FREE ELECTRON LASER PROJECT AT SINR

Yang Fujia (杨福家), Zhao Xiaofeng (赵小风), Zhang Zhongmu (张仲木)
and Sheng Shugang (盛树刚)
(Shanghai Institute of Nuclear Research, Academia Sinica, Shanghai 201800, China)
Wang Zhijiang (王之江) and Fu Ensheng (傅恩生)
(Shanghai Institute of Optics and Fine Mechanics, Academia Sinica, Shanghai 201800, China)

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ABSTRACT

The Shanghai FEL (SFEL) project at SINR is based on a RF linac in collaboration with the SIOFM. The prime goal of the project is to provide laser beams from the ultraviolet,visible to mid–IR with a few tens of MW in peak power and of Watts in average power. In the future, the wavelength region will be extend to the far–IR and vacuum ultraviolet. The SFEL will be a user facility for interdisciplinary studies.

Keywords: Free electron laser Accelerator

1 INTRODUCTION

Free electron laser (FEL) has come to be known as an exiting new type of coherent radiation source with the merits of high peak and average power, broad tunability and a flexible temporal pulse structure. FEL facilities have been increasingly applied to biotic, medical and material studies in recent years.

The 0.7— 3.0 μm wavelength range is of interests for most of the biotic and medical applications, whereas the near and far infrared region for material studies. Up to now FEL in just the visible to the near–IR wavelength range have been generated by radio frequency (RF) linear accelerators (linac). A RF linac produces an electron pulse (macropulse) which consists of a large number of short micropulse from a few ps to several tens of ps. This temporal format of the electron pulses are especially desirable for biomedical and material researches.

The SFEL (Shanghai FEL) project at SINR is based on a RF linac. This is a project in collaboration with the Shanghai Institute of Optics and Fine Mechanics Academia Sinica. The prime goal of the project is to build a tunable laser and provide laser beams from the ultraviolet, visible to mid–IR with a few tens of MW in peak power and a few tens of Watts in average power. In the future, the system will extend its operation to the far–IR and vacuum ultraviolet region. The SFEL will be applied to interdisciplinary studies, but further efforts will be made to develop FEL and relevant techniques.

2 ACCELERATORS AND THREE OPERATION MODES

A 90 MeV S–band RF linac, the prototype injector of the Beijing Electron Positron Collider (BEPC) is to be remodelled into a FEL system. In this way, we can save the time and money by carrying out the project with what have been gained in building the BEPC. We decided to build the FEL system with three operation modes, as shown in Fig 1, in the hope of broadening its energy range and getting more flexibility in its applications.

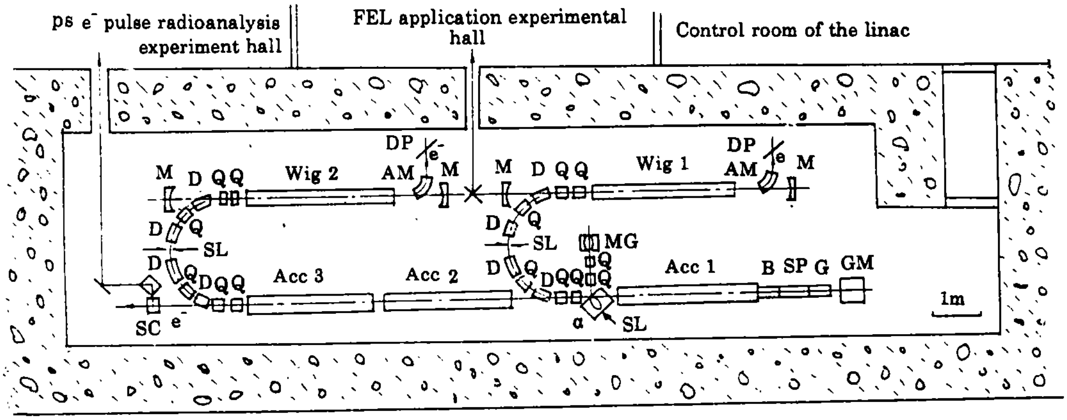

Fig.1 Schematic of the SFEL experiments

GM—ns puls e modulator of gun, G—Grided e⁻ gun, SP—Subharmonic buncher, PB—Prebuncher, B—Buncher, α —Alpha magnet, Acc 1, Acc 2, Acc 3—Accelerating section, Q—Quadrupole, D—Dipole, SL—Slit, MG—Microwave gun, Wigl, Wig 2—Wiggler, M—Mirror, AM—Analyzing magnet, SC–Sample case, DP—Spectrometer

2.1 The Acc 1 mode

In this mode, the injector consists of an electron gun, a subharmonic buncher, a prebuncher and a buncher. The electron gun is of the thermoionic dispenser type (2A–1ns grided). The subharmonic buncher is a quarter–wave resonant cavity of coaxial type. The prebuncher is a tunable reentrant type cavity.

