HARMONIC LASING OPTIONS FOR DALIAN COHERENT LIGHT SOURCE *

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Abstract

Harmonic lasing of the Free Electron Laser can be achieved by disrupting the electron interaction with the usually dominant fundamental while allowing the increasing of a harmonic interaction. It's a cheap and relatively efficient way to extend the photon energy range of a particular FEL. In this paper, we discussed the possibility of harmonic lasing concept at Dalian Coherent Light Source by using the combination of tapered undulators and phase shifters. Our calculation shows that it's feasible with the present layout to provide intense, stable, and narrow-band harmonic radiation, the FEL wavelength could be down to 20 nm and the corresponding pulse energy is about 35 μJ.

INTRODUCTION

In recent years, enormous progress has been made in high gain free-electron lasers (FELs). It hold great potential to deliver high brilliance radiation pulses in the extreme ultraviolet and even x-ray regions, the excellent characters of FEL has paved the way for novel types of experiments in many scientific disciplines. High brilliance and short wavelength is the main tendency of the high gain FEL development, many proposals, such as tapered undulator [1-3] or harmonic lasing [4-6] have been made to enhance the capability of FELs. The realization of performance improvement will provide more opportunities by opening up more detailed investigations of many new areas of science.

Harmonic lasing is a promising way to extend the FEL tuning range without too much hardware modification for a particular beam-line. As we known, odd higher harmonics will be associated with fundamental when FEL amplification happened in a planar undulator [7]. Normally, the higher harmonics is several orders of magnitude smaller than the fundamental radiation, while the performance of harmonic lasing scheme can be reversed by successful suppression of the fundamental frequency and provide much more intense, stable and narrow-band FEL radiation with the brilliance comparable to that of the fundamental. Some methods has been proposed to suppress the fundamental radiation in FEL process, such as, using periodic phase shifter to introduce a non-integer 2π phase shift between the field and e-beam for the fundamental while inter 2π for the high harmonics [4]; utilizing the periodically filter to decrease the fundamental while allowing the higher harmonics pass [8]. The mechanism of harmonic lasing has been experimentally demonstrated in long wavelength range [9-11], and its application in X-ray FEL is also extensively studied. In this paper, we studied the application of phase shifter tuning method in the case of Dalian Coherent Light Source (DCLS) [12], simulation shows that the harmonic lasing options could extend the tuning range down to 20 nm and the FEL pulse energy is also over 30 μJ, when DLCS is operated in 50 nm, the FEL pulse energy of 3rd harmonic is about 100 μJ, 75 percent of the fundamental. What's more, the saturation length of 3rd harmonic lasing is much shorter than lasing at the same wavelength with the normal fundamental mode.Each author should submit the PDF file and all source files (text and figures) to enable the paper to be reconstructed if there are processing difficulties.

HARMONIC LASING IN DCLS

DCLS is designed as a fully coherent FEL user facility, which wavelength can be continuously tuned from 50 nm to 150 nm. The layout of DCLS consists of linear accelerator, undulator system and a seed laser system. In the nominal design of DCLS, an 300 MeV electron beam with sliced energy spread of 30 keV, e.g., a relative energy spread of 1×10^{-4}, normalized emittance better than 1.0 μm-rad, bunch charge of 500 pC, and peak current of 300 A is expected at the exit of the LINAC for efficient FEL lasing. The undulator system includes 1 segment of modulator and 6 segments of radiator, where the period length is 50mm and 30mm, respectively. What's more, tapered undulator technique will also be utilized to further enhance the pulse energy to hundreds of micro-joule level. Benefit from the OPA technique, the seed laser is tunable at the wavelength range of 240-360 nm, the seed laser pulse energy is more than 100μJ, and the pulse duration can be switched between 1ps and 100fs, thus to generate FEL pulse with different temporal properties.

Inspired by the user requirements for different FEL application, such as catalytic process on surface, gas phase chemical reaction and cluster geometry within the liquid phase. A harmonic lasing option is proposed for DCLS (seen in Figure 1). Between each undulator segment, a phase shifter is utilized to introduce a phase shift between the electron beam and the FEL radiation, a multiples of 2π phase shift could enable the FEL process interfere constructively. When the phase is mismatched, the FEL radiation will lose energy to electrons, interrupting the amplification process. This potential of phase shifter is fully explored in harmonic lasing scheme, by adjusting the phase to a particular working point $\Delta\theta = 2\pi/3$, then the phase shift will be 2π for the 3rd harmonic and non-integer of 2π for the fundamental, this will disrupt the exponential growth of fundamental, while the 3rd harmonic can be reserved.

