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ON OPTIMIZATION OF THE DISPERSIVE SECTION STRENGTH IN HGHG FREE ELECTRON LASER

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Abstract

In HGHG FEL the optimum strength of dispersive section is determined by the maximum bunching that beam obtains after interaction with seed laser. In this paper we present a simple semi-analytic expression of the required dispersive section strength for a wide range of laser power, intrinsic energy spread and harmonic number.

1 THE OPTIMUM DISPERSIVE SECTION STRENGTH AND E-BEAM BUNCHING

The complete description of HGHG FEL can be found in [1,2]. In the HGHG FEL a coherent seed interacts with an electron beam in the first (energy-modulating) undulator, which is tuned to be resonant to the seed laser frequency. The resulting energy modulation is then converted to spatial bunching while the electron beam traverses a dispersive section. In the second undulator, which is resonant to the harmonic of the seed frequency, the microbunched electron beam initially emits coherent radiation and then amplifies it exponentially until saturation is achieved. In this paper we present a simple semi-analytic expression of the required dispersive section strength for wide range of laser power, intrinsic energy spread and harmonic number.

In the modulator seed laser interacts with electron beam and creates the energy modulation [2], defined by the following expression.

$$\Delta_\gamma = \frac{eK[JJ]L_m}{\sqrt{2\pi}\cdot E}\sqrt{\frac{Z_0}{Z_R}k_s P_L}, \qquad (1)$$

where K is undulator parameter, $[JJ] = J_0(\eta) - J_1(\eta), \eta = \frac{K^2}{4+2K^2}$, $Z_0 = 377$ Ohm, E – electron beam energy, Z_R – Raleigh range of the seed laser, P_L – seed laser power, k_s – seed laser wavenumber, L_m – modulator length.

Dispersive section (DS) converts laser-induced energy modulation into a density bunching with the bunching parameter, given by (2).

$$b_n = \exp\left(-\frac{1}{2}\left(\frac{\partial\psi}{\partial\gamma}\sigma_\gamma\right)^2\right)J_n\left(\frac{\partial\psi}{\partial\gamma}\Delta_\gamma\right), \qquad (2)$$

where $\frac{\partial\psi}{\partial\gamma}$ is the DS strength, σ_γ is intrinsic (uncorrelated) energy spread and n is the harmonic number. The bunching parameter has to be maximized in order to achieve the optimum conditions for the HGHG FEL performance. As it follows from the analysis of (2), the optimum value of DS exists for any combination of harmonic number, intrinsic energy spread and energy modulation amplitude. In the following we neglected the dispersion of modulator and radiator undulators.

In order to find the optimum DS strength we approximate the solution of (2), using the 6th order polynomial (3).

$$\left(\frac{\partial\psi}{\partial\gamma}\right)_{opt} = \sum_{i=0}^{5}\sum_{j=0}^{5} D_{ij} n^i \frac{\sigma_\gamma^{\,j}}{\Delta_\gamma^{\,j+1}}, \qquad (3)$$

where coefficients D_{ij} are listed in the Table 1.

The accuracy of the approximation is less than 0.5 %. Approximation covers the range of parameters from 1st to 10th harmonic and from zero energy spread up to the energy spread equal to the modulation amplitude.

For the maximum value of the bunching parameter we can directly use (2), substituting the optimum value of the DS strength, given by (3). In order to simplify the calculation of the maximum bunching we also provided polynomial (4) with coefficients B_{ij}, shown in Table 2.

$$(b_n)_{\max} = \exp\left(-\frac{1}{2}\left(\left(\frac{\partial\psi}{\partial\gamma}\right)_{opt}\sigma_\gamma\right)^2\right)J_n\left(\left(\frac{\partial\psi}{\partial\gamma}\right)_{opt}\Delta_\gamma\right) = \sum_{i=0}^{5}\sum_{j=0}^{5} B_{ij} n^i \frac{\sigma_\gamma^{\,j}}{\Delta_\gamma^{\,j+1}} \qquad (4)$$

The dependence of the scaled optimum DS strength on harmonic number and the ratio of $\frac{\sigma_\gamma}{\Delta_\gamma}$ is plotted in Fig. 1. The same dependence for the maximum bunching parameter is shown in Fig. 2. The points on the plot correspond to the exact values, the lines represent polynomial approximation (3) and (4).

