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SIMULATION STUDIES OF THE PROPOSED FAR-INFRARED FEL AMPLIFIER AT ISIR, OSAKA UNIVERSITY

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Abstract

Computer simulation studies are currently underway for the proposed FEL amplifier experiment to be carried out using the existing 38 MeV, L-band linac based FIR FEL system at the Institute of Scientific and Industrial Research (ISIR), Osaka University. This paper describes the time dependent and time independent simulation results using Genesis code. Dependence of FEL amplifier characteristics are investigated such as power spectrum and profile, frequency spectrum and FEL bunching parameter on parameters like beam current, input power and interaction length. The operating current regime and input seed laser powers required for optimum amplification are given. The code has also been used to compare SASE experimental data with simulation results with a reasonably good correlation.

1. INTRODUCTION

The Free-Electron Laser (FEL) has been deemed to be the 'next generation light source'. With the extensive research and development in the field of single pass, Self Amplified Spontaneous Emission (SASE) FELs, the accessible wavelength of the FEL has now been extended far beyond the UV region. The SASE being the best suited configuration because of problems pertaining to use of optical elements at shorter wavelengths.

SASE was first observed here at the Radiation Laboratory of the Institute of Scientific and Industrial Research (ISIR), Osaka University in 1991 during the course of developing the infrared FEL using the 38 MeV, L-band linac [1]. Detailed experimental study on SASE is currently being conducted using the wiggler for the infrared. Although strong SASE has been observed, it is not possible to go into the saturation regime under the present experimental conditions due to the limited number of wiggler periods (32). It was proposed that the above mentioned FEL system could be used to conduct single-pass FEL amplifier experiments using an injected seed laser source, which would help understand the phenomenon of SASE in the strong signal regime. It is also necessary to know the behavior of the system and its dependencies on various experimental parameters before actually conducting the experiment. The one-dimensional (1-D) theory does offer an insight into the behavior, but due to the fact that many factors are often neglected in 1-D estimations, the results may not correlate exactly with the experimental observations. Hence it is essential that a more detailed, realistic simulation is carried out, taking into account as many experimental parameters as possible. This paper attempts to study the effect of the beam current, input seed laser power and interaction length on the FEL amplifier experiment.

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2. GENESIS 1.3 - THE SIMULATION CODE

Ever since the design and building of FELs started, different simulation codes [2] have been developed, each one tailored to describe the phenomenon of FEL occurring in different regimes. Genesis has evolved from an earlier 3-D FEL simulation codes TDA [3], and then TDA3D. Genesis, like its predecessors, solves the paraxial FEL equations with the approximation of slow varying amplitude of the radiation field. Also, in Genesis, time dependent simulation as well as simulation of single-pass SASE has been added [4].

In the time dependency studies, to avoid the limitations imposed by the CPU time and available memory, the code does not simulate the bunch as a whole, but divides it into thin time samples of length of one radiation wavelength each, equally distributed over the simulated time window.

In the proposed experiment, high-intensity, single bunch e-beam of charge up to 73 nC and a pulse length in the range 9-50 ps from the 38 MeV ISIR linac is traversed through a 32 period Halbach type, permanent magnet (Nd-Fe-B) planar wiggler of 60mm period. The wiggler gap can be adjusted from 30 to 120 mm and hence the wiggler constant K can be varied from 1.47 to 0.013. A seed laser source at appropriate wavelength and power would be injected along the axis of the beam and this would be amplified by the single- pass FEL process. The simulation parameters are given in Table.1,

Table.1. The parameters used in the simulation

Beam energy	12.42 MeV
Energy spread (HWHM)	2.18 %
Wiggler K parameter	1.472
Wiggler period	6.0 cm
No. of periods	32
Simulation wavelength	166 μm
Normalized Emittance (x)	150 π mm mrad
Normalized Emittance (y)	93 π mm mrad
e-beam radius (x)	3.3 mm
e-beam radius (y)	1.1 mm
Optical beam waist location	0.96 m
Optical beam waist radius	5.64 mm
Raleigh length	0.6 m
No. of slices	150
Current length	6.0 mm
No. of particles	4096

and they are obtained from real-time, measured data from on-going SASE experiments.

3. RESULTS & DISCUSSION

In this paper, the influence of three basic parameters *viz.*, the beam current, interaction length and the input seed power on the output power and frequency spectrum are studied.

