A 5-MeV ELECTRON INJECTOR AND FELI LINAC FOR FEL FACILITIES COVERING SPECTRAL RANGE FROM 20 μ m to 0.3 μ m

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Abstract

FELI is aiming at IR-FEL generation by the end of 1994 using a 75-MeV beam and a 3-m long undulator and UV-FEL generation by the end of 1996 using a 165-MeV beam and a 3-m long undulator. The linac is composed of a 5-MeV electron injector and seven ETL type accelerating waveguides with a length of 2.93m ($2\pi/3$ mode, linearly tapered type). The injector consists of a 150-kV DC thermoionic triode gun operated by a 178.5-MHz, 500-ps pulser, a 714-MHz prebuncher (SHB), and a 2856-MHz standing wave type buncher (SWB).

The linac will be operated in three modes of 24 μ s, 12.5 μ s and 0.5 μ s. With a choice of three modes, the maximum accelerated energy can be changed from 165 MeV to 310 MeV.

The linac beam will be sent to four undulators using S-type BT systems installed at 30-MeV, 75-MeV, 120-MeV, and 165-MeV sections at 24- μ s rf pulse operation. The ratio of the cavity length to the undulator length is designed to be less than 3. The beam, once used for lasing at 30-MeV section or at 75-MeV section, can be bent back to the following accelerating waveguide and is reacclerated and reused for lasing.

Introduction

A number of approaches have been proposed for the generation of UV and short wavelength FELs[1,2]. One of the key technologies is keeping the emittance of high-current and long-pulse electron beam low from a gun to the end of the linac, and further to an undulator. Of several candidate electron guns at the present time, a high DC voltage thermoionic triode gun is the best choice for the capability of emitting intense microbunches at a repetition rate of 1 GHz, during a macropulse of 20 μ s[3].

Another technology keeping the high-current and long-pulse electron beam in the smaller-energy spread region depends on the development of stably operable long-pulsed klystrons and their modulators being capable of driving them very stably. Since the FEL gain is getting smaller for the shorter wavelength FELs, a considerably long beam is necessary to ensure saturation of UV and shorter wavelength FELs and to improve the FEL generation efficiency. The FELIX group has succeeded in these developments.

5-MeV Electron Injector

The layout of a 5-MeV electron injector is shown in Fig. 1. It is composed of a 150-kV thermoionic triode gun, a 714-MHz prebuncher, and a 2856-MHz standing wave type buncher. The gun is a Pierce type gridded gun with a thermoelectronic dispenser cathode (EIMAC Y646B model). A cathode voltage of 150 kV for the gun was chosen because of easy operation in air without a tank filled with SF_6 gas. The gun is triggered by a 178.5-MHz 500ps pulser (Kentech Instruments, Ltd. England). In the subnano-pulsed operation, it is expected that the emittance of the gun is less than 5π mm•mrad at 1.6A[3]. These parameters are shown in Table 1.

The 714-MHz prebuncher acts as a subharmonic buncher (SHB) and is made from stainless steel to reduce the influence of a substantial rf field introduced in the cavity by the subnano-beam current from the gun. The rf frequency of 714 MHz is chosen 1) to make the cavity as compact as possible, 2) to meet the short bunch (<0.5ns) mode operation of the gun, and 3) to coincide the micropulse FEL beam with a micropulse conventional laser generated with a frequency of 2856 MHz/2n(n is an integer).

The buncher is of a standing wave type (SWB) and its total length is around 49cm. The peak electric field will be around 10 MV/m for the rf input of 2MW. In order to reduce the influence of space-charge fields as much as possible, the distance from the gun cathode to the first cavity of the buncher is designed to be less than 80cm for the 0.5 ns-pulse injection mode.

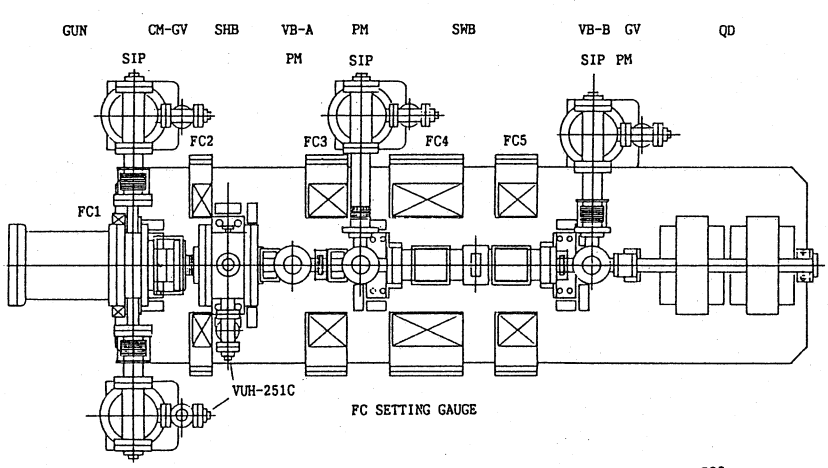

Fig. 1 A 5-MeV Electron Injector

Table 1 Main Parameters of the FELI linac injector

Gun	Type	Thermoionic triode
	Energy	≦150 keV
	Micropulse	0.4~0.5 ns
	Microcharge	1.2 nC
	Normalized emittance	<10 π mm mrad
	Macropulse	≦24 μ s
	Repetition frequency	1~10 Hz
Prebuncher	Type	Re-entrant cavity
	Frequency	714 MHz
	Q-Value	~2000
	Peak field	~50 kV
Buncher	Type	Standing wave
	Length	~49 cm
	Energy	~5 MeV for 2-MW rf
	Energy spread (FWHM)	<130 keV

