MAGNETIC DESIGN AND LIGHT CHARATERISTICS OF THE LLS UNDULATORS

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Abstract

In this paper we present the theoretical design of two undulators for the LLS storage ring, to be built in Barcelona, as they are described in the design report. These undulators, called U73 and U44, will cover the needs of the Spanish scientific community in the soft X-ray range (50-2000 eV). The constraints of the design are given by the LLS storage ring characteristics and the proposed types of experiments foreseen at the LLS. The design of the undulators is based on the use of the 1st, 3rd and 5th harmonics, they are 4.5 m long and the gap can range from 2 to 5 cm. The undulators will be made of NdFeB permanent magnet blocks to achieve high peak field and sinusoidal profile. The calculation of the field and optimization of the undulators are made with the codes PMU3d and OPERA-2d. The characteristics of the resulting light are studied with the codes LUX and SpontLight.

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 SL should be provided over a range spanning photon energies from the IR (< 1eV) to the intermediate energy X-ray region (ca. 25 keV). The BMs and multipole wigglers at the LLS should provide high quality light with energies up to 26 keV [2]. 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.

In this paper we present the theoretical design of two planar undulators, dubbed U73 and U44, for the LLS storage ring, which will be capable of covering the needs of the Spanish scientific community. The main parameters defining this design are listed in table 1.

2. CHOICE OF UNDULATORS

To satisfy the currently perceived needs of the LLS´s user community with the minimum number of undulators, at a minimal cost and within the limitations imposed by the LLS characteristics and geometry, we apply the following constraints:

- To produce high brightness soft X-rays in the region 50-2000 eV. Here we define the useful spectral region of undulator utilisation as that where flux (photons/s/0.1%BW) and brightness (photons/s/mm^2/mrad^2/0.1%BW) do not drop by more than 1/10 of their values at the energy of maximal emission.
- A length of 4.5 meters because of manufacturing and optical reasons.
- Magnetic period made from 4 blocks to achieve an optimal sinusoidal magnetic field.
- Minimum undulator gap of 2 cm. This is the best compromise between undulator performance and electron beam lifetime.
- We base the design on the study of the 1st, 3rd and the 5th harmonic only.
- By tuning the undulators, the energies from the various harmonics should overlap.

The length of the magnetic period and the height of the magnetic blocks are the variables one can play with to satisfy these constraints.

Table 1. Main parameters of the undulators for the LLS

Name	ε	$\lambda_{u,w}$	N_p	L	B_0	K	h
	Energy (1st & 3rd harmonics)	period length	number of periods	length	B at 2 cm gap	ID const.	Block height
	[eV]	[mm]	[#]	[m]	[T]	[#]	[cm]
U73	47-750, 142-1600	73	60	4.38	0.812	5.66	1.825
U44	360-1310, 1077-2700	44	102	4.488	0.558	2.34	2.2

3. OPTICAL CHARACTERISTICS OF U73 AND U44 UNDULATORS

Figure 1 compares the output spectral brightness of these undulators with that of the BMs. Note that values of the spectral brightness typical of 3rd generation SL sources, i.e. 10^{18}-10^{19} photons/s/mm^2/mrad^2/0.1%BW, are achieved. The gap can change between 2 and 5 cm, therefore good tunability is achieved with large overlap between harmonics, as well as between both undulators. Figure 2 shows their output spectral flux in the central cone. Note that using only up to the 5th harmonic the spectral flux can be kept over 10^{15} photons/s/0.1%BW in the whole of the desired range.

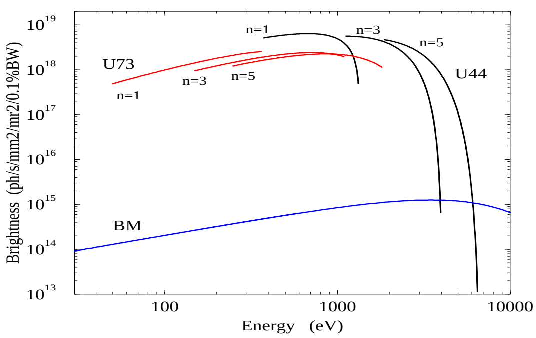

Figure 1. Spectral brightness of LLS undulators U73 and U44 compared with the bending magnet brightness.

