STUDY ON ACCELERATOR NOISE EFFECTS ON A FAR-INFRARED FEL OSCILLATOR *

Shinian Fu, Yinbao Chen, Zhibin Huang
(China Institute of Atomic Energy, P.O.Box 275(17), Beijing,PRC)

A far-infrared free electron laser driven by an L-band RF-linac is developed in our institute. In the linac some kinds of noise exist and they induce beam instability. Optical cavity detuning characteristics and the effects of accelerator noise on the FEL are simulated by an 1-D pulse code. It is found that the time jitter and energy ripple of electron beam during a macropulse modulate the laser power, and even decrease the power. Dependence of the noise effects on cavity detuning and beam parameters are also studied.

I. INTRODUCTION

Extending FEL wavelength to soft X-ray and to far-infrared or submillimeter is now a very interesting subject in FEL research for the reason that FEL in these wavelength ranges may fill in the blank of coherent radiation source. A far-infrared FEL project is launched out at CIAE for science research. The FEL will be driven by an L-band RF-linac which consists of a thermionic pulsed gun, subharmonic buncher, fundamental frequency buncher and an accelerator[1]. It is well known that the good electron beam quality, including intense current, low energy spread and low emittance, is very important for the successful operation of an FEL. And it is also found from the experiment results of Los Alamos National Laboratory FEL oscillator[2,3] that the FEL oscillator performance may be degraded by the e-beam instability generated from the accelerator noise. In the beam test of our injector we also found a serious trouble of time jitter in the gun pulser. Consequently, the phase and energy of the beam fluctuate as the beam passes through the following sections of the linac. The experience of other laboratory and the reality of our facility call for better understanding to the effects of accelerator noise. In this paper, we will investigate the influences of the e-beam instability on the far-infrared FEL oscillator by means of an 1-D pulse FEL code. In the following contents, we will briefly introduce the linac facility and discuss the noise. Then the optical cavity detuning of the FEL is studied to show the sensitivity of the FEL to the cavity length in the case that the bunch length is almost equal to the slippage in the far-infrared FEL driven by RF-linac. Finally the time jitter and energy ripple of the electron micropulse during a macropulse time are simulated to predict the effects of the accelerator noises on the performance of our FEL oscillator, and therefore, to give a requirement on the beam stability. In the simulation study it is also found the effects of accelerator noise are relative to some other beam parameters and the optical cavity detuning.

II. THE LINAC AND ITS NOISES

The grid of the electron gun will be pulsed at the frequency of 108 MHz to provide a string micropulse with length of 3 ns and current of 2.5 A during about 10 μs macropulse time. The electron beam from the gun with energy of 80KeV is injected into the subharmonic prebuncher with frequency of 108MHz. The beam is bunched in the following drift space and then inters the 1300MHz buncher for further bunching and acceleration. Finally the beam is accelerated in the 1300MHz accelerator. According to the PARMELA simulation the beam emerges from the linac with energy of 4-6MeV by varying the input power in the accelerator. The micropulse current is about 75A in length of 45ps.

In each of these components, there may be some kind of instability which can induce beam energy ripple and time jitter at the exit of the linac. In the gun, the fluctuation of pulse time makes the electron bunches emit from the gun at different time and then arrive at the following components on different phases. Fortunately, the subharmonic buncher can function as time stabilizer and therefore the time jitter in the gun can be immediately suppressed several times in the subharmonic buncher according our PARMELA simulation. In the heavily loaded linac, the fluctuation in the emitted current from the gun will induce beam energy change due to beam loading effect by the relation $\frac{\delta\gamma}{\gamma}=0.35\frac{\delta I}{I}$. In the subharmonic buncher a quick variation in bunching voltage or in the bunching phase will result in the beam time jitter at the entrances of the downstream elements and finally at the exit of the linac time jitter and energy ripple appear. For example, when there is a phase fluctuation of 1° in the subharmonic prebuncher, it will induce about 3ps time jitter and 0.7% energy ripple at the exit of the linac. Similarly, the fluctuations in amplitude and phase of acceleration field in the fundamental prebuncher and the accelerator will also result in beam instability, as shown in ref.[1]. All of these fluctuations will affect the interaction between the electron and laser in the FEL oscillator as we will discuss in the following sections.

