DESIGN OF MAGNET PROTOTYPES FOR THE NEW BRAZILIAN SYNCHROTRON LIGHT SOURCE - SIRIUS

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Abstract

"Green solutions" using permanent magnets are being proposed for the dipoles and quadrupoles of the second Brazilian Synchrotron Light Source - LNLS2 - magnetic lattice. The main purpose is to reduce as much as possible the electrical energy consumption, assuring the reliability of the magnets during several years. Sextupoles will have multiple functions due to the limited space in the lattice design.

INTRODUCTION

The second Brazilian Synchrotron Light Source (LNLS2) is under development and will operate at 3GeV, with 0.5 Amps and emittance close to 1 nm.rad. An Electron Storage Ring has been proposed exploring as much as possible the utilization of permanent magnetic materials (PMMs) in the magnetic lattice. This is a feasible option at present due to the advances in PMMs quality and their cost reduction. Many advantages can be listed:

- Depending on the field amplitude and the magnet length of the dipole, the usage of permanent magnets has a lower cost when compared to electromagnetic ones;
- Operational costs related to electrical energy and cooling systems can be drastically reduced;
- There are no failures in the control system as well as in the power supplies, which increases the accelerator reliability;
- Maintenance of coils, cables and power supplies is not required;
- Magnets made with permanent magnetic materials can be more compact, since they do not have coils, which in general reach longitudinal sizes bigger than the ferromagnetic core.

Nevertheless, there is also a list of challenges:

- Change of the remanent field with the temperature. Notwithstanding, there are procedures to compensate it [1];
- Demagnetization risk caused by irradiation [2];
- Difficulties associated to assembling, since the blocks are always turned on;
- Baking for vacuum is not an easy procedure, since it can modify the magnetic properties of the magnets;
- Aging effect [3] – decreasing of remanent field as a function of time;

In the following sections the proposed design project of dipoles, quadrupoles and sextupoles will be described in a summarized way.

DIPOLES

Figure 1 shows the arrangement of dipoles by superperiod with their respective angular deflections. The outer dipoles (3.5° and 5°) have low field (0.5 Tesla) and are used for the main bending of the electron beam, producing a small radiation power (Figures 2). The central dipole (1°) has a 2 Tesla magnetic field and it will supply a hard x-ray beam line (Figures 4). The electrical power required to reach such field through an electromagnetic device would be around 3 kWatt per dipole. All dipoles can have their field changed by means of control gaps, laterally located. With these control gaps it is possible to adjust the integrated field of each individual dipole so that all dipoles fall within specified tolerance. A small adjustment is possible even in the case of some demagnetization of the permanent magnets.

About 350 kW would be the total consumption to keep electromagnetic dipoles with the same characteristics in operation, considering 3.5 A/mm2 in the coils and not computing the powers related to cooling systems.

Figure 2 shows the first dipole prototype, made with strontium ferrite magnets [4]. Posterior analysis showed advantages in dipoles made with NdFeB (Figures 3): smaller size, less thermal variation of the remanent field and better mechanical tolerances.

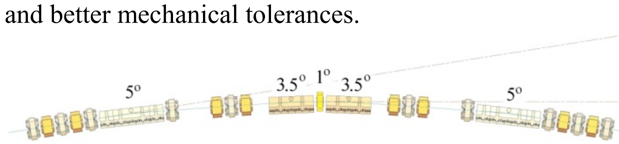

Figure 1. Dipoles pattern for one superperiod arc.

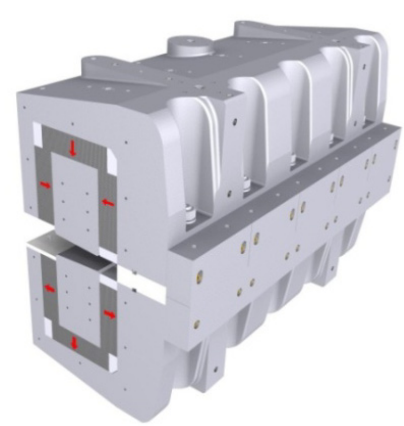

Figure 2. Mechanical design of the dipole based on ferrite – first prototype. The arrows indicate the direction of the ferrite magnetization. The main steel body was cast and the critical dimensions were machinated after.

