LNLS SYNCHROTRON LIGHT SOURCE MAGNETS

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Abstract

We present a general review of the LNLS Synchrotron Light Source magnets, outlining the most important parameters related to their design, construction and characterization.

1. INTRODUCTION

The LNLS ring consists of a 1.2 GeV electron storage ring with injection at 110 MeV. The 12 dipoles, 36 quadrupoles and 16 sextupoles form a 6-fold symmetric ring with double-bend achromatic arcs. The 1.4 m dipoles achieve their nominal field of 1.4 T at 236 A and the injection field of 0.12 T at 19 A. The quadrupoles are 0.25 m long and reach a maximum gradient of 17.8 T/m at 225 A. The sextupoles (0.1 m) produce a 770 T/m^2 gradient at 200 A. The transport line magnets have been described in ref.[1]. All these magnets are laser cut from 1.5 mm thick low carbon steel laminations[2]. The magnets have all been assembled and installed in the UVX ring, which is currently under commissioning[3]. In this report we describe the main characteristics of the design, construction and characterization of these magnets. Results on measured magnetic performance are compared with the specified values. Since the magnets must operate at large dynamic range, particular attention is devoted to the accuracy and repeatability of the measurements at low excitations.

2. DESIGN AND CONSTRUCTION

The design of the magnets was optimized by numerical simulations using the 2d code Poisson[4]. Fine adjustments in the lamination profiles to reduce end-field errors are achieved by trying different shim configurations. The dipole non uniformities could be reduced to within few parts in 10^4 in a ±20 mm region.

All magnet cores are fabricated from 1.5 mm thick laser-cut steel laminations, with accuracy of ±0.05 mm. The dipoles showed 0.02 mm standard deviation of the gap (58 mm). The laminated magnets are assembled without welding by using tie rods.

The storage ring dipoles, quadrupoles and sextupoles have water-cooled coils. Insulation and mechanical stiffness is assured by epoxy resin impregnation.

3. MAGNETIC MEASUREMENTS

The magnetic measurements include evaluation of multipole and main components as a function of the excitation current. The measurement methods are the usual rotating coil (using a PDI-5025 Digital Integrator) for harmonic analysis and Hall probe for field mapping. An additional coil to compensate the main field is used in multipole content measurements with the rotating coil.

The storage ring straight section magnets are aligned using reference girder rails[5]. Fiducial marks are therefore provided only for the dipoles. The geometrical accuracy of the laser cutting technique assures that the distance between geometric and magnetic centers will be within the required alignment tolerance of 0.2 mm. Quadrupoles and sextupoles were thus measured in their geometric centers. Results show that the magnetic center is displaced from the geometric center by 0.1 mm (rms) or 0.2 mm (maximum).

3.1 Dipoles

The LNLS dipoles are parallel faced, C shaped, staggered magnets. Their cross section can be seen in figure 1. The magnetic field is mapped in the midplane for low (injection), nominal and maximum currents (respectively 19, 236 and 300 A). The multipole content of the field is obtained by polynomial fitting to the longitudinally integrated field along 15 different transverse trajectories. The field integral along the central trajectory is acquired for more current steps (excitation curve). The spread in excitation curves for the 12 dipoles is summarized in figure 2. The differences can be compensated by steering magnets. Reproducibility after 4 cycling procedures is within 1 part in 10^3 for low

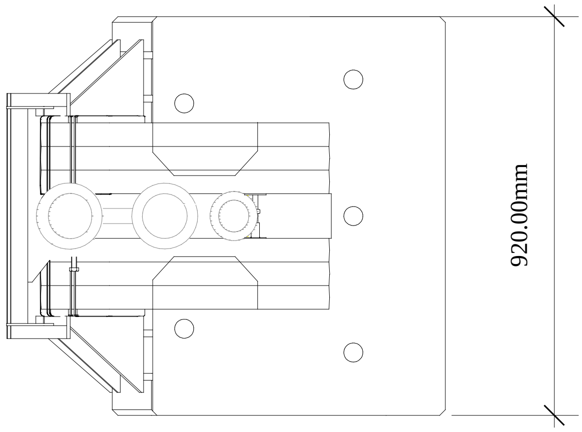

Figure 1: Dipole cross section. Length: 1.442 m. Bend. radius: 2.735 m. Gap: 58 mm. Field (@300A): 1.65 T.

energy and 2 parts in 10^4 for high energy. The multipole components at different excitation levels are shown in figure 3.

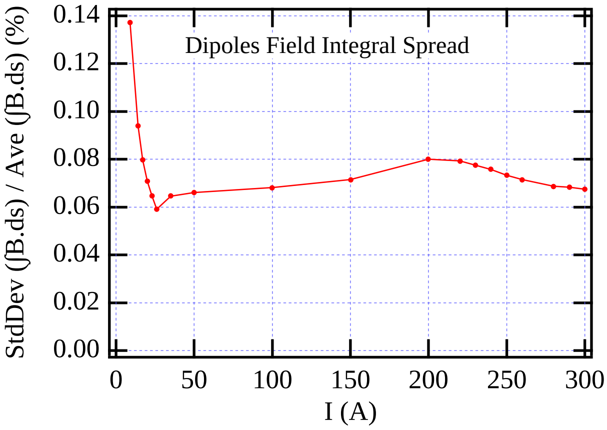

Figure 2: R.m.s. spread in measured excitation curves for the 12 dipoles. The specified tolerance for excitation error is 0.1% r.m.s. Note that the spread at injection current (19 A) is already within specified value.

