LNLS-2: A NEW HIGH PERFORMANCE SYNCHROTRON RADIATION SOURCE FOR BRAZIL

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Abstract

We present an overview of a new synchrotron radiation source currently being designed at the Brazilian Synchrotron Radiation Laboratory (LNLS) in Campinas. The LNLS-2 light source will consist of an injector system and a low emittance 2.5 GeV electron storage ring capable of delivering undulator radiation with exceptional brightness in the few hundred eV to several tens of keV photon energy range. High flux radiation up to 100 keV will also be available with the use of superconducting wigglers.

WHY A NEW SYNCHROTRON LIGHT SOURCE IN BRAZIL?

Brazil developed its own technology for the production of synchrotron light, designing and building LNLS-1, the first synchrotron light source in the southern hemisphere (still today the only one in Latin America). Along over 10 years of routine operation for users, not only were relevant scientific results obtained with the use of the source (reaching in 2007 222 papers published in refereed journals, equivalent to 1.5% of the Brazilian scientific production, all fields of research included), but also the LNLS installations have undergone continuous improvements and upgrades, reaching performance levels significantly higher than originally foreseen in its design. However, over the past years, the expansion capabilities for the LNLS-1 light source, either in terms of new beamlines or upgrades to its accelerators have come close to physical limits which can no longer be overcome. In order to keep the competitiveness of the Brazilian scientific and technological community over the next decades, it is fundamental to provide it with tools that enabled the analysis of materials at the molecular and atomic scales under increasingly more demanding conditions from the experimental point of view. In the case of synchrotron radiation, this means providing light beams which are much brighter than what can currently be obtained at LNLS, which can be focused down to sub-micrometer spots and reach the more penetrating hard x-ray region of the electromagnetic spectrum with controllable time structure and polarization properties. All of this can only be made possible by the construction of a new synchrotron light source with higher energy and larger circumference.

GENERAL REQUIREMENTS FOR A NEW LIGHT SOURCE AT LNLS

The experience gathered along 11 years of operation of LNLS-1 and the resulting interaction with the LNLS user community allows us to establish a preliminary set of requirements to be satisfied by the future LNLS-2. These requirements are based on the experimental and instrumental demands determined from the various scientific cases [1] listed by the LNLS in-house scientific staff and in several aspects represent a natural evolution of the performance parameters of the existing light source, in particular, the source intensity, spectral coverage, brightness, stability, control over radiation time structure and polarization.

General Characteristics

- LNLS-2 should be designed to meet the present and future (time scale of 15 to 20 years) demands of the Brazilian and Latin-American scientific communities in synchrotron radiation based characterization techniques.
- The LNLS-2 design must consider the possibility of future upgrades to new concepts not yet completely established such as the so called fourth-generation sources. Examples include Free Electron Laser in the Injector LINAC, Coherent Harmonic Generation in the storage ring and an Energy Recovery LINAC.
- The LNLS-2 design must consider the possibility of manufacturing a significant fraction its components in Brazil, emphasizing the involvement of Brazilian industry.
- High priority must be given to obtaining high reliability of the facility (comparable to the reliability reached in the present source). This implies reaching an adequate balance between using new high performance technologies versus resorting to well know and previously demonstrated technical solutions: the design must be conservative where possible without compromising the required performance.
- The LNLS-2 design must be optimized with respect to both capital investment and future operational costs, taking into account the increasing costs of electricity.
- Proper consideration should be given to making the most out of the existing LNLS infrastructure in reducing capital investment costs for the project.

Synchrotron Radiation Characteristics

- LNLS-2 must be designed to generate high brightness beams, comparable or higher than what can be achieved in present day third-generation sources. This implies a storage ring design to reach very low emittance– on the order of or below 1 nm.rad.
- LNLS-2 must be capable of providing – with the use of a combination of conventional permanent magnet, in-vacuum and superconducting undulators – optimal

photon beam brightness above 10^{21} photons/sec/0.1%bandpass/mrad^2/mm^2 in the 1 to 20 keV photon energy range.

- LNLS-2 must also be capable of producing high brightness in excess of 10^{19} photons/sec/0.1%bandpass/mrad^2/mm^2 in the 100 eV to 1 keV spectral range.
- LNLS-2 must also be capable of generating high flux radiation (e.g. using superconducting wigglers) up to 100 keV.
- LNLS-2 must provide high transverse coherence up to about 10 keV.
- The LNLS-2 design must consider the need for manipulation of the radiation time structure allowing various storage ring filling modes.
- The LNLS-2 building design must allow for the construction of very long (about 100 m) beamlines.
- Priority must be given to obtaining high photon beam stability.