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III. CAVITY DETUNING OF THE FEL

The electron beam from the linac will be sent into the undulator through a transport line and a set of bending magnets. In the undulator the first electron bunch generates a spontaneous radiation pulse taking after the form of the electron bunch. This radiation pulse is reflected back on the end mirror of the optical cavity while the electron bunch is deviated out of the cavity to a dump. The optical cavity length is so set that the radiation pulse overrides on the next electron bunch in the forward direction. In FEL mechanism, the electrons in the bunch will interact with the radiation coherently and give part of their energy to the radiation pulse. In many round trips the laser pulse becomes more intense until saturation. But, in fact, there is a slippage between electron bunch and laser pulse as they go through the undulator due to the slower longitudinal velocity of electron than that of laser. The slippage is approximately equal to $N\lambda$, where N is undulator period number and λ the laser wavelength. Therefore in far-infrared FEL the slippage length may be comparable with the electron bunch length. So the overlap between the laser and electron becomes poor and the interaction is week. The leading part of the laser pulse disappears for the gain is mainly obtained at the end of the undulator. And consequently, the laser pulse becomes shorter than electron bunch and the centroid of the pulse lags behind, or equivalently speaking, the speed of the laser pulse is slower than the light velocity in vacuum. Laser lethargy occurs. Slightly shortening the cavity length can ameliorate the case. By solving 1-D pulse self-consistent FEL equations[4], 1-D pulse code traces the evolution of laser pulse in many round trips in optical cavity with certain losses(including output coupling). In the simulations electron beam emittance is taken into account by an equivalent filling factor calculated from small signal theory of FEL. So does for beam energy spread to diminish the run time of the code, even though it can be included in the initial conditions in the simulation by adopting much more sample macroparticles. In our simulation, N=50, λ=200μm, and electron current is 40A in 45ps. So the short pulse effect is obvious, as shown in Fig.1. When the optical cavity detuning length is zero dL=0, the gain is small during the early time and the laser power drops down after 80 passes, and finally vanishes around 200 passes. Slightly shortening the cavity dL=20μm, the laser power increases greatly during the early round trips and then keeps stable level after saturation. If dL is too short there is no obvious improvement comparing with the case of dL=0 because it can not completely offset the lag of the laser pulse. But if the cavity is over-shortened, the laser power decreases quickly after some passes and can not reach a stable level, but the gain is very large during early passes, as shown in curve B of Fig.1. This means there is a good coupling between laser and electrons during early time due to the enough detuning. But as laser becomes stronger in the following passes the gain decreases and the laser pulse lags at a lower speed comparing with that during the early passes, while the detuning offset effect remains the same. Therefore the coupling becomes poor and the laser power decreases. It is found that in our case, dL=20μm is the best detuning length.

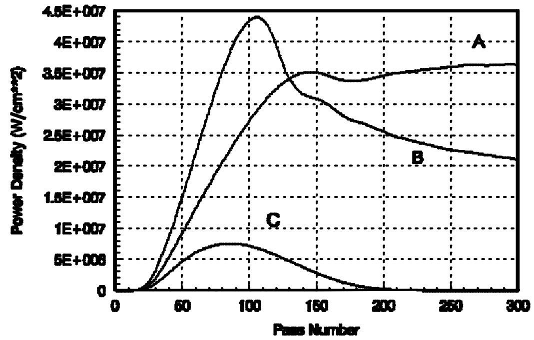

Figure 1. Laser power vs. pass number at different optical cavity detuning length: A--20μm; B--40μm; C--0μm

IV. EFFECTS OF TIME JITTER ON THE FEL

From the previous section we have seen that poor coupling between laser pulse and electron bunch due to slippage can result in a severe degradation of the FEL performance and the FEL is very sensitive to the cavity detuning length. Since 0.1ps time jitter is equivalent to a cavity length change of 15μm, it is necessary to exam the influence of the time jitter on our FEL oscillator in detail and consider the dependence of time jitter effects on some other FEL parameters.

For simplicity, one Fourier component of the jitter noise is taken into the simulations. Because the accelerator has filling time of 0.16μs, only these noise with frequency lower than 6.3MHz can effect the beam instability. Fig. 2 shows the laser power evolution as the pass number in the FEL oscillator under the influence of the noise. It is found that with the same noise amplitude Δt=3ps, different frequency noises result in different modulations in the amplitude of laser power. Noise

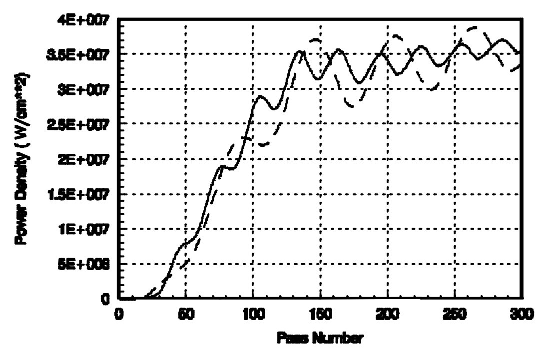

Figure 2. Laser power density vs. pass number with time jitter noise : Δt=3ps, f_1=3.6MHz (solid line) , f_2=1.8MHz (dashed line).

with lower frequency generates deeper modulation in laser power. In Fig.3, the time jitters with amplitudes of 3ps and 10ps induce 7% and 30 % modulations respectively on laser power at the same frequency of 3.6MHz and at the optimum detuning length. If the FEL does not operate at the optimum detuning, the effect of the time jitter becomes more severe. The time jitter effect also relates to the FEL gain. It is found as the electron current increases 2 times the modulation percent of laser power decreases 2 times. If the electron bunch length is suppressed from 45ps to 30ps while the charge in the bunch keeps the same, no obvious change was found in the effect of time jitter on laser power modulation. But there is a strong modulation at frequency of 3.6MHz up to 70% due to 5ps time jitter when shortening electron bunch to 30ps while keeping the same current.

