BENDING MAGNETS MADE WITH PERMANENT MAGNETS FOR LNLS-2 ELECTRON STORAGE RING

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Abstract

Some models of bending magnets made with hard ferrite are being designed for the new Brazilian storage ring - LNLS-2. Their main magnetic and mechanical characteristics are presented, as well as a new way to compensate demagnetization effects caused by temperature variation.

DIPOLAR MAGNETS

The electron beam orbit is closed by means of bending magnets, also called dipoles. In the present report, a magnetic lattice containing 48 dipoles is considered. Each super period (Fig. 1) is composed of three dipoles, where two dipoles deflect the beam in 6.5 degrees and one in 9.5 degrees. Dipoles combining homogeneous dipolar fields with gradients - called combined dipoles - are being considered, since LNLS-2 is designed to be a very low emittance machine. Even though insertion devices are the primary source in LNLS-2, its bending magnets are also a very bright source of UV radiation.
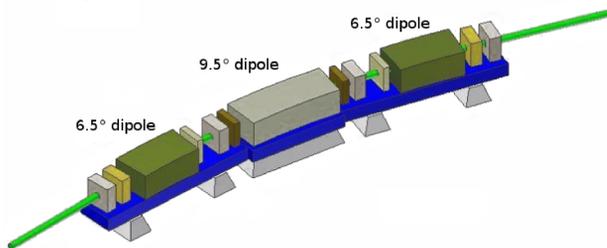

Figure 1: One super period of LNLS-2 Storage Ring, with three dipoles.

The use of permanent magnet technology for construction of the dipole magnets has been proposed a couple of times [1-4] and would present the following potential advantages:

- Considering the desirable field in the air gap (0.45 tesla) and the dipole lengths (2 and 3 meters), the employment of permanent magnets could provide a less costly design, when compared to conventional electromagnetic technology.

- Operational costs, in particular, electricity costs can be drastically reduced.

- Power supply or control system failures will not interrupt the operation of the magnets, improving overall machine reliability.

- Permanent magnets can be made more compact, since there are no coils, which, in general, are larger than the ferromagnetic core. By the same reason, the fringe field drops down faster.

- The magnetic field is held constant, not requiring cycling procedures before electron beam injections, saving time.

On the other hand, some potential disadvantages or challenges related to the use of permanent magnet technology can also be listed:

- Potential risk of demagnetization due to radiation damage. This topic must to be better investigated for Barium or Strontium ferrite under the radiation environment of the LNLS2 storage ring.

- Remanent field variation by thermal effects, reaching 0.2%/°C for ferrites. It will bring the need of some procedure to keep constant the field in the gap. One possibility already used is to shunt the magnetic flux by means of an iron-nickel alloy with low Curie temperature (~ 50 °C).

- A mechanical structure made of non-magnetic material to keep the magnets and polar pieces joined must be developed, as well as a robot to assembly the magnets due to strong forces among them.

- Some difficulties will be introduced for baking and NEG coating activation since temperature increasing demagnetizes the remanent field of magnetic blocks.

Strontium ferrites, with 0.4 tesla of remanent field, are taken as the hard ferromagnetic material, because besides they attend the field specifications, they are also easily found and have low cost. For high permeability and high saturation magnetization, carbon steel was chosen as the soft magnetic material.

MECHANICAL DESIGN

Three models are being proposed: the first one is a straight magnet, whereas the other two are bent magnets (Fig. 2). For the straight magnet, the good field region (±30 mm) must be larger because the sag of the electron beam curvature is added.

Table 1: Main Parameters of the Dipoles

Dipole	6.5°	9.5°
Quantity	32	16
Angular Deflection [deg]	6.5	9.5
Length [m]	2.1	3.07
Minimum gap [mm]	35	35
Field [T]	0.45	0.45
Integrated field [T.m]	0.95	1.38
Sag [mm]	29.8	63.7
Good field region around the central orbit = 1/1000 [mm]	60	60
Good field region around the central orbit = 1/10000 [mm]	20	20
Field repeatability among dipoles [%]	0.1	0.1
Gradient [T/m]	1.25	1.25

The straight dipole is simpler to be manufactured; however, it occupies an area bigger than the bent does. One bent model has armature (steel lateral plate) just in one side to allow vacuum pumping access and freedom to collect the dipole radiation. Table 1 lists the main parameters of both dipoles.

MAGNETIC CALCULATIONS

All 3D simulations were made using the Magnet® code [5]. Pandira [6] was also used for initial analysis in order to find out the pole shapes. The basic midplane design is composed of two side magnets and one top magnet (in the open bent model), which magnetize, in the vertical direction, the central polar piece made of carbon steel. The magnetic field of 0.45 tesla was specified for the central orbit. Around this value, a gradient of 1.25 tesla/m was required.

