CIRCULAR POLARIZATION CONTROL FOR THE LCLS BASELINE IN THE SOFT X-RAY REGIME

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Abstract

Several schemes have been discussed to obtain soft-polarization control in the context of the LCLS. We propose a novel method to generate 10 GW level power at the fundamental harmonic with 99% degree of circular polarization from the LCLS baseline. Its merits are low cost, simplicity and easy implementation. As in previously proposed methods, the microbunching of the planar undulator is used here as well. After the baseline undulator, the electron beam is sent through a 20 m long straight section, and subsequently through a short helical (APPLE II) radiator. The microbunching is easily preserved, and intense coherent radiation is emitted in the helical radiator. The background radiation from the baseline undulator can be suppressed by letting radiation through horizontal and vertical slits upstream the helical radiator, where the radiation spot size is about ten times larger than the electron bunch transverse size. Electrons are bypassed using a short chicane before the slits. Other facilities e.g. LCLS-II or the European XFEL may benefit from this work as well, due to availability of sufficiently long free space at the end of undulator tunnel. **These proceedings are based on the article [1], to which we address the interested reader for further information and references.**

INTRODUCTION

There is an increasing demand for circularly-polarized X-ray pulses at the LCLS, especially in the soft X-ray region and, in particular, in the spectral range between 550 eV and 900 eV, which covers many important absorption edges of transition metals like Cr, Mn, Fe, Co, Ni. The relevance of these metals is evident if one reminds, for example, that the elementary ferromagnetic Fe, Co, Ni, form a basis for information storage. The LCLS covers the photon energy range down to 550 eV, so that the region between 550 eV and 900 eV can now be generated by the LCLS baseline at the fundamental harmonic. Several schemes using helical undulators have been proposed for polarization control at the LCLS (see references in [1]). The SASE process already provides electron beam microbunching, and the microbunches radiate coherently when passing through an helical undulator tuned at the same radiation wavelength. Therefore, it is not necessary that all the undulators in the line be helical. Along these lines of reasoning, all schemes proposed up to now exploit the microbunching of the planar undulator, and make use of a short helical radiator at the end of the undulator beamline. However, the exploitation of planar undulators leads to background problems, since the linearly-polarized radiation should be suppressed. It has been proposed (see [1] for references) that the radiation in the helical radiator can be tuned to the second harmonic (second harmonic afterburner helical radiator), and is therefore characterized by a different frequency compared to the linearly polarized radiation, tuned at the fundamental. However, for the LCLS this option can be extended only down to 1 keV and cannot cover the most interesting region between 550 eV and 900 eV. Another possible solution is based on the use of APPLE III type undulator modules (see references in [1]). At the LCLS, saturation of the linearly polarized radiation at 1.5 nm is reached after 6 undulator modules, and the power at saturation is about 10 GW. In order to reduce the linearly-polarized background, and to reach a degree of circular polarization larger than 95% , APPLE III undulators need to be installed before the linearly polarized output reaches the 0.1 GW power level, i.e. one needs to install three undulator modules. The main drawback of this scheme is constituted by the technical challenge of producing long helical insertion devices, since APPLE III type undulators have not yet come into operation. Here we consider a third option, which mainly consists of sending the electron beam, after the passage through the baseline undulator and through the second harmonic afterburner undulator (SHAB) (rolled away), through a short helical radiator. We propose a filtering setup consisting of a pair of water cooled slits for X-ray beam filtering and of a few-m-long magnetic chicane, which creates an offset for slit installation immediately behind the helical radiator. Electrons and X-rays are separated before the slits by the magnetic chicane, so that the electron beam can pass by the filtering setup without perturbations. We demonstrated by simulations performed with the code GENESIS (see references in [1]) that in order to transport the microbunched electron beam through the 20 m-long straight section corresponding to the five SHAB undulator modules, it is sufficient to use, as a focusing lattice, the existing SHAB undulator FODO system with usual 10 m betatron function function. The new setup is extremely compact, and is composed of as few as three simple elements: a 5 m-long APPLE II undulator module, slits and a magnetic chicane.