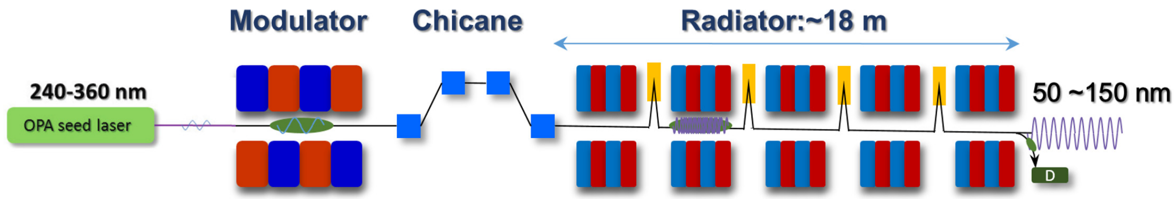

Figure 1: The schematic layout of harmonic lasing scheme in DCLS.

Following the definition in Ref. [7], using the parameter of DCLS, we compare the gain length evolution for different FEL wavelength. The harmonic lasing gain length l_{3h} and fundament l_{3f} are scaled with respect to the undisrupted fundamental gain length l_{1f}. In Figure 2, we can see that the gain length of harmonic lasing is always shorter than the fundamental FEL scheme, benefit from this unique characters, a shorter wavelength and powerful FEL radiation can be generated within a particular undulator configuration.

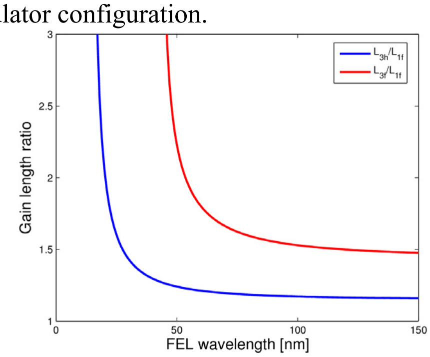

Figure 2: Comparison of gain lengths as a function of FEL wavelength.

We take the realistic parameters of DCLS as an example to compare the 50 nm FEL radiation generated by harmonic lasing and fundamental. The electron beam dynamics in photo-injector was simulated with ASTRA [13] to take into account the space-charge effects and ELEGENT [14] was used for the simulation in the remainder of the LINAC. The universal FEL simulating code GENESIS [15] was utilized to calculate FEL performances, the beam energy and current distribution at the exit of the LINAC is shown in Figure 3.

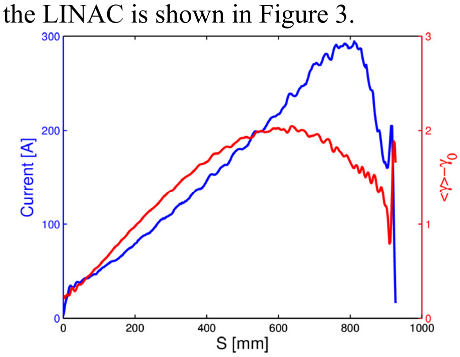

Figure 3: Beam current and energy distribution along the electron beam coordinate.

In FEL simulation, the slice energy spread of about 10 keV is obtained in the central part of the e-beam, in view of the tradeoff between the seed laser induced energy spread and the available bunching factor, a moderate modulation amplitude of $A = 5$ is chosen for FEL gain process in the radiator. For harmonic lasing, the seed laser wavelength is 250 nm and the radiator is resonant at 150 nm, then no FEL bunching in the fundamental while about 0.1 in the 3rd harmonic. In fundamental, the initial bunching of 50 nm FEL is about 0.15, and the 5th harmonic is picked up in radiator. Figure 4 shows the comparison of output pulse energy along the radiator. The saturation length for harmonic lasing is about 5 m, only about 1/2 of the fundamental, the power of harmonic lasing is about 60 percent of the fundamental.

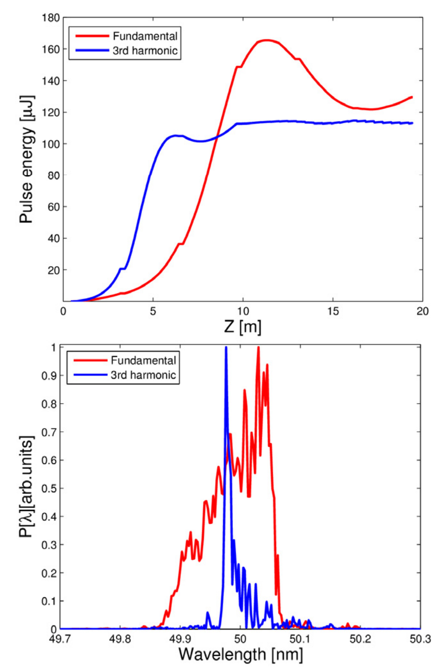

Figure 4: Comparison of 50 nm radiation of DCLS, the saturation length of harmonic lasing is about 5 m, while the fundamental is still in exponential gain regime.

