The Study of an Independent Tunable Electron Gun for a Compact Terahertz Source Based on Free Electron Lasers*

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***Abstract*-In this paper an independent tunable electron gun for a compact Terahertz Source Based on Free Electron Lasers is studied. In order to obtain a compact Terahertz Source, An electron gun played a dominant role. In this paper an independent tunable electron gun was designed and calculated. The gun was composed of two independent cavities. The feeding and the phase are independent, respectively. The acceleration of electron beams was calculated The electron gun can create high-brightness and short-pulse beams (less than 2 ps). The energy spread is less than 0.5%, the normalized rms beam emittance and longitudinal rms emittance are both low. So the α magnet is not needed. Thus, a compact Terahertz source can be obtained. In order to illustrate that case, the acceleration of these electron beams in a linac was calculated. When the feeding power is 7.0MW, 10MeV, the energy of electron beams, can be obtained at nearly 0.744-0.745m. the energy spread and the length of micropulse were satisfied with the THz radiation. The impedance of the linac was constant.**

I. INTRODUCTION

Recently THz sources such as ring-based and linac-based sources are rapidly developed[1-2]. In this paper, an electron gun for THz sources based on a linac will be discussed. We know that a system of a Terahertz source based on free electron lasers (FEL) has to include an electron gun, an electron accelerator, an undulator and an optical resonance cavity so on. In order to obtain a compact Terahertz source[3], an electron gun plays a dominant role. It is much important that an electron gun can provide high-brightness and short-pulse beams. So we emphasized the electron gun and designed an independent tunable electron gun. In order to illustrate the effect of the independent tunable electron gun, we also study the motion of electron beams in a linac. In this paper, in section II we studied the case that electron beams were emitted from LaB_6 with the microwave field action. Relations between the number and the phase of electrons were studied. In section III the configuration and field distribution of the RF gun were discussed. In section IV Accelerating and compressing electron beams in the RF gun were researched. In section V the acceleration of these electron beams in a linac was computered.

II. RELATIONS BETWEEN THE NUMBER AND THE PHASE OF ELECTRON BEAMS

In fig.1 the configuration and volume mesh of the independent tunable electron gun with two cavities are shown. The material of cathode is LaB_6 and its radius is

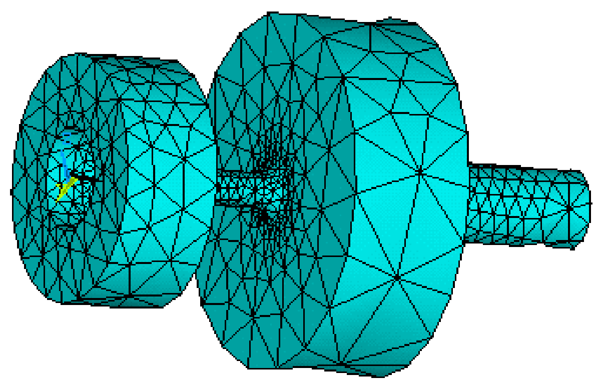

Fig.1 The Configuration and Volume Mesh of the RF Gun

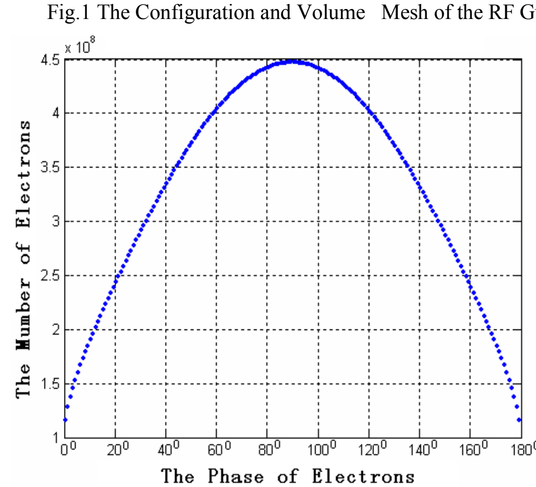

Fig.2 Relations Between the Number and the Phase of Electrons

4mm. when temperature T_c is 1750K, in terms of current density

$$J = J_0 \exp\left[0.4403(E_c \sin\phi_0)^{1/2} / T_c\right] \qquad (1)$$

and the number

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$$K_i = \frac{\exp\left[0.4403(E_c \sin\phi_i)^{1/2}/T_c\right]\Delta\phi}{\int_0^{\pi}\exp\left[0.4403(E_c \sin\phi)^{1/2}/T_c\right]d\phi} \qquad (2)$$

Where E_c is the amplitude of microwave field on the surface of LaB_6 and ϕ_i is the phase of electron beams. The number K_i of electrons emerging from the cathode are calculated, as shown in fig.2. Obviously, from phase 60^0 to 120^0, the number of electrons is larger than that from 0^0 to 60^0 or 120^0 to 180^0. the frequency of the microwave field is 2.856GHz.

