IRANIAN LIGHT SOURCE FACILITY STORAGE RING LOW FIELD MAGNETS

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Abstract

Iranian Light Source Facility (ILSF) is a 3 GeV Synchrotron light source with the circumference of 489.6m. Using locally available material and the emittance of less than 1 nm-rad are two main points of the ILSF storage ring lattice, consisting of 56 low field pure bending magnets, 252 quadrupoles and 196 sextupoles with additional coils for the correctors and skew quadrupoles. The physical designs of these magnets have been performed relying on two dimensional codes POISSON [1] and FEMM [2]. Three dimensional RADIA [3] was practiced too, to audit chamfering values.

INTRODUCTION

Using locally accessible materials has bound the beam dynamic group to utilize the magnets with upper field limits of 1.6 T for the dipoles, 0.8 T for the pole tip of quadrupoles and 0.4 T for the pole tip of sextupoles in their design [4].No gradient in the low field dipoles has been considered in the design stage of the lattice to ease alignment. The focusing in horizontal and vertical direction is performed in each super period with 8 focusing quadrupoles in three families and 10 defocusing quadrupoles in 4 families, with 14 sextupoles within 6 families [4]. All quadrupole magnets have the same cross section. This is the same for sextupole magnets that differ by their sextupole components and lengths.

STORAGE RING MAGNETS

Dipoles

Through a none symmetric standard shim the field quality would be lower than 0.02% within the good field region ±18mm. Figure 1 shows the magnet's dimensions and magnetic field lines inside one half of the dipole as simulated by "POISSON" code.

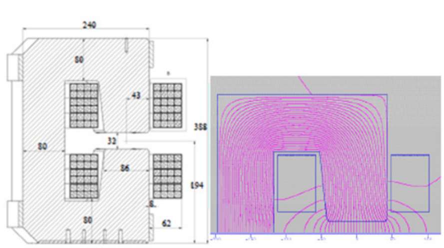

Figure 1: Magnetic field lines and geometry of the dipole magnet in ILSF.

Stainless steel M800-100A, a low-carbon (< 0.01%) steel with medium silicon content (1.5%), prepared by MAPNA company in Iran was used for our prototypes in the simulation. The main parameters of the C-type dipole magnet in ILSF storage ring are shown in the Table 1.

Table 1: ILSF Dipole Parameters

Parameter	Value	Parameter	Value
QTY	56	Water cooling tube diameter	5.5 mm
Bending radius	13.82 m	Total amp-turns	9570.4 A
Deflecting angle	6.43 Deg	Operating current per coil	398.77 A
Magnetic field	0.7239 T	Current density	3.3A/mm^2
Total gap	32 mm	Voltage drop per magnet	11.00 V
Magnetic length	1550 mm	Power per magnet	4.41 KW
Good field region	±18 mm	No. of cooling circuits	2
No. of turns per coil	24	Water temperature rise	10° C
No. of pancakes per coil	3	Cooling water speed	2.11 lit/min
Conductor cross section	12× 12mm^2	Pressure drop	6.7 bar
Copper area	120.2 mm^2	Reynolds Number	4070

3D simulations by RADIA were done to evaluate the integrated multipoles along the beam trajectory. The 3D model was also used to predict the shape of the end chamfer [5]. For a 30 deg cut with 30 mm dept size on the edges of the poles, either effective length agrees with that from theory as shown in Figure 2, or normalized integral field harmonics are reduced like that in the Figure 3.

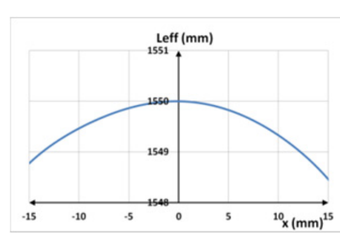

Figure 2: Effective length for a chamfered 1510 mm long dipole in ILSF.

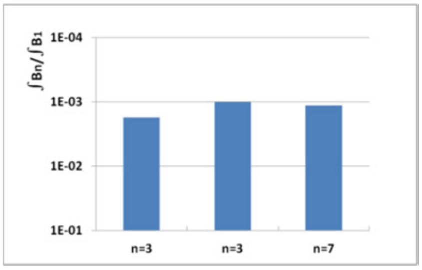

Figure 3: Normalized integral field harmonics for a chamfered dipole in ILSF.

Quadrupoles

There are 252 quadrupoles in 7 families including 84 quadrupoles with the length of 0.2 m, 112 with the length of 0.27 m and 56 of them with the length of 0.5 m. The calculated gradient field quality by POISSON for all is lower than 0.04% with good field region of ±21mm.

