ILSF LOW EMITTANCE STORAGE RING MAGNETS

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Abstract

The Iranian Light Source Facility (ILSF) is a new 3 GeV synchrotron radiation laboratory in the design stage. The ILSF storage ring (SR) is based on a Five-Bend Achromat lattice providing an ultralow horizontal beam emittance of 0.48 nm-rad. The ring is consisting of 100 pure dipole magnets, 320 quadrupoles and 320 sextupoles. In this paper, we present some design features of the SR magnets and discuss the detailed physical and mechanical design of these electromagnets. The physical designs have been performed relying on two dimensional codes POISSON [1] and FEMM [2]. Three dimensional RADIA [3] and MERMAID [4] were practiced too, to audit chamfering values and get the desired magnetic length.

INTRODUCTION

The ILSF storage ring circumference is 528 m with 20 super periods which mechanical drawing is displayed in Fig. 1. Each super period is composed of 5 dipoles with the magnetic field of 0.748 T without any field gradient. Focusing is performed with the use of 16 quadrupoles grouped in 8 families with the maximum gradient of 25 T/m and pole radius of 26 mm. The natural chromaticity is corrected close to a positive value by the use of 16 sextupole magnets grouped in 8 families with the maximum strength of 1200 T/m^2 and pole radius of 26 mm. [5]

In this paper the physical design of all SR magnets including electrical and cooling calculations will be discussed. The magnetic field quality, harmonic analysis, and end poles chamfering process are included. It is worthwhile to mention that the experiences of R&D fabricated magnet prototypes with home industries demonstrated that the laminated low carbon steel ST14 which is locally available can be employed as the main fabrication material [6],[7].

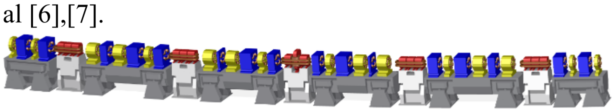

Figure 1: The mechanical design of one super period of the ILSF storage ring [7].

DIPOLE MAGNETS

The C type ILSF dipole magnet is designed in the straight shape rather than curved form to simplify the fabrication procedure of the magnet core and coils [8]. The main dipole is divided in three straight sections all with the same specifications. This is rather feasible since the short bulk magnet yields a smaller sagitta, smaller pole width and significant savings in the amount of iron core material. The middle section of the central low field dipole is replaced with a thin high field section for required high energy bright radiation see Fig 2 [8].

Through none symmetric standard shims, the field quality is lower than 0.01% within the GFR, see Fig. 3.

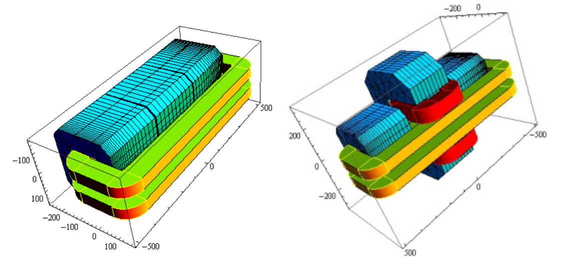

Figure 2: 3D design of the main (left) and high field inserted (right) SR dipole magnets[8].

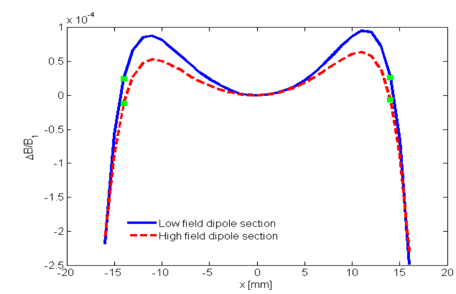

Figure 3: Field quality of the 2D designed high and low-field dipole sections within ±14 mm GFR.

The normalized systematic multipole errors obtained by POISSON code are plotted in Fig 4. As given, the relative sextupole component is less than 1.7×10^{-4} which indicates expected small impact on the dynamic aperture.

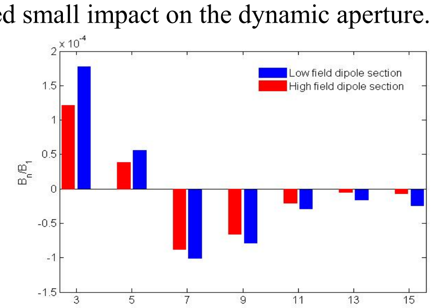

Figure 4: Normalized multipole errors at +14 mm in high and low field sections.