III. THE CONFIGURATION AND FIELD DISTRIBUTION OF THE GUN

We have to design the configuration of the gun carefully and calculate the amplitude of electric field along the axial path of the gun. The dimensions of the two cavities are shown in Fig.3. For example, the radius R1 of the first cavity is 28.23mm, the length nL1 from the original to the cathode is 12mm, and L1 from the cathode to the port of the cutoff waveguide is 10mm. The first cavity can be fed independent and thus the phase of its microwave field is also independent. In the same way the second cavity is fed independently and the phase of its microwave field can be tuned independently. The section between the first and second cavity is called as the cutoff waveguide. The length of the cutoff waveguide can be adjusted, as can cause the electron beams to be accelerated and compressed effectively. At the same time, by altering the microwave phase difference between in the first cavity and in the second one electron beams can also be accelerated and compressed effectively.

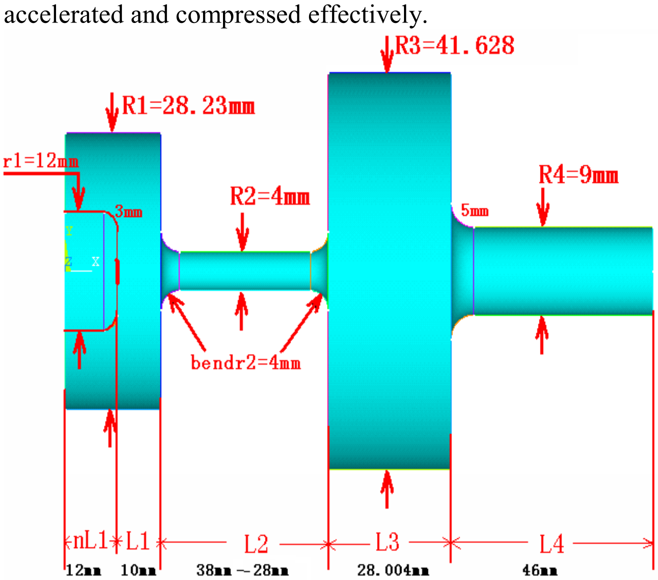

Fig. 3 The plane structure and dimensions of the RF gun

By applying finite element method, the field distributions in these two cavities was analysed. The electric field distributions of the first cavity were shown in fig.4. The field distributions of the second cavity were shown in fig.5. The electric field intensity along the electron beams axis were plotted in fig.6.

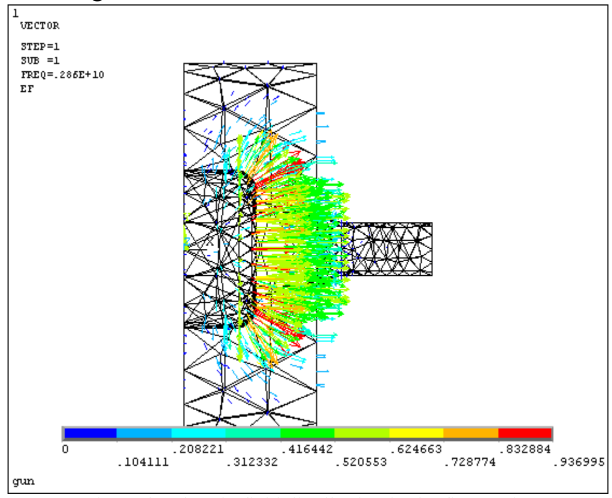

Fig.4 The electric field distribution in the first cavity

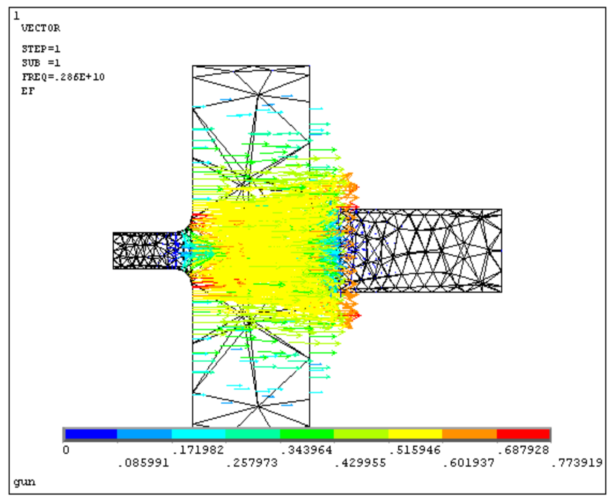

Fig.5 The electric field distribution in the Second cavity

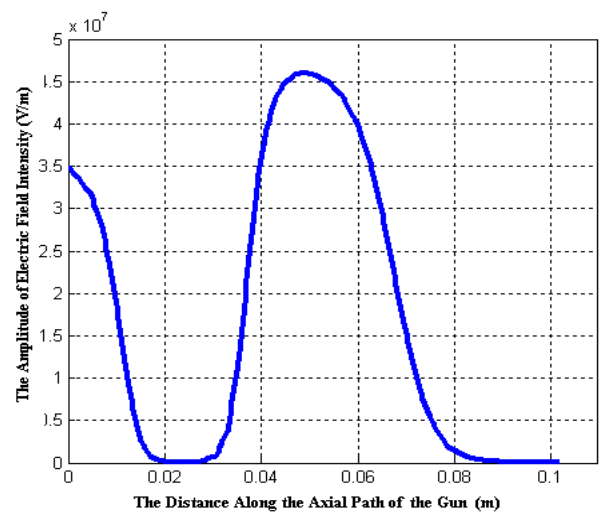

Fig.6 The electric field distribution along the axis of the RF gun

The configuration and field distributions can cause these electron beams to be accelerated and compressed within a

shorter distance. It will be illustrated in section IV.