Considering simulation of one with the maximum field gradient and length of 25 T/m and 0.5 m the same path to go for the rest is deduced, as well changing the amp-turns.

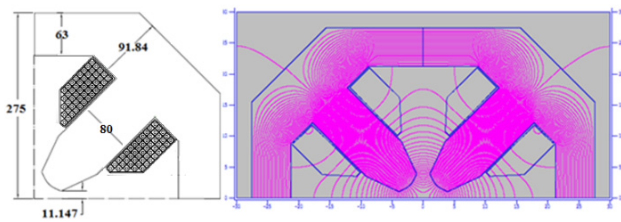

Figure 4: Magnetic field lines and geometry of the quadrupole magnet in ILSF.

Figure 4 displays the geometry and magnetic field lines inside the half of the quadrupole simulated by POISSON code with steel ST14 (local material). The Main parameters for such a quadrupole are in Table 2.

Table 2: ILSF Quadrupole Parameters

Parameter	Value	Parameter	Value
QTY	252	Total amp-turns	9375 A
Aperture radius	30 mm	Resistance of magnet	84.8 mΩ
Pole tip field	0.750 T	Voltage drop per magnet	16.51 V
Field gradient	25 T/m	Power per magnet	2.98 kW
Magnetic length	0.500 m	No. of cooling circuits	4
Good field region	±21 mm	Water temperature rise	10° C
Number of turns per coil	50	Cooling water speed	1.42 m/s
Conductor cross section	8 × 8 mm^2	Pressure drop	5.79 bar
Water cooling tube diameter	4 mm	Reynolds Number	2840

One can also study magnet end fields and development of chamfering algorithms by creating 3D RADIA model of the magnet.

Assigning 483 mm long yoke with 45º and 3.94 mm deep chamfer, satisfies required magnetic length with minimum integral harmonics. Figure 5 displays calculated magnetic lengths for both chamfered and un-chamfered states.

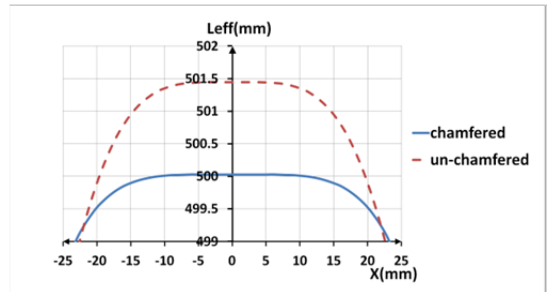

Figure 5: Effective length for a 483 mm long quadrupole before and after chamfering.

From Figure 6 that is clear how the first normalized integral harmonic field falls off after chamfering.

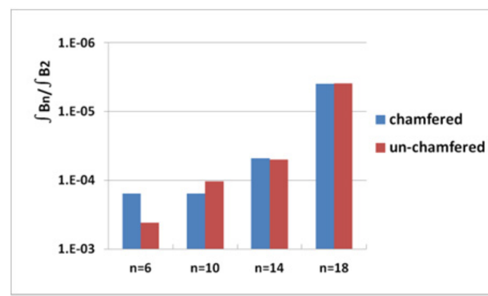

Figure 6: Normalized integral field harmonics for the chamfered and un-chamfered quadrupole.

Sextupoles

ILSF storage ring sextupole magnets are in 6 families with additional coils for horizontal, vertical steering with maximal angle 0.5 mrad, and skew quadrupole correction.

Stainless steel M800-100A is used here again for the simulation. Figure 7 shows the geometry and field lines of half of the longest sextupole, simulated by "POISSON" code.

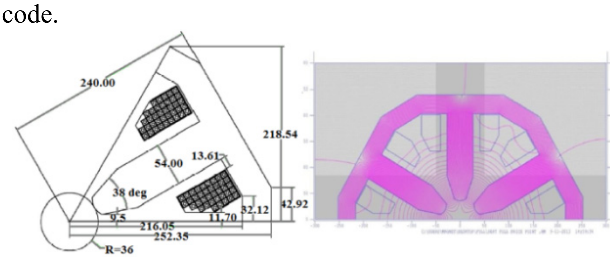

Figure 7: Magnetic field lines and geometry of the sextupole magnet in ILSF.

The main parameters of such a sextupole have been displayed in Table 3.

