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ILSF BOOSTER MAGNETS FOR THE NEW LOW EMITTANCE LATTICE

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Abstract

Iranian light source facility is a new 3rd generation light source with a booster which is supposed to work at 150 keV injection energy and guide the electrons to a 3GeV ring. It consists of 50 combined dipole magnets in one type, 50 quadrupoles and 15 sextupoles in one family. Using POISSON and OPERA3D codes [1,2], pole and yoke geometry was designed for each magnet and also cooling and electrical calculations have been done. ILSF has attempted to mechanical design and build prototype magnets which are ongoing at this stage too.

INTRODUCTION

ILSF booster ring with the circumference of 504 m is supposed to work at injection energy of 150 keV and leads the electrons to the ring energy of 3 GeV and the horizontal emittance of 3 nm rad. Fifty combined bending magnets in one type are supposed to provide horizontal focusing and correct natural chromaticity in addition to their bending roles. There are also 50 pure quadrupole magnets for vertical focusing and 5 defocusing quadrupoles for tune adjustment. Moreover, 15 SF for correcting natural chromaticity and 5 SD defocusing sextupoles are assigned to correct eddy current effects. The arrangement of magnets in one super period of the booster lattice is depicted in Fig. 1.

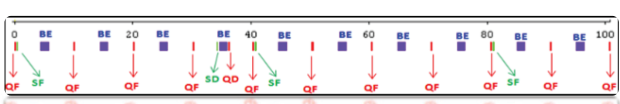

Figure 1: Schematic layout of magnets in one super period of booster lattice. The blue, red and green boxes represent dipoles, quarupoles and sextupoles respectively.

In booster ring, where we have AC currents, eddy currents are objectionable, not only because they decrease the flux, but also as they produce heat and power loss proportional to i^2R, where i is the eddy current and R is the resistance of its path [3,4]. To avoid eddy currents, Silicon-steel 3% with lower electrical conducting should be used. So in ILSF booster yoke is considered to be a collection of M330-50A laminations, with nominal thickness of 0.5 mm. The dipoles are planned to be run in series with a common power supply and due to having one family of quadrupole and one for sextupoles, they will be connected in series.

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DIPOLE MAGNETS

ILSF booster dipole is combined H-type bending magnet having an imposed quadrupole and sextupole components with parallel-ends and a curved yoke as shown in Fig. 2.

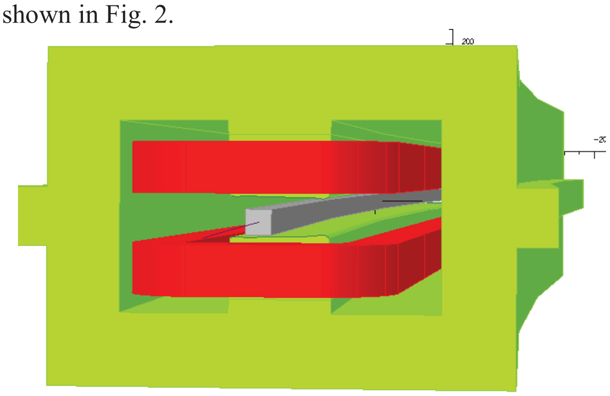

Figure 2: 3D design of the booster dipole magnet created in OPERA simulation code.

For electrical and cooling calculations in Table 1,conductor and cooling duct dimensions should be chosen to provide optimum current density, power, inductance, cooling water speed and pressure drop [3]. Inasmuch as using one cooling system for all booster magnets, the same pressure drop of 6 bar is committed for the whole coils in the calculations.

Table 1: The ILSF Booster Dipole Specifications

Parameters	Values
Bending radius (m)	10.34
Field (T)	0.9967
Field gradient (T/m)	-1.791
Sextupole component (T/m^2)	-44.28
Half gap (mm)	12
Magnetic length (m)	1.3
Operating current (A)	808
Number of turns per coil	12
Conductor dimensions (mm2)	12×12×ø6
Current density (A/mm^2)	6.98
Voltage drop per magnet (V)	8.6
Resistance per magnet (mΩ)	33
Power per magnet (kW)	6.96
Number of water circuits	1
Water temperature rise (°C)	5.5
Cooling water speed (m/s)	2.67
Pressure drop (bar)	6.0

Also, field tolerances are calculated to be less than 1×10^{-4} within the good field region (GFR) ±6 mm (Fig. 3).

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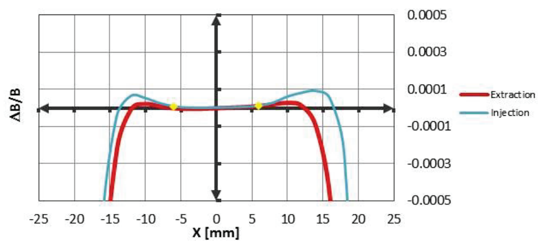

Figure 3: Field quality of the BR dipole sections within ±6 mm GFR at injection and extraction.