CIRCULAR POLARIZATION CONTROL SCHEME WITH SPATIAL FILTERING

The principle upon which our scheme for polarization control is based is straightforward, and is illustrated in Fig. 1 and Fig. 2. The electron beam first goes through the

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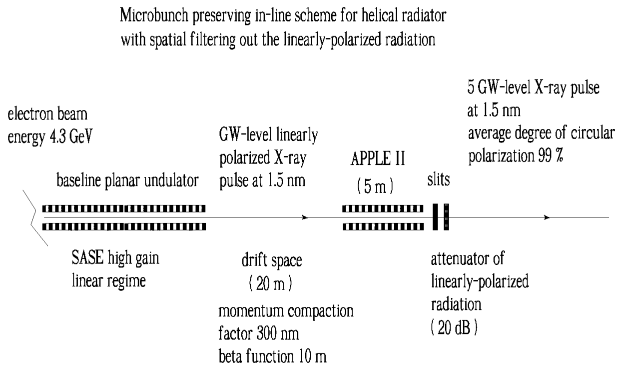

Figure 1: Concept of circular polarization control at the LCLS baseline.

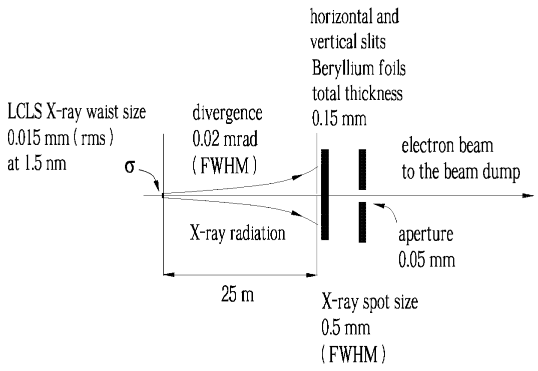

Figure 2: Simple method for suppressing the linearly-polarized soft X-ray radiation from the LCLS baseline undulator.

baseline undulator, it produces SASE radiation and is modulated in energy and density.

We assume here as well that the five second harmonic afterburner (SHAB) modules are rolled away from the beam line. In this way we provide a total 20 m-long straight section for the electron beam transport, corresponding to the length of the SHAB modules. At the end of the straight section, that is immediately behind the SHAB undulator, we install a 5 m-long APPLE II type undulator. While passing through this helical radiator, the microbunched electron beam produces intense bursts of radiation in any selected state of polarization. Subsequently, the polarized radiation from the APPLE II undulator and the linearly polarized radiation from the baseline undulator pass through horizontal and vertical slits, while the electron beam bypasses the slits through a short chicane. This results in a suppression of the linearly polarized radiation. In fact, since the slits are positioned 25 m downstream of the planar undulator, the linearly-polarized radiation has about ten times larger spot size compared to the circularly-polarized radiation spot size, and the background radiation power can therefore be diminished of two orders of magnitude.

The influence of the propagation of the electron beam through the drift section on the electron beam microbunching should be accounted for. One should account for the fact that the straight section acts as a dispersive element with momentum compaction factor $R_{56} \simeq 300$ nm at an electron beam energy of 4.3 GeV. The influence of the betatron motion should be further accounted for. In fact, the finite angular divergence of the electron beam, which is linked with the betatron function, leads to longitudinal velocity spread yielding microbunching suppression. We simulated the evolution of the microbunching along the straight section, and we concluded that the transport of the microbunched electron beam through the 20 m - long straight section does not constitute a serious problem for the realization of the proposed scheme.

Table 1: Parameters for the low-charge mode of operation at LCLS used in this paper.

	Units	
Undulator period	mm	30
K parameter (rms)	-	2.466
Wavelength	nm	1.5
Energy	GeV	4.3
Charge	nC	0.02
Bunch length (rms)	μm	1
Normalized emittance	mm mrad	0.4
Energy spread	MeV	1.5

FEL SIMULATIONS

In this Section we report on a feasibility study performed with the help of the FEL code GENESIS 1.3 (see references in [1]) running on a parallel machine. We will present a feasibility study for our method of polarization control at the LCLS, based on a statistical analysis consisting of 100 runs. Parameters used in the simulations for the low-charge mode of operation are presented in Table 1. The choice of the low-charge mode of operation is motivated by simplicity.

