2
Magnetic Length [mm]	250	210
Strength [m^{-3}]	- 35.1	29.7
Sextupole Strength [T/m^2]	175.58	148.5
Inscibed Radius [mm]	45	45
Excit. Curr. (Amp-Turns/Pole)	4335	3662
Turns per Pole	33	33
Current [A]	132.6	111

Both magnet yokes are made from one type of lamination reducing number of parts and components of magnet. 0.5 mm tick laminations have non-symmetrical positioned ears and stacked alternatively in packs in order to provide space for bolts. Laminations are assembled into three separate sections. Pole leg shape is asymmetrical to provide enough space for vacuum chamber and yet coil is far from pole tip to allow good performance. Table 5 presents the properties of magnetic steel used in the both 2D (POISSON) and 3D (RADIA) simulations of all types of magnets.

Table 5: Magnetic material properties

Magnetizing force [A/m]	Relative Permeability
90.05	5871.066
100	6051.099
270.14	3631.385
318.42	3208.102
384.71	2720.949
470.76	2258.708
608.885	1834.613
755.84	1503.191

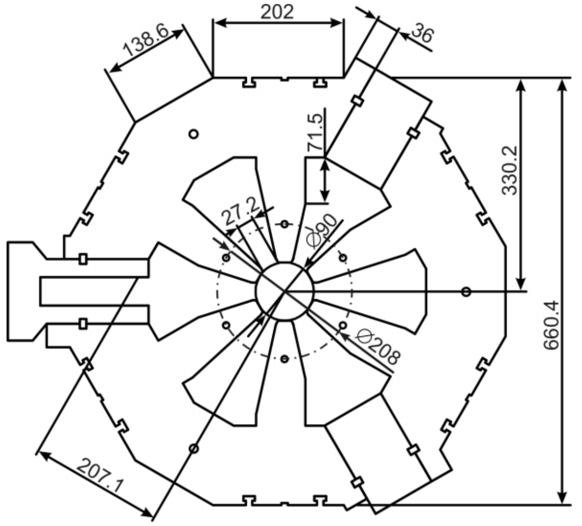

Figure 6: Front view of the sextupole magnet yoke. It consists of three stacks of identical laminations.

CONCLUSIONS

- In the process of CANDLE storage ring conventional magnets design available world experience proved to be fruitful.
- Free RADIA code is useful and effective tool for 3D simulation of the magnet construction and their field and RADIA simulation of all conventional magnets of CANDLE is in the process.
- Since RADIA allows definition of the magnets end fields realistic investigation of the impact of the end fields on the beam dynamics becomes possible.

REFERENCES

[1] CANDLE Design Report, Yerevan, 2002.

[2] POISSON/SUPERFISH Group of Codes, LANL, LA-UR-87-126 (1987).

[3] www.esrf.fr/machine/groups/insertion_devices/Codes

[4] SPEAR3 Design Report, Stanford Synchrotron Radiation Laboratory, 1999.

[5] http://www.wolfram.com/