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DESIGN STUDY OF 30 MeV LINAC FOR A COMPACT THz RADIATION SOURCE*

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Abstract

A compact THz radiation source plays a possibility to achieve intense THz radiation at tunable frequencies between 0.5 and 5.0 THz, with a peak power of several MW and narrow bandwidth. This source requires essentially the reliable high gradient s-band linear accelerator (linac) to provide an electron beam energy up to 30 MeV with high bunch charge. In order to obtain a high gradient linac mentioned, the cell shape of cavity has been preliminary optimized and performed using the softwares Superfish and CST-MWS. The preliminary design of linac and beam dynamics study are presented in this paper.

THz SOURCE

The terahertz (THz) region of the electromagnetic spectrum in the range from 0.1 to 10 THz, is a rich zone and has attracted much attention in terms of new scientific and industrial applications. Nowadays, several types of efficient THz radiation sources are available as useful tools for producing high-power THz radiation to fulfill specific requirements. One effective way of producing this radiation is with an accelerator source based free-electron laser (FEL). The main goal is to achieve intense THz radiation at tunable frequencies of between 0.5 and 5.0 THz, with a peak power of several megawatts (MWs) and narrow bandwidth.

The proposed system consists of a 1.6-cell photocathode RF gun operated in the S-band of 2856 MHz to generate electrons with high brightness. The electron beam will then be focused and accelerated up to an energy of 10–30 MeV. To generate coherent radiation, the electron bunch length must be compressed to 100 fs by a chicane bunch compressor, before being passed to an undulator as shown the layout in Fig. 1. The details will be reported in Ref [1]. Based on the details reported, we can produce intense tunable THz radiation with narrow bandwidth in the frequency region of 0.5–5 THz to support a wide variety of applications.

Since FELs are the most powerful and wavelength-tunable radiation sources in the THz region, the facility generally needs a huge space with high cost in construction and operation. Therefore, a compact THz source considered will be based on super-radiant source or coherent radiation. It requires very good quality electron beams, corresponding to high brightness electron beams with 1 mm-mrad emittance, 1 nC bunch charge, and short bunch length in sub-picosecond. To be regarded as superradiance or coherent condition, the coherent superposition leads to a spectrally narrow and extremely intense THz beam. The radiation frequency in the range from 0.5 THz up to 5 THz can be covered, with the use of beam energies ranging from 10 to 30 MeV and magnetic field strength of undulator running up to 6.5. The spectral width is in the order of the inverse number of undulator periods. As a source of narrow-band THz radiation an undulator with 7 cm period length is foreseen.

In this paper, we focus on a preliminary design of high-gradient linac for a high-power THz FEL radiation source and present the beam dynamics required.

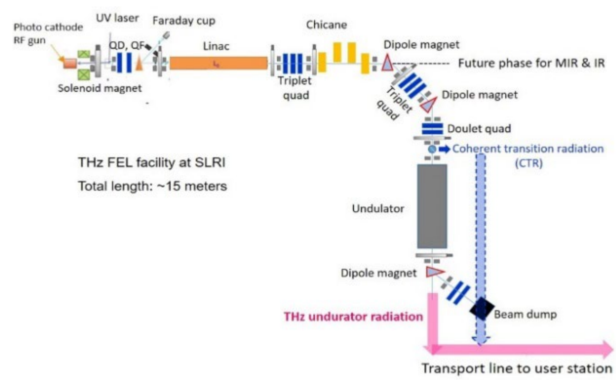

Figure 1: Layout of THz FEL source with the total length of 15 meters.

STUDY DESIGN OF LINAC

As mentioned about the short pulse required for THz source, in the process of accelerating the travelling-wave (TW) structures will achieve higher efficiency than that of standing wave (SW) structures because of providing smaller filling time and getting higher shunt impedance per unit length. For high efficiency, the high-gradient TW accelerating linac based on constant gradient structure with the mode TM010 fundamental electric field is considered with a phase advance per cell of 2π/3 [2, 3].

In order to obtain a high gradient linac mentioned, the cell shape of cavity has been optimized and performed using the software tools Superfish [4] and CST-MWS [5]. The TW cells are optimized with having high shunt impedance, high quality factor, constant gradient field, and short filling time. For preliminary study, the aims of linac design are to provide the shunt impedance of higher than 60 MΩ/m, quality factor of higher than 14,000, filling time less than 1 μs, and the constant gradient field generated. Adjusting dimension of cell structure is the most important role to require attention. Figure 2 shows the model parameters for the linac cells optimization.

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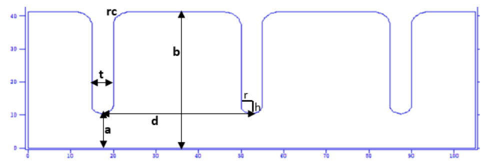

Figure 2: Schematic of three cells of TW electron linac.