First, the baseline SASE undulator output was simulated. The result, in terms of power and spectrum, is shown in Fig. 3, while the angular distribution of the radiation is shown in Fig. 4. In order to obtain Fig. 4, we first calculated the intensity distribution along the bunch, so that in the upper plot we present the energy density as a function of the transverse coordinates x or y, as if it was measured by an integrating photodetector. A two-dimensional Fourier transform of the data finally yields the angular distribution of the X-ray radiation pulse energy. The x and y cuts are shown on the lower plot.

The influence of quantum fluctuations in the baseline undulator was also studied. Only the five last cells were used, but one needs to account for the fact that beam passed, before the last five cells, through many detuned cells. Such influence is negligible.

The GENESIS particle file was downloaded at the exit of the baseline undulator. For simulating the straight section in GENSIS, we used the same 5-cells undulator structure

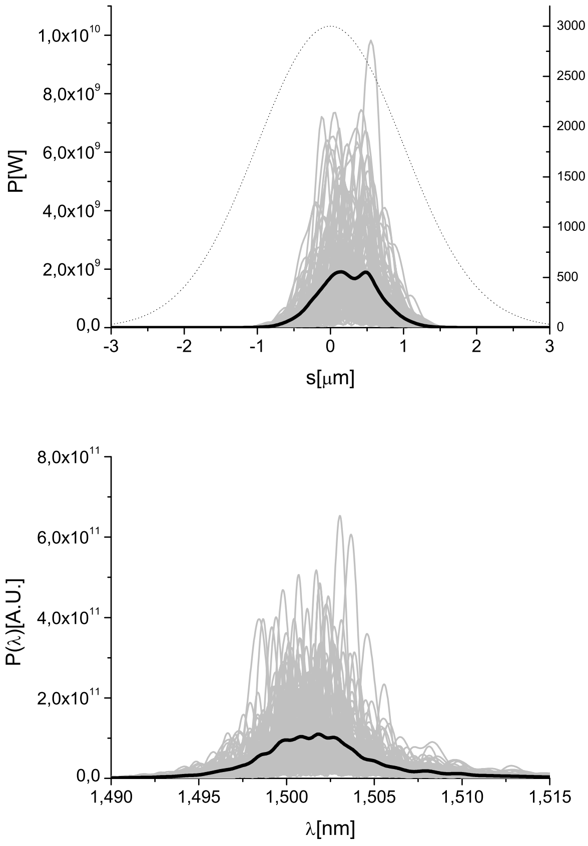

Figure 3: Upper plot: power distribution after the SASE undulator (5 cells). The dotted line refers to the original electron bunch profile. Lower plot: spectrum after the first SASE undulator (5 cells). Grey lines refer to single shot realizations, the black line refers to the average over a hundred realizations.

