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THE OPTICAL RESONATOR OF CTFEL FOR RANGE OF 1 TO 2 THz*

Xiaojian Shu†, Yuhuan Dou, Institute of Applied Physics and Computational Mathematics, 100094 Beijing, China

Abstract

A high power THz free electron laser (FEL) facility is under construction at China Academy of Engineering Physics (CTFEL). The radiation frequency of the FEL facility will be tuned in range of 1~3 THz and the average output power is about 10 W. The system mainly consists of a GaAs photoemission DC gun, superconductor accelerator, hybrid wiggler, optical cavity. The first lasing is obtained on Aug. 29, 2017, and CTFEL is operated in range of 2-4THz, but cannot lasing at the frequency below 1.8 THz. The optical resonator of CTFEL must be optimized to ensure lasing in range of 1 to 2 THz.. The lasing strongly depends on the performance of the optical resonator including output efficiency, gain and round-trip loss. The optical resonator consists of metal-coated reflect mirror, the centre-hole output mirror, waveguide. The influence of waveguide on the quality of optical cavity is evaluated by the 3D OSIFEL code. The waveguide size and output hole radius is optimized to different frequencies between 1 THz to 2 THz.

INTRODUCTION

THz radiation is being increasingly adopted in a wide variety of applications. FEL systems can offer the tunability, high power and flexible picoseconds-pulse time structure of THz radiation [1-4]. A free-electron laser facility based on photocathode DC-gun and superconducting accelerator at China Academy of Engineering Physics (CAEP) in a radiation frequency range of 1~3 THz has been demonstrated[5-8]. The facility operates in the quasi CW mode and the average output power is about 10 W. The first lasing is obtained on Aug. 29, 2017, and CTFEL is operated in range of 2-4THz[7,8], but cannot lasing at the frequency below 1.8 THz. The optical resonator of CTFEL must be optimized to ensure lasing in range of 1 to 2 THz.. The lasing strongly depends on the performance of the optical resonator including output efficiency, gain and round-trip loss. The optical resonator consists of metal-coated reflect mirror, the centre-hole output mirror, waveguide. The influence of waveguide on the quality of optical cavity is evaluated by the 3D OSIFEL code[9]. The waveguide size and output hole radius is optimized to different frequencies between 1 THz to 2 THz.

RESULTS

The cavity length is designed to be 276.9 cm long according to the repetition rate of the micro bunch is 54.17 MHz. The period length and period number of the wiggler are designed as 3.8 cm and 42. The electron beam current is 12.5 A and its pulse length is 8 ps. The main parameters of CAEP THz FEL are listed in Table 1.

Table 1: Main Parameters of CAEP THz FEL

Electron beam		Wigglerr	
Energy /MeV	6~8	Period /cm)	4.2
Peak current /A	12.5	Peak field strength /kG	2.5~5.0
Micro bunch /ps	8	Number of periods	38
Emittance /πmm mrad	10	Cavity length /m	2.769
Energy spread /%	0.75		
Repetition rate /MHz	54.17		

Influence Of Waveguide

The large diffraction loss inherent in long wavelength radiation implies the use of waveguide in THz- FEL resonator, which can substantially improve the overlap between the optical and electron beams, and consequently the FEL gain as compared to open resonators.

Using our the 3D-OSIFEL code, Simulations of the waveguide in the whole optical cavity of CAEP high power THz-FEL device are achieved. In the simulations, the distribution functions of transverse position and velocity and energy of the electrons are assumed to be Gaussian. The corresponding initial values of sample electrons are determined by a Monte Carlo method, and the initial phases are loaded according to the 'quiet start' scheme to eliminate numerical noise. The energy spread and emittance are specified as FWHM and RMS, respectively.

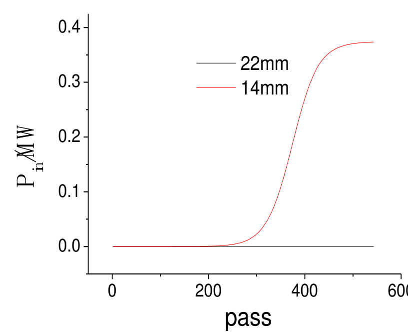

Figure 1: Resonator power as a function of the optical pass to waveguide gap 14mm and 22mm when the radiation frequency is 1THz.

The influence of different waveguide size is compared according to different frequency of 1-3THz by simulations, Fig 1. shows that output power as a function of the optical pass to waveguide gap 14mm and 22mm

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† shu_xiaojian@iapcm.ac.cn

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when the radiation frequency is 1THz. It can been seen that the output power is higher when waveguide size is 10mm X 14mm than that of 22mm X 28mm. It can be seen that when the gap of waveguide is 22mm, the lasing will not start up. So when the radiation is about 1THz, the gap of waveguide must be 14mm to make the facility can work. The shape of the waveguide is adopted a rectangle (28mm×14mm).

