OPTIMIZED DESIGNS FOR CAEP IR FREE-ELECTRON LASER

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Abstract

The characteristics of CAEP IR free-electron laser are estimated and the optimized designs of the resonator parameters such as the radius of output hole, the size of mirror and the length of the resonator are carried out using our 3D FEL oscillator code. With the appropriate parameters, the saturated power, output power, gain and the construction of optical modes are calculated.

INTRODUCTION

Infrared free-electron lasers (FELs) have broken important ground in optical science for many attractive features such as most notably wavelength tunability, control of spectral and temporal pulse width. In order to bring along the development of correlative technologies such as superconducting technology, linear accelerator technology and optical cavity technology, an infrared FEL device is built at the China Academy of Engineer Physics (CAEP) which driven by superconducting linear accelerator. The radiation wavelength of the device will be in the range from 3 to 8μm.

In this paper, The characteristics of CAEP IR free electron laser devices will be estimated and the optimized design of the resonator parameters such as radius of output hole, the size of mirror, the resonator length will be carried out by using our 3D FEL oscillator code (OSIFEL)[5-7]. The design is achieved by considering two factors as optical cavity character and the transverse optical modes. Based on the appropriate parameters, the saturated power, output power, the resonator gain, the construction of optical modes are calculated.

THE ESTIMATE OF THE OPTICAL CHARACTERISTICS

Table 1: CAEP IR FEL Parameters

Electron beam	
Energy (MeV)	37
Peak current (A)	30
Micro bunch (ps FWHM)	2.5
Energy spread (%)	1
Emittance (π mm mrad)	20
Wiggler	
Period (cm)	3.2
Peak field strength (kG)	3.2
Number of periods	44
Optical	
Wavelength (μm)	4.4
Cavity length (m)	2.769
Mirror curvature (m)	1.499

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The electron-beam and wiggler parameters used are listed in Table 1. The energy spread and emittance are specified as FWHM and RMS. Using the parameters of the optical cavity, we can attain that the Rayleigh length is 40cm, the optical waist radius is 0.7mm, and the radius of the optical beam on the cavity mirror is 2.6mm.

THE NUMERICAL SIMULATIONS

To attain optimized the radius of the mirror of the optical cavity and the coupling hole, the numerical simulations are performed using the 3-D OSIFEL code. In the simulations, the distribution functions of transverse position and velocity, energy of the electron are assumed as Gaussian. The corresponding initial values of the sample electrons are given by Monte Carlo method and the initial phases are loaded according to the ‘quiet start’ scheme to eliminate the numerical noise.

Selection of the Radius of Coupling Hole

The influences of the hole-coupling on the gain, power, output and the mode construction are simulated and studied, as shown in Table 2, where r is the radius of the coupling hole, G_{net} the net gain, P_{in} the saturated intracavity power, P_{out} the output power, η_{loss} the total loss of the resonator, f_{00} the ratio of the fundamental mode, η_{out} the coupling efficiency, which is defined as the ratio of the useful loss to the total loss. It can be seen that the total loss of resonator and coupling efficiency decrease as a reduction in the size of hole, however, the ratio of the fundamental mode increases. If the size of hole is increase, the interaction of the optical radiation with the electrons will become weaker so the net gain of resonator is decreased. According to Table 2, we may select the optimum size of radius r as 0.3 to 0.4mm.