The optimized steps of cell structure are as follows

1. To define the cell period length (d), the cell length is set for the mode phase advance of 2π/3. The fundamental accelerating mode cell length must be d=βλ/3, which would be 34.98 mm.
2. To tune the resonant frequency of 2856 MHz by adjusting the cell radius (b) without changing any other geometric parameters. Initially, the iris thickness (t), the iris shape (r, h), and the rounded edge of the cell (rc) were fixed at 5 mm, 2.5 mm. and 5 mm, respectively.
3. To vary the rounded edge of the cell (rc) in order to obtain higher Q-factor value. To keep remain unchanged the resonant frequency at 2856 MHz, the cell radius (b) was adjusted with small step.
4. To optimize the iris shapes (r, h) for the electric field distribution and constant gradient value. Although, the elliptical iris shape is good choice. However, for preliminary study, we set the same iris shapes r and h.
5. To obtain a higher shunt impedance (rs), the iris radius (a) was adjusted. It was found that a smaller iris radius only can get higher shunt impedance but also resulting in quite small group velocity that cause to high filling time.

For all steps of optimization, the mode of electric field keeps remain at TM010 with phase of 2π/3. The configuration of electric field is shown in Fig. 3 and electric field distribution from a simple three cells of TW electron linac in Fig. 4. From this accelerating structure with mode TM010-2π/3, the shunt impedance and quality factor are 65.42 MΩ/m and 14,614.8, respectively.

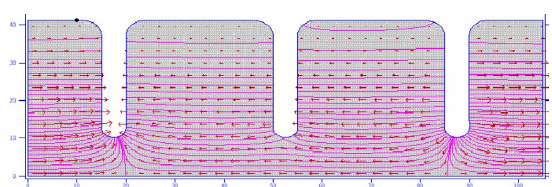

Figure 3: Electric field of the TM010-2π/3 accelerating mode.

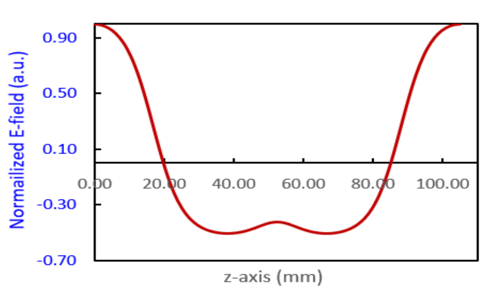

Figure 4: Electric field generated from three cells of TW electron linac.

Table 1: Parameters for the Linac Cells and Coupler

Parameters	Value
Accelerating cell	
Iris radius, a (mm)	10.3
Cavity radius, b (mm)	41.15
Cell period, d (mm)	34.98
Iris thickness, t (mm)	5
Iris shape, r and h (mm)	2.5
Rounded edge of the cell, rc (mm)	4
Coupler	
Hole width, Lw (mm)	12
Hole length, Li (mm)	36
Hole height, Lh (mm)	4
Coupling cell radius, Rc (mm)	40.635
Coupling cell length, Lc (mm)	19.59

In addition, the good coupling between waveguide and accelerating cell structure is required. The coupling consists in reducing as much as possible power reflections at the entrance of section. The aim of the coupler tuning is not only to minimize the reflected power at the input/output coupling port but also to tune the phase advance per cell of the TW structure for 2π/3 mode and the constant electric field amplitude. The parameters of linac cells and coupler are listed in Table 1.

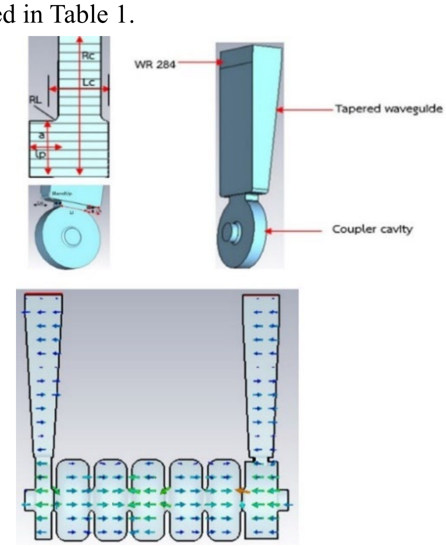

Figure 5: Coupling geometry and longitudinal electric field distribution of the 7-cells.

Figure 5 presents the longitudinal electric field distribution with obtaining the 2π/3 mode performed by CST-MWS after combing the couplers and waveguides. To mitigate the pulsed heating, the surfaces of cell have been strongly rounded. As mentioned, the linac dimensions need to be optimized in order to achieve a good linac performance such as obtaining high shunt impedance, high Q-factor, and constant gradient field. At present, it is in process of optimization to complete accelerating structure along with the input/output coupler performed by using the frequency domain solver of software CST-MWS.

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BEAM DYNAMICS SIMULATIONS

A high brightness electron beam with the energy of 6 MeV is generated from photocathode RF gun with bunch charge of 1 nC. The electron beam is accelerated to the required energy of 30 MeV in the linac at the frequency of 2856 MHz. The linac is located at the downstream of solenoid. The beam energy at the exit of the linac was 30 MeV with the accelerating field gradients of 11 MV/m. A total of 84 accelerating cells is required. In case the field gradient can reach to 20 MV/m, the electron beam can be accelerated up to 50 MeV. The beam dynamics was performed by using ASTRA code [6].