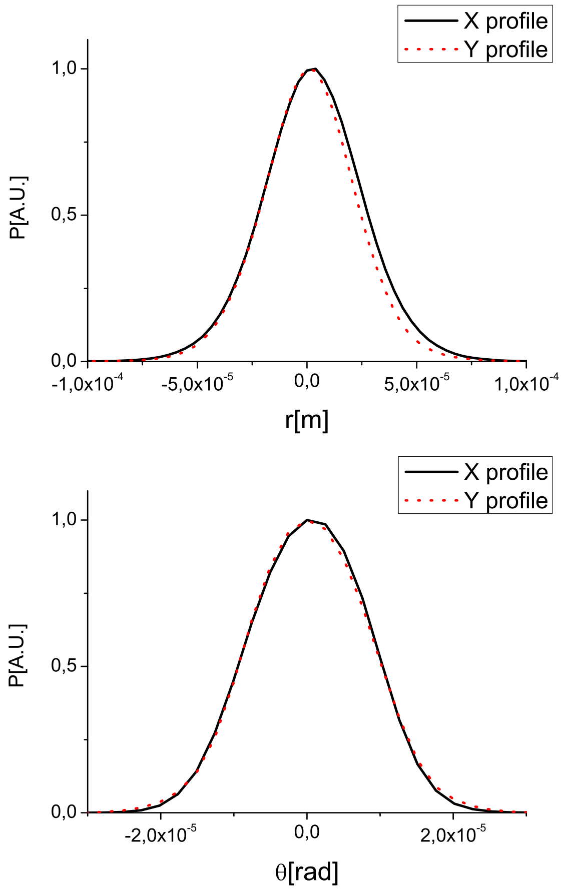

Figure 4: Upper plot: Transverse plot of the X-ray radiation pulse energy distribution after the first SASE undulator (5 cells). Lower plot: Angular plot of the X-ray radiation pulse energy distribution after the first SASE undulator (5 cells).

as for the baseline undulator, but we changed the undulator parameter to $K = 0.1$. This choice allows one to have, with an accuracy of a fraction of percent, the same momentum compaction factor as in free space. Then, the electron beam current was set to zero, and the undulator focusing was switched off (although for $K = 0.1$ the undulator focusing effects are negligible). The GENESIS particle file was used as an input for the propagation of the bunch along the 20 m-long FODO lattice. The average betatron function is assumed to be $\beta = 10$ m. GENESIS automatically accounts for momentum compaction factor and betatron motion effects on the evolution of the microbunched beam. Note that each cell begins with an undulator, and finishes with a quadrupole. Therefore we downloaded the particle file immediately after the first quadrupole related with propagation inside the APPLE II undulator. This guarantees correct propagation along the APPLE II undulator section, which is 4.85 m long. The output files are downloaded immediately after the APPLE II undulator.

The final output from our setup is shown in Fig. 5, upper plot, in terms of power and in Fig. 5, lower plot, in terms of spectrum. In order to optimize the APPLE II output, the fifth section of the upstream planar undulator was detuned of $\Delta\omega/\omega = -0.02$ by changing the undulator parameter K from the number corresponding to exact resonance at 1.5 nm and at 4.3 GeV. In this way a few-GW output power figure is granted, which is about the input level reported in Fig. 3. The transverse distribution of the radiation is shown in Fig. 6 in terms of transverse coordinates (upper plot) and angles (lower plot). From the analysis of Fig. 4 one finds an angular size of 20 μrad FWHM. As a result, after 25 m propagation, the transverse size of the SASE radiation is about 0.5 mm FWHM, to be compared with the APPLE II radiation spot size, which is just 60 μm. The SASE radiation spot size is, therefore, about ten times larger than the APPLE II radiation spot size. We assume, conservatively, the same energy level in both pulses. A slit system letting through the FWHM of the APPLE II radiation would let pass a relative contribution of linearized radiation of about $(60/500)^2 = 0.014$, yielding a degree of circular polarization in excess of 98%.

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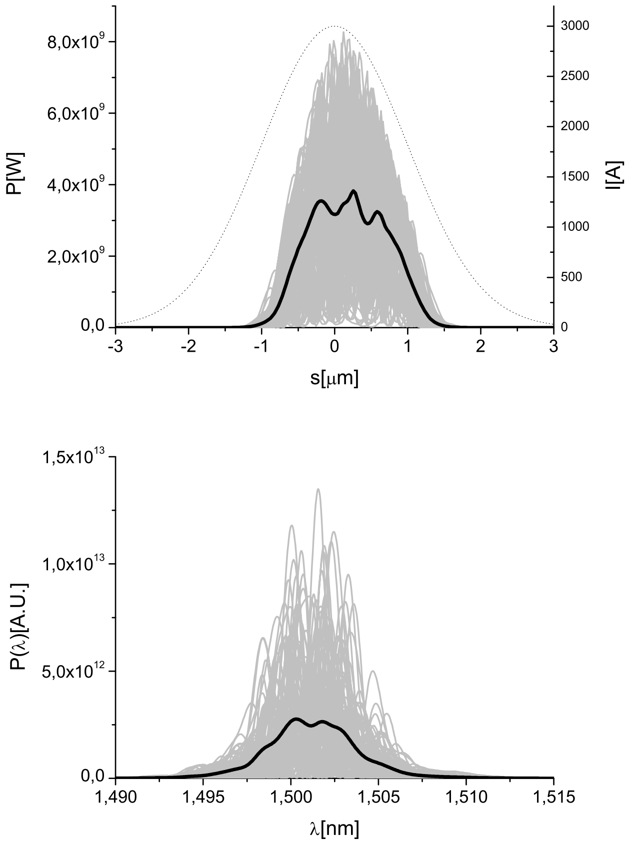

Figure 5: Upper plot: output power distribution from the APPLE II undulator. The dotted line refers to the original electron bunch profile. Lower plot: output spectrum. Grey lines refer to single shot realizations, the black line refers to the average over a hundred realizations.