Accelerator System Characteristics

- The injector system must be full energy, so as to allow the implementation of top-up injection, resulting in an essentially infinite lifetime even in conditions of restricted aperture for the electron beam.
- Intensive use of narrow gap undulators, including in-vacuum undulators and superconducting undulators and use of damping wigglers to reduce emittance for a given machine circumference.
- Large scale use of small aperture permanent magnet technologies for the lattice magnets should be analyzed as a potentially cost effective alternative to conventional electromagnets.
- Use of a superconducting RF system should be considered to reduce power consumption and Higher Order Mode (HOM) related effects. Solid state amplifiers should be considered as potential candidates for the RF power source.
- Large scale use of NEG-coating of vacuum chambers and high conductivity materials (e.g copper) should be considered.
- High reliability and stability requirements translate into system redundancy and tight component tolerances.

These latter requirements, related to the accelerator system characteristics are probably the most uncertain at this moment and are most likely to change as the detailed design progresses. In particular, the use of permanent magnets is still highly speculative at this point and further engineering and economic analyses must be done.

LNLS-2 PARAMETER LIST AND GENERAL LAY-OUT

In an insertion device based light source such as LNLS-2, the properties of the radiation produced, in particular the photon spectral range covered by the machine and the photon beam brightness, depend on the characteristics of each specific insertion device (peak field, period length and total length) and on the energy, intensity and the equilibrium electron beam dimensions (in the horizontal, vertical and longitudinal planes). These equilibrium dimensions are in turn determined by the magnet lattice, whereas the characteristics of the insertion devices, in particular the relationship between the peak field, period length and magnet gap are determined by technological limitations or by the properties of materials used in their fabrication. Moreover, the maximum length of these devices (or conversely the number of periods) is limited by the available longitudinal space in the storage ring straight sections.

The need to produce high brightness radiation up to about 20 keV and available insertion device technology result in a choice of beam energy on the order of 2 to 3 GeV. A higher beam energy would enable the production of harder bright radiation at the expense of generating lower brightness for longer wavelengths as a result of the need to go for longer period length undulators which would mean a smaller number of periods can be made to fit into a straight section of a given length. For the present LNLS-2 lattice design study, we assume an electron beam energy of 2.5 GeV.

Once the electron beam energy is defined according to the reasoning presented above, there still remains the issue of determining the basic geometry of the magnet lattice responsible for recirculating the electron beam and providing the necessary focusing. That choice is constrained by the high brightness requirements that translate into the need for a low emittance lattice design. For typical lattice types, reaching a 1 nm rad emittance at 2.5 GeV implies using about 40 to 50 dipoles for bending. Even though the brightness/emittance requirements impose restrictions on the total number of periods in the storage ring, many alternatives are possible for the choice of lay-out for the magnet lattice and its deflecting magnets. In particular, there is no a priori condition on the intensity of the bending field in those magnets.

Table 1: LNLS-2 Parameter List

Parameter	Value
Beam Energy	2.5 GeV
Beam Current	500 mA
Bending Field	0.45 T
Natural Emitt. (No Damp. Wigg)	2.6 nm.rad
Natural Emittance(Damp. Wiggl.)	0.8 nm.rad
Circunference	332 m
Number of Dipoles	48
Critical Energy (dipoles)	1.87 keV
Harmonic number	554
RF frequency	500 MHz
RMS Hor. Beam Size @ Insertion	162.9 μm
RMS Vert. Beam Size @ Insertion	3.4 μm
Synch. Rad. Power From Dipoles	93 kW
Synchrotron Radiation Power	384 kW

However, the choice of bending field has important consequences on the overall machine dimensions and resulting investment and operation costs and also depends on the available magnet construction technologies. In the present LNLS-2 design we have chosen the relatively low field for the bending magnets of 0.45 T. This choice was made for two reasons. First, the use of low bending fields allows an efficient use of damping wigglers to further reduce the electron beam emittance and increase the radiation brightness. This choice also helps reduce the requirements on the RF and vacuum systems as the total beam power and corresponding synchrotron radiation induced gas desorption rate is reduced.