From the Kapchinsky-Vladimirsky equation[4], an axial field Bs of a focusing solenoid keeping a beam radius r constant from the SHB to the SWB is given by

$$Bs=2\sqrt{2}\, m_0 c/(e\sqrt{Ia}) \cdot \sqrt{I/\beta\gamma}/r, \qquad (1)$$

where m_0 is the electron rest mass, c is the light velocity, Ia is the Alfven current (~17000A). I is the peak current, β=v/c is the nominal particle velocity, and γ is the Lorentz factor. The maximum focusing field is designed to be about 0.19T near the entrance of SWB. The field distribution obtained by five focusing coils is shown in Fig. 2. It is expected that a 0.5-ns injection beam of 120 keV electrons (the corresponding bunch length is 8.7cm) is bunched in a bunched length less than 1.5cm at the entrance of SWB by the bunching system of SHB and a drift space. Two beam position monitors are installed in the drift space.

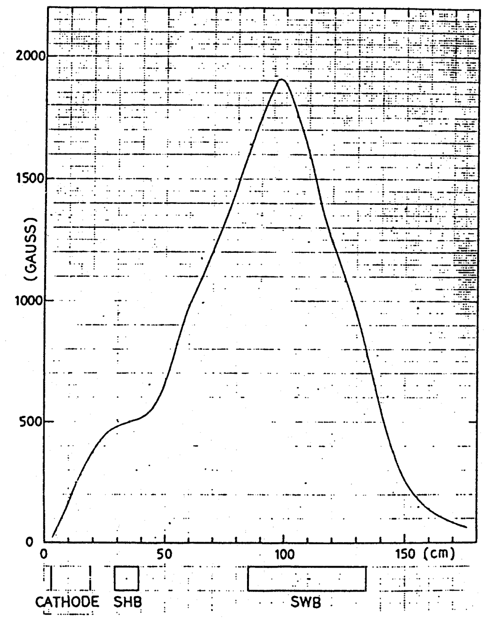

Fig. 2 Magnetic Field Distribution

Linac and FEL Facilities

The regular sections of FELI linac are composed of seven ETL type accelerating waveguides with a length of 2.93m ($2\pi/3$ mode, linearly tapered type)[5]. A set of steering coils, focusing coils, quadrupole magnets, optical and core monitors for beam diagnosis, and a sputter ion pump, are installed at each accelerating waveguide. The length of the injector and regular sections including bending sections for BT systems is 46m. The buncher and these accelerating waveguides will be powered by two klystrons (E3729, 2856MHz, total 48MW, 24-μs flat top long pulses). Fig. 3 shows a schematic layout of the FELI linac including rf systems and four undulators.

The klystron used here is a klystron E3729 manufactured by Toshiba Corp. E3729 is a modified version of E3712. Since the latter is usually used in the short pulse mode (4 μs-80MW, 50pps), the test operation is necessary at a long pulse mode of 24 μs. The linac will be operated in the following modes, that is, 1) 24-μs mode, 2) 12.5-μs mode, and 3) 0.5-μs mode, in which the beam is used for the injection to storage rings and slow positron generations. With a choice of three modes, the maximum accelerated energy can be changed from 184 MeV to 310 MeV.

KLYSTRON POWER

pulse length	KLY1, KLY2	P1	P2	Ea	Eb	Ec	Ed
24.0 μs	24MW	12.0MW	6.0 MW	35MeV	82MeV	132MeV	184MeV
12.5 μs	34MW	17.0MW	8.5 MW	42MeV	97MeV	156MeV	216MeV
0.5 μs	70MW	35.0MW	17.5 MW	58MeV	141MeV	224MeV	310MeV