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	j					
i	0.548580	0.336778	8.959748	34.163008	46.398688	20.692565
	1.354414	1.175938	-7.610372	9.876402	-4.155292	0
	-0.077013	-0.167947	0.205692	-0.067588	0	0
	0.011829	5.22378E-3	-2.986481E-3	0	0	0
	-9.168639E-4	-7.169209E-5	0	0	0	0
	2.772608E-5	0	0	0	0	0

Table 1. List of coefficients in (3)

	j					
i	0.688031	1.880900	-8.138632	14.583039	-12.249332	3.886234
	-0.179475	-1.097114	1.554471	-1.19944	0.405316	0
	0.057974	0.163152	-0.079604	0.013094	0	0
	-0.011048	-0.013039	2.395328E-3	0	0	0
	1.023126E-3	4.084406E-4	0	0	0	0
	-3.573361E-5	0	0	0	0	0

Table 2. List of coefficients in (4)

The dependence of the scaled optimum DS strength on the harmonic number and the ratio of $\frac{\sigma_\gamma}{\Delta_\gamma}$ is plotted in Fig. 1. The same dependence for the maximum bunching parameter is shown in Fig. 2. The points correspond to the exact values, the lines represent polynomial approximation (3) and (4).

As an example we calculate optimum DS value for the usual DUV FEL parameters [3]: electron beam energy of 175 MeV (HGHG output wavelength is 266 nm), modulator length of 0.8 meters with undulator parameter of 1.64, seed laser wavelength of 0.8 micron (harmonic number of 3) and Raleigh range of 2.4 m, seed laser power of 30 MW. Assuming intrinsic energy spread to be 4×10^{-5}, we get $\Delta\gamma_{mod}$=0.482 MeV and optimum value of the DS strength of $\left(\frac{\partial\psi}{\partial\gamma}\right)_{opt} = 8.75\cdot$

The bunching parameter at this value of dispersion is equal to 0.434.

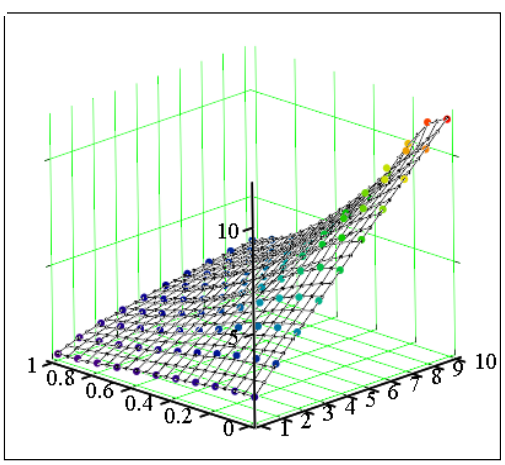

Fig. 1: $\Delta_\gamma\left(\frac{\partial\psi}{\partial\gamma}\right)_{opt}$ as a function of $\left(\frac{\sigma_\gamma}{\Delta_\gamma}, n\right)$

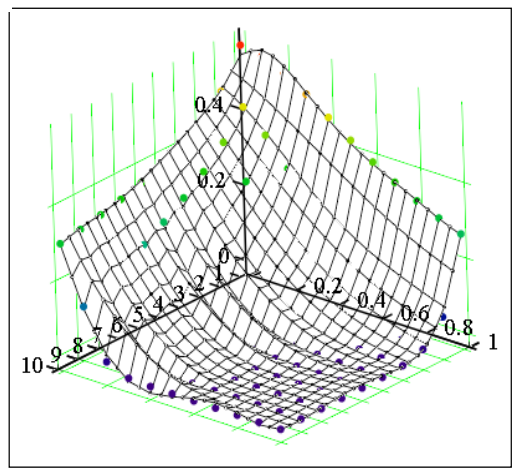

Fig. 2: $\Delta_\gamma(b_n)_{\max}$ as a function of $\left(\frac{\sigma_\gamma}{\Delta_\gamma}, n\right)$

2 REFERENCES

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