DESIGN OPTIMIZATION OF 100 KV DC GUN WEHNELT ELECTRODE FOR FEL LINAC AT LEBRA

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Abstract

The electron gun wehnelt employed in the FEL linac at Nihon University was originally designed for extraction of the long duration macropulse beam with a peak current of 200 mA. Since 2011, the electron gun system has equipped with the high-speed gridpulser, which has made it possible to extract the burst beam with a higher peak current. A computer simulation of the burst beam extraction with the present gun wehnelt design showed a large divergence of the beam at the first magnetic lens in the injector line. Calculation with an improved wehnelt design adjusted for the burst mode beam extraction has suggested a possibility of achieving smaller divergence and approximately 20% reduction of the beam emittance.

INTRODUCTION

The 125-MeV electron linac at the Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University has been used for generation of the near infrared FEL and the quasi-monochromatic Parametric X-rays. In addition, the THz beam generated in a bending magnet became available in the FEL experimental rooms in 2012 by transporting along the FEL optical beam line [1]. Since 2011, the electron gun system for the LEBRA linac has been capable of operation in three different modes of the beam extraction i.e., the full bunch mode, the burst mode, and the superimposed mode of the former two modes [2][3][4]. The electron gun wehnelt electrode was originally designed for use in the full bunch mode operation; no upgrade in the wehnelt electrode has been made for optimization of the beam focusing in the superimposed/burst mode operation. The beam trace simulation for the present geometry of the wehnelt suggested that the emittance of the beam extracted in the superimposed/burst modes was considerably increased due to the strong space charge effect resulted from a high peak extraction current. This paper reports on the result of a design simulation made to optimize the shape of the wehnelt for the superimposed/burst beam operation modes.

LEBRA 100 KV DC ELECTRON GUN

Electron Gun Specifications

The present electron gun has been used since 2000 when the design of the wehnelt electrode was changed to get an optimum beam extraction property for the beam extraction current of 200 mA with the CPI EIMAC Y-646B cathode [5], which was introduced in place of Y-646E cathode [6][7]. The cross-sectional drawing of the electron gun is shown in Figure 1. The parameters of the electron gun and Y-646B cathode are shown in Table 1. The anode plate has a flat surface.

The Kentech high-speed gridpulser was installed in the gun high voltage terminal in 2011, which made it possible to extract a train of short beam pulses with 0.7 ns FWHM at a peak current of several amperes. Simultaneous or exclusive use of the high-speed gridpulser and the normal gridpulser allows extraction of the electron beam in three different modes i.e., the full bunch mode, the burst mode, and the superimposed mode of the former two modes. Since the wehnelt electrode of the gun was designed for operation at the full bunch mode, the beam transparency and the acceleration efficiency in the linac is very low in the superimposed/burst mode operations where the peak extracted beam current is more than 10 times higher.

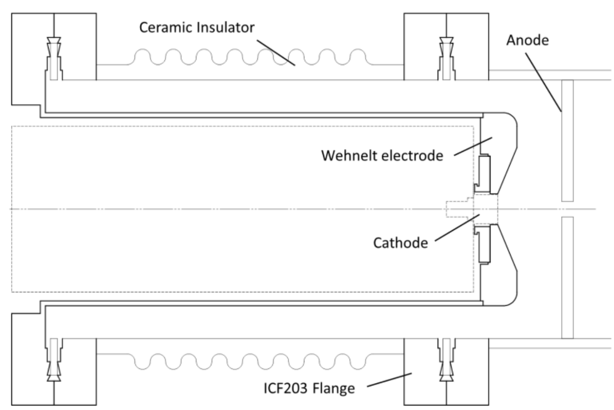

Figure 1: Present LEBRA 100 kV DC electron gun system. The focus effect is suppressed by the shallow slope of the wehnelt around the cathode. The anode plate has a flat surface.

