MAGNETIC DESIGN AND LIGHT CHARACTERISTICS OF A WIGGLER FOR THE LLS

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Abstract

In this paper we present the theoretical design of a wiggler for the LLS storage ring, to be built in Barcelona, as it is described in the design report. This wiggler, dubbed W120, will provide photons from 4 to 26 keV, which are the main needs of the Spanish scientific community in the X-ray range. The constraints of the design are given by the LLS storage ring characteristics and the proposed types of experiments foreseen at the LLS. This wiggler is 4.5 m long, the gap is 2 cm wide, and it is made of blocks of NdFeB permanent magnet and FeCo (50%) blocks to achieve high peak magnetic field. The calculation of the field and the optimisation of the wiggler are made with the code OPERA-2d whereas the characteristics of the resulting light are studied with the LUX and SHADOW codes.

1. INTRODUCTION

From a survey carried out among the potential user community of the LLS [1] it can be concluded that the LLS should provide facilities for research over a broad range of disciplines (e.g. Physics, Chemistry, Materials Science and Biology). It can also be concluded that to carry out this research synchrotron light (SL) should be provided over a range spanning photon energies from the IR (< 1eV) to the intermediate energy X-ray region (ca. 25 keV). In the soft X-ray region, i.e. in the energy range from 50 eV to ca. 2000 eV, high brightness synchrotron light (SL) should be available, and therefore undulators are needed [2]. In addition, the BMs at the LLS should provide high quality light with energies up to ca. 15 keV. Finally, those users requiring high intensity SL in the X-ray region extending from ca. 4 to 26 keV (i.e. from the K-edge of Ca to that of Ag) can be catered for by MPWs.

In this paper we present the theoretical design of a generic wiggler, dubbed W120, for the LLS storage ring, which will be capable of covering these needs. The main parameters defining this design are listed in table 1.

2. CHOICE OF THE MPW

The primary criteria with which to define the characteristics of the MPWs must be the needs of the user community as well as the features of the LLS storage ring. Altogether we have defined the following constraints:

- MPWs have to optimally cover the X-ray spectrum from the K edge of Ca (4038 eV) to the K edge of Ag (25514 eV). Here, we define the spectral range to be optimal when either the flux (photons/s/0.1%BW) or the brightness (photons/s/mm^2/mrad^2/0.1%BW) are within 1/10 of their maximum value
- MPWs with a length of 4.5 meters length meters because of manufacturing reasons.
- To achieve high enough peak magnetic fields we shall use hybrid magnets.
- The minimum MPW gap should be 2 cm. This is the best compromise between MPW performance and electron beam lifetime.

Within these criteria the variables of a MPW design are materials, pole geometries, period lengths and magnetic block heights.

With only one generic MPW design of the W120 type, which we describe below, the LLS will be capable to satisfy the constraints imposed above. Different units of the same design can be placed in the storage ring to cover most of the demanded techniques requiring this energy range.

However, there is the possibility that in future more exotic MPWs may be installed to cover more specific needs

Table 1. Main parameters of the IDs for the LLS

. Name	ε	λ_w	g	N_p	L	B_0	K	h
	Useful energy range	period length	gap	number of periods	ID length	Magnetic induction	ID const.	Block height
	[keV]	[mm]	[cm]	[#]	[m]	[T]	[#]	[cm]
W120	4-26	120	2	36	4.32	1.634	18.3	8

3. OPTICAL CHARACTERISTICS OF THE W120 MULTIPOLE WIGGLER

3.1. Flux and brightness

The spectral flux per horizontal angle and spectral brightness for the W120 are shown in Figures 1 and 2, respectively. These are compared with the flux and brightness delivered by the BMs of the LLS storage ring. From the point of view of the flux this MPW has an excellent behaviour as it remains above 10^{14} ph/s/mrad/0.1%BW in the whole of the useful range. The brightness is over $3{\cdot}10^{16}$ photons/s/mm^2/mrad^2/0.1%BW throughout the whole energy range and also remains practically constant in the useful range. This constancy is important for the control of the experimental equipment.