Table 2 Characteristics of resonator as a function of the radius of the coupling hole

r /mm	G_{net} /%	P_{in} /MW	P_{out} /MW	η_{out} /%	η_{loss} /%	f_{00} /%
0.30	23.4	131	3.58	52.7	5.40	98.0
0. 35	20.0	110	3.61	53.0	6.60	97.1
0. 40	15.5	67	3.41	54.6	10.1	94.2
0. 50	10.3	41	2.82	56.0	14.0	90.0

Effects of the Mirror Size

There are mainly two aspects from the influence of the cavity mirror size. One is the influence on the characteristics of the resonator, the other is the influence on the structure of transverse optical modes. That is, when the radius of cavity mirror becomes large, the net gain and the saturated intracavity power will increase; however, the proportion of fundamental mode will decrease because the loss of the high order modes is small. So the optimum size of the mirror of the resonator must be selected. The characteristics of the resonator as a function of the radius of the mirror of the resonator R are simulated as shown in Table 3, the evolvement curves of fundamental mode as a function of optical pass for different radius of the mirror of the resonator are plotted in Fig. 1. It can be seen from Table 3 as the radius of the mirror of the resonator increases, the quality of resonator becomes better such as the little loss of the resonator, lager output power, and higher coupling efficiency. However, from Fig. 1, it can be seen that when the radius of the mirror of the resonator increases, the distributing of modes becomes more complex and the proportion of fundamental mode will decrease. When the radius of the mirror of the resonator is 1.5cm, the proportion of fundamental mode is about 75%. Considering the quality of resonator and structure of mode, it is suggested that the suitable range of mirror-radius is 0.8-0.9cm. In this range, the proportion of fundamental mode is above 90% in the whole cavity.

Table 3 The characteristics of resonator as a function of the radius of the mirror of the resonator

R/cm	G_{net}/%	P_{in} /MW	P_{out}/MW	η_{out} /%	η_{loss} /%
0.5	20.0	107	3.50	51.4	6.8
0. 8	20.0	110	3.61	53.0	6.6
0.9	20.4	108.6	3.81	55.9	6.68
1.0	20.5	108	4.29	63.4	6.8
1.2	20.0	114	4.38	63.9	6.37
1.5	20.0	117	4.46	66.2	6.1

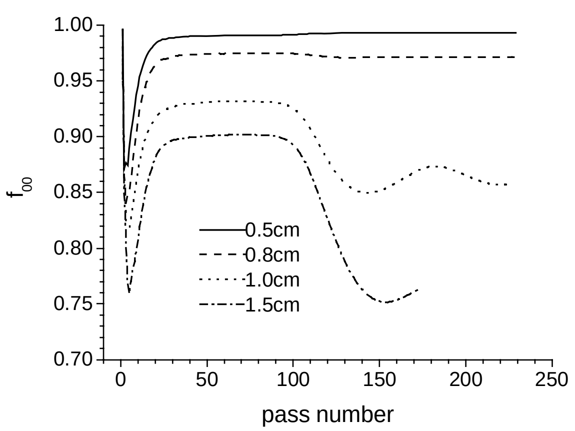

Fig. 1. The evolvement of fundamental mode for different radius of the mirror.

The Detuning Curve

Furthermore, the detuning curves of free-electron laser oscillators are calculated using the 3-D OSIFEL. The result is shown in Fig. 2. It can be seen that the range of the detuning curve is from about –0.2 μm to –7 μm and the detuning length is about 7 μm. Note that the curve is very sharp and the detuning length is shorter because the small signal gain of CAEP IR FEL device is smaller.

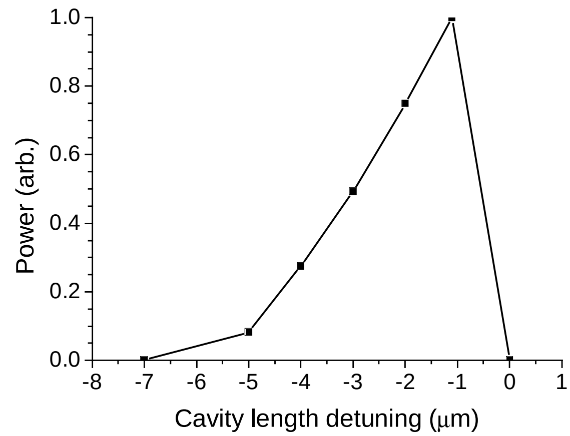

Fig. 2. Detuning curve of CAEP IR FEL from 3D simulations.