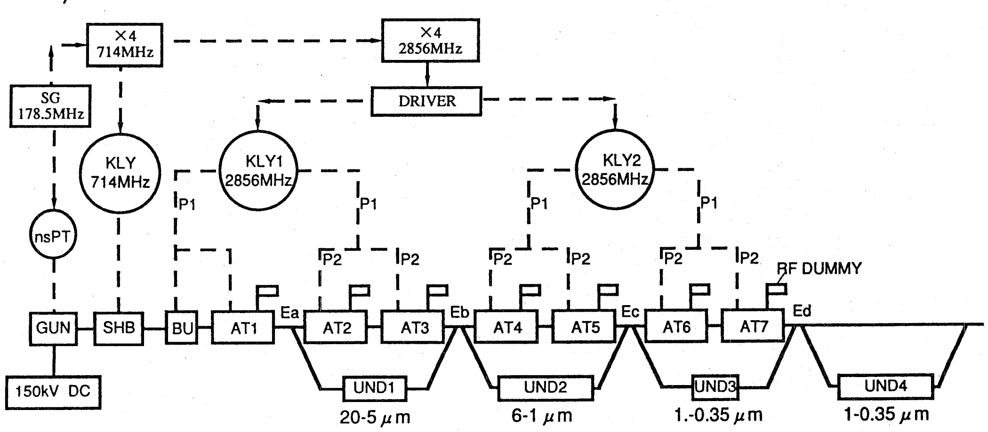

Fig. 3 FELI Linac including rf Systems and Four Undulators

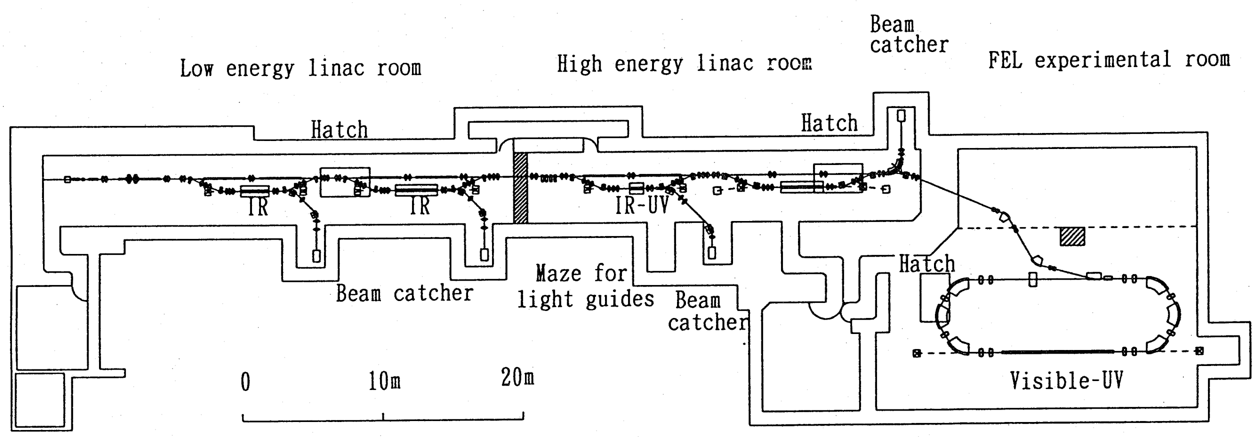

Fig. 4 Layout of IR and UV-FEL facilities of FELI including a future SR-FEL project

The klystron is powered by a pulse-forming-network (pfn) modulator including a stack of optical thyristors and a pulse transformer. The pfn consists of four-parallel lines so as to optimize the pulse flatness like FELIX[6]. The pfn signal is fed to the klystron cathode by means of a 1:15 pulse transformer. The cathode voltage stability of the order of 0.08% is necessary for keeping an rf 0.2%. Details of the rf system of FELI is presented in this meeting[7].

The BT system for the linac has a quadrupole doublet every 2m on average as shown in Fig. 4 to keep the emittance and position of the accelerated beam small and on the axis of the accelerated waveguide, respectively, from the injector to the end of the linac.

The four BT systems for the corresponding undulators have been designed as an achromatic and nearly isochronous (22.5° bend x 2) BT systems. The bending angle (α) of 22.5° and the bending radius (R) of 0.5m were chosen to reduce the residual non-isochronicity c$\triangle$t (c is the light velosity), since c$\triangle$t is proportional to α^3R $\triangle$P/P, where $\triangle$P/P is the relative momentum spread.

The beam passed through the undulator at 30-MeV and 75-MeV sections can be bent back to the following accelerating waveguide using the BT (22.5° bend x 2) system and can be reaccelerated, since an energy loss due to lasing is less than 1% and the residual non-isochronicity due to the two BT systems (22.5° bend x 4) is less than 0.6ps for a beam with an energy spread of 0.5%. The reaccelerated beam is reused for lasing at the following undulator and bent back again for injection to storage rings and slow positron generations. A lattice design of the BT system of FELI is presented in this meeting[8].

Table 2 is beam quality values desired for FEL oscillations and intended FEL applications at FELI.

Table 2 Beam quality values desired for FEL oscillations and intended FEL applications at FELI

Electron energy	≦30MeV	≦75MeV	≦120MeV	≦165MeV
Peak current				≧100 A
Normalized emittance				≦10 π mm mrad
Energy spread (FWHM)				≦0.3 %
Micropulse duration				≦5 ps
Micropulse repetition frequency				178.5 MHz
Macropulse dulation				≦24 μs
Macropulse repetition frequency				≦10 Hz
Average beam power				<3.06 kW
FEL wavelength	20-7 μm	≧1.5 μm	≧0.54 μm	≧0.25 μm
FEL average power	3 W	8 W	12 W	5 W
FEL applications	Separation	FEL-CT	Purification	Photosynthesis

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