PHYSICAL DESIGN ON AN RF-LINAC FOR FAR-INFRARED FREE ELECTRON LASER*

Fu Shinian, Chen Yinbao, Yang Tianlu
(China Institute of Atomic Energy, P.O.Box 275(17), Beijing 102413)
Zhang Zhenhai
(Tsinghua University, Beijing 100084)

Abstract

Beam dynamics of the L-band electron linac for free electron laser at wavelength about 200 μm is studied by means of PARMELA code. In order to satisfy the FEL's requirements on electron beam qualities, such as current intensity, energy spread, emittance, micro-pulse length as well as stability, a careful physical design on each part of the linac, including subharmonic buncher, prebuncher and accelerator, is worked out.

1. Introduction

Submillimeter and far-infrared free electron laser can be applied to the researches of solid state and biology because of its characteristics of tunability, ps time structure and very high micro-pulse power[1]. An RF-linac of 4-6 MeV is now under construction at China Institute of Atomic Energy to drive an FEL oscillator at wavelength about 200 μm.

It is well known that good quality of an electron beam is very important for FEL performance. Beam intensity, energy spread, emittance, micropulse length and the stability of micropulse energy and period are the basic parameters to characterize the quality of an electron beam. At long wavelength, the requirement on emittance is relatively low according to the relation $\varepsilon < \lambda$. But on the other hand, the slippage between the electron beam and the laser beam as they pass through the undulator (Slippage = $N_u \lambda$) becomes long. Thus, for good overlap between electron pulse and laser pulse and a high gain, the accelerator must provide very long pulse with intense current (more than 20 A) and small energy spread (less than 1 %). It is the goal of the physical design of the accelerator. The stability during a macropulse must also be ensured for an FEL oscillator. The central energy shift of each micropulse during a macropulse should be less than 1%, the same requirement as to energy spread. The arrival time fluctuation at the entrance of undulator must be limited within several ps to have good overlap of electron pulse with the laser pulse bouncing between the two reflecting mirrors of optical cavity.

* This project is supported by National Natural Science Foundation of China and China Science Foundation of Nuclear Industry.

According to the requirements to beam quality and the status of CIAE injector [2], a satisfactory design of the linac has been achieved through a lot of simulations by PARMELA and analysis. The results will be reported in this paper.

2. Simulation Study of Particle Dynamics

The linac consists of an electron gun with cathode-grid assembly, a subharmonic buncher, a fundamental frequency buncher and an accelerator. The gun provides an electron beam with energy of 80 KeV, intensity of 2.5 A, pulse length of 3 ns, normalized emittance of 0.006 cm-rad and beam radius of 0.5cm at a repetition rate of 108.3 MHz. Drifting a distance, the electrons in the beam enter the 108.3 MHz subharmonic buncher of $\lambda/4$ coaxial resonator and accept the energy modulation at 41 KV. They are gradually bunched during the following drift of 140 cm. And finally, at the entrance of the fundamental frequency prebuncher, an asymmetric pulse referred to the reference particle is formed and most of the electrons concentrate in a length of 0.4 ns.

The pulse is then further bunched in the prebuncher at 1300 MHz with 3 MV/m gradient . The first six cells of the buncher have tapered phase velocity β_p from 0.55 to 0.91 and the following three cells have phase velocity $\beta_p = 1$. A strong bunching is not wanted in this unit for the reason that a long micropulse is required as mentioned in the proceeding section. But a high capture efficiency is pursued and it finally achieves 80 % by adjusting the entrance phase . And another target to select the entrance phase is to generate a proper longitudinal phase space for the following accelerator unit.

After drifting a distance of 50 cm, the bunch enters the accelerator of 9 cells with mode $2\pi/3$ at 1300 MHz. It emerges from the accelerator with a variable energy from 4 to 6 MeV by controlling the input power into the accelerator. The electron bunch is not positioned at the peak of the microwave because we pursue a beam with low energy spread and long pulse length instead of high acceleration efficiency. A proper phase is chosen so that the energy spread is suppressed while the beam is accelerated. By matching the acceleration wave with the longitudinal phase space at the entrance, the electrons with higher energy are located at low acceleration field while the electrons with lower energy at high acceleration field. As a consequence, the energy spread is reduced and the pulse length becomes longer. The results at the exit of the accelerator from PARMELA simulation is shown in Figure 1., in which (a) is phase distribution with unit of degree, (b) the beam cross-section with unit of cm, (c) the phase-energy space and (d) the energy spectrum with unit of KeV. The reference particle locates at the origin of the coordinates in these plots. 900 particles are put into the simulation and 737 particles remain at the exit of the accelerator. And 68.1% of the captured particles are within 1% energy spread with a phase width of about 25°, i.e. 53ps, and current of 78 A at energy of 5.2 MeV. For other energy a similar result can be obtained.

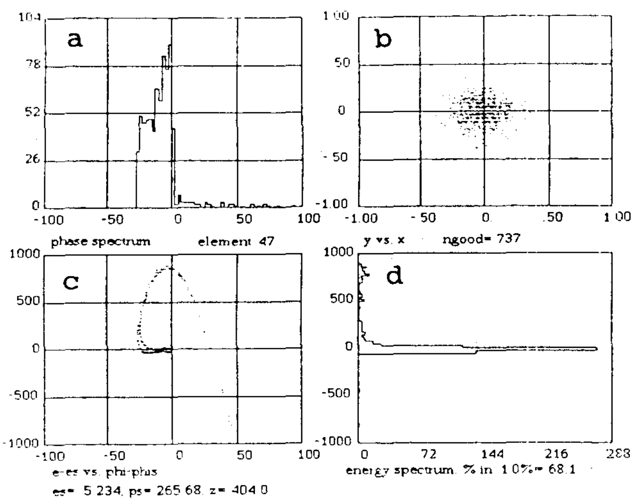

Figure 1. Electron distribution at the exit of the accelerator

As we know there is a common relation between the energy spread and pulse length in linac. But it may be broken by matching the phase -energy relation between the prebuncher and the accelerator in order to get a long pulse with low energy spread. And there is no obvious reduction in the pulse current. These just fit the requirements of long wavelength FEL.