The beams pulsed are approximately 50 ps in width at the entry of the buncher, which further compresses the beam pulsed to about 20 ps while accelerating the electrons up to 260 keV. The beam goes then into the 3 m long accelerating section of constant impedance. The electrons are accelerated to 30 MeV by the travelling waves applied to the disk–loaded structure around with solenoids. Electrons leaving the accelerator are bended by the magnet and finally come into wiggler 1. At this stage, the electron beams are IR FEL in nature, with which some oscillator experiments can be done.

The Acc 1 mode is designed to make use as much as possible of the exciting equipments for working in the mid–IR wavelength region. In the second phase of the operation mode, a longer wiggler will be constructed to extend the wavelengths to the far–IR (~100 μ m) region with increased peak power of a few tens of MW.

2.2 The Acc 2+Acc 3 mode

A single–cavity microwave gun similar to the one on the Stanford Mark Ⅲ produces electron beams of higher brightness while accelerating them to approximate 1 MeV. The electron beams are transported through an alpha magnet which offers both pulse compression and momentum filtering, and then injected into Acc 2 and Acc 3, the two constant gradient accelerating sections that are similar to the 3 meter SLAC–type linac structure. At the end of Acc 3, the beams are accelerated to 60 MeV. They are transported into wiggler 2, where FEL oscillator experiments in the 2—10 μ m wavelength region can be performed. With the higher brightness of the beams, peak power output will be high enough for us to extend the wavelengths down to 0.5 μ m by adding two stages of harmonic generations.

Table 1

Design parameters of the SFEL

Operation mode 1		Operation mode 2		Operation mode 3	
Wavelength range		Wavelength range		Wavelength range	
on 1st harm.	10—25 μ m	on 1st harm.	3—10 μ m	on 1st harm.	1—3 μ m
in 2nd phase	~100 μ m	on two stages		on harmonic generation	0.25 μ m
Peak power (micropulse)	10 MW	of harmonic generation	0.75 μ m		
in 2nd phase	50 MW	Peak power	10—50 MW	Peak power	10 MW
Energy/macropulse	150 mJ	Energy/macropulse	100 mJ	Energy/macropulse	50—100 mJ

2.3 The Acc 1+Acc 2+Acc 3 mode

In the third operation mode, the machine works in same way as the 90 MeV linac.However a subharmonic (1/6 RF of 2856 MHz) buncher is added to the linac system, in order to bunch electrons from the gun into a 180 ps domain as much as possible. As the result, an intense and narrow micropulse could be obtained.

Efforts will be made to run the machine in even shorter wavelengths and even higher peak power to carry out the MOPA experiment.

The laser beam characteristics that can be obtained from above three operation modes are summarized in Table 1. And the related accelerator characteristics are listed in Table 2. In this way, the system is able to deliver FEL of 0.25—100 μ m with a peak power of about 10 MW. It will be a powerful tool for the biomedical and material studies.

Table 2

Main features of accelerators

Type	2856 MHz RF linac
Energy range	20—90 MeV
Operation mode 1	20—30 MeV
Operation mode 2	40—60 MeV
Operation mode 3	60—90 MeV
Micropulse length	6—8 ps
Macropulse length (flat—top)	3 μs, up to 8 μs
Micropulse peak current	up to 100A
Macropulse peak current	<240 mA
Micropulse interval	The round–trip time of optical pulse in the cavity
Macropulse repetition rate	12.5, 25 Hz
Normalized emittance (90% particles)	
Operation mode 1	150 π mm · mrad
Operation mode 2	50 π mm · mrad
Operation mode 3	50 π mm · mrad
Energy spread (90% particles)	1%
Injector	
Operation mode 1 and 3	Gridded thermo–ionic dispenser cathode gun, subharmonic buncher, prebuncher and fundamental buncher
Operation mode 2	LaB_6 cathode microwave gun and alpha magnet
Accelerating section	Travelling wave, 3 m SLAC–type structure
Klystron	HK–1
Pulse power	30 MW
Number	2
Modulator	
Flat top length	Up to 8 μs
Peak power	75 MW
Pulse height deviation (unflatness)	<0.5 %

3 DESCRIPTION OF THE COMPONENTS

Performance of FEL system depends critically on the beam quality in terms of the peak current and shape of the micropulse, the energy spread and fluctuations, beam emitance, and timing jitters. And one has to care about all these from the vary beginning.