The desired magnetic length will be achieved by using chamfers at the pole ends. The chamfering will additionally control higher integrated multipoles. The optimized chamfer angle from the pole edge of both lateral low field sections is 52 degrees with the depth of 15 mm. So, the

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maximum effective length deviation within the GFR of ±14 mm is less than 0.15 mm which is acceptable.

In order to provide good integrated field quality along the HFI dipole magnet, both pole ends of the high field section are chamfered by 26 degrees too. As compared in Fig.5 the integrated field quality is improved from 1.5×10^{-3} to1.5×10^{-4} within the total GFR.

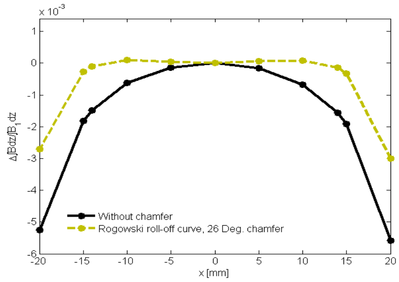

Figure 5: Integrated field quality of the HFI dipole magnet in the y=0 plane with and without chamfer. [8]

The designed ILSF dipole magnet is composed of three straight yokes placed on one girder. The mechanical angle between the middle yoke and the side ones is 1.2 degrees. Each straight yoke is based on the stacked C-type laminations. The mechanical 3D model of the SR dipole magnets is shown in Fig. 6. For electrical and cooling calculations given in Table 1, conductor and cooling duct dimensions should be chosen to provide optimum current density, power, inductance, cooling water speed and pressure drop [9]. Inasmuch as using one cooling system for all SR magnets, the same pressure drop of 6 bar is committed for the whole coils in the calculations.

Table 1: The dipole electrical and cooling specifications.

Parameters	Shared coil	Individual coil
Operating current (A)	382	312
Number of turns per coil	24	36
Current density (A/mm^2)	3.64	3
Voltage drop per magnet (V)	8.81	5.13
Power per magnet (KW)	3.37	1.60
Cooling water speed (m/s)	2.25	1.84
Pressure drop (bar)	6.0	6.0

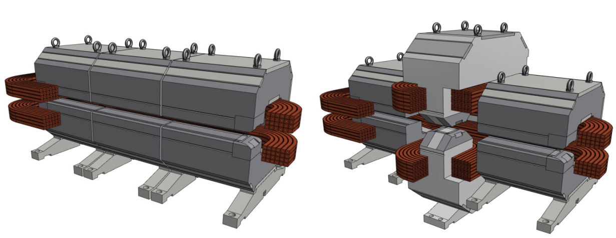

Figure 6: Perspective mechanical design of the main (left) and HFI (right) dipole magnets [7].

QUADRUPOLES

There are 320 quadrupoles in 8 families including 80 quadrupoles with the magnetic length of 0.44 m, 120 with the length of 0.36 m, 80 with the length of 0.27 m and 40 of them with the length of 0.10 m. Considering simulation of one with the maximum field gradient 24.78 T/m and length of 0.44 m, the same path to go for the rest is deduced, as well changing the current of the power supply.

Figure 7 shows the field quality which is lower than 0.02% with GFR of ±13.5 mm and 2 mm clearance between pole and chamber is regarded. The normalized values of higher order multipoles are also represented in Fig. 8.

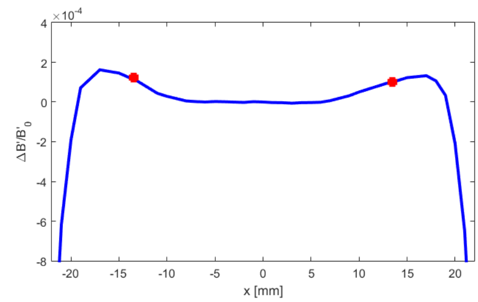

Figure 7: The field quality of the SR quadrupole within horizontal distance. The red points are the GFR.

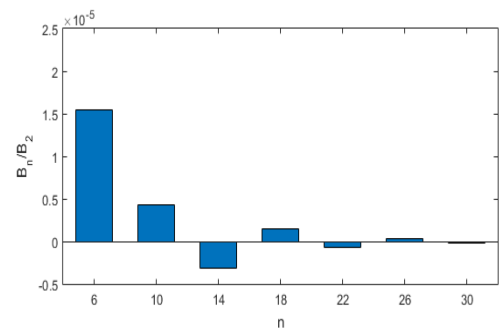

Figure 8: Normalized multipole errors at +13.5 mm.

Required magnetic length with the minimum integral multipoles are realized by a 45 degrees and 7 mm deep chamfer while the iron yoke length of the simulated quadrupole is assumed to be 405 mm. The integrated gradient field quality of the quadrupole before and after chamfering are compared in Fig. 9. The mechanical design of the SR quadrupole shown in Fig. 10 is finalized. The calculated electrical and cooling parameters of the SR quarupole are given in Table 2.

