NUMERICAL STUDY OF COHERENT HARMONIC GENERATION IN THE VUV ON THE NIJI-IV FEL

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Abstract

Generation of the VUV radiation has been numerically performed based on coherent harmonic generation (CHG) scheme at NIJI-IV with an external laser. The CHG process in an optical klystron was simulated using the code GENESIS1.3 incorporating with its extended code. After performing the optimization of the parameter for the optical klystron, the dependence of the input laser power and the effect of the energy spread on the output radiation power are discussed.

INTRODUCTION

Coherent harmonic generation (CHG) is an attractive method as a source of tunable coherent radiation in the VUV. Considering advantage of operation without an optical cavity in CHG, we are preparing to produce the harmonics in the storage ring NIJI-IV FEL [1] by using either an external laser focused into an optical klystron [2,3] or the FEL oscillator itself. In this study we focus on the investigation of the harmonic generation by an external laser (3rd harmonic of Nd:YAG laser) with Monte Calro simulation.

The layout of the CHG in the transverse optical klystron, which consists of three sections, is illustrated in Fig. 1. In the first section, the energy exchange between the electron beam and the optical wave, supplied by an external pulsed laser, induces the energy modulation of the electron. In the second section, the energy modulation is transformed into an electron density modulation. The amplitude of the magnetic filed in the dispersive section is optimized so as to obtain the maximum radiation intensity at the end of the optical klystron. Consequently, in the last section, the coherent harmonic radiation is emitted from the second undulator. In this work, this CHG process is
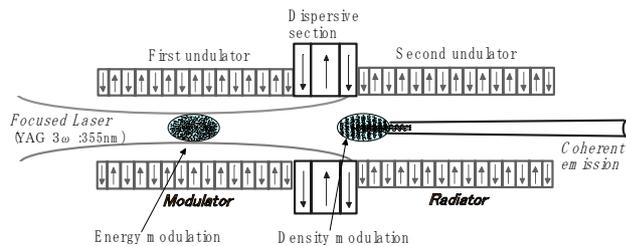

Figure 1: Schematic view of the setup for Coherent Harmonic Generation (CHG).

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simulated in the case of a 6.3-m optical klystron ETLOK-II [1].

PROCEDURE OF SIMULATION

The electron beam is interacted with the third harmonic at 355nm of an external Nd:YAG laser which is focused into the center of the first undulator as shown in Fig.1. The electron beam dynamics in the first undulator is simulated along the undulator axis by using the code GENESIS 1.3 [4] which allows for the treatment of three-dimensional electron dynamics and non-axi-symmetric radiation field. The initial parameters for the electron beam at the entrance of the optical klystron are listed in Table 1. The external laser beam field is taken to be a fundamental Hermite-Gauss mode, and the magnetic field parameter of the undulator is chosen so that the wavelength of the external laser is resonated with the fundamental radiation of the undulator. As a result, the 6D phase space distribution $(x, y, p_x, p_y, \gamma, \theta)$ of the electron beam at the exit of the first undulator is obtained by GENESIS 1.3.

Table 1: Simulation parameters for the NIJI-IV FEL system.

Electron beam	
Energy	310 MeV
Relative energy spread	3.3×10^{-4}
Bunch length	17.4mm
Beam size σ_x	~0.8mm
σ_y	~0.3mm
Emittance ε_x	6.0×10^{-8}m rad
ε_y	8.4×10^{-9}m rad
Optical Klystron	
Magnetic period	
Undulator section	72mm
Dispersive section	216mm
Number of period	42×2
Total length	6.288m
K-value	2.29
Input laser (Nd:YAG)	
Wavelength	355nm
Energy	300mJ/pulse
Peak power	60MW
Repetition rate	10Hz

In the dispersive section, the phase shift is induced by the different transit time depending on the difference of the electron energy. We took the phase energy relation [5]

$$\Psi_j = \frac{\omega_{s1}}{\omega_{s2}} \left[\theta_j + \frac{d\theta}{d\gamma} (\gamma_j - \gamma_0) \right] \qquad (1)$$

between the ponderomotive phase of the electron θ_j and Ψ_j at the entrance and the end of the dispersive section for jth electron, respectively. Here $\gamma_j - \gamma_0$ is the energy deviation from the mean energy of the electron beam in terms of the Lorentz factor, and the ratio ω_{s1}/ω_{s2} gives the harmonic number of the input laser. The factor $d\theta/d\gamma$ is a function of length and field strength of the dispersive section. Inserting the phase distribution at the end of the first undulator calculated by GENESIS 1.3 into Eq.(1), the 6D phase space distribution $(x, y, p_x, p_y, \gamma, \Psi)$ at the exit of dispersive section is determined.

Thus, the obtained parameters $x, y, p_x, p_y, \gamma, \Psi$ are written into a file as an input to GENESIS 1.3 for calculation in the second undulator. The coherent emission from the bunched electrons is again simulated along the second undulator axis using GENESIS 1.3, and then we get the harmonic radiation distribution at the exit of the optical klystron.