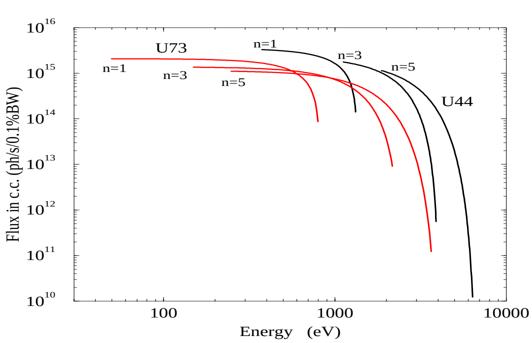

Figure 2. Spectral flux in central cone of LLS undulators U73 and U44.

In figures 3 and 4 we show the flux at minimum gap calculated with the SpontLight code [3]. The harmonic contents is high because of the high value of the ID parameter *K*.

The sizes of undulator light sources are practically constant over the whole of their tuning ranges. Their rms value amount to ca. 350 µm and 46 µm in the horizontal and vertical direction, respectively. The rms divergence of the undulator light for the first harmonic and at minimum gap (i.e. the worst case) are ca. 40 µrad and 17 µrad for the U73 and U44 undulators, respectively.

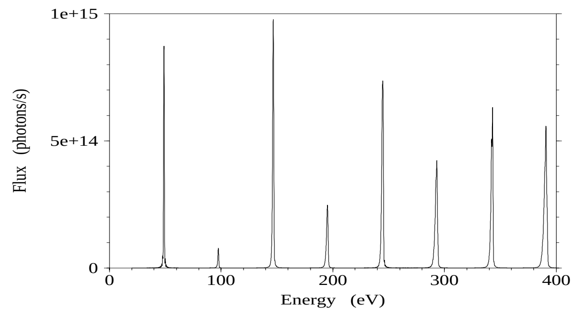

Figure 3. Spectral flux of U73 undulator at 2 cm gap in 100 µrad in each direction

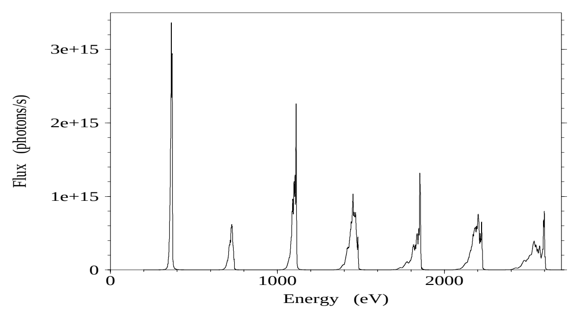

Figure 4. Spectral flux of U44 undulator at 2 cm gap in 100 µrad in each direction.

4. MAGNETIC DESIGN OF THE U73 AND U44

4.1. *Materials choice*

We have chosen the *pure permanent magnet* (PPM) approach because even though hybrid undulators can reach higher fields and their field quality (in terms of approaching a sinusoidal pattern) is not so dependent on the properties of the material, the field quality in PPM undulators is easier to achieve by sorting and shimming the blocks. Moreover, the design and field calculations of PPM undulators are simpler.

To produce the required magnetic fields we propose that the best commercially available material (in terms of magnetic energy and hardness) should be used. In the current state of the technology this means the use of NdFeB alloys, with a remanent induction B_r = 1.41 T. We have ignored SmCo alloys, because they have lower remanent induction and worse mechanical properties.

4.2. *Design of the basic undulator cell*

The design of the 2-dimensional basic undulator cell is the first step in the evolution towards the final detailed design. To this end we have calculated the cell characteristics using both analytical expressions and finite element analysis methods with OPERA-2d (see figure 5).