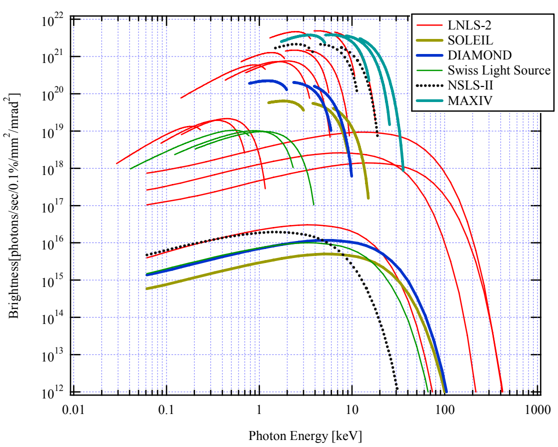

Figure 1: Brightness from various insertion device and bend magnet sources at LNLS-2 (red curves) and from a typical devices in other sources.

Moreover, the use of low field bend magnets also opens up the possibility of large scale use of permanent magnet technology for the lattice magnets. Even though permanent magnets are routinely used in many synchrotron sources in wiggler and undulator insertion devices, its large scale use in lattice (dipole, quadrupole, sextupole) magnets is much less common. However, for LNLS-2 this may be a very attractive option to reduce the investment and operation costs with the elimination (or significant reduction of) of power supplies and cooling systems [2].

Table 1 shows a preliminary LNLS-2 parameter list defined following the reasoning outlined above. Fig. 1 shows the brightness to be expected at LNLS-2 from various insertion devices and Fig. 2 shows an overview of the proposed LNLS-2 facility.

The LNLS-2 magnet lattice is a 16-cell triple-bend achromat (TBA), with a circumference of 332.2 m and 16 equally long (7 m) dispersion-free straight sections for insertion devices and machine utilities, which include, apart from the injection and radiofrequency systems, two damping wigglers to lower the emittance (which are also very intense sources of hard x-rays). Matching between the straights and arcs are performed by quadrupole doublets. To achieve a small electron beam emittance the TBA arcs are optimized by using transverse field gradients in the dipoles and a longer length for the middle dipoles. We can reach with this lattice (and damping wigglers) a natural emittance of 0.8 nm.rad for a beam energy of 2.5 GeV. The optical functions for one superperiod are plotted in Figure 3 below.

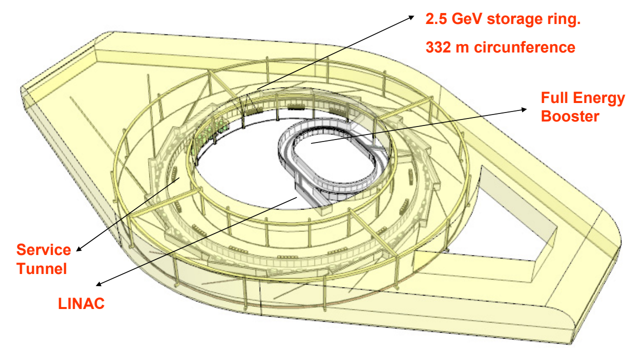

Figure 2: Preliminary general lay-out of the LNLS-2 light source.

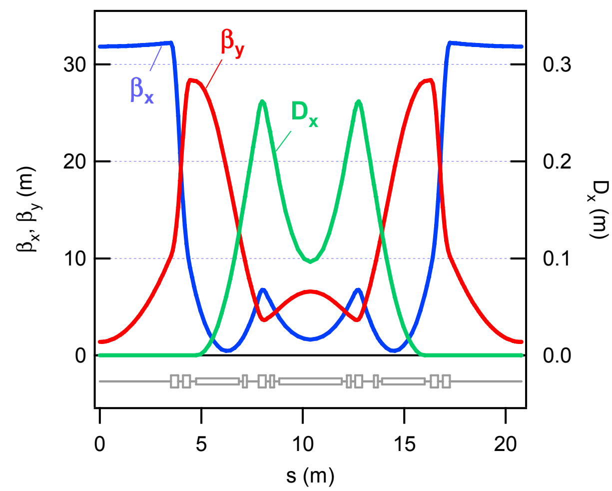

Figure 3: Lattice Functions for the LNLS-2 Light Source.

CONCLUSIONS

We have presented the basic design considerations and parameters for a new proposed light source at LNLS, with special attention to providing solutions for the realization of low emittance which are cost effective regarding both the construction investment as well as the operation of the facility. In particular, the large scale use of permanent magnet technology for the lattice magnets is being considered. Partial funding for the preparation of a detailed Conceptual Design report has been recently obtained for the Brazilian Ministry of Science and Technolgy.

REFERENCES

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