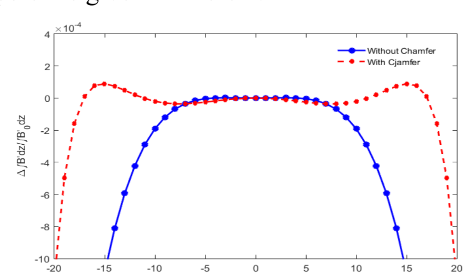

Figure 9: Integrated field quality of the quadrupole before and after chamfering.

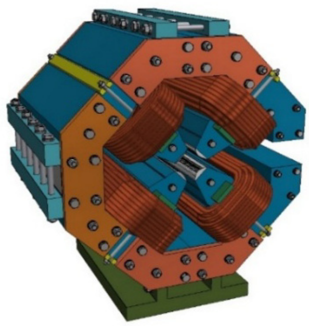

Figure 10: Perspective mechanical design of the SR quadrupole [7].

Table 2: The quadrupole electrical and cooling specifications.

Parameter	Value	Parameter	Value
Aperture radius	26 mm	Voltage drop per magnet	11.3 V
Field gradient	24.78 T/m	Power per magnet	2.34 kW
Magnetic length	440 mm	No. of cooling circuits	4
Conductor cross section	7.5 × 7.5 mm^2	Water temperature rise	8.12°C
Water cooling tube diameter	3.5mm	Cooling water speed	1.79 m/s
Aamp-turns per pole	6835 A	Pressure drop	6 bar

SEXTUPOLES

ILSF storage ring sextupole magnets are in 8 families with additional coils for correction. Figure 11 depicts the expected sextupole field quality which is lower than 0.02% within GFR of ±13.5 mm, simulated by POISSON code with 0.5 mm clearance with chamber. Given unique pole profile considering with and without return yoke, one can implement corrector coils even when antechamber exceed the back-legs. So that three-fold symmetry is regarded whenever back-leg is removed or attached by return yoke.

The normalized values of higher order multipoles are also represented in Fig. 12.

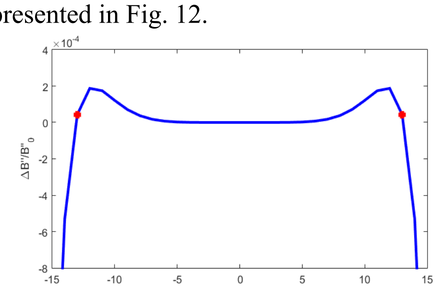

Figure 11: The field quality of the SR sextupole within horizontal distance.

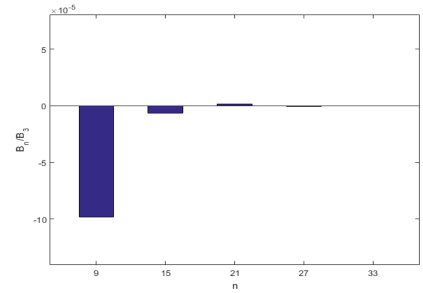

Figure 12: Normalized multipole errors at +13.5 mm.

The electrical and cooling parameters of the designed sextupole have been displayed in Table 3. The mechanical design of the SR sextupole is also finalized, see Fig. 13.

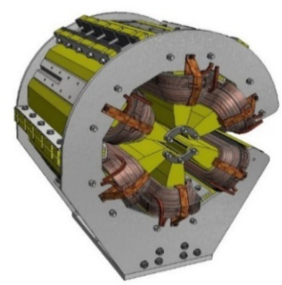

Figure 13: Perspective mechanical design of the SR sextupole [7].

Table 3: The SR sextupole electrical and cooling specifications.

Parameter	Value	Parameter	Value
Aperture radius	26 mm	Amp-turns per pole	2957 A
Field gradient	1200 T/m^2	Voltage drop per magnet	8.67 V
Magnetic length	0.360 m	Power per magnet	1.22 KW
Conductor cross section	6.5 × 6.5 mm^2	No. of cooling circuits	3
No. of turns per coil	21	Water temperature rise	5.81°C
Water cooling tube diameter	3.5 mm	Cooling water speed	1.74 m/s
Operating current per coil	140.8 A	Pressure drop	6 bar

CONCLUSIONS

The design of the ultralow emittance storage ring magnets have been physically and mechanically described. The proper shims and end chamfers for them are developed and fully determined to meet the field and integrated field uniformity requirement.

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