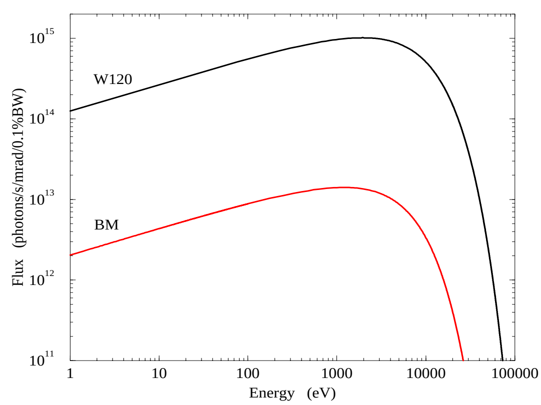

Figure 1. Spectral flux of LLS W120 multipole wiggler compared with the bending magnet brightness.

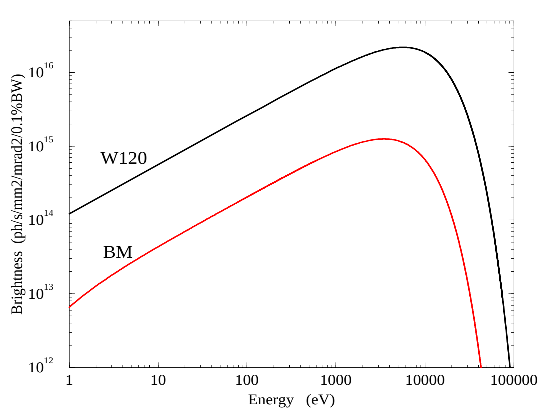

Figure 2. Spectral brightness of LLS W120 multipole wiggler compared with the bending magnet brightness.

3.2. Sizes and divergences

The horizontal fan of light delivered by W120 is ca. 7 mrad (see Figure 3), allowing to feed 2 beamlines comfortably. The electron beam undergoes a horizontal oscillation of ca. 143 µm. The horizontal and vertical source dimensions are essentially independent of the photon energy and, including the effect of the horizontal oscillation, amount to ca. 350 and 46 µm, respectively. The photon source is drawn with the SHADOW code [3] in figure 4. The vertical divergence depends on photon energy. At energies of 4, 12 and 26 keV it corresponds to 175, 97 and 64 µrad respectively.

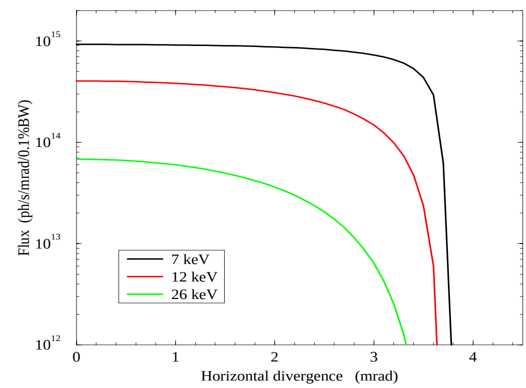

Figure 3. Flux versus the horizontal opening angle for light emitted by W120 at 3 different energies.

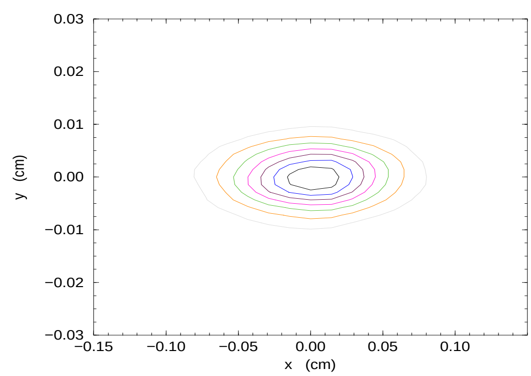

Figure 4. W120 source size. The lines correspond to points with the same intensity. Every region between 2 contours includes 1/8 of the total radiation.