Figure 1 shows the dependence of the of the output power on the peak beam current. It can be clearly seen that there are two distinct regimes of current indicated by the two distinct slopes. The output in the lower current regime (slope ~ 1.9 ± 0.2) may not be wholly due to the SASE but due to a major contribution from coherent spontaneous emission which has a square dependence on the number of electrons. But at higher currents (slope ~ 4.9 ± 0.15), the SASE process is dominant which can also be inferred from the plots of the FEL bunching factor which is a measure of the spatial modulation of the electrons in the wiggler (Fig.2). The bunching factor is not very well defined until the current approaches the second regime. The temporal profile of the electron bunch is also indicated in the graph (dashed line).

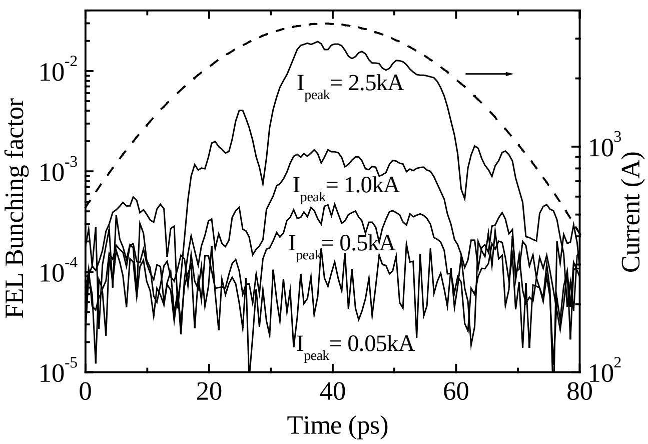

Fig.2. The dependence of the bunching factor on beam current

The dependence of the output power on the input seed power is shown in Fig.3. The shot noise power of the system is given by [5]

$$P_{shot} \approx \frac{3\sqrt{4\pi}\rho^2 P_b}{N_\lambda \sqrt{\ln\left(\frac{N_\lambda}{\rho}\right)}} \quad , \qquad (1)$$

where ρ is the FEL parameter, P_b is beam power and N_λ is the number of electrons in one wavelength. This power is typically in the 10^{-3} to 10^{-2} W range for the parameters used in this simulation. It can be seen that for input powers less than the shot noise power, the output is more or less constant. Thus, it is important to keep the input seed laser power above the shot noise power level in order that the system effectively acts as an amplifier of the input seed laser.

Figure 4 shows the power spectrum at different input seed laser powers. It can be seen that the power spectrum for higher input power is narrower as