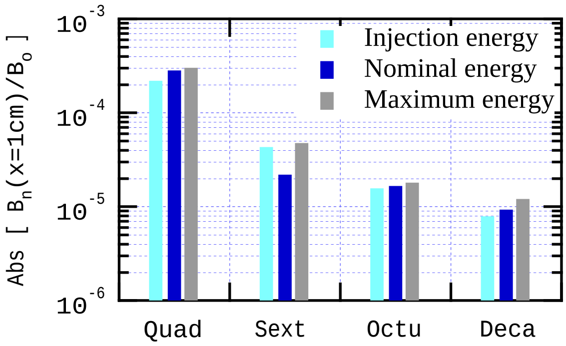

Figure 3: Dipole multipole field components. Except for the quadrupole term, which is now incorporated in linear optics calculations, the results show that the dipoles are adequate.

3.2 Quadrupoles

The quadrupole yoke is composed of 4 equal blocks with a clear bore diameter of 70 mm and a length of 250 mm. The quadrupole cross section is shown in figure 4. The end poles are shaped to reduce the 12 pole and 20 pole magnetic field components. In the injection straight section, the quadrupole pole profile has been extended to increase the linear gradient region and accommodate the incoming beam from the transport line. Additional windings in the quadrupoles can provide dipole field for horizontal or vertical steering. Each pair of symmetrically distributed quadrupoles in the dispersion free straight sections have independent power supplies and form a Q2 family. Each set of 6 dispersive quadrupoles form a Q6 family. We have a total of 12 Q2 and 2 Q6 families in UVX, which provides the flexibility for the ring to operate either in 6, 3 or 2 fold

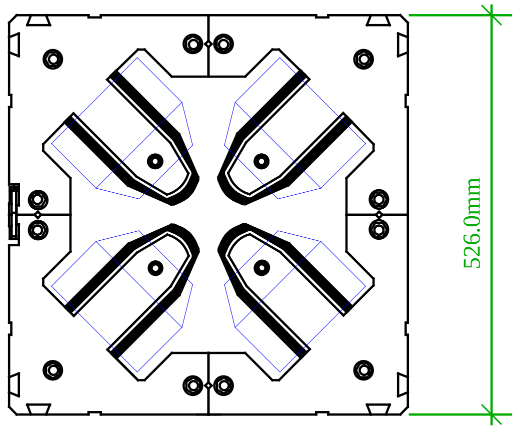

Figure 4: Quadrupole cross section. Length: 250.4 ± 0.5 mm. Turns per coil: 37. Power @225A: 1700 W. Gradient @225A: 18 T/m, 1.5% saturation.

symmetry configurations. In order to control the beam emittance coupling, a pair of skew quadrupoles is introduced in the lattice.

Both the main component and the multipole coefficients are obtained from Fourier transformation of the integrated flux through the rotating coil. The spread in excitation curves and the multipole components are shown respectively in figures 6 and 7.

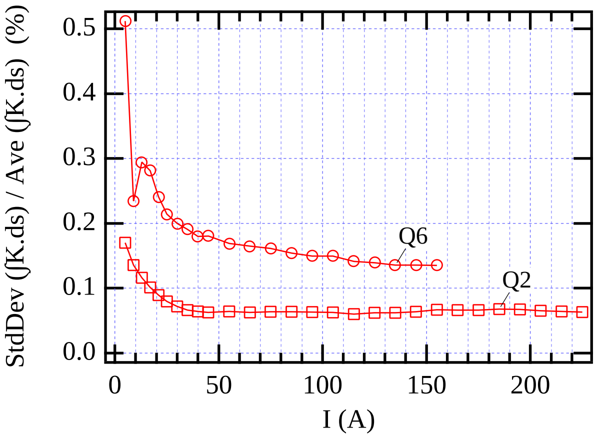

Figure 5: R.m.s. spread in measured excitation curves for the 2 and 6 quadrupole families. The specified tolerance for excitation error is 0.2%.