4. MAGNETIC DESIGN OF THE W120 MULTIPOLE WIGGLER

4.1. Design of the basic cell.

We have concluded that the current objectives for the quality of the light can be achieved with the use of permanent magnets and soft magnetic materials (i.e. hybrid MPWs), disregarding the option of using either pure permanent magnets or electromagnetic poles. As things are today, hybrid MPWs can reach a higher peak value for the magnetic field, good magnet compactness, reasonable cost and they can deliver an excellent light emitting performance.

To make the hybrid wigglers with the desired strength one must use materials, like SmCo or NdFeB alloys, with high remanent magnetic induction (B_r), and soft materials with a high saturation induction (B_{sat}) and high relative permeability (μ_r>>1). The materials we propose for the W120 are listed below.

Table 2. Characteristics of the materials to be used at the W120 multipole wiggler

Soft iron (Co-Fe 50%)		Permanent magnet (NdFeB alloy)	
B_{sat}	μ_r	B_r	$(B{\cdot}H)_{max}$
2.35 *T*	6000	1.41 *T*	385 *kJ/m*^{3}

The first step is to define the basic cell. We have made extensive use of the finite element analysis code OPERA-2D because the soft iron is magnetically non-linear and therefore analytical methods are not suitable.

Maximum peak field (B_0) and minimum cost are conflicting requirements because high fields increase the block height, thus the cost. We found that a good compromise occurs when using rectangular blocks and h/λ_w = 2/3 is met. Once the h/λ_w = 2/3 was applied as a constraint we are left with 6 geometrical parameters of the poles susceptible to variation. By inspecting the behaviour of the magnetic field in the y-s plane over one half period, we converged to the best geometry compatible with our requirements (see figure 5).

4.2. *W120 field quality.*

Figure 5 shows the distribution of the magnetic induction lines for a basic cell with the dimensions arrived at above.

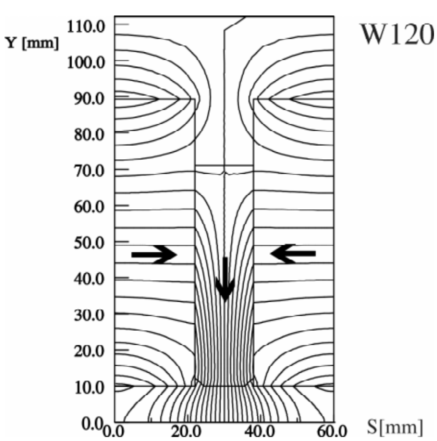

Figure 5. Half cell of the optimised W120 multipole wiggler. The lines are the induction lines as calculated with OPERA-2D. The central piece is the pole and the surrounding pieces are the PM blocks.

The resulting field of this basic cell is shown in figure 6. The field profile is not sinusoidal and a harmonic analysis reveals that the 3rd and the 5th harmonics are 13 % and 1.3 % of the 1st one, respectively.

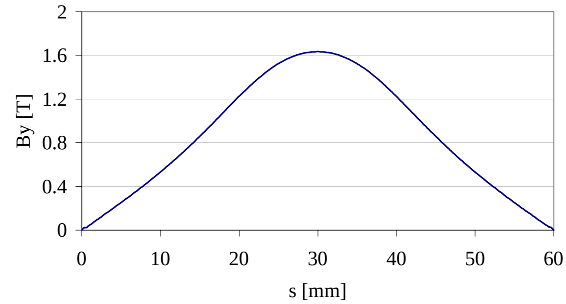

Figure 6. Field profile in a half cell along the electron path.

5. CONCLUSIONS

With only one generic MPW design, the LLS is able to satisfy the constraints imposed from the users needs and the machine characteristics. Using 3 units of the proposed wiggler design, we can cover the intermediate X-ray range likely to be needed by the first generation of LLS users.

The horizontal divergence of the light fan permits the wiggler to hold two beamlines easily. The resulting flux and brightness at 8 keV are over 10^{15} ph/s/mrad/0.1%BW and $2{\cdot}10^{16}$ ph/s/mm^2/mrad^2/ 0.1%BW, respectively.

The magnetic design of the basic cell is the best compromise in field performance and cost. The peak magnetic field value, B_0=1.634 T, exceeds comfortably that in the BMs.

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