LINEAR POLARISATION VIA A DELTA AFTERBURNER FOR THE COMPACTLIGHT FACILITY*

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Abstract

We studied the degree of polarisation of the FEL radiation from the diverted-beam scheme [1, 2] using the layout of the CompactLight facility [3], which is in the process of being designed. To satisfy the polarisation requirements defined by the users [4] without compromising the aim of the facility to be compact, we studied a configuration comprising a helical Super Conductive Undulator (SCU) followed by a Delta afterburner (configured to generate linearly polarised light). The trade-offs between the SCU length, afterburner length, degree of polarisation and pulse energy are presented and discussed.

INTRODUCTION

The CompactLight project aims to design next generation light sources which provide competitive FEL performance whilst aiming for a compact design and lower maintenance costs [3]. A study is carried out to characterise a scheme with an afterburner to generate linearly polarised radiation for the CompactLight project. The FEL performance of the undulator line with the afterburner is compared to the case where a variable polarising undulator is considered as stand-alone (set up to generate linearly polarised coherent radiation). The afterburner in the undulator line constrains the beam energy, radiation wavelength and degree of polarisation of the facility. The design choices on the undulator and the afterburner will provide an optimization of the pulse energy without losing sight of the objective of being compact.

AFTERBURNER AND FEL PERFORMANCE (SIMULATION)

A comparison of FEL performance is done for two scenarios:

I. An undulator line with a stand-alone undulator delta undulator configured to generate linearly polarised light.

II. Helical SCU as main undulator and delta undulator to generate linearly polarised radiation as afterburner (see Fig. 1).

Both options are tuned up to the same resonant wavelength, corresponding to 16 keV photon energy (list of design parameters for both undulators displayed in Table 1). An electron beam traversing the undulator line with beam parameters listed in Table 2 is simulated in Genesis1.3 [5] to assess the FEL performance of the proposed scenarios. Preliminary estimations of the FEL saturation length and saturation power for the SCU and delta undulators (in stand-alone mode) are calculated and shown in Table 3.

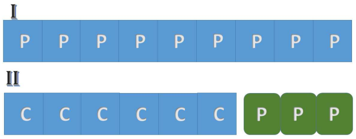

Figure 1: Options to generate linearly polarised radiation.

Table 1: Undulator Parameters Defined for SCU and Delta Undulator

Undulator type	a_w	λ_u (mm)	$l_{section}$(m)
SCU	0.907	9.85	2.27
Delta (AB)	0.546	13.83	2.28

Table 2: Electron Beam Parameters

Electron beam parameter	Value
Beam Energy	5.5 GeV
Peak Current	5 kA
Normalised $\epsilon_{x,y}$	0.2 mm−mrad
RMS slice energy spread	0.01%
Average β function	9 m

Table 3: FEL Figures of Merits for Both SCU and Delta Undulator in its Configuration to Generate Linearly Polarised Radiation

Undulator type	$L_{sat.}$ (m)	$P_{sat.}$ (GW)	$E_{sat.}$(μJ)
SCU	15.61	9.53	52.11
Delta	29.13	7.53	41.19

Given that the normal saturation length for the SCU is 15.61 m and the saturation length for the delta undulator is 29.13 m, option II is more compact than option I as long as the length of the afterburner is less than 13 m. Table 4 shows the amount of space saved by different afterburner lengths (with ΔL being the difference between the lengths of both options).

Figure 2 shows the ratio of pulse energies obtained for option II compared to option I. The green dotted line in Fig. 2 corresponds to the maximum pulse energy obtained per number of afterburner sections (from 1 to 5). As shown, the maximum pulse energies for option II take values between 17% up to 68.4% of the pulse energy of the radiation

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Table 4: Reduction in Length of the SCU + Afterburner Option Compared to the Delta Undulator Option

AB length (m)	ΔL(m)	$E_{AB}/E_{delta\text{-}sat}$
2.28	10.9	17.2%
4.56	8.7	24.4%
6.84	6.4	31.3%
9.13	4.1	42.6%
11.4	1.8	68.4%

generated for option I. The shortest afterburner will provide a more compact option II layout compared to the option I (saving around 11 m in space), but will also provide the poorest performance in terms of pulse energy obtained at the end of the afterburner (ratio of pulse energies around 17%). On the other hand, the largest afterburner (with 5 sections) provides the closest pulse energy compared to the one generated by option I at saturation (68%). The space saved by adding this afterburner is only 1.8 meters. Thereby, a compromise between the compactness of the undulator line and the FEL performance in terms of pulse energy must be made. A shorter undulator line gives linearly polarized radiation but at the cost of reduced pulse energy.