3.3 Sextupoles

The sextupole core consists of 2 main blocks with 2 poles each and 2 fitted poles which are attached to the main blocks. These fitted poles must be taken off when assembling the sextupole coils. Figure 7 shows a cross sectional view of the sextupoles. This essentially 2 fold symmetric pole geometry requires special care in the magnet mechanical construction and assemblage, since strong dipole fields can arise. The sextupoles were designed to produce maximum gradients of 770 T/m^2 at 200 A and require water-cooled coils. The magnet yoke

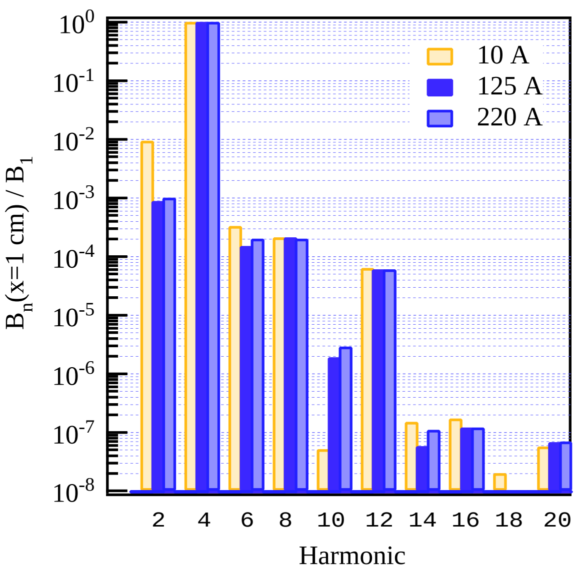

Figure 6: Harmonic analysis in the geometric center., Multipole field components normalized to the quadrupole component at 1 cm from center. Values are within specified tolerances.

starts saturating at 150 A.

The sextupoles are grouped in three families with six components. The multipole contents are obtained from rotating coil measurements and are shown in figure 8. The excitation curve spread in each family is about ±0.5% at low energy and ±0.2% at high energy.

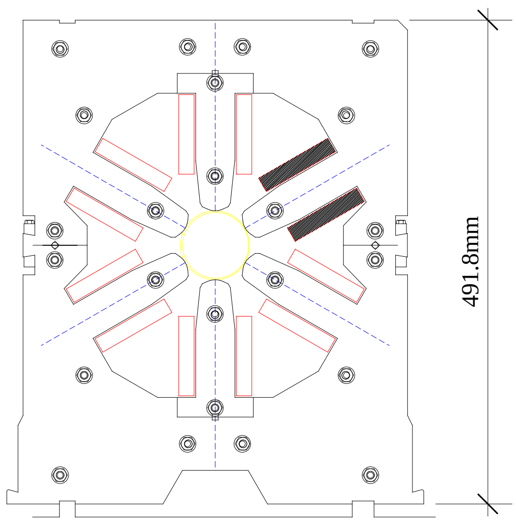

Figure 7: Sextupole cross section. Core length: 99.1 ± 0.3 mm. Turns per coil: 20. Power @225 A: 1400 W. Gradient @150 A: 635 Tesla/m^2, 1% saturation. Gradient @200 A: 770 Tesla/m^2, 15% saturation. Effective length: 120 mm.

3.4 Steering magnets

The 18 horizontal and 12 vertical steering magnets are designed to provide 1 mrad deflection each to the 1.37 GeV beam. The magnets have 80 mm long cores

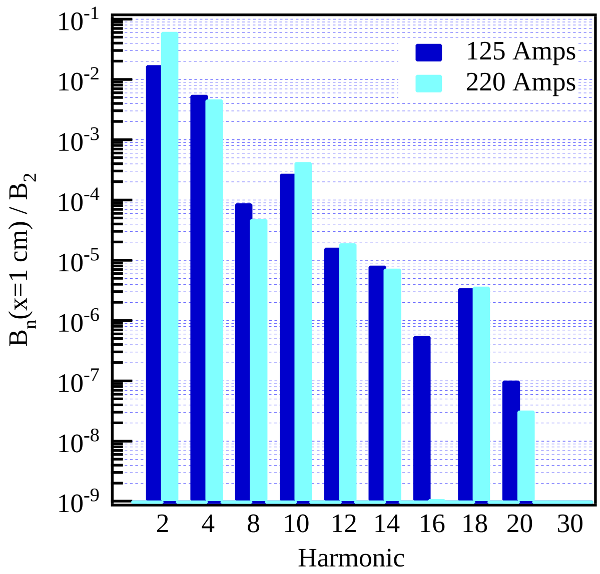

Figure 8: Sextupole multipole field components normalized to the main component at 1 cm from the magnet center.

and 143 mm effective lengths indicating the prevalence of fringe field effects. The field homogeneity is 0.1% for ±10 mm, and 1% for ±30 mm.

4. CONCLUSIONS

We have presented a general description of the LNLS magnets with emphasis on the measurement results. The magnets have been designed to operate at large dynamic range, from 100 MeV to 1.37 GeV. The most stringent demand is to keep the magnetic field accuracy and repeatability within the required values for the whole operation range. The measurement results show that the magnets satisfy the required tolerances for almost all energies, except for the lowest energies where difficulties related to remnant fields were expected. These effects are more evident for the quadrupoles and sextupoles, which showed long term repeatability about 2 times worse than the specified value. The troubles associated with low energy injection seem, however, to be surmountable as demonstrated by the results of the low energy commissioning[3].

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