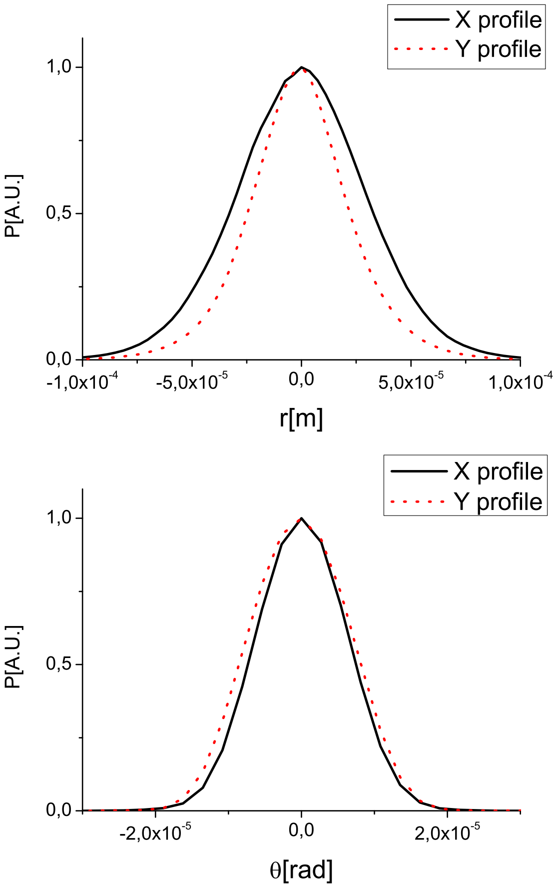

Figure 6: Upper plot: Transverse plot of the X-ray radiation pulse energy distribution after the APPLE II undulator (5 cells). Lower plot: Angular plot of the X-ray radiation pulse energy distribution after the APPLE II undulator (5 cells).

CONCLUSIONS

The LCLS baseline does not offer the possibility of polarization control. The output radiation is simply linearly polarized. Implementation of polarization control at the LCLS baseline is a challenging problem, subject to many constraints including the request of low cost, little available time for implementing setup changes, and guarantee of safe return to the baseline mode of operation. It is clear that the lowest-risk strategy for the implementation of polarization control at the LCLS baseline involves adding an APPLE II-type undulator at the end of the LCLS baseline undulator and exploiting the microbunching of the baseline planar undulator. Detailed experience is available in synchrotron radiation laboratories concerning the manufacturing of a 5 m-long APPLE II undulator (see references in [1]). However, the choice of short radiator leads to background suppression problems. In fact, the linearly-polarized radiation from the baseline undulator should be separated from the variably-polarized output from the APPLE II undulator. The driving idea of our proposal is that the background radiation can be suppressed by spatial filtering. This operation consists in letting radiation through slits immediately behind the APPLE II undulator, which is placed immediately behind the whole (33 cells) baseline undulator. The electron beam bypasses the slits via a short chicane. The estimated cost is low enough to consider adding this scheme to the LCLS baseline in a two-years period.

REFERENCES

[1] G. Geloni, V. Kocharyan and E. Saldin, ”Microbunch preserving in-line system for an APPLE II helical radiator at the LCLS baseline”, DESY 11-083 (2011), http://arxiv.org/abs/1105.4783 and G. Geloni, V. Kocharyan and E. Saldin, ”Circular polarization control for the European XFEL in the soft X-ray regime”, DESY 11-096 (2011), http://arxiv.org/abs/1106.1776, concerning the idea of bypassing the slits with a magnetic chicane.