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Calculation of Electron Orbital for the Design of the X-band LINAC

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Abstract

The X-band linear accelerator, which can generate such a short pulse as 100fs, is under design at the Nuclear Engineering Research Laboratory, the University of Tokyo. The design study of the X-band linac is carried out by using PARMELA and SUPERFISH. Then it is found that 600 ps (tail-to-tail) emission from a thermionic gun can be bunched to about 1ps (FWHM) at the end of the 2nd accelerating tube and 80 % of the initial charge is transmitted.

1. Introduction

Femtosecond technology is going to become a key technology in radiation physics, chemistry and material science to investigate ultrafast and fundamental quantum phenomena. Up to now, 700 ps electron single bunch has been successfully generated at the S-band linear accelerator of the University of Tokyo by magnetic pulse compression[1]. However the X-band linac whose main RF frequency is 11.424 GHz is thought to be more effective for generation of shorter electron single pulse than the S-band linac. The X-band linac for a linear collider is already under design at Stanford[2] and KEK[3]. The X-band linac is discussed as the femtosecond accelerator in this paper. As to the design of the X-band linac, the most difficult problem is an increase of the space charge effect, which is accompanied with shortening of an electron bunch.

In order to generate a 100fs single pulse, an electron beam from the electron gun must be compressed till a pulse length is shorter than one period of the X-band RF (87.5 ps).

Taking that point into account, transport simulation of an electron beam has been carried out by using PARMELA and the feasibility of a generation of a femtosecond single pulse has been confirmed.

2. Design

The layout of the X-band linac designed here is shown in Fig. 1 It consists of a thermionic gun, a subharmonic buncher (SHB), two accelerating tubes and achromatic magnetic pulse compression system. And there are solenoid coils along the linac to generate axial magnetic field for controlling the transverse beam size. The final energy of the beam is 35MeV. Parameters of the components and calculated results are described in the following.

Thermionic Gun The present thermionic gun Y796 has achieved 500 ps (tail-to-tail) at the voltage of 90 kV so far[4]. In this design, Gun voltage is increased up to 200 kV. This is because both an increase of emission current and a decrease of the space charge effect are expected. Other parameters are determined as follows. Rms normalized emittance is 50 πmm mrad, the pulse length (tail-to-tail) is 600 ps, peak current is 10 A, and the space distribution of an electron beam is assumed to be K-V distribution.

