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Development of Infrared Free Electron Laser System Using Compact Linac

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Abstract

The present status of infrared free-electron laser (FEL) system using compact linac in Sumitomo Electric Industries Ltd. (SEI) is reported. Characteristics of the beam transport system was studied through numerical simulations. For precise simulating, initial condition of the beam at the end of the linac was examined in details. As a result, beam transport condition to realize well-focused beam in undulator was obtained. Spontaneous emission of peak power of 0.4mW was observed in recent experiment.

1. Introduction

We have developed a compact 100MeV linac in Harima Research Laboratories. This linac not only provides electron beam for compact superconducting SR ring NIJI-III, but is utilized for infrared FEL experiments.

2. Compact linac [1]

Main design parameters of the compact linac are listed in Table I. The linac produces electron beam with pulse width of 1μs for injection into NIJI-III, 10μs for FEL experiments. Accelerating rf power is supplied by klystron (Thomson-CSF TH2146). Pulse length depends on the connections in pulse forming network (PFN) in the klystron modulator.

Table I Main design parameters of the linac.

Electron gun	Cathode	EIMAC Y646B
	Voltage	200 kV - DC
	Emission current	1.5 A
	Normalized emittance	7 π mm mrad
SHPB	Type	Standing wave
	Frequency	476 MHz
	Input power	4.6 kW
Prebuncher	Type	Standing wave
	Frequency	2,856 MHz
	Input power	5 kW
Buncher	Type	Traveling wave
	Frequency	2,856 MHz
	Input power	8 MW
Accelerator	Type	Traveling wave
	Mode	2π/3
	Frequency	2,856 MHz
	Beam energy	100 MeV(short pulse) 76 MeV(long pulse)
	Macropulse current	100 mA
	Energy spread	0.5 %
	Normalized emittance	60 π mm mrad
	Repetition rate	2 pps
	Accelerating gradient	22 MeV/m

Since the long-pulse operation mode has been designed to marking FEL oscillation in target, which includes some of the essential elements to obtain high quality electron beam suitable for FEL.

First of all, emittance of the beam should be reduced for FEL experiments. We have acomplished normalized emittance of 7 π mm mrad in the electron gun, where small-size thermionic dispenser cathode (EIMAC Y646B) is assembled and high DC voltage of 200kV is applied to anode-cathode gap. The gun container is filled with SF_6 insulation gas, and the structure around the gun is determined by numerical simulation to avoid electric field concentration.

Secondary, energy spread of the electron beam from linac should be narrow. Fluctuation of resonant frequency of the accelerating tube causes energy shift of the beam. To avoid that, temperature of accelerating tubes are precisely controlled within ±0.02℃ by water cooling system. Beam energy spread is also strongly influenced by the stability of pulses generated by klystron modulator. To obtain flatness and stability of output pulses, PFN is composed of two parallel 21 stages, each using the capacitors with low self inductance less than 0.1μH. We achieved the pulse voltage deviation from flatness less than 0.3%, and the long term voltage drift less than 0.5%/Hr.

Next, subharmonic prebuncher system (SHPB) is installed. Accelerating rf frequency is selected to be 476MHz, that is one-sixth of the dominant frequency of 2,856MHz. Power supply system for SHPB is constructed by full solid-state circuits for its maintainability. Also inner surface of the stainless-steel cavity is partially coated with OFHC to optimize the Q-value, intending to reduce filling time and wake-field effect.

3. FEL experiment system

Figure 1 shows the schematic view of our FEL experiment system. The FEL beam transport system (FEL-BTS) contains two bending magnets and five quadrupoles, showing S-shape with bending angle of 25 degrees. Beam slit installed at down-stream of BM1 is expected to cut the tail of energy distribution. Equipments for beam diagnostics; two current monitors and five position monitors, also installed to observe focusing property in the undulator. To realize efficient and precise adjustment of beam trajectory, 1mm-thick aluminum OTR position monitors in the undulator section have 3mm-radius pin-hole in the center,