Rayleigh Length

Table 2: Characteristics of the Resonator for Various Mirror Curvature Radii

R_{curv}/cm	P_{peak}/kW	G_{net}/%	η_{loss}/%
185	114.5	27.4	4.9
196	124.9	25.6	5.2
221	139.2	23.3	5.0
320	166.6	16.6	4.8

The Rayleigh length is decided by the mirrors curvature radii. The optical waist radius on the middle of resonator and the optical radius on mirror are closely related to the Rayleigh length, the mini-extremum of optical waist radius exists when changing the Rayleigh length. Rayleigh length influences on the FEL interaction and single-pass extraction, that is, on resonator loss and gain. A more accurate determination of optimum value is obtained to different frequencies by simulations. The resonator loss η loss and gain G_{net} and output peak power P_{peak} are calculated corresponding different Rayleigh length when radiation frequencies is 2 THz. The results are shown in Table 2. From the table, it can be seen that when mirror curvature radius is 185cm, the gain of wiggler is largest and when mirror curvature radius is 320cm the resonator loss is smallest. The optimum mirror curvature radius is 221cm.

Output Coupling-Hole

For the CAEP THz FEL, the facular image on the mirror is an ellipse due to a waveguide is needed to reduce the diffraction loss due to longer wavelengths. To increase the output power and resonator quality, the scheme of elliptical hole-coupling optical resonator is proposed instead of circular hole-coupling resonator which is used in facility. The size of coupling-hole is optimized to different frequencies between 1 THz to 3 THz. The results show that the optimum size of elliptical hole is 1.6mm×0.8mm in 1 THz.

Table 3: Characteristics of the Round Hole-Coupled Resonator in Different Radiation Frequency

f/THz	R_{round}/mm	G_{net}/%	$P_{average}$/W
1	0.9	33.6	48.8
1.6	1.2	21.7	141.7
2.6	1.2	20.4	181.4
3	0.9	17. 6	121.3

CONCLUSION

In conclusion, parameters of the optical resonator is optimized corresponding to different frequencies between 1 THz to 2 THz. The influence of waveguide and Rayleigh length on the quality of optical cavity is evaluated by the 3D-OSIFEL code. The waveguide size, mirror curvature radius, output hole radius is optimized. To increase the output power and resonator quality, the scheme of elliptical hole-coupling optical resonator is proposed. Compared with the case of round-hole coupling, the output power and coupling efficiency of elliptical-hole coupling are higher.

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REFERENCES

[1] Tonouchi M., "Cutting-edge terahertz technology", *Nature Photo*. 1, 97, 2007.

[2] Bratman V. *et al.*,"Review of subterahertz and terahertz gyrodevices at IAP RAS and FIR FU", *I*EEE *Trans.on Plas. Sci.* 37(1), 36-43, 2009.

[3] Williams G. P., "Far-IR/THz radiation from the Jefferson Laboratory, energy recovered linac, free electron laser", *Rev. Sci. Instr.* 73, 1461, 2002.

[4] Tecimer M. *et al.*,"Dynamically tunable mirrors for THz free electron laser applications", *Phys. Rev. S T Accel. Beams*, 13 (030703), 1-10, 2010.

[5] Xingfan Yang, Ming Li, Xu Zhou, Xiaojian Shu, Yuhuan Dou *et al.*, "The terahertz FEL facility project at CAEP", in *Proc. FEL 2012*, Japan, Aug 26-31, 2012.

[6] Zhou Xu, Xingfan Yang, Ming Li *et al.*, "Design of a high average power terahertz-FEL facility", *J. Tera. Sci. Elc. Infor. Tec.* 11(1) 2013.

[7] Xiaojian Shu, Yuhuan Dou, Xingfan Yang *et al.*, "First Lasing of CAEP THz FEL Facility", in *Proc. IRMMW-THz 2017*, Mexico, Aug 27-Sep 1, 2017.

[8] Yuhuan Dou, Xiaojian Shu, Xingfan Yang *et al.*, "Lasing and saturation of CAEP THz FEL facility", in *Proc. IRMMW-THz 2018*, Nagoya, Japan, Sep 10-14, 2018.

[9] Yuhuan Dou, *et al.*, "3D-simulations of Optical Modes of the Free Electron Laser Resonator with Hole Output coupling", *Com. in Com. Phy.* 1, 920, 2006.