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LINAC FOR FREE ELECTRON LASER AT JAERI

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Abstract The superconducting linear accelerator is under construction for free electron laser aiming at 10.6μm infrared oscillation. The linac consists of a thermionic gun, a sub-harmonic buncher, a buncher, superconducting pre- and main accelerator. Each element of the linac is so designed as to achieve good beam quality.

INTRODUCTION

A free electron laser (FEL) is a tunable and high power laser. This is very attractive to the application of the isotope separation (Uranium enrichment, incineration) as well as the basic researches of the various fields, including the accelerator technology.

The superconducting linac driven FEL system for infrared oscillation is being constructed at JAERI. Outline of the JAERI FEL program has been reported elsewhere[1,2,3]. This system consists of a thermionic cathode electron gun with a grid structure, a sub-harmonic buncher, a buncher, superconducting pre- and main accelerator and an undulator with an associated optical instrument shown in Figure 1.

Both high brightness (low emittance and high current) and high energy resolution are required essentially for the injection system of FEL. Detailed designs of each element are described in following sections.

ELECTRON GUN

Beam quality such as less than 10π mm·mrad emittance, 100mA peak current and 1mm beam diameter is required for the injection system of FEL for our purpose. The design was done by using the SLAC electron trajectory program, E-GUN[4], by changing the parameters: cathode radius, shape of the focusing electrode, distance between cathode and anode, shape of the anode, current density and the anode voltage.

It has been found that the obtained emittance is exponentially decreased by decreasing the cathode diameter and that the cathode diameter should be less than 4mm to satisfy the beam specification. The radial distribution of the electrons has generally a peak at the edge, a hollow beam, due to the space charge force inside the beam as shown in Figure 2. Figure 3 shows the shape of the electrode and the equi-potential lines.

The increase of the emittance becomes linear about the decrease of the anode voltage between 200 and 300kV, however in this region the required condition is always satisfied.

SHB AND BUNCHER

It is necessary to make the phase spread narrow to get small energy spread through the RF linac. The beam pulse width from the gun is 4ns, correspondent to 720 degrees of the phase spread of main frequency. A 1/6 sub-harmonic buncher (84.7MHz) is chosen in our case.

However it is so difficult to bunch the beam of 4ns width to rather narrow using the only SHB that a buncher is located behind the SHB with some drift length. In case of no or less space charge effect, it is possible to bunch the beam to a few degrees phase spread by optimizing the amplitudes and phase angles of the SHB and the buncher. Table 1 shows the phase and energy spreads at the entrance of the pre-accelerator.

In real bunches the space charge effect is not avoidable. As the drift length becomes long, the space charge effects becomes large. Figure 4 shows the difference of the bunch length between with and without space charge effect as a function of the drift length. Table 1 indicates that the lower SHB voltage causes the less energy spread and the longer drift length. But according to Figure 4 longer drift length has disadvantage of the wider phase spread. On the basis of these results we determined the parameters of the SHB and buncher as shown in Figure 1.

However under the above procedure, the phase spread as well as the energy spread is not small enough to accelerate the beam not to make the energy spread wide through the pre- and main accelerators. In order to get required phase spread by chopping the extra phase spread, the energy selector is necessary to be inserted at the entrance of the superconducting pre-accelerator or the main accelerator. Several types of the energy selectors are compared with each others by utilizing the beam transport calculations as shown in Table 2. The comparison shows that bending the beam at the entrance of the main accelerator is preferable in order not to increase the transverse emittance.

PRE- AND MAIN SUPERCONDUCTING ACCELERATOR

In the RF linac based FEL oscillations, an energy recovery configuration is desirable for high power operation. As the FEL efficiency is around several percents, the remaining beam power is dumped out unless it is subject to be reused. The energy recovery configuration can be realized by means of a beam recirculation technique, which also can serve as an energy multiplier. The best choice for the main accelerator for this configuration is the superconducting cavity units.

The main superconducting linac uses 508MHz, which is the same structure of the TRISTAN Main Ring accelerator developed at KEK by Kojima et al[5].

The pre-accelerator consists of two superconducting cavities, which accelerates the 250keV beam to 2-3MeV. As the velocity of 250keV electron beam is 0.74c, the pre-accelerator will consist of two cells, whose length corresponds to β=0.9 and 1.0 respectively. The RF amplitude and the phase angle of each cell can be independently controlled.

FEL OSCILLATION

Table 3 shows typical gains calculated in small signal gain and homogeneous broadening regime[6] with the beam quality and the undulator parameters. These values would be enough for the FEL operation.

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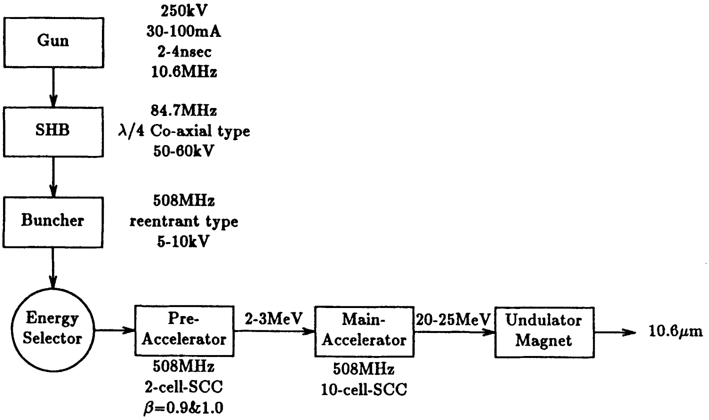