20 NM CASE

Limited by beam energy and undulator parameters, the shortest nominal wavelength in DCLS is about 50 nm. In this section, we simulate the FEL performance in 20 nm without any modification of the facility. The central wavelength of seed laser is 260 nm, the laser power is 10 MW to introduce sufficient energy modulation in higher harmonic. The radiator is resonant at 60 nm, then 20 nm FEL radiation is amplified as the 3rd harmonic. To improve the FEL performance in 20nm case, we increase the beam energy to 400 MeV, then the 4 Toshiba klystron

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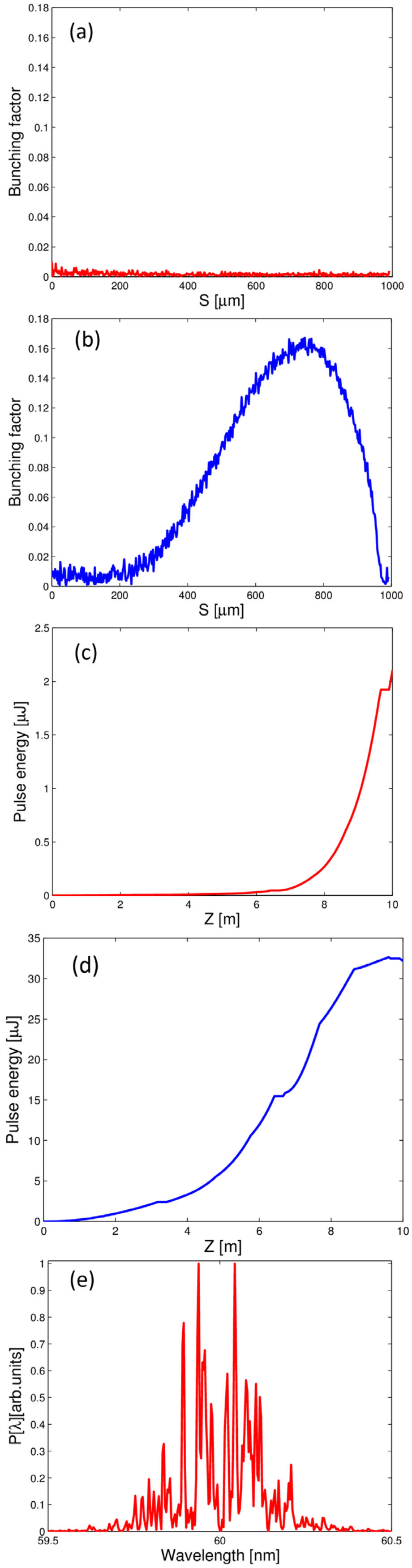
will be working at 80% of the nominal power in beam operation.



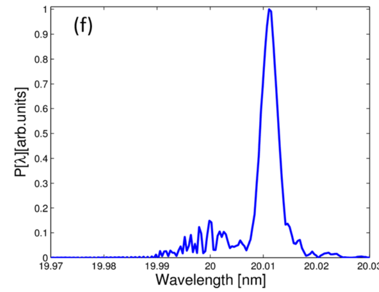


Figure 5. FEL performances in fundamental and 3rd harmonic. (a) the 5th harmonic bunching factor distribution along the electron beam at the entrance of the radiator for fundamental; (b) the bunching factor distribution along the electron beam at the entrance of the radiator for the 3rd harmonic; (c) the output radiation peak power of the fundamental; (d) the output radiation peak power of the 3rd harmonic lasing; (e) the spectrum of the radiation generated by the fundamental; and (f) the spectrum of the radiation generated by the 3rd harmonic.

The simulation results are illustrated in Figure 5, the bunching factor of 20 nm radiation is optimized to 16% at the entrance of the radiator, while nearly noise level for the 60 nm fundamental. The 20 nm FEL radiation pulse is generated with the output pulse energy over 30 μJ, and the pulse energy of fundamental is about 1 μJ, less than 5 percent of the 3rd harmonic. The saturation length of 3rd harmonic is obviously shorter than the fundamental, after passing through 9 m long radiator, the 3rd harmonic FEL radiation is approaching to saturation, while the fundamental is still in lethargy region. The relative FWHM bandwidth of the 20 nm radiation is about 1×10^{-3}, the spectral emission presents regular quasi perfect Gaussian shape pulse to pulse, the noisy spike is due to the inevitable SASE process.

CONCLUSION

Dalian Coherent Light Source is expected to generate fully coherent laser pulses by seeded FEL scheme in the wavelength range between150-50 nm with pulse photon number of 10^{13} order. In this paper, we extend the tuning range of DCLS down to 20 nm by harmonic lasing option. The simulation results show that a pulse energy over 30 μJ can be realized in practice in a relatively simple way based on the existing FEL configuration of DCLS, and the saturation length of harmonic lasing is obviously shorter than fundamental. Finally, it's worth emphasizing that the requirements of e-beam and undulator field is also more stringent in harmonic lasing, then for the real FEL experiments, the machine flexibility, the beam quality and the commissioning experience will determine the final results of this proposal.

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