IV. TECHNOLOGY OF ACCELERATING COMPRESSING ELECTRON BEAMS IN THE RF GUN

We should notice that the field distribution in the RF gun belongs to the pure standing wave. In terms of

$$\frac{d\gamma}{dz} = \frac{eE(z)}{m_0 c^2}\sin(\omega t + \phi_0) \quad (3)$$

$$\frac{d\phi}{dz} = \frac{2\pi}{\lambda}\frac{1}{\beta} = \frac{2\pi}{\lambda}\frac{\gamma}{\sqrt{\gamma^2 - 1}} \quad (4)$$

we can computer the motions of electron beams in the RF gun.

After electron beams from phase 0^0~40^0 passing through the RF gun, A short pulse of less than 2ps can come out from the gun and its electron energy spread $\Delta E/E$ is also less than 0.5%, as shown in fig.7.

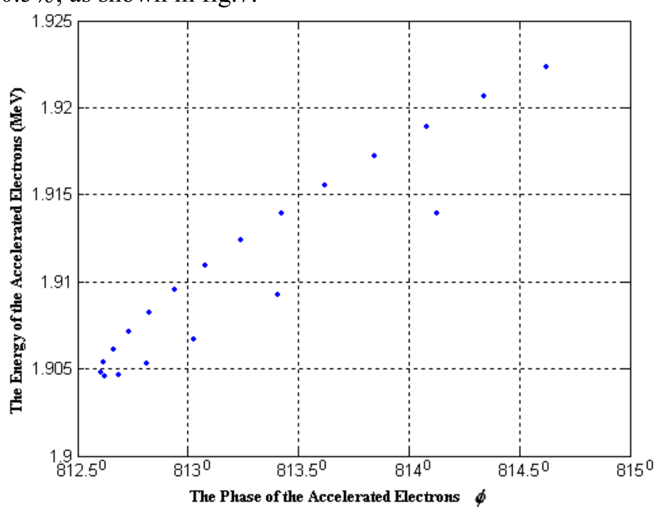

Fig.7 Relations between Energy and Phase of electron beams.

By a hard calculating and analysing we find that the shift between the two cavities is 175^0 or so is suitable to accelerate and compress electron beams. The parameters of the RF gun is satisfied with those conditions of a linac accelerating electron beams, as is listed in the following table:

TABLE I: THE PARAMETERS OF THE RF GUN

RF frequency	2.856GHz
The Maximum of The amplitude of Electric field	35MV/m (the 1st) 46MV/m(the 2nd)
Bunch length	<2ps
Bunch charge	649.12pC
Energy Spread($\Delta E/E$)	<0.5%
The Total Energy Gain	>1.4MeV
The Total Length of the Gun	<0.125m

Obviously, these electron beams need not be compressed by a α magnet[4]. These electron beams can directly enter a linac and be accelerated effectively.

V. TECHNOLOGY OF ACCELERATING ELECTRON BEAMS IN A LINAC

Electron beams emerging from the gun enter a line accelerator. Electron beams will be accelerated further in the accelerator. By designing the linac these electron beams can be accelerated effectively. When the feeding power is 7.0MW, 10.0MeV can be obtained in nearly 0.744-0.754m and the energy $\Delta E/E$ is less than 0.5%, the length of micropulse is less than 3^0, as shown in fig.8. The parameters are satisfied with the THz radiation[3,5].

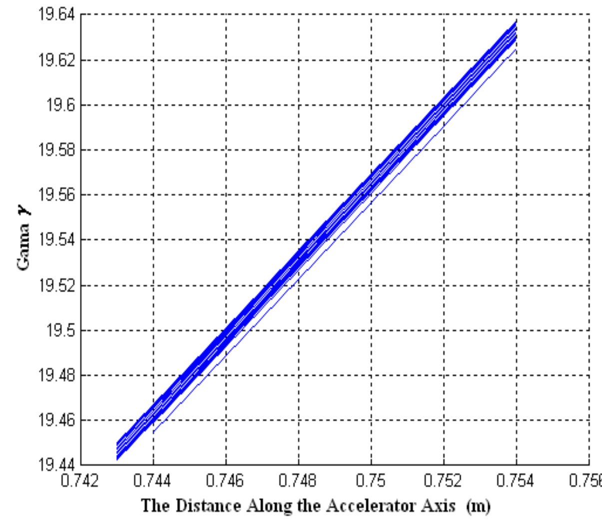

Fig.8 Relations Between Electron Beams Energy and The Distance Along the Accelerator Axis.

VI. CONCLUSION

An independent tunable RF gun was designed and calculated, high-brightness and short-pulse beams can be obtained by the RF gun. These electron beams need not be compressed by a α magnet. Considering the dimension of the whole system we can obtain a compact Terahertz source.

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