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ILSF ULTRALOW EMITTANCE STORAGE RING MAGNETS

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Abstract

Iranian Light Source Facility (ILSF) is a 3 GeV synchrotron which is in the basic design phase. The ILSF storage ring (SR) is based on a Five-Bend Achromat lattice providing a low horizontal beam emittance of 270 pm-rad. The ILSF storage ring consists of 100 combined dipole magnets of 2 types, 240 quadrupoles in 5 families and also 320 sextupoles in 6 families. In this paper, we present some design features of the SR magnets and discuss the detailed physical design of these electromagnets including electrical and cooling calculations. Using POISSON and OPERA codes [1,2], pole and yoke geometry was developed for each magnet.

INTRODUCTION

The ILSF storage ring circumference is 528 m with 20 super periods which mechanical schematic is displayed in Fig. 1. Each super period is composed of 5 dipoles with the magnetic and gradient field of 0.5672 T and -7.026 T/m. Focusing is performed with the use of 12 quadrupoles grouped in 5 families with the maximum gradient of 40.86 T/m and pole radius of 22 mm. The natural chromaticity is corrected by the use of 16 sextupole magnets grouped in 5 families with the maximum strength of 1562 T/m^2 and pole radius of 28 mm and one type with the strength of 2111 T/m^2 and pole radius of 23 mm.

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 low carbon steel M1200-100A is employed as the main fabrication material [3].

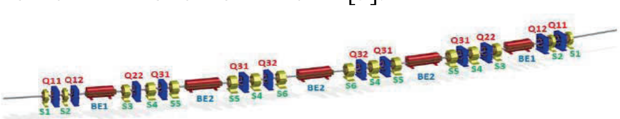

Figure 1: The magnets arrangement of one super period of the ILSF storage ring [4].

DIPOLE MAGNETS

The C type ILSF dipole magnet is designed in curved form for two different lengths, with such a spectacular pole profile to include quadrupole strength too, see Fig. 2.

Through none symmetric standard shims with the total gap of 16 mm, the field quality is lower than 0.01% within the Good Field Region (GFR), see Fig. 3.

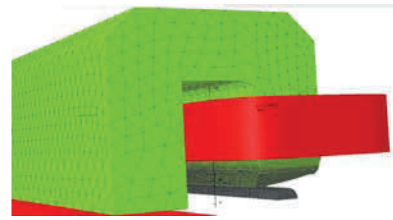

Figure 2: 3D design of the SR dipole magnets in OPERA.

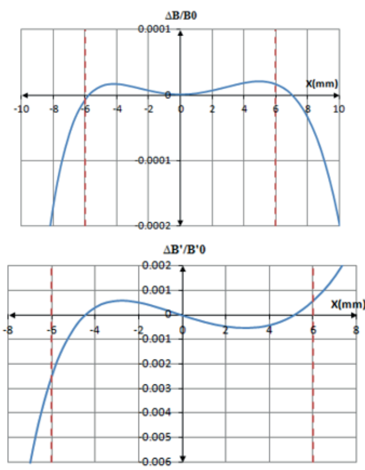

Figure 3: Field quality of the 2D designed dipole sections within ±6 mm GFR for both dipolar (up) and quarupolar components(down).

The normalized systematic multipole errors obtained by POISSON code are plotted in Fig. 4. As given, the relative sextupole component is less than 6×10^{-5} which indicates expected small impact on the dynamic aperture.

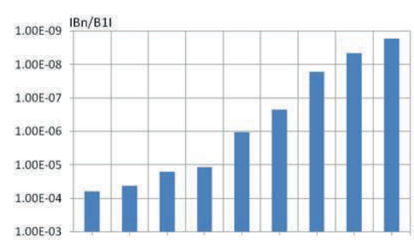

Figure 4: Normalized multipole errors of SR dipole magnet at +6 mm.

The desired magnetic length will be achieved by using chamfers at the pole ends. The chamfering will additionally control higher integrated multipoles. So, the relative growth of dipolar (purple), quadrupolar (green) and sextupolar (blue) fields in respect to their referential values in the center, through half of the magnet are depicted in Fig. 5.

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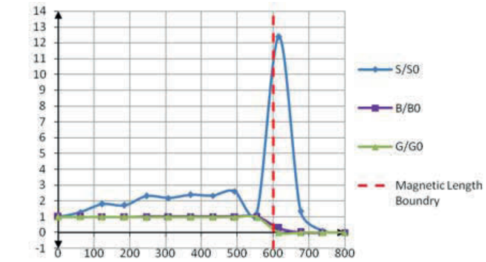

Figure 5: Relative deviation of fields on the central line along half of the dipole magnet.