Although the two dimensional field may have the desired properties, 3D design is necessary to study the longitudinal field distribution and end effects. 3D magnetic simulations of ILSF booster dipole have been carried out with OPERA-3D software.

The chamfers of the dipole's ends are to get the same effective length along the transverse, i.e. within ±6 mm at two different extraction and injection excitations of the magnet. The optimized end chamfer is a 20 mm cut that has 40 degrees in the ZY-plane and 2.5 degrees in the YX-plane. In order to investigate the integrated field quality at the beam pass limit, field integral is calculated at 10 trajectories by ±2 mm parallel to the central one, which is the actual beam trajectory. From here, the normalized integrated multipole errors affected by chamfering, are plotted in Fig. 4 and then the integrated field tolerances at both injection and extraction can be obtained, see Fig. 5.

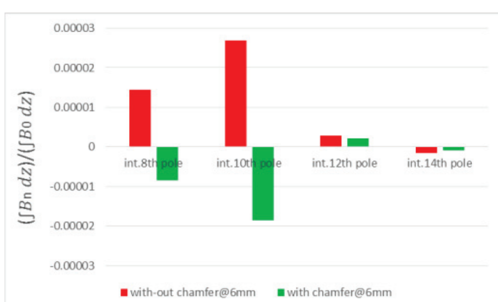

Figure 4: Normalized integrated multipole errors at 6 mm in dipole sections.

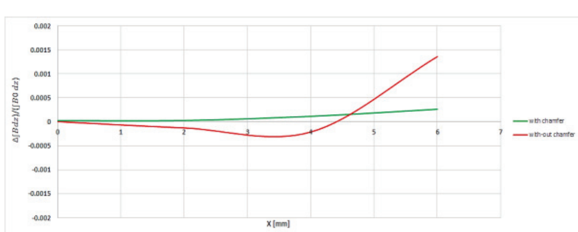

Figure 5: Integrated field quality of the booster dipole magnet in the y=0 plane with and without chamfer.

As compared here the maximum integrated field quality is improved from 1.5×10^{-3} to less than 2×10^{-4} within the total GFR.

QUADRUPOLES

ILSF booster has 50 quadrupoles with 19 mm aperture and 15 cm length. The general layouts and length of all the quadrupoles are the same. The quadrupole is simulated in 3D using OPERA that depicted in Fig. 6.

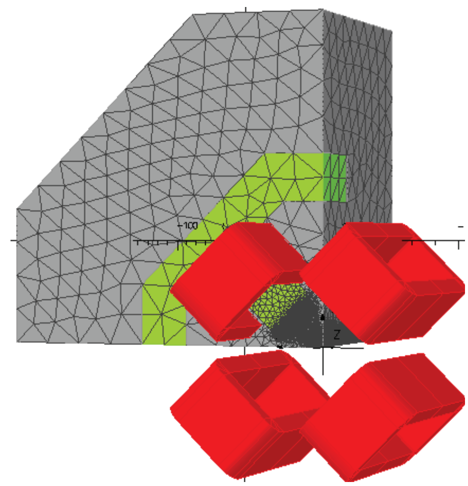

Figure 6: 3D design of the booster quadrupole magnet created in OPERA.

Main parameters for the designed quadrupole are given in Table 2.

Table 2: The ILSF Booster Quadrupole Specifications

Parameters	Values
Aperture radius (mm)	19
Field gradient (T/m)	24.67
Magnetic length (m)	0.15
Operating current (A)	184
Number of turns per coil	22
Conductor dimensions (mm^2)	6.5×6.5×ø4
Current density (A/mm^2)	5.93
Resistance per magnet (mΩ)	28.67
Voltage drop per magnet (V)	5
Power per magnet (kW)	0.9
Number of water circuits	1
Water temperature rise (°C)	5
Cooling water speed (m/s)	1.7
Pressure drop (bar)	6.0

Field tolerances are likely to be less than 2×10^{-4} within the GFR ±12.5 (Fig. 7).

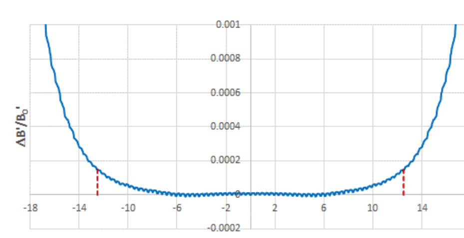

Figure 7: Field quality of the booster quadrupole within ±12.5 mm GFR.

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Regarding 3D simulations, the optimized end chamfer is a 3mm cut that has 45 degrees in the ZY plane. From Fig. 8 one can see how integrated gradient tolerances are less than 4×10^{-4} in the GFR of ±12.5mm too.