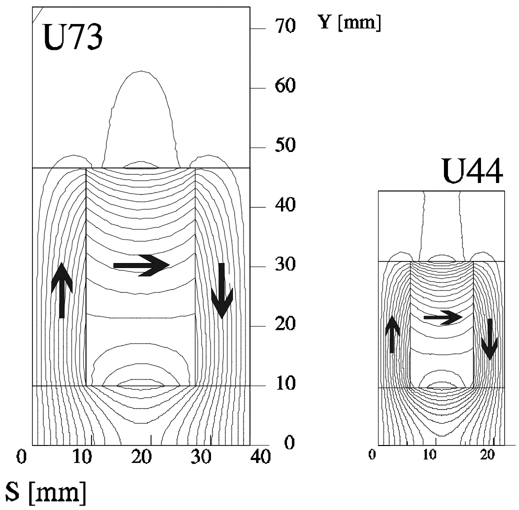

Figure 5. Basic cell of the U73 and U44 undulators.

4.3. Undulator field quality.

Using OPERA-2d and with a gap of 2 cm, we have found that the peak fields in the undulator axis are $B_0(U73)$ = 0.8125 T and $B_0(U44)$ = 0.5578 T. A Fourier analysis of the magnetic field $B_y(s)$ of U73 and U44 undulators shows the quality of the field produced by the basic cell of the U73 and U44 designs (figure 6). Essentially one can say that the magnetic field is sinusoidal because higher order harmonics are smaller than 1% in relative units.

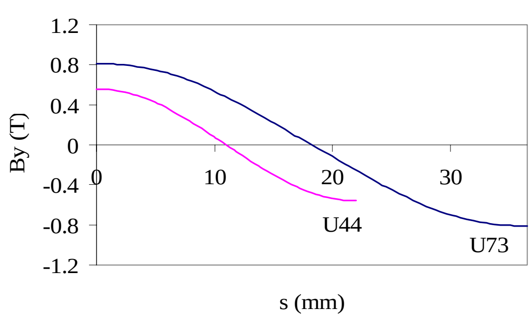

Figure 6. Field profile along the beam path for the U73 and U44.

The 1st field integral of both U73 and U44 undulators is ca. 1 Gauss-m and should/will be corrected by dedicated correcting coils installed at both ends of the IDs. The 2nd field integrals vanish because the correct position of the poles produces a magnetic field along *s* which is an even function. Therefore, the U73 and U44 are not expected to produce any closed orbit distortion for on-axis particles.

To translate and optimise the 2D undulator cell into a 3D design we used the analytical code PMU3D [4]. The horizontal stability of the field of the U73 and the U44 has been calculated for the most critical condition, i.e. for a maximum gap of 5 cm. The calculations indicate that the variation of the vertical magnetic field component along the horizontal direction (x), at the height of the nominal orbit, is very adequate for the proper operation of the device, as shown in figure 7. The magnetic field component in the *x* direction, B_x, is essentially zero and, therefore, we do not expect any vertical excursions of the electron beam as it propagates along the undulators.

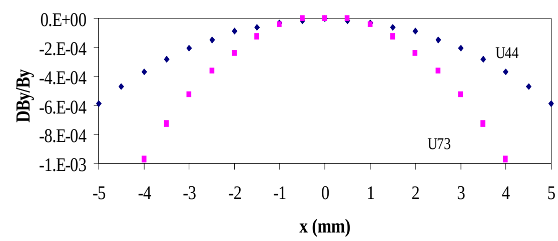

Figure 7. Relative transverse field uniformity of the LLS undulators at a gap of 5 cm.

5. CONCLUSIONS

The LLS will able to cover the whole soft X-ray range likely to be used by the first generation of LLS users with only two undulators. They are planar, made of NdFeB and designed to have both good optical quality (brightness, tunability, source dimensions) and simple magnetic design. The magnetic field quality seems easy to be achieved. They can be manufactured with available technology at a reasonable cost.

The brightness is greater than 10^{18} ph/s/mm^2/mrad^2/0.1%BW in almost the whole energy range for both undulators.

Given that IDs are easily exchanged from the storage ring, more specialised designs could be introduced at a later date if and when needed.

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