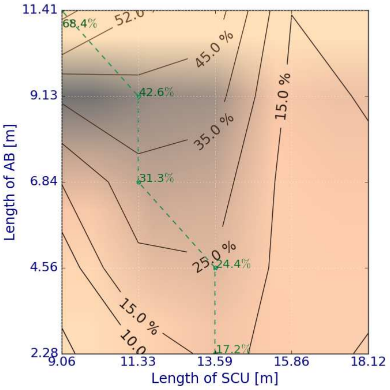

Figure 2: Ratio of the pulse energy for the SCU + afterburner option to the saturation pulse energy from the delta undulator, as a function of the lengths of the SCU and afterburner (green dotted line: maximum pulse energy ratio per afterburner length).

Option II assumes that the radiation coming from the SCU is blocked such that the electron bunch will not interact with it further down the line. Therefore, the degree of polarisation coming out of the afterburner is exactly 100%. In practice, the beam-diverted scheme together with the inverse taper [1] provides a natural solution in order to suppress the background radiation coming from the main undulator before the electrons arrive to the afterburner. In the following, an analysis of the FEL performance of option II, with an inverse tapered helical SCU is performed in accordance to what was proposed in an earlier work by Schneidmiller and Yurkov [1].

IMPACT OF INVERSE TAPER ON FEL PERFORMANCE

For option II, a scan over different linear inverse tapers was done for different SCU and afterburner lengths. To identify the optimal taper, the ratio between bunching parameters and peak power obtained at the end of the tapered undulator and at saturation for the untapered SCU are compared. The growth rate is reduced and the gain length gets longer in the presence of an inverse taper. Therefore, the radiation power at the end of the SCU is noticeably suppressed, whereas the bunching keeps growing [1].

Figure 3 shows the bunching and peak power ratios at the end of the tapered SCU compared to the untapered SCU at saturation. The largest bunching ratio between the tapered and untapered SCU corresponds to a SCU with 8 sections (L_{SCU}=18.12 m). For tapers within the range of $\Delta aw_0 \in$(-0.006, -0.0045), optimal taper range, the bunching ratio is between 75% and 82% (blue contour lines in Fig. 3) The peak power ratio is between 7% and 20% (red contour lines in Fig. 3).

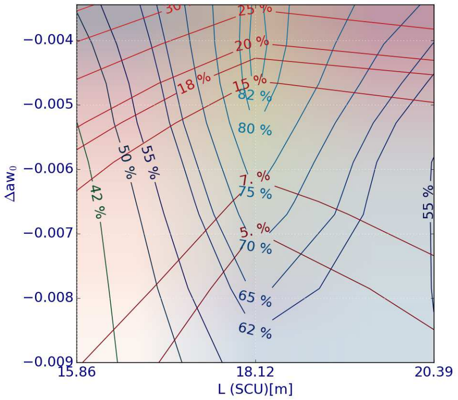

Figure 3: Bunching and peak power ratios obtained at the end of the tapered SCU compared to the untapered SCU (blue contour lines: peak power ratio. Red contour lines: bunching ratio).

Figure 4 shows the ratio of pulse energies obtained for option II compared to option I (for different number of afterburner segments). For afterburners with one to three sections and tapers within the optimal taper range (-0.045 ≥ Δaw_0 ≥-0.006, L_{SCU} = 18.12 m), the maximum ratio of pulse energies covers a range between 18% and 62%. Larger afterburners will generate pulses with larger pulse energies for the same taper range (91% of the pulse energy obtained for option I in the case of an afterburner with 4 sections), but will not fulfil the requirement of a compact undulator line. The compromise between total length of option II and FEL performance is still necessary. As shown in Fig. 4, shorter afterburners will have poorer performances in terms of pulse energy (reaching up to 18% of the saturation pulse energy generated via option I).

Following Schneidmiller and Yurkov, the degree of polarisation is defined in terms of the peak power obtained at the