Table 3: ILSF Sextupole Parameters

Parameter	Value	Parameter	Value
QTY	196	Operating current per coil	129 A
Aperture radius	36 mm	Total amp-turns	4902 A
Pole tip field	0.486 T	Resistance of magnet	93.4 mΩ
Field gradient	750 T/m^2	Voltage drop per magnet	12.05 V
Magnetic length	0.24 m	Power per magnet	1.55KW
Good field region	± 21 mm	No. of cooling circuits	3
No. of pancakes per coil	-	Water temperature rise	9° C
Conductor cross section	$6.5\times6.5mm^2$	Cooling water speed	1.43 m/s
No. of turns per coil	38	Pressure drop	6.22 bar
Water cooling tube diameter	3.5 mm	Reynolds Number	2500

Simulations in 3D by RADIA code were done to predict desired magnetic length and reduce the first integral field harmonics. From Figures 8 and 9 clearly we see even without chamfering expected length and minimized harmonics are deduced.

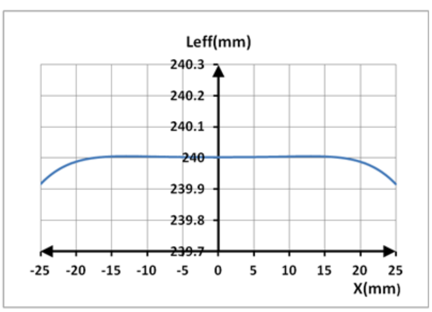

Figure 8: Effective length for a 216.5 mm long sextupole in ILSF.

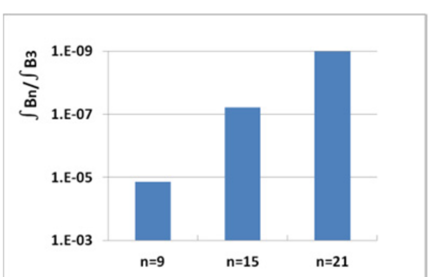

Figure 9: Normalized integral field harmonics for a sextupole in ILSF.

The sextupoles have additional coils for horizontal, vertical steering with maximal angle 0.5 mrad, and skew quadrupole corrections. The coils are powered according to Figure 10 depending on the desired correction. Table 4 summarizes the main electrical corrector parameters.

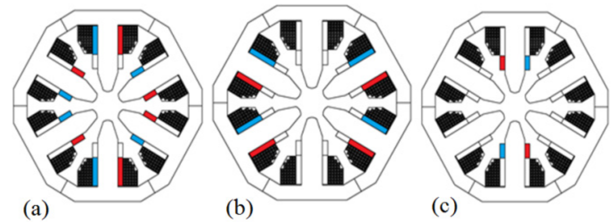

Figure 10: Coils configurations for (a) Horizontal steering; (b) Vertical steering; (c) Skew quadrupole correction. Red and blue represent, the positive and negative current flux in each coil respectively.

Table 4: Typical Corrector Parameters

Magnetic Properties	Horizontal Corrector	Vertical Corrector	Skew Quadrapole
Magnetic field	0.021 T	0.021 T	-
Effective magnetic length	240 mm	240 mm	240 mm
Ampere-Turns per pole	734 A	638 A	367 A
Turns per coil	100+50	100	50
Conductor size	$4.5\times2\ mm^2$	$4.5\times2\ mm^2$	$4.5\times2\ mm$
Magnetic resistance	0.48 Ω	0.48 Ω	0.12 Ω
Magnetic inductance	30.1 mH	38.7 mH	40.2 mH
Current	7.5 A	6.4 A	7.5 A
Total voltage	3.6 V	3.1 V	0.9 V
Total power	30.1 W	35.7 W	6.5 W

CONCLUSIONS

The magnetic design of the magnets for ILSF storage ring is done and the magnets are now in the production phase. Using typical 2-D codes, POISSON and FEMM along with the 3-D code, RADIA, to provide an authentic investigation on the magnets end fields have been fruitful.

REFERENCES

[1] uspas.final.gov/PCprog
[2] www.FEMM.info
[3] www.esrf.fr/machine.groups/inserion_devices/Codes/Radia/Radia
[4] H. Ghasem, F. Saeidi, I. Ahmadi, “Low field low emittance lattice for the storage ring of Iranian Light Source Facility”, Journal of Instrumentation 8, P02023 (2013).
[5] Jack Tanabe, “Iron Dominated Electromagnets Design, Fabrication, Assembly and Measurements”, SLAC-R-754, June 2005.