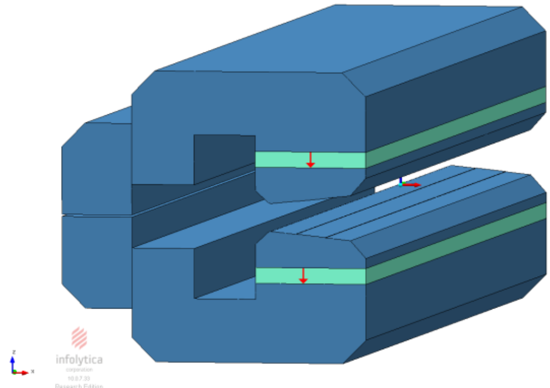

Figure 3. Mechanical design of the 0.5 Tesla dipoles.

Table 1. Main characteristics of the 0.5 Tesla dipole.

Main field [Tesla]	0.5
Gradient[Tesla/m]	2.0 and 2.3
Integrated field [Tesla.m]	0.87 and 0.61
Angular deflection [^{o}]	5 and 3.5
Mean gap [mm]	43.7and 45
Minimum gap [mm]	35
Transverse good field region [mm]	± 30 and ± 25
Field homogeneity	< 0.001
Magnetic Material	NdFeB
Remanent field [Tesla]	1.37
Coercivity – Hcj [kAmp/m]	> 1350
Relative Permeability	
Main dimensions of 5^o dipole [mm3]	1750x710x410
Main dimensions of 3.5^{o}dipole [mm3]	1222x710x410
Total radiated power [kWatt]	2.5 and 1.75
Maximum pole deformation [µm]	20
Number of external dipoles	40
Number of central dipoles	40
Maximum field -control gap closed [T]	0.54 and 0.525

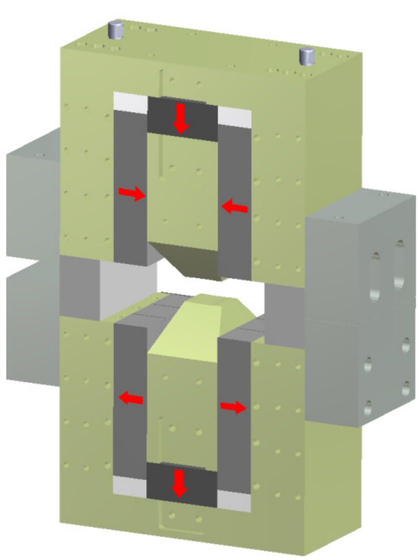

Figure 4. Mechanical design of the 2 Tesla dipole.

Table 2. Main characteristics of the 2 Tesla dipole.

Main field [Tesla]	2
Integrated field [Tesla.m]	0.1747
Angular deflection [^{o}]	1
Mean gap [mm]	35
Transverse good field region [mm]	± 10
Field homogeneity	< 0.001
Magnetic Material	NdFeB
Remanent field of NdFeB [Tesla]	1.35
Coercivity – Hcj [kAmp/m]	≥ 1114
Relative Permeability	1.05
Main dimensions [mm3]	654x 525x165
Total radiated power [kWatt]	2
Number of dipoles	20

QUADRUPOLES

Besides the dipole, we are also exploring the possibility of using permanent magnet materials for quadrupoles. One possibility for the quadrupole has been studied in which 70% of the field is supplied by permanent magnets. The remaining 30% is controlled by coils given the necessary flexibility to compensate the insertion devices disturbances on the electron beam. Many configurations were suggested for the permanent magnets placement and it was found that their installation in diagonal lines optimized the field and the quadrupole size. The drawback of this position are the field losses close to the permanent magnets, near to the quadrupole backsides, requiring a thin layer of steel to shield them. The total power saved by employing permanent magnet quadrupoles is around 270 kWatt.