Figure 6 also shows how the integrated field quality which is lower than 0.01% behaves within the GFR after chamfering.

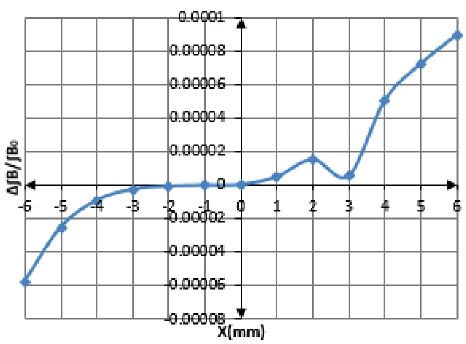

Figure 6: Integrated field quality of the SR dipole magnet in the y=0 plane with chamfer.

For electrical and cooling calculations given in Table 1, conductor and cooling duct dimensions should be chosen to provide optimum current density, power, water speed and pressure drop [5]. 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 SR Dipole Electrical and Cooling Specifications

Parameters	**Values**
Operating current (A)	364.5
Number of turns per coil	20
Conductor dimensions (mm^2)	11×11×ø4.5
Current density (A/mm^2)	3.47
Voltage drop per magnet (V)	6.2
Resistance per magnet(mΩ)	17
Power per magnet (kW)	2.26
Number of water circuits	2
Water temperature rise (°C)	9.7
Cooling water speed (m/s)	1.75
Pressure drop (bar)	6.0

QUADRUPOLES

There are 320 quadrupoles in 5 families with the same magnetic length of 20 cm and aperture radios of 22 mm but different strengths. Considering simulation of one with the maximum field gradient 40.858 T/m, see Fig. 7, the same path to go for the rest is deduced, as well changing the current of the power supply [5].

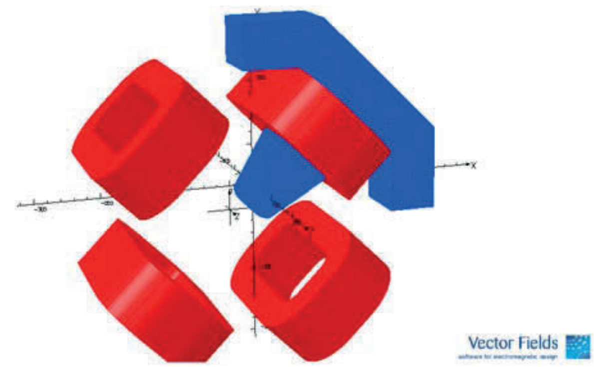

Figure 7: 3D design of the SR quadrupole magnets in OPERA.

Figure 8 shows the field quality which is lower than 0.05% with GFR of ±12 mm. The normalized values of higher order multipoles are also represented in Fig. 9.

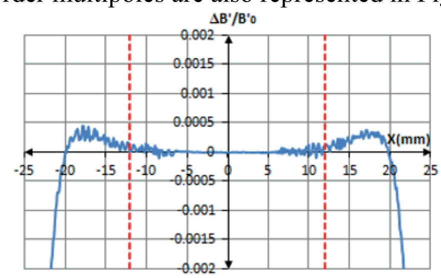

Figure 8: The field quality of the SR quadrupole within horizontal distance. The red dotted lines are GFR limits.

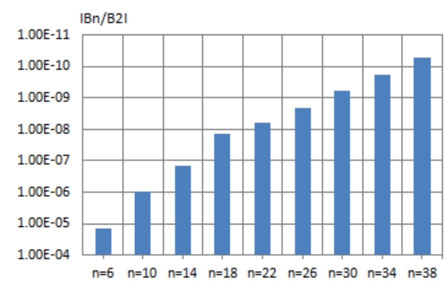

Figure 9: Normalized multipole errors at +12 mm.

Required magnetic length with the minimum integral multipoles are realized by a 45 degrees and 8.72 mm deep chamfer while the iron yoke length of the simulated quadrupole is assumed to be 184 mm. The integrated gradient field quality of the quadrupole after chamfering are in Fig. 10.