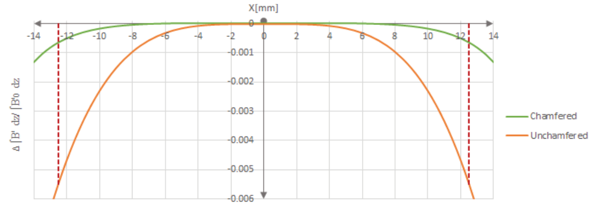

Figure 8: Integrated field quality of the booster quadrupole magnet in the y=0 plane with and without chamfer.

The optimization of the end chamfer is based on the minimum achieved value of the generated systematic multipoles at nominal excitation of the magnet. Fig. 9 depicts absolute normalized integrated multipoles' errors at the GFR of 12.5 mm before and after chamfering.

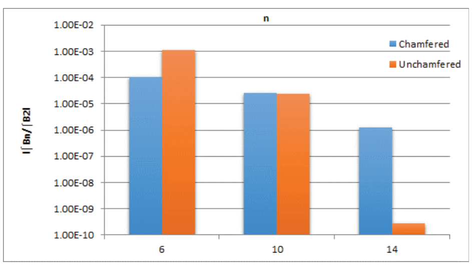

Figure 9: Absolute normalized integrated multipoles' errors at 12.5 mm GFR with (blue) and without (orange) chamfer.

SEXTUPOLES

ILSF booster has 15 focusing sextupoles with 19 mm aperture and 10 cm magnetic length. The general layouts and length of all the sextupoles are the same, which the simulated sextupole by OPERA3D is shown in Fig. 10.

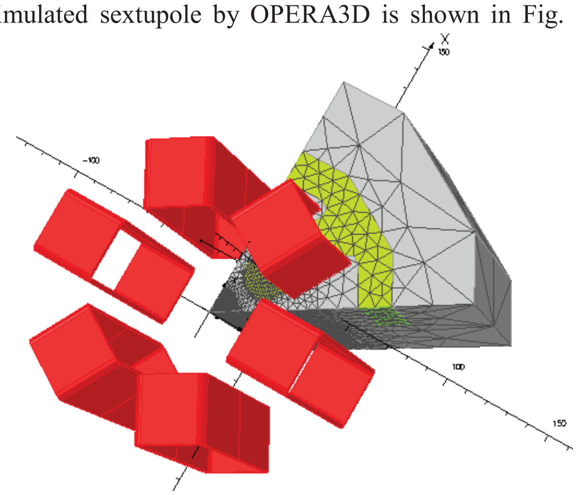

Figure 10: 3D design of the booster sextupole with meshed regions.

Main parameters for the ILSF booster sextupoles with no need for water cooling are given in Table 3.

Also, field tolerances and integrated multipoles are obtained to less than 5×10^{-4} within the GFR ±12.5 mm, shown in Fig. 11 and Fig. 12 respectively.

Table 3: The ILSF Booster Sextupole Specifications

Parameters	Values
Aperture radius (mm)	19
Field gradient (T/m^2)	430.32
Magnetic length (m)	0.1
Operating current (A)	20.75
Number of turns per coil	20
Conductor dimensions (mm^2)	2.8×1
Current density (A/mm^2)	7.4
Resistance per magnet (mΩ)	185
Voltage drop per magnet (V)	3.8
Power per magnet (W)	80

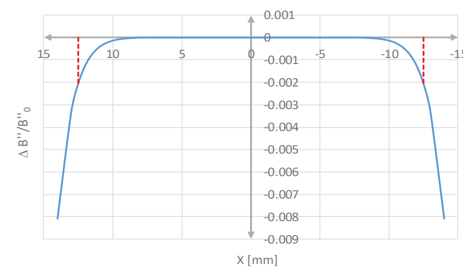

Figure 11: Field quality of the booster sextupole within ±12.5 mm GFR.

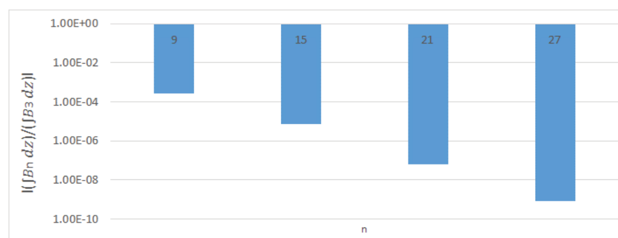

Figure 12: Absolute normalized integrated multipoles' errors at 12.5 mm GFR.

CONCLUSIONS

The design of the booster ring magnets has been described. Magnets were designed for the critical parameters. Field uniformity of $\Delta B/B_0<\pm1\times0.01\%$ in the dipoles, $\Delta G/G_0<\pm2\times0.01\%$ in the quadrupoles and, $\Delta S/S_0<\pm5\times0.01$ % in the sextupoles at GFR are predicted.

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