3.1 The ns grid—controlled gun

The BEPC injector uses a ns grid–controlled electron gun. This SLAC–type gun has a high brightness at relatively low grid drive voltage (~150 V). Its cathode–grid spacing is only 0.15 mm, and the grid cut–off voltage is –30 V. The gun creates very short pulse with high repetition. The normalized emittance of the gun is 10 π mm · mrad or <100 π mm · mrad at 5A, 80 keV.[1–4] And it has been demonstrated that the trapping efficiency is 50—60 % and beam energy spread is about 1 %. Therefore the electron gun can be used in the SFEL project to provide a new drive circuit that gives higher repetitions is designed.

3.2 The subharmonic buncher

The subharmonic buncher (SHB) is to operate at 476 MHz, 1/6 of the main accelerating microwave frequency of 2856 MHz.

The SHB operation guarantees higher peak current and lower average current. In the third operation mode, one is able to get a FEL beam of 1 μm in wavelength and 90 MeV in energy by decreasing the load of the accelerating sections. Electron beams of lower average current are more desirable, because as far as the users are concerned, the average power of the SFEL is of less importance than the peak power and tunability. Also it will be a possible cure of the BBU effect (if any), allowing one to work at a more moderate klystron power and minimize radiation damage to the targets.

3.3 The LaB_6 cathode microwave gun

The Mark III microwave gun (LaB_6 cathode) is one of the brightest electron sources. The brightness of this gun is $\sim 10^{12} A/(m \cdot rad)^2$. A typical LaB_6 cathode, as a thermoionic electron source, operates at 1800 K. If the cathode produces electrons by pure thermal emission, the electrons are emitted at all phases of the RF. Most of the electrons are accelerated at the wrong phases and fail to be matched into the linac. Moreover, the current emission from the cathode is limited by average–power heating. If a laser, however, is used to coordinate the electron emission with the correct RF phase, the peak current can be much higher. The LaB_6 cathode is to operate just below the temperature of normal electron emission with a mode–locked ND: YAG laser (40 MJ, 100ps). The Stanford group[5] increased the peak current from 33A to 75A without obserable change in beam emittance.

3.4 Beam transport

The beam is focused by a set of solenoidal focusing coils from the gun anode to the end of the first accelerating section. A beam leaving the accelerator is guided through a 180° bending section into the wiggler.

The bending section maintains the necessary beam quality for the wiggler. The major considerations in designing the bending section are as following:

a. It is symmetric in arrangement. This makes it doubly achromatic (first and second order) to maintain the emittance of beam constant.

b. In the middle, the beam image widens due to the energy dispersion, and allows inserting an analyzing slit for energy spread filtering, if desired. Also it cleans up the beam during particularly the beam loading process.

c. Great care should be taken to minimize aberrations and higher–order effects and the bending section will be as completely isochronous and achromatic as possible.

The beam size or the waist position inside the wiggler is tuned by adjusting the quadrupoles, two before the first dipole and two after the last dipole, i.e. in the optical cavity.

The magnetic spectrometer will be installed downstream of the optical cavity to measure the beam–laser interaction.

3.5 The others

Two home-made HK–1 type klystrons (30 MW peak power) with five cavities are chosen as the RF power sources, one for the Acc 1 and the other for the Acc 2 and Acc 3. A new modulator will be designed in order to power each of the klystrons with a macropulse length of 6—8 μs. The unflatness of modulator pulse (or pulse height deviation) affects seriously the energy homogeneity of the accelerated electron beam. Efforts are being made to achieve better than 0.5% of the the pulse flatness to meet the requirement of the FEL experiments.

As described in section 2, the accelerating sections (Acc 1, Acc 2 and Acc 3) are identical with those of the BEPC injector. The structure is featured by the high threshold current of BBU. Under our conditions the accelerating stucture should allow a macropulse average current of more than 250 mA to be accelerated.

4 THE CAVITY AND THE WIGGLER

The optical cavity is composed of two spherical mirrors in a quasi-confocal arrangement. The cavity length requires that the cavity round trip be a multiple of the electron bunch–bunch distance, namely $2L=md$, where m is an integral number, d is the distance between the micropulses. For mode 1 and 2, the L is 588.0 cm.

Both the mirrors of the cavity are made of gold–plated copper and have the same radius of curvature, $R=6$ m. The output coupler is a rotating ZnSe plate at near Brewster's angle. The beam waist occurs at center of the wiggler and has 0.3 mm for 1 μm. The Rayleigh length is 2.98 m. The mirrors will be tilted and moved in automatic control along the optical axis for resonator tuning.

The tapered wiggler consists of a pair of linear arrays of $SmCo_5$ permanent magnets. It is constant in wavelength $\lambda_w=3$ cm but varies axially in field amplitude. The wiggler length is 3 m.

In the next step, the REC–steel hybrid configuration will be used, and a 40 % increase of the peak field is expected.

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