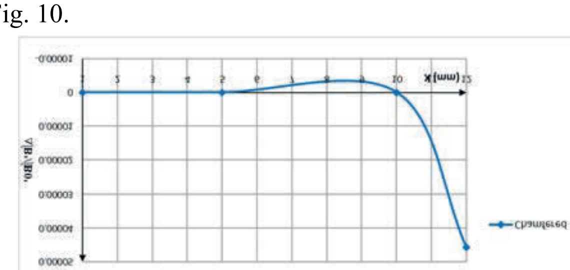

Figure 10: Integrated field quality of the quadrupole after chamfering.

The calculated electrical and cooling parameters of the SR quarupole are also in Table 2.

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Table 2: The SR Quadrupole Electrical and Cooling Specifications

Parameters	**Values**
Operating current (A)	132.3
Number of turns per coil	62
Current density (A/mm^2)	4.5
Conductor dimensions (mm^2)	6.5×6.5×ø4
Voltage drop per magnet (V)	13.4
Resistance per magnet(mΩ)	101.3
Power per magnet (kW)	1.77
Number of water circuits	4
Water temperature rise (°C)	4.7
Cooling water speed (m/s)	1.8
Pressure drop (bar)	6.0

SEXTUPOLES

ILSF storage ring sextupole magnets are in 6 families with additional coils for correction and with no chamfer. Regarding pole tip field considerations we have assigned two cross sections with two aperture radiuses, one for a family with 2111T/m^2 strength and 23 mm radius and another for the rest with maximum strength of 1562T/m^2 and 28 mm radius aperture (Fig. 11).

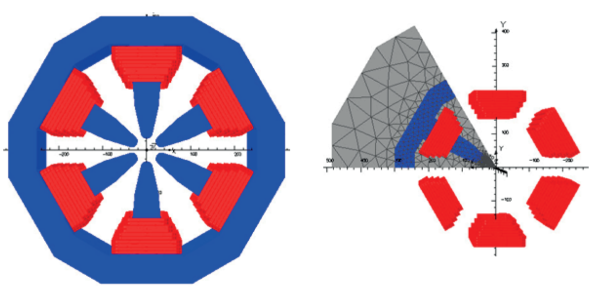

Figure 11: 3D design of the one of the SR sextupole magnets in OPERA with 28 mm aperture radius.

Figure 12 depicts the expected sextupole field quality less than 0.1% within GFR of ±12 mm, simulated by POISSON code with 1.5 mm clearance with chamber for both cases. The normalized values of higher order multipoles are also represented in Fig. 13.

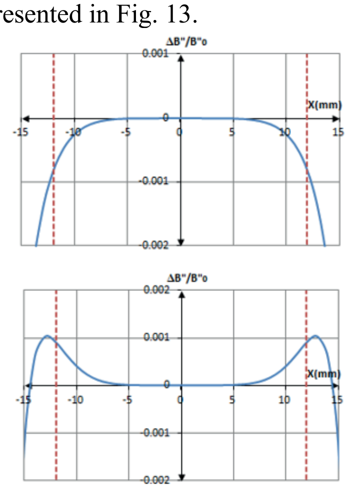

Figure 12: The field quality of the sextupoles with 28 mm (up) and 23 mm (down) aperture radius.

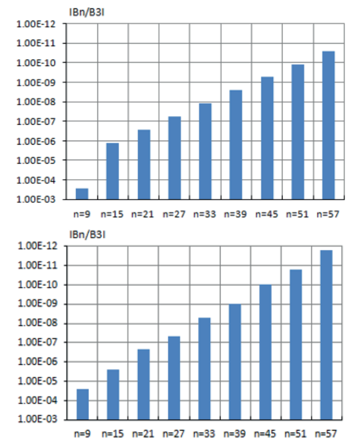

Figure 13: Normalized multipole errors of the sextupoles with 28 mm (up) and 23 mm (down) radius at +12 mm.

The electrical and cooling parameters of the designed sextupoles have been displayed in Table 3.

Table 3: The SR Sextupole Electrical and Cooling Specifications

Parameters	**Values (28 mm radius)**	**Values (23 mm radius)**
Operating current (A)	129.7	125
Number of turns per coil	36	28
Current density (A/mm^2)	4.4	4.24
Conductor dimensions (mm2)	6.5×6.5×ø4	6.5×6.5×ø4
Voltage drop per magnet (V)	12.56	8.66
Resistance per magnet(mΩ)	96.87	69.3
Power per magnet (KW)	1.36	1.08
Number of water circuits	3	3
Water temperature rise (°C)	6.6	3.6
Cooling water speed (m/s)	1.57	1.88
Pressure drop (bar)	6.0	6.0

CONCLUSIONS

The design of the ultralow emittance storage ring magnets has been 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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