Simulation Results

Based on the above numerical simulations, we select the radius of the coupling hole as 0.35mm, the radius of the mirror as 0.8cm. The evolvement curves of the total gain G_t and the net gain G_{net} are shown in Fig. 3. The evolvement curves of intracavity optical power P_{in} and the output power P_{out} are shown in Fig. 4. It can be seen that after 100 pass number, the intracavity optical power is saturated, the total gain is about 28%, the net gain is about 20%, the saturated power is about 110MW, the output peak power is about 3.6MW. The proportion of fundamental mode is about 97%.

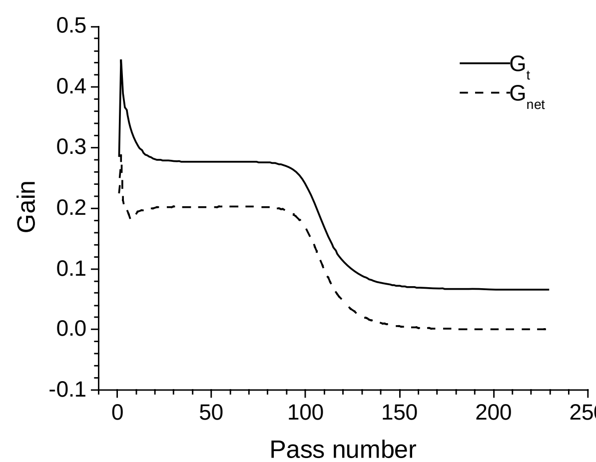

Fig. 3. The evolvement curves of the total gain (G_t) and the net gain (G_{net}).

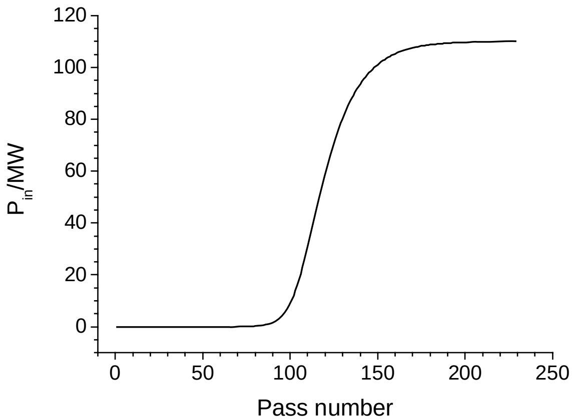

Fig. 4a. The evolvement of the intracavity power.

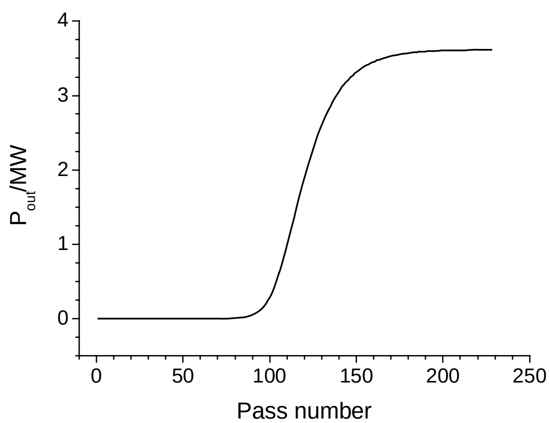

Fig. 4b. The evolvement of the output power.

CONCLUSIONS

In general, the simulation and optimized design of the CAEP IR FEL has been made with the help of our 3-D OSIFEL code. Considering the quality of resonator and structure of mode, the optimum radius of the coupling hole and the radius of the mirror of the resonator have been chosen. It can be attained that the range of the detuning curve is from about –0.2 μm to –7 μm and the detuning length is about 7 μm. With the appropriate parameters, the saturated power, output power, the resonator gain, the construction of optical modes are calculated.

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