SIMULATION RESULTS

Optimization of the optical beam waist

First of all, the dependence of the third harmonic intensity on the radius of the optical beam waist w_0 was investigated. The number of emitted photons corresponding to the three different input laser powers P_{in}=30, 60 and 90 MW is plotted in Fig.2. In this simulation, the factor $d\theta/d\gamma$ in Eq.(1) was chosen so as to obtain the maximum harmonic intensity for the corresponding P_{in} and harmonic number. For example $d\theta/d\gamma$ = 0.3 is the optimum value for the third harmonic at P_{in} = 60 MW.

As shown in Fig.2, the output intensities grow with increasing the waist size w_0 up to $w_0 \sim 1.0$ mm since the overlap of the electron beam with the optical wave increases. On the other hand, above $w_0 \sim 1.4$ mm, the intensities decrease due to diminishing electric field of pumping laser. It is interesting to note that the waist size w_0, which gives the maximum harmonic intensity, increases with increasing P_{in}. This optimum w_0 shift can be understood as the inhomogeneous transverse profile of electron bunching. For the low P_{in}, electric field of laser is insufficient to produce the electron density modulation, so the waist size w_0 must be reduced. On the contrary, for the high P_{in}, overbunching of the electron density occurs in the center of the beam, thus reducing the efficiency of the harmonic generation. To avoid the overbunching, the w_0 should be larger value, giving constant radial profile of the electron bunching.
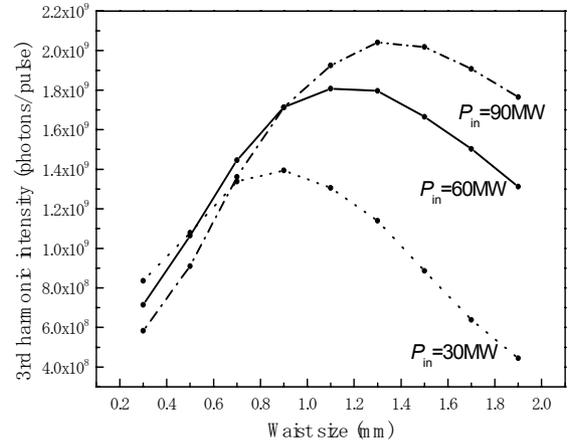

Figure 2: Dependence of the third harmonic intensity on the radius of the optical beam waist at the input laser power P_{in}=30, 60 and 90 MW with the electron average current 1 mA.

Power Dependence

Figure 3 shows the calculated photon intensities on the third and fifth harmonics of a pumped laser at 355 nm as a function of the laser peak power P_{in}. The calculation has been also performed taking into account an optimization of $d\theta/d\gamma$ parameter for each P_{in}, while w_0 is fixed at 1.1mm. The number of photons increases proportional to P_{in} in low laser power region, and is saturated above ~ 60 MW owing to the overbunching effect, giving a limit of the harmonic intensity. In the case of our laser power, P_{in} = 60MW, the number of photons were calculated as $\sim 2 \times 10^9$ and $\sim 3 \times 10^8$ photons/pulse for the third and fifth harmonics, respectively, at the electron average current 1mA in one bunch ring operation.
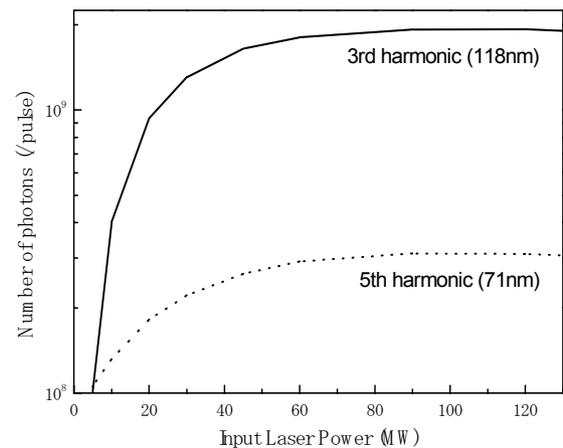

Figure 3: Calculation results of number of photons on the third and fifth harmonics as a function of the input laser power with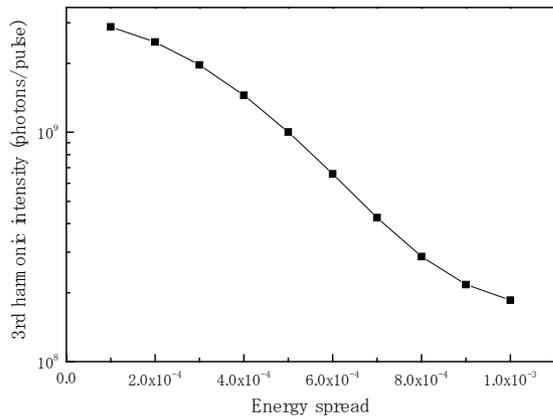 the electron average current 1 mA.