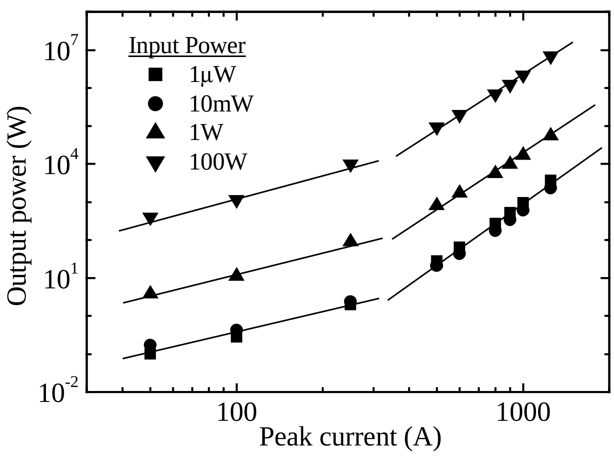

Fig.1. The dependence of the output power on beam current

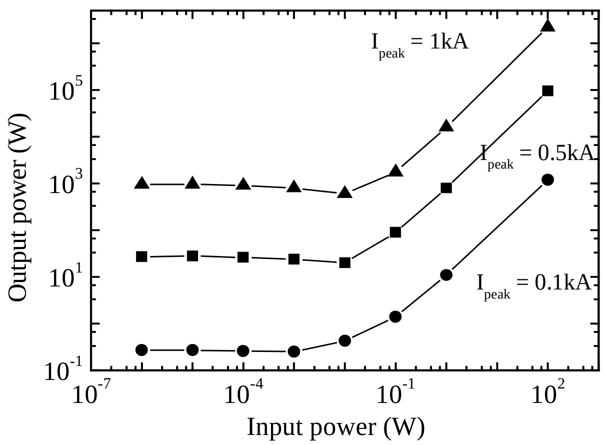

Fig.3. Dependence of the output power on input seed laser power

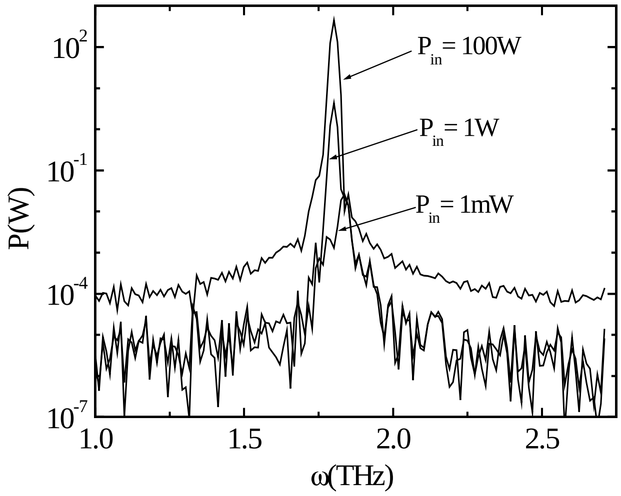

Fig.4. The dependence of the power spectrum on the input power

compared to the noise-startup.

The saturation of the system is studied as a function of the interaction length as well as beam current and input laser power, and it is shown in Fig.5. Saturation occurs in the region of 60 periods when the peak current is 1 kA and input power is 1 W while it occurs at about 130 when current is 500 A and input power is 1W. Hence it is experimentally possible to approach saturation by controlling all of these three parameters *viz.*, interaction length, beam current and the input power.

Genesis was also used to check the validity of the code and also to correlate the experimental data of the currently ongoing SASE experiments. Figure 6 shows the preliminary results of one such comparison of experimental SASE power spectrum with simulation. The experimental peak wavelength as well as bandwidth of emission are comparable to the simulation. It is planned to carry out such comparisons in more detail in the near future.

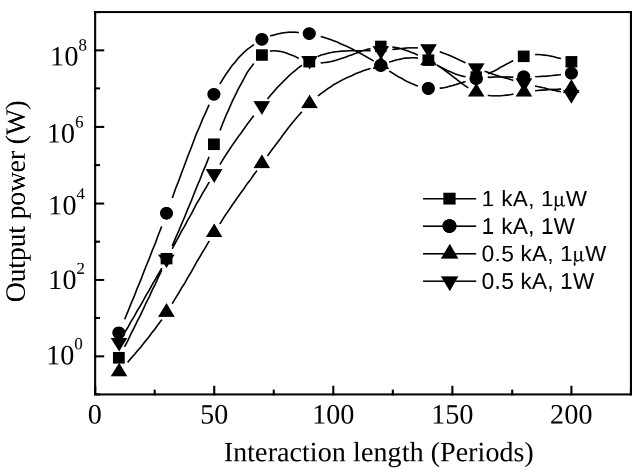

Fig.5. The dependence of saturation on N at different input powers and beam current.

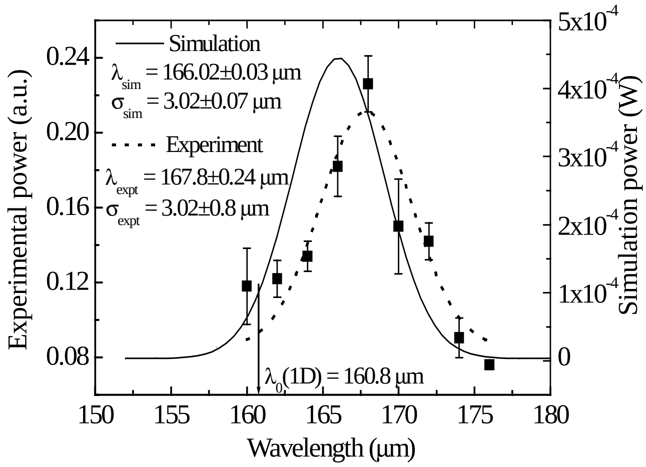

Fig.6. Comparison of the SASE experiment and simulation

4. CONCLUSIONS

The time dependent 3-D simulations for the proposed FEL FIR amplifier experiments are underway using Genesis code. Dependencies of the output power on beam current, input power as well as interaction length are presented. In order that amplification actually occurs, it is essential that the input power be kept well above the shot noise power and beam currents above the threshold value above which the SASE contribution to the output is predominant. The code has also been used to correlate on-going experimental SASE data.

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