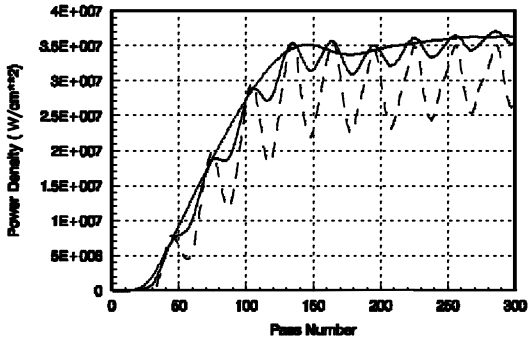

Figure 3. Laser power vs. pass number with time jitter noise at same frequency but different amplitude: f=3.6MHz, Δt_1=3ps, Δt_2=10ps(dashed line)

V. EFFECTS OF ENERGY INSTABILITY ON THE FEL

In the accelerator, the variations in the acceleration field due to instabilities of the input power and beam loading, and changes in acceleration phase can induce the electron energy ripple during a macropulse, as discussed in the second section. From FEL small signal gain curve we know when deviation from the resonant point $\Delta\nu=\pm\pi$, the FEL may work in the absorption or amplification regimes and the gain spectrum has a bandwidth of about π. Therefore electron energy ripple will result in the gain reduction or even absorption according to the relation $\Delta\nu= 4\pi N\delta\gamma/\gamma$. For simplicity, a single fourier component of the noise is again adopted in the simulation. Fig.4 shows the simulation results when the noise amplitudes are 0.5% and 1% respectively with the same frequency. These curves are calculated at the optimum cavity detuning length. It is shown the energy ripple not only modulates the laser power, but also decreases it greatly. Simulations with different noise frequencies but the same amplitudes indicate that as the noise frequency decreases, the noise effects in the power modulation become strong, as shown in the dashed curve B in the figure. Deviation from the optimum detuning length makes the modulation stronger than that at the optimum detuning, as shown in Fig.5.

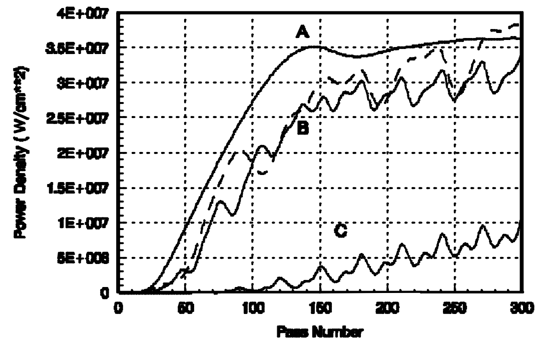

Figure 4. Laser power modulation due to electron energy ripple. A: $\Delta\gamma/\gamma$=0; B: $\Delta\gamma/\gamma$=0.5% , f=3.6MHz and 1.8MHz (dashed line); C: $\Delta\gamma/\gamma$=1% , f= 3.6MHz

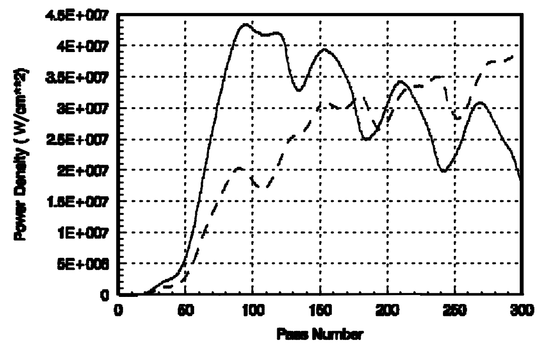

Figure 5. Effect of the same electron energy ripple on laser power at different cavity detuning length ΔL: —— : ΔL=40μm; ------: ΔL=20μm

VI. CONCLUSIONS

The effects of accelerator noise of time jitter and energy ripple on a far -infrared FEL oscillator is investigated by means of an 1-D pulse FEL code. The results show that the time jitter must be less than 3ps and the energy ripple should be controlled under 0.5% for our FEL oscillator. The current ripple should be less than 1.4%. And the optical cavity detuning has the optimum length of 20μm for stable operation during a macropulse.

VII. REFERENCES

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