The field homogeneity was checked through the angular deflections, which correspond to the field integrations over the electron beam trajectories. The trajectory of an electron passing through a dipole and its angular deflection with respect to the longitudinal direction (y-axis) were calculated for different starting points over the x-axis (at the center of the dipole, using its symmetry). For this purpose, the magnetic fields obtained from simulations in *Magnet* were considered. The electrons were launched with energy 2.5 GeV in the *y* direction. The trajectory was numerically calculated by solving the relativistic Lorentz Equations of motion by using *Mathematica* [7]. Once the solution for positions x, y and z was obtained, the angular deflections were calculated considering the relation between the velocity components at points out of the dipole, where the field was negligible, and the field integral over the trajectory.

In this way, homogeneity has been defined as the maximum variation of the angular deflection inside the good field region, after subtracting a sloped straight line from the graph where the angle is plotted as a function of the transverse beam position. Figure 3 illustrates the angular deflection, for the open bent magnet, with gradient and after the gradient subtraction.
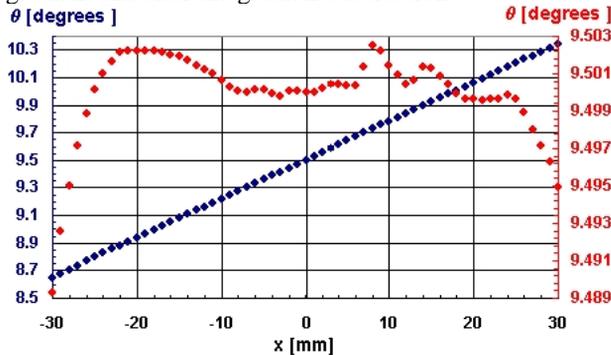

Figure 3: Graphs showing the angular deflection caused by the 9.5° dipole (left Y-axis) and the angular deflection after a perfect gradient is subtracted (right Y-axis). This last graph can be taken as a reflex of the field homogeneity.
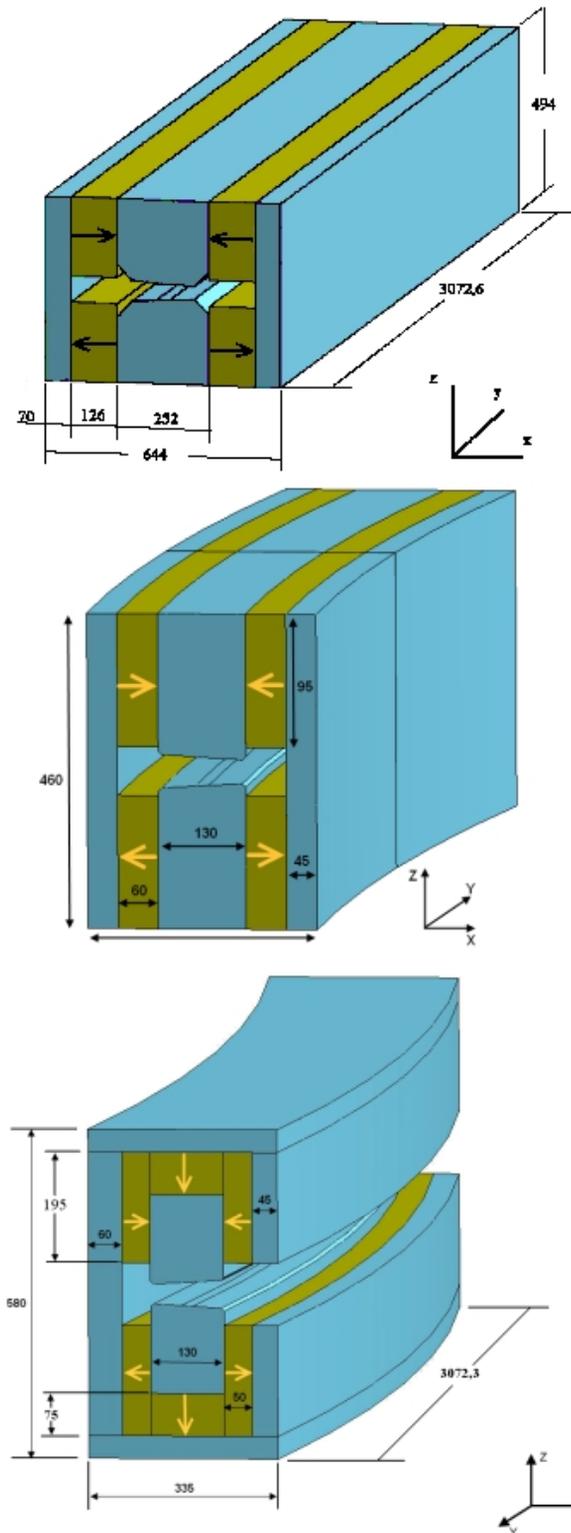

Figure 2: Mechanical design of the 9.5-degree dipole showing three different models: straight, bent with two external armatures and bent with one armature. Dimensions are in mm. The arrows indicate the magnetization direction of ferrite blocks. Dimensions are the same for the 6.5-degree model, except for the straight model, in which they are a little smaller.