FIGURE 1 Outline of JAERI FEL project

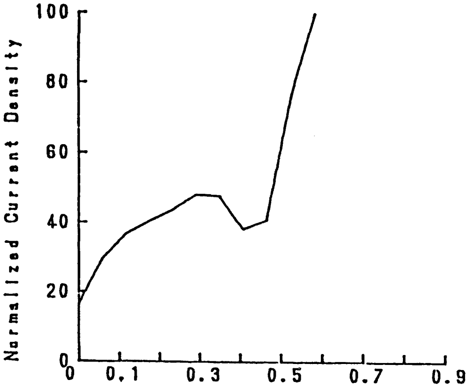


FIGURE 2 Normalized current density at 100mm from cathode as a function of radial point

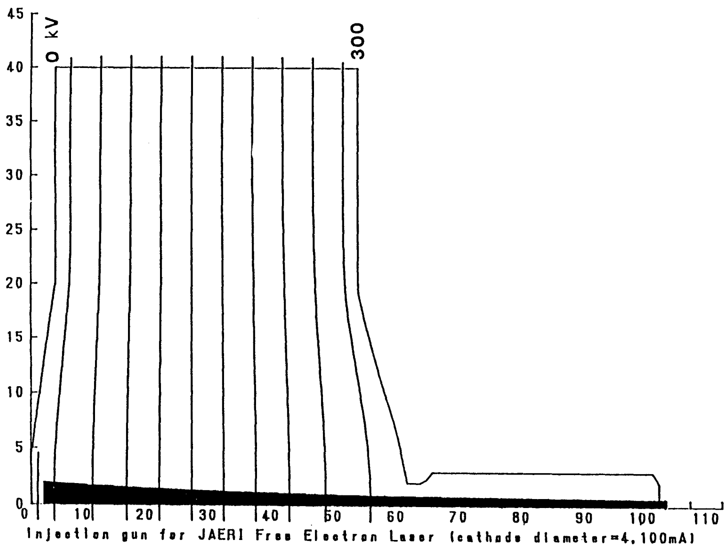


FIGURE 3 Shape of the problem region boundary and the equi potential lines for the cathode with 4mm diam and 100mA peak current and 300kV anode voltage

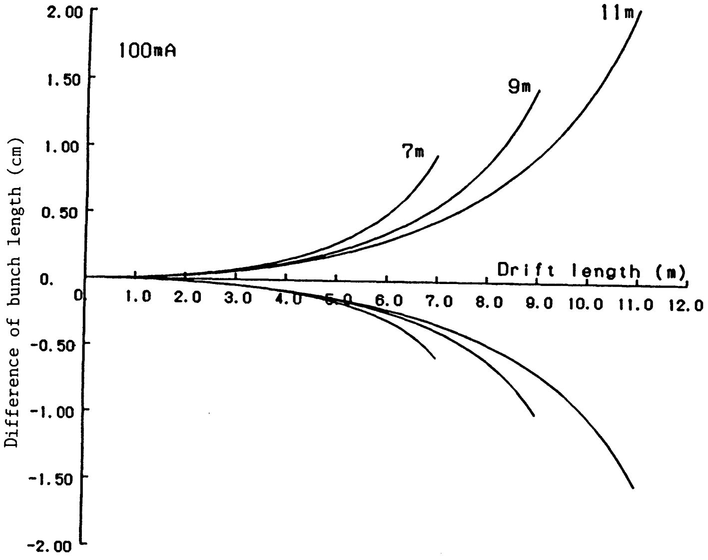


FIGURE 4 Difference of bunch length between with and without space charge effect as a function of drift length

TABLE 1 Phase and energy spread at the entrance of pre-accelerator in case of no space charge effect

Parameters of injector					Phase space	
V_{SHB} (kV)	ϕ_{SHB} (deg)	$V_{buncher}$ (kV)	$\phi_{buncher}$ (deg)	Drift length (m)	$\Delta\phi$ (deg)	ΔW (keV)
40	-14.5	5.0	174.5	11.3	1.7	68.9
50	-16.7	6.5	175.6	8.9	2.2	85.0
60	-20.8	7.5	172.6	7.2	2.5	100.7

V_{GUN}=250kV Δt=4nsec (≃720deg)

TABLE 2 Transverse emittance at the exit of energy selector

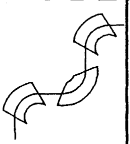
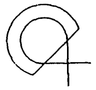
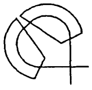
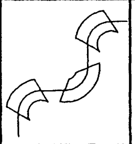
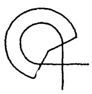
Initial	x=y=1mm x'=y'=10mrad ΔE=±50keV				
Energy	250keV			3MeV	
Type	3-bending system	1 pole α-Mag	2 pole α-Mag	3-bending system	1 pole α-Mag
					
x(mm)	1.22	7.86	1.64	1.03	1.06
x'(mrad)	10.24	14.05	14.36	10.00	9.40
y(mm)	2.95	6.76	1.64	1.06	1.05
y'(mrad)	11.44	12.55	14.45	10.01	9.44

TABLE 3 Gain of FEL oscillation

Beam Quality	ε (mm mrad)	15 π			
	ΔE (keV)	80			
	E (MeV)	20		25	
	I_{peak} (A)	8	9	8	9
Undulator Parameters	K	1.1			
	N	60			
	B (Gauss)	10780		6970	
	λ_u (cm)	1.55		2.39	
FEL Osc.	λ (μm)	10.6			
	Gain(%)	13.6	16.2	15.8	18.6
	T_{Rise} (μsec)	14.6	12.2	12.5	10.6