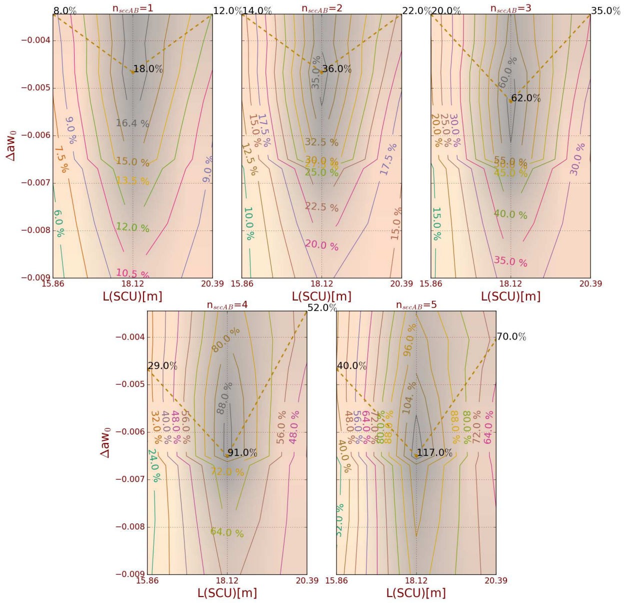

Figure 4: Ratios of pulse energies at the end of the afterburner (option II) compared to the saturation pulse energy obtained for option I (dotted black line: maximum ratio of pulse energies ratio per SCU length).

end of the SCU and the afterburner as follows [1]

$$\text{Deg. Pol.} = 1 - \frac{P_{\text{end-SCU}}}{P_{\text{end-AB}}} \tag{1}$$

The degrees of polarisation for different afterburner lengths are shown in Fig. 5. For the shortest afterburner (one section), the degree of polarisation for the optimal taper is shown to be mainly circular (Deg. Pol. ≪ 1). The degree of polarisation grows more linear (closer to 100%) as larger afterburners are considered for option II. For an afterburner with 3 sections, the degree of polarisation corresponding to the tapers in the optimal taper range takes values between 55% and 82%. Therefore, a new compromise between the afterburner length and the degree of polarisation needs to be made. A shorter afterburner will defines a more compact option II layout, but the background radiation from the SCU is more prominent. For longer afterburners, the FEL performance improves noticeably (pulse energy ratio of 91% for a four section afterburner within the optimal taper range) and the degree of polarisation shows a suppression of the background radiation from the SCU (around 85%), but the length of the undulator line is less compact.

CONCLUSION

A study was carried out to show the FEL performance of a linearly polarising afterburner for the H2020 CompactLight Project. Comparisons of pulse energy, degree of polarisation and total length of the undulator line (SCU and a delta afterburner to generate linearly polarised radiation) were performed (with and without the installation of an inverse taper in the SCU). For the untapered case, the pulse energy obtained at the end of the afterburner took values between 17.2% and 68.4% of the saturation pulse energy of the delta undulator as stand-alone. The shortest afterburner had the poorest performance, but saved the largest amount of space in the undulator line(10.9 m). In the case of a inverse tapered SCU, a range of optimal tapers was chosen (corresponding to a tapered SCU with 8 sections, a suppression of the peak power obtained at the end of the tapered SCU between 7% and 20% of the saturation peak power of the untapered SCU and a bunching ratio between 75% and 82%). A shorter afterburner satisfies the main objective of the H2020 CompactLight project to design a compact facility (saving up to 10.9 m), but will provide a poorer FEL performance in pulse energy (around 18% of the saturation pulse energy of the delta undulator as stand-alone for the inverse taper scheme) and a poor degree of polarisation (much less than 1 for the tapered SCU). The degree of polarisation grows and gets closer to 1 as larger afterburners are considered. Generation of variable polarised radiation by changing the configuration of the delta afterburner is a desirable feature and will be studied in the future.

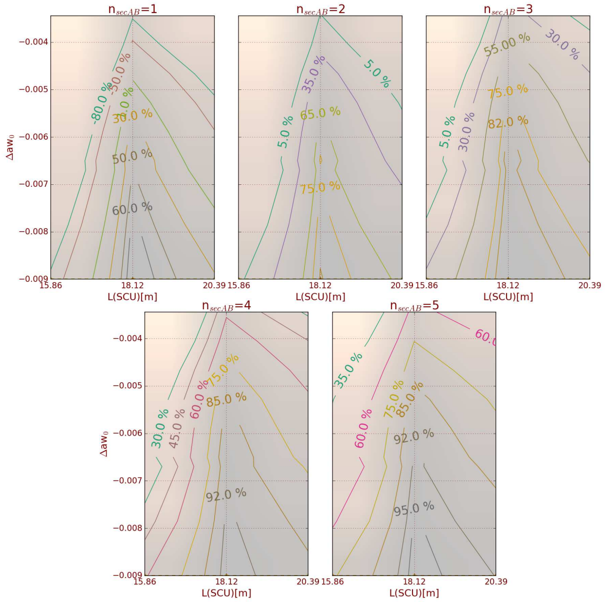

Figure 5: Degree of polarisation, Eq. (1), for different number of afterburner sections.

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