Table 1: Electron Gun Specifications

Electron sources	EIMAC Y-646B
Cathode area	0.5 cm^2
Cathode filament voltage	6.0 V
Cathode filament current	1.3 A
Cathode voltage	-100 kV
Macropulse width	50 μs
Macropulse current	200 mA
Cathode to anode distance	30 mm
Gridpulse voltage	53 ~ 63 V
Grid bias voltage	53 V

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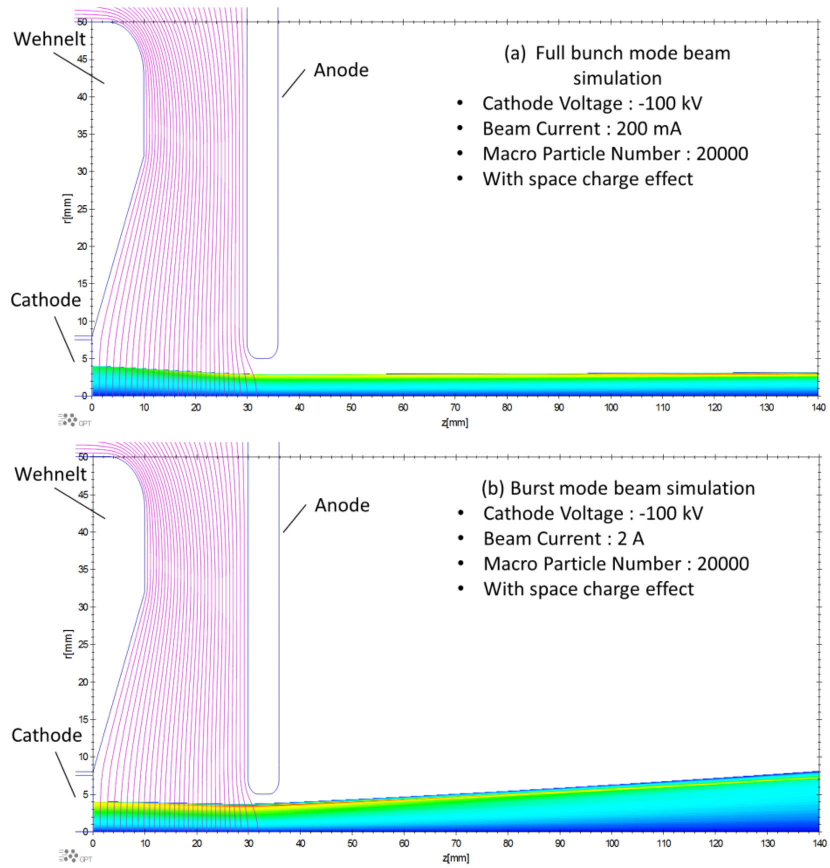

Figure 2: Simulation results for full bunch mode and burst mode beam extractions. (a): Full bunch mode operation. (b): Burst mode operation. The details of the grid were ignored in the calculations.

Simulation of Electron Beam Trajectories

Calculation of the electron beam trajectories for the present wehnelt electrode were carried out from the electron gun cathode to the position of the first magnetic lens by using the code General Particle Tracer (GPT) [8], where the electric field distribution between the cathode and the anode was calculated by using the code Poisson Superfish [9]. The beam simulation results for the full bunch mode and the burst mode are shown in Figure 2. The cross-sectional drawing of the gun and the potential contour lines are superimposed on the beam trace results obtained by GPT. The beam current of the full bunch mode and the burst mode are 200 mA and 2 A, respectively. The cathode voltage and the cathode size used in the simulation are the same values as listed in Table 1. The thermal motion of the electrons in the cathode and the mesh-grid was ignored in the calculation. The beam trajectories were calculated for 20,000 macro particles by taking into account of the space charge effect. The electron beam was assumed to be emitted in the direction normal to the cathode surface.