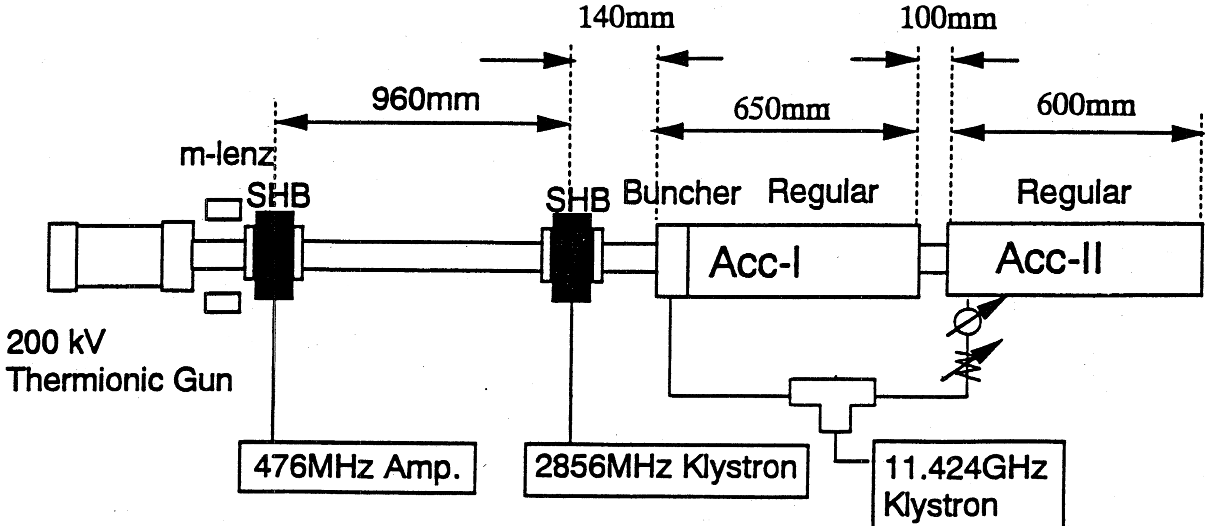

Fig. 1 Layout of the X-band linac

SHB Even though the pulse from the gun can be bunched to 87.5 ps by only one 476 MHz SHB, max energy gain must be more than 0.09 MV, which reduces engineering design mergin. Therefore double SHB system is adopted here. In this system, the voltage required for each SHB is reduced down to 0.05MV. Frequencies of SHB are determined 476 MHz and 2856 MHz, respectively, as the subharmonic numbers of 11.424 GHz.

Solenoid Coil In the non-relativistic region along the low energy part, the space charge effect has an large influence on a growth of emittance in the transverse direction. As the aperture of the accelerating tube is 8.4mm in diameter, the beam must be controlled in the transverse direction by an external longitudinal magnetic field. In the calculation with PARMELA, the external magnetic field is supplied by various kinds of circular coils with different radius and current. There are 52 coils. Radius of a coil changes from 50 mm to 150 mm and supplied current to the coil changes from 200 to 6000 A turn. The longitudinal magnetic field distribution by these coils is shown Fig. 2. The magnetic field at the entrance of the former accelerating tube is about 1000 Gauss. Variation of both pulse length and beam size as a function of the distance from the anode is shown in Fig. 3. It shows that the required conditions are satisfied at the entrance of accelerator.

Accelerating tube There are two accelerating tubes in this linac. The former consists of a buncher section and a regular section and the latter consists of only regular section. This is because magnetic pulse compression is scheduled and the 2nd accelerating tube is used for energy modulation. It is designed to carry the 11.424GHz constant-impedance travelling wave with the $2/3\pi$ mode. Input power for each accelerating tube from the X-band Klystron is about 15MW and the field gradient at the entrance of the accelerating tube is just below 40MV/m. In the first accelerating tube, the first 6 cavities form the buncher section and the rest 69 cells form a regular section. The second accelerating tube consists of 69 regular cells. Travelling wave inside the accelerating tubes is numerically evaluated by SUPERFISH as an input to PARMELA. The results are explained as follows. Table 1 shows the

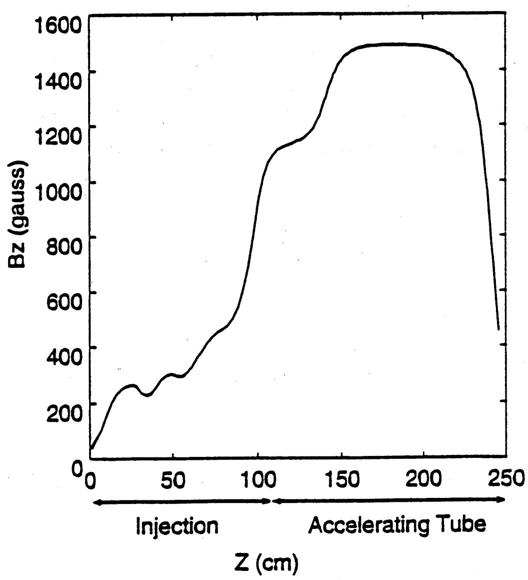

Fig.2 Manetic field distribution along the accelerator

Table 1 Parameters in the buncher section

cell No.	Length of a cell L (cm)	Energy of the beam (MeV)	Velocity
1	0.64	0.304	0.78c
2	0.71	0.505	0.86c
3	0.75	0.728	0.91c
4	0.78	0.832	0.92c
5	0.81	1.085	0.95c
6	0.83	1.343	0.96c