An interesting question arises from the straight model. As the magnet has a gradient and being this field kept transversally constant, the field felt by the beam in a perfect orbit is changing for every longitudinal position. The same does not happen for the bent dipole: a perfect beam displaces in a line of constant field. However, the straight model can have the same behavior of the bent one if some adjustments are made. As the average field felt by the beam goes stronger than in the bent model causing a larger deflection, we can shift the value of the field by a small amount in order to compensate this extra deflection. Simulations for hard-edge model showed us that, for the 6.5-degree dipole, a field about 97.3 % of the original value produces the same deflections for all transverse beam positions inside the good field region. We still have the same slope for angular deflections as a function of beam starting transverse positions. Furthermore, the final positions of electrons at the end of the dipole have an offset of 0.50 mm when compared to the positions at the end of the bent dipole. This effect can be easily corrected by a transverse dipole displacement of -0.50 mm, the same happens for the 9.5-degree straight dipole. In this case, the constant term of the field required to keep the same angular deflections is about 94.3 % of the bent dipole value. The electron positions at the end of the dipole are now shifted 1.99 mm from where they would be if calculated in the bent model.

MAGNETIC FIELD COMPENSATIONS

In dipoles made with permanent magnets the field stability essentially depends on the effect of the temperature on the remanent and coercive fields. In other words, once the temperature changes in the magnetic blocks it brings variations to the remanent fields, changing the field in the gap consequently. A mechanism to maintain the field in the gap constant is demanded in order to compensate this thermal effect. One way to solve this thermal behavior is by using magnetic flux shunts [1,4]. Also a mechanical compensation using materials with different expansion coefficients is being studied as an alternative for the same purpose (Fig. 4). The expansions of these two different materials move the carbon steel blocks placed in the dipole back side, controlling a small air gap (less than 1 mm). An initial gap could adjust the magnetic field in such a way to guarantee the required repeatability of 0.1% among all dipoles. A sorting procedure for the magnetic blocks must be done, independently of this mechanical tuning availability.

CONCLUSIONS

Preliminary designs were presented showing the viability of dipoles made with permanent magnetic materials, like ferrite, for the next Brazilian Synchrotron Light Source (LNLS-2). Three different models were analyzed, as well as a new mechanical way to compensate the influence of the temperature on the remanent field of the ferrite blocks.
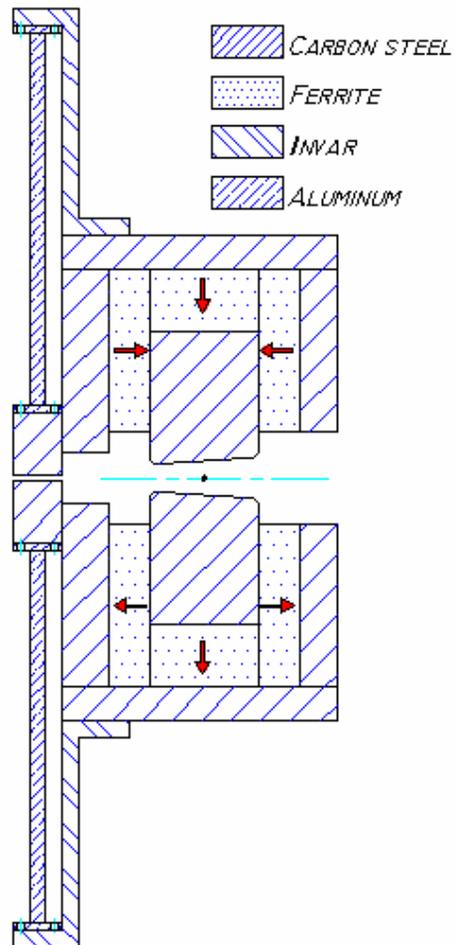

Figure 4: Mechanical construction proposed to compensate the magnetic changes caused by temperature variations.

REFERENCES

[1] G. W Foster, Experience with Permanent Magnets in the FermiLab 8 GeV Line and Recycler Ring, Proceedings of the 1998 European Particle Accelerator Conference, Stockholm, p. 189.

[2] G. Li et.al., Permanent Magnet vs. Electromagnet Dipoles for Synchrotron Radiation, Proceedings of the 2001 Particle Accelerator Conference, Chicago, p. 3224.

[3] F. Hellberg et. al., Low Power consuming Hybrid Bending magnet at XFEL Beam Dump, Proceedings of the 2007 International Free Electron Laser Conference, Novosibirski, p. 435.

[4] E. Nakamura et al, Permanent Magnets for the 500 MeV Accumulator Ring of the Intensity Doubler Project in KEK-PS, Proceedings of the 2001 High Energy Accelerators International Conference, Tsukuba, Japan.

[5] *Magnet* 6.13, Infolytica Corporation.

[6] *Pandira-Poisson Superfish*, Los Alamos Accelereator Code Group.

[7] *Mathematica* 6, Wolfram Research.