The simulation result shows that the present wehnelt electrode has an optimum shape for the full bunch mode extraction at 200 mA (See Figure 2-(a)). In contrast, the result for the burst mode extraction at 2 A suggests growth of more than 2 times in the beam diameter at the position of the first magnetic lens (the right endpoint of the horizontal axis) due to strong space charge effect (See Figure2-(b)).

OPTIMIZATION OF WEHNELT ELECTRODE SHAPE

Figure 2 shows that the beam extracted with the burst mode at 2 A is not sufficiently focused in the electric field generated by the present wehnelt electrode. Therefore, beam trace simulations were made for different shapes of the wehnelt electrode in order to improve the focusing and reduce the beam size at the position of the first magnetic lens. The optimization was made at a beam current of 2 A and only for the angle of the wehnelt slope around the cathode. The result is shown in Figure 3. As seen in Figure 3-(a), a strong focusing in the electric field results in an over focus for the full bunch mode beam extraction at 200 mA. For the burst mode extraction at 2 A, however, Figure 3-(b) shows that the beam diameter at the right endpoint of the horizontal axis can be reduced to approximately 60 % of that resulted from the present wehnelt shape in Figure 2-(b).

Figure 4 compares the normalized emittances estimated by the beam trace simulations for the different wehnelt electrode shapes in each operation mode. Since every electron is assumed to be extracted in the direction normal to the cathode surface by the simulation condition, the

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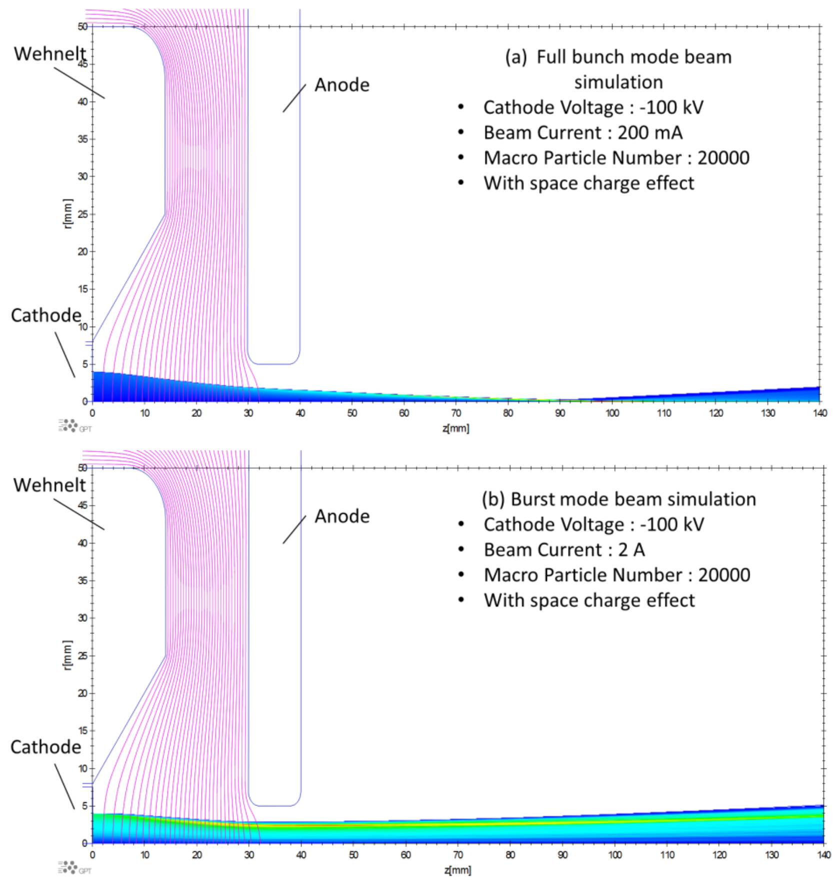

Figure 3: Beam simulation results for the wehnelt electrode shape optimized at a beam current of 2 A. (a): the full bunch mode beam simulation at 200 mA. (b): the burst modes beam simulation at 2 A. The details of the grid were ignored in the