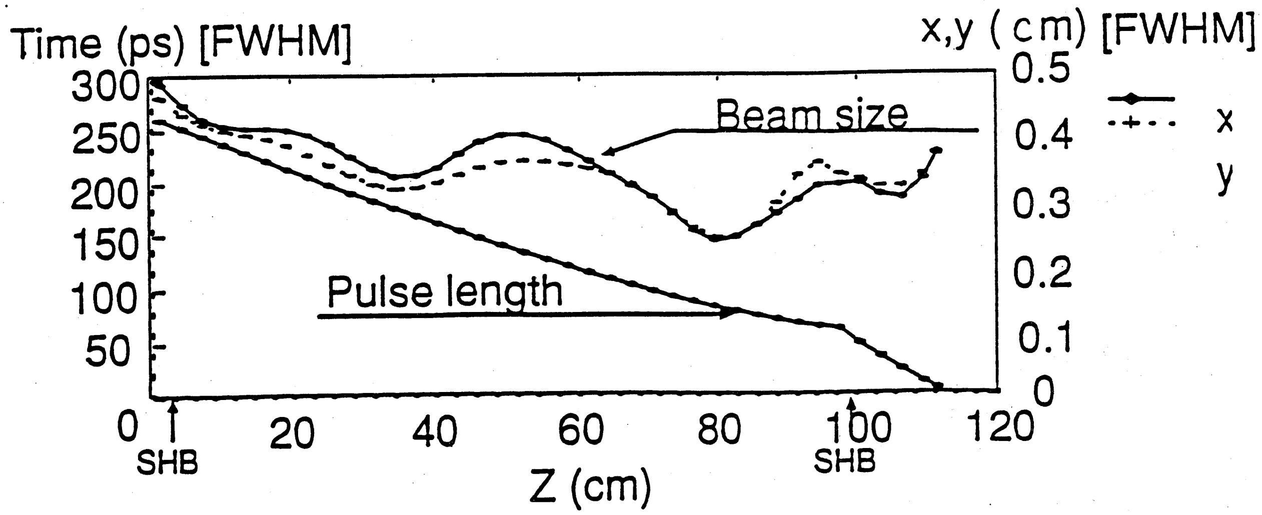

Fig.3 Beam size and pulse length along the injector

variation of the length of each cell, the energy and velocity of an electron beam through the buncher section. Parameters of the regular section determined by SUPERFISH is shown in Table 2 Table 3 shows the final beam parameters calculated by PARMELA. In this calculation, 80 % of the initial electric charge is transmitted and the resultant pulse length is 1.04 ps (FWHM). At the present S-band linac, the pulse length at the end of the 2nd accelerating tube is about 10ps and it is compressed 1/10 by magnetic pulse compression. If we can achieve the same compression ratio, a 100 ps single pulse can be expected by this X-band linac.

Table 2 Parameters in the regular section

Q value	6663
Shunt Impedance (r_0)	78.034 MΩ/m
Attenuation Constant (a)	0.473N/m
Group Velocity (Vg/c)	3.79%

Table 3 Final beam profile

[FWHM]

Pulse length (ps)	1.04
Beam size (mm)	X = 0.55 Y = 0.58
Momentum (mrad)	Px = 7.8 Py = 7.5

3. Conclusion

Transport simulation of an electron beam is carried out by using PARMELA and SUPERFISH associated with the design of the X-band linac for generating a femtosecond single pulse. The layout of the accelerator is arranged as follows. After the thermionic gun, there are the double SHB, two accelerating tubes and achromatic magnetic pulse compression system. According to the results by PARMELA, 80% of the initial electric charge is transmitted and pulse length at the end of the 2nd accelerating tube is 1.04 ps (FWHM). Therefore, the feasibility of generating the 100 femtosecond single pulse is confirmed.

4. Reference

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