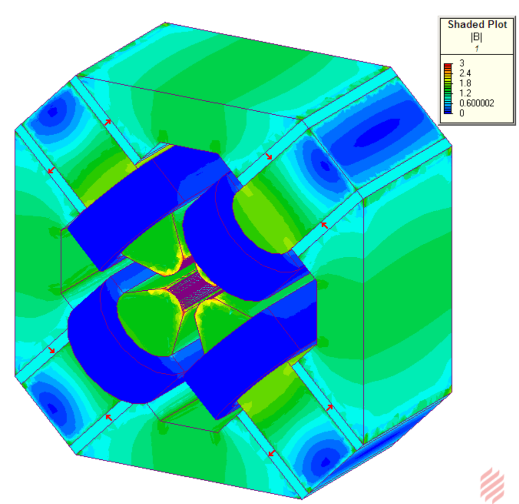

Figure 5. Magnetic simulation of the quadrupole.

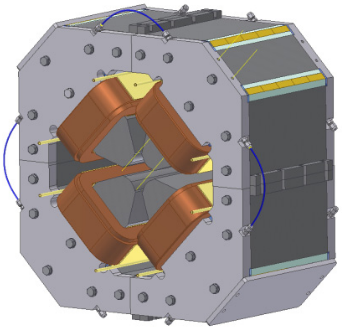

Figure 7. Mechanical design of the quadrupole.

Table 3. Main characteristics of the quadrupole.

Maximum gradient [Tesla/m]	30
Integrated gradient [Tesla]	7.5
Bore radius [mm]	27.5
Gradient flexibility [%]	± 15
Gradient by permanent magnets [Tesla/m]	25.5
Magnetic Material	NdFeB
Remanent field [Tesla]	1.35
Coercivity – Hcj [kAmp/m]	> 1350
Relative Permeability	1.05
Multipolar composition	
B_6/B_2 @10mm	5. 10^{-5}
B_{10}/B_2 @10mm	5. 10^{-8}
Total electrical power [W]	100
Main dimensions [mm3]	570x330x250
Number of quadrupoles	160

SEXTUPOLES

For the sextupole, a multifunctional electromagnet has been proposed [5, 6] in order to save space. It contains the sextupolar field, both horizontal and vertical steering fields and the skew quadrupole field. In this case there is also an initial concern about obtaining the lowest power by having smaller bore radius and not cooled wires, which make it harder to achieve the specified multipolar harmonics. The planned refrigeration system consists of cooled copper plaques surrounding the coils.

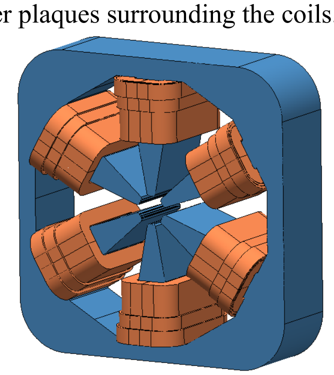

Figure 8. Multifunctional Sextupole with steering coils and skew quadrupole corrections.

Table 4. Main characteristics of the multifunctional sextupole.

Maximum Sextupole integrated field gradient [T/m]	80
Effective length [mm]	150
Bore radius [mm]	27.5
Vertical Steering deflection [mrad]	0.1
Vertical Steering integrated field gradient [T.m]	0.001
Horizontal Steering deflection [mrad]	0.1
Horizontal Steering integrated field gradient [T.m]	0.001
Skew Quadrupole correction integrated field gradient [T]	0.04
Multipolar specification	
B_9/B_3 @28mm	8. 10^{-5}
B_{15}/B_3 @28mm	5. 10^{-5}
Total electrical power [W]	200
Number of sextupoles	200

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