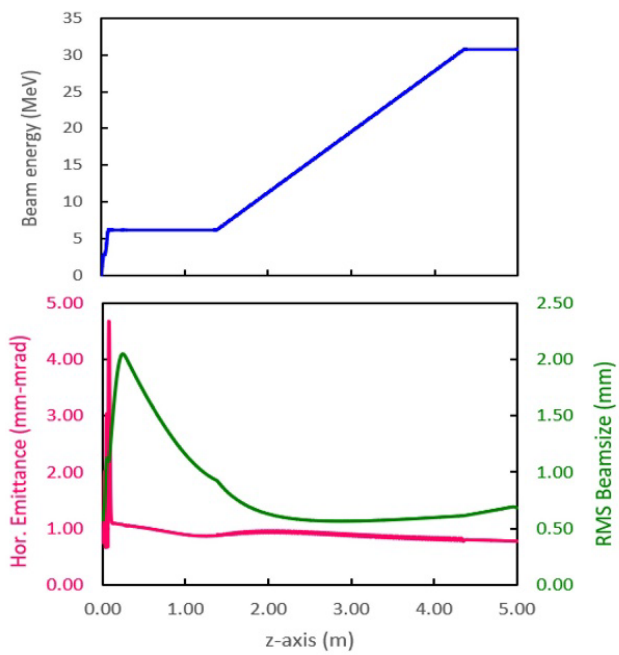

Figure 6: (top) Beam energy along z-axis and (botoom) Normalised transverse emittance (pink) and beam size (green) with 1 nC bunch charge.

Since the optimized beam emittance is also dependent on laser pulse distribution, the laser pulse shape was varied to minimize the normalized transverse emittance. It was found that the use of ellipsoidal distribution can achieve the minimize emittance. In order to reduce the space charge effect, the ellipse shape of the photocathode laser pulse was selected.

With using the solenoid, the emittance can be able to decrease less than 1.0 mm-mrad, corresponding to a better matching of the beam envelope in the linac. In addition, the triplet quadrupoles are placed at upstream of linac at z-axis of 5 meters to minimize the electron beam size less than 1 mm as shown in Fig. 6. Figure 7 shows the phase space at the of linac. That guarantees to have a good quality of electron beam, which is a suitable optics of electron beam into undulator. Taking into account the compression factor of the magnetic chicane, the electron bunch length at the exit of the magnetic chicane can be compressed because the electrons at the tail move on a shorter orbit than those at the head.

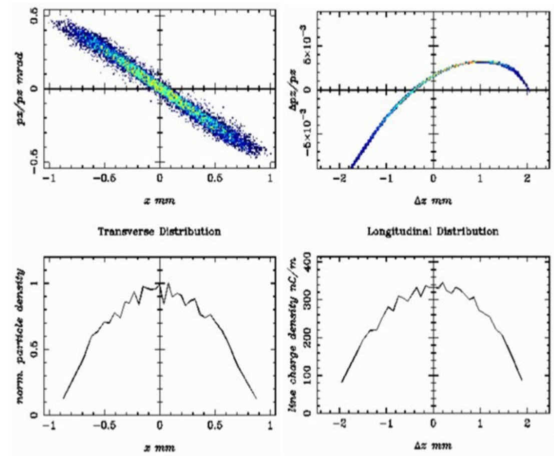

Figure 7: Phase space at the end of linac.

SUMMARY

A compact THz radiation source requires essentially the reliable high gradient s-band linac to provide an electron beam energy up to 30 MeV with high bunch charge. An accelerating part is the most crucial component of an electron linear accelerator in order to increase energy of the electrons up to 30 MeV with high brightness. The conceptual design of linac for a compact THz radiation source is proposed. In order to guarantee with achieving a high-performance of high-field gradient linear accelerator, the beam dynamics of the electron beam are studied. The 3D simulation of electric field, engineering design, thermal analysis and vacuum performance will be presented in the next study. The aim of high gradient structure design is to successfully accomplish a travelling wave constant-gradient type with 84 accelerating cells. Regarding this design, it will probably be used to provide for the industrial application which is one of the key applications of electron linear accelerators.

ACKNOWLEDGEMENT

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REFERENCES

[1] S. Jummunt, “Conceptual design of a compact THz radiation source”, unpublished.

[2] N. Kulkarni, *et. al.*, “Physics design of a 10 MeV, 6 kW travelling wave electron linac for industrial applications”, *Pramana – J. Phys*, vol. 87, Oct. 2016. doi: 10.1007/s12043-016-1279-6

[3] M. El Khaldi, M. Alkadi, C. Bruni, L. Garolfi, A. Gonnin, and H. Monard, “Design Study of High Gradient Compact S-band TW Accelerating Structure for the ThomX LINAC Upgrade”, in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 2807-2810. doi:10.18429/JACoW-IPAC2019-WEPRB008

[4] J. H. Billen and L. M. Young, "POISSON SUPERFISH", Los Alamos National Laboratory Rep. LA-UR-96-1834, revised Jan. 2006.

[5] CST Studio Suite 2022, https://www.3ds.com/.

[6] ASTRA Space Charge Tracking Algorithm, http://www.desy.de/~mpyflo/.