In the simulation, the beam loading effect on the reduction of the pulse energy is considered , but the effect on the pulse energy spread is not included. It will be calculated in the next step.

In transverse, 20 focusing coils are equipped along the whole linac to offset the space charge effect of the intense beam and the defocusing force of the RF field. By adjusting the current in each coil to control the magnetic field in the simulation, the cross section of the beam along the system is always less than 0.5 cm and the emittance growth is limited within an acceptable range.

3. Stability Requirements to the Linac

It is well known[3,4] that the stability of the accelerator for FEL oscillator experiment is very important and the requirements are sometimes very high. Two basic conditions are: 1. Precise period between micro-pulses; 2. highly stable energy between micro-pulses.

In the following, the effect of instability of each part of linac on the beam quality is checked by simulations.

(1) Electron Gun

The instability of gun comes from the RF time fluctuation of grid ΔT_0 and the voltage ripple of the anode $\Delta V/V$. In Table 1, the influences of the two instabilities on electron beam at the exit of the linac are listed. It is noticed that the RF time fluctuation is finally suppressed greatly by the time stable function of subharmonic buncher. But the time fluctuation resulted from the voltage ripple never gets any chance of suppression in any subsystem of the linac.

Table 1. Instability effects of gun on beam parameters

Machine \ Beam		ΔT_1 (ps)	$\Delta E/E$ (%)	τ (ps)	I (A)
ΔT_0 (ps)	250	1.6	0.3	44	75
	378	5.6	1.0	40	66
$\Delta V/V$ (%)	1	3.4	0.7	41	78
	2	6.2	1.3	40	66

In the table, the meanings of symbols are as follows:

ΔT_1---- Micropulse time fluctuation at the exit of the linac;
$\Delta E/E$---- Energy shift of micropulse;
τ ---- Micropulse length within 1% energy spread;
I ---- Micropulse current within 1% energy spread.

These symbols will also be used in the following tables.

(2) Subharmonic Buncher

Table 2 lists the influences of the bunching phase shift $\Delta\Phi$ and bunching voltage ripple ΔV on the beam parameters. It is found that the effect of the phase shift is obvious for the reason that it brings about the energy change of the pulse.

Table 2. Instability effects of the subharmonic buncher on beam parameters

Machine \ Beam		ΔT_1 (ps)	$\Delta E/E$ (%)	τ (ps)	I (A)
$\Delta\Phi$	1°	2.8	0.7	44	75
	2°	9.6	1.3	27	86
ΔV (KV)	1	1.9	0.3	53	70
	2	5.7	0.6	42	74

(3) Prebuncher

From Table 3 it is found that the exit time fluctuation of the beam is very sensitive to the phase shift of the prebuncher but the input power variation makes no much changes on beam parameters.

Table 3. Instability effects of the prebuncher on beam parameters

Machine \ Beam		ΔT_1 (ps)	$\Delta E/E$ (%)	τ (ps)	I (A)
$\Delta\Phi$	3°	5.0	0.4	42	76
	5°	11.0	0.6	43	63
$\Delta P/P$ (%)	4	1.5	0.1	49	72
	6	5.0	0.1	44	72

(4) Accelerator

Different from the case in the prebuncher, the input power fluctuation in the accelerator section has a significant effect on the energy shift of the micropulse, but the phase shift gives less influence upon the exit time, as shown in Table 4.

Table 4. Instability effects of the accelerator on beam parameters

Machine \ Beam		ΔT_1 (ps)	$\Delta E/E$ (%)	τ (ps)	I (A)
$\Delta\Phi$	3°	2.0	0.4	45	70
	5°	6.0	0.6	38	63
$\Delta P/P$ (%)	2	1.7	1.0	47	67
	4	3.0	1.7	46	70

In addition to the machine instability, the variation in beam parameter, such as current intensity, can also give rise to the changes of other beam parameters. 10% current variation will result in the energy change about 0.5% and exit time jitter about 2ps through beam loading in our linac.

It should be pointed out that in the about study, the effects of instability are investigated for each element of the linac. The total influence from instability of the linac as a whole must be much greater.

4. Conclusion

A simulation study on the RF-linac for a far-infrared FEL oscillator is made by means of PARMELA code for the design of the linac. The results show the linac can provide a satisfactory beam with variable energy from 4 to 6 MeV, current intensity of 70 A and pulse length of 45 ps within 1% energy spread. The instability effects of each part of the linac on the beam parameters are also discussed.

Acknowledgements

We are very grateful to Prof. Zhao Xiaofong and Dr. Li Xingyue for their help in using the code.

References

[1] Pantell, R.H., Free Electron Laser, Edt. by Chen Jiaer, Xie Jialin, Du Xiangwan, Zhao Kui, World Scientific (1988) P.54

[2] Zhou W. Z. , et. al., Nucl. Instr. & Meth. in Phys. Res. A341(1994) ABS37

[3] Lynch, M.T., et.al., IEEE-J.of Quant. Electr., Vol. QE-21 (1985) P.904

[4] Stein, W.E., et.al., Nucl. Instr. & Meth. in Phys. Res. A296(1990) P.697