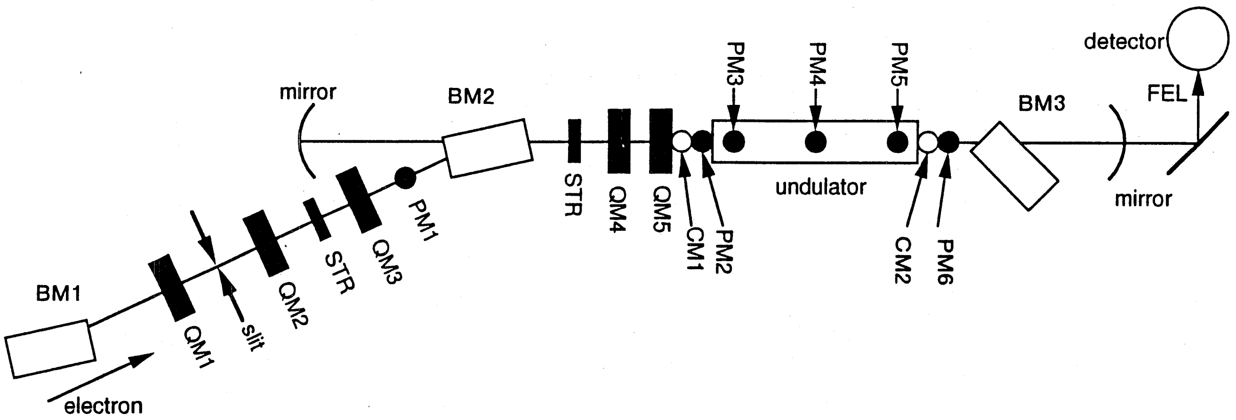

Fig. 1. FEL experimental system.

Table II Parameters of the undulator.

Type	Halbach
Magnet material	Nd-Fe-B
Period length	4.0 cm
Number of periods	50
Total length	2.0 m
Gap width	16~32 mm
Magnetic field	0.62 ~ 0.18 T
K parameter	2.4 ~ 0.7

aligned to designed orbit using He-Ne laser.

Table II shows main parameters of our horizontal polarized Halbach type undulator with Nd-Fe-B permanent magnet. Magnetic field was accurately measured with BELL-9900 Gauss meter. Dispersion of peak value (dB / B) was less than 1.0%, and second-order integral was less than 5.4×10^5 Gauss mm^2.

Optical resonators consists of two concave Au coated OFHC mirrors with the curvature of 4.42m and 4.14m. Resonator length between up- and down-stream mirrors was designed to be 7.5576m. Up-stream mirror has reflectance of more than 99.2%, and down-stream mirror has 1mm-radius pinhole to extract FEL.

Down-stream mirror can be adjusted manually with precision of 0.01mm, and remote-controllable driver unit with stepping motors and piezoelectric actuator enables fine position adjustment of up-stream mirror. In particular, piezoelectric actuator gives the precision of 10nm to the adjustment along the z-axis.

4. Beam transport experiments

Lattice structure of FEL-BTS was designed through the numerical simulation with evaluation of (i) achromaticity, (ii) quasi-isochronism and (iii) focusing property of the beam in the undulator section.

In FEL experiments the electron beam envelope should be well-focused and finely matched to the optical beam envelope in the undulator section to increase their interaction. To simulate characteristics of the beam in the FEL-BTS, particularly in the undulator section, we studied initial condition in details; not only the size and divergence

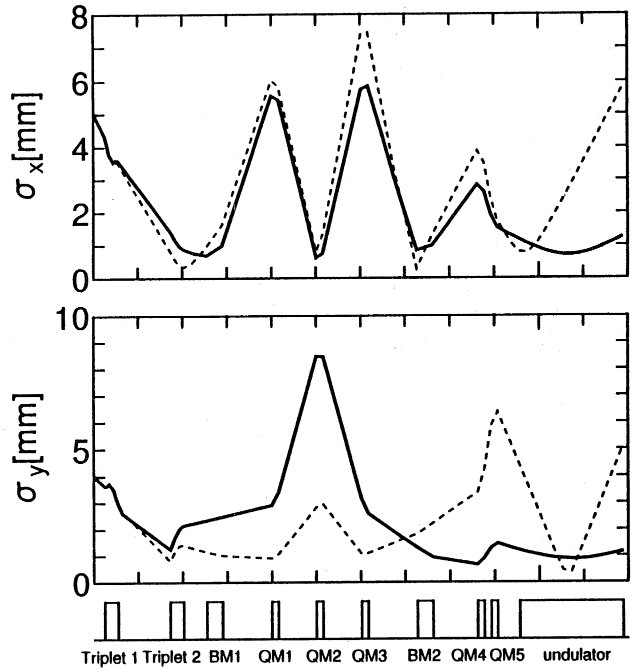

Fig. 2. Calculated beam size in FEL-BTS. Characters σ_x and σ_y stand for half-width of the beam envelope in the x- and y-plane respectively; result of parametric fitting to observed beam size (dashed line), and well-focused beam with initial condition estimated at the exit of linac (solid line).

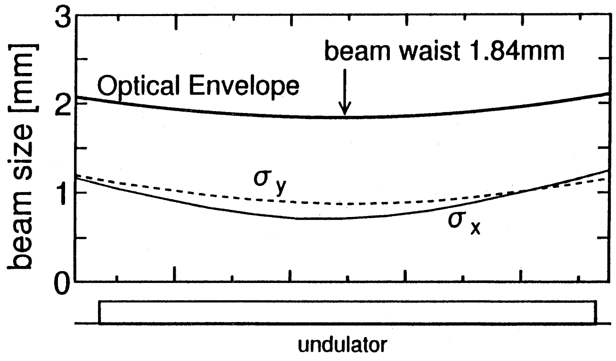

Fig. 3. Electron beam and optical envelope in the undulator.

but also focusing or defocusing character of the beam at the exit of the linac was taken into account.

As the first step, we injected the beam into actual FEL-BTS to collect the experimental parameters such as beam energy and energy spread, beam size at the position monitors and magnetic fields applied to Q-magnets. Setting these parameters as input values, we simulated beam transportation to search for initial condition that satisfies characters of the beam observed in the experiment. Calculated Twiss parameters α, β, and γ of the beam at the exit of linac are listed in Table III. We can see the parameter α has negative value, which means the beam initially has focusing character at the exit of the linac.

Table III
Twiss parameters of the beam at the exit of linac. Negative values of α corresponds to the focusing character of the beam.

	α	β	γ
x-plane	-22.3	41.7	119.9
y-plane	-9.9	26.7	37.6

In the next step calculation with the initial condition of the beam obtained above, we changed the combination of fields of Q-magnets to produce well-focused beam matched to optical envelope, as shown in Fig.2 . Envelope of optical beam and electron beam in the undulator are shown in Fig.3, where the optical envelope of the wavelength of 2.78μm is assumed to be Gaussian beam that has beam waist of 1.84mm at the center of the undulator. Through the study of initial condition of the beam at the end of the linac, we can precisely predict the beam characteristics in the FEL-BTS by the numerical simulation, and it is helpful to arrange the operating parameters.

5. FEL experiments

Referring the result of transport experiments, we carried out spontaneous emission experiment. Figure 4 shows observed spontaneous emission under the conditions listed in Table IV. With the assumption the micropulse is 10ps-long, the peak power is estimated to be 0.4mW.

Table IV Conditions of FEL experiment.

Beam energy	50 MeV
Peak current	25 A
K parameter	0.84
Magnetic field	0.23 T
FEL wavelength	2.8 μm
Gain	10 %

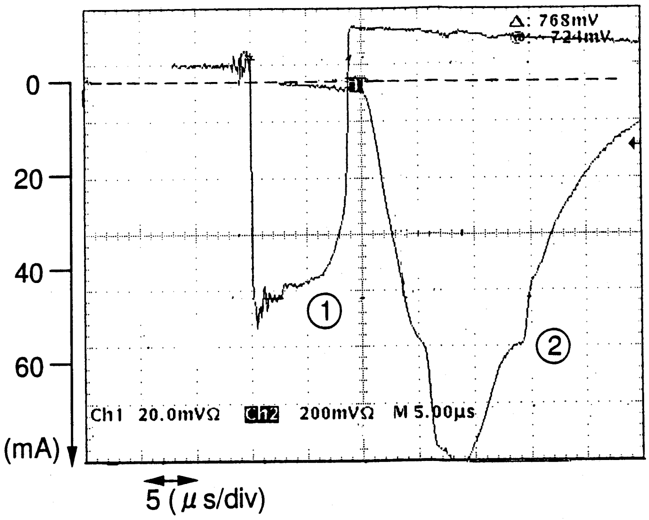

Fig. 4. Result of spontaneous emission experiment; (1) beam current at the entrance of undulator, (2) spontaneous emission.

We also roughly estimated the small-signal gain to be 10% through the calculation method used in the FELIX facility[2]. Though energy spread is known to eliminate gain, it is hard to make it narrower only by adjusting operational parameters of linac. Subharmonic prebuncher system (SHPB) can increase the micropulse current and it will lead to increase of the gain. Recently we observed desirable bunching effect throughout the macropulse.

6. Summary

Characteristic behavior of the beam in our FEL experiment system can be well predicted through the numerical simulation with the initial condition at the end of the linac. The calculation result indicates the experimental condition of the next stage that we can produce the beam well-focused and matched to optical envelope in the undulator.

Spontaneous emission was observed as the primary stage of our FEL experiments using the compact linac.

Also we intend to achieve FEL oscillation through the increase of micropulse current by SHPB system and fine adjustment of the optical resonator.

References

[1] T.Haga et al., on this proceedings.
[2] P.W. van Amersfoort et al., The FELIX project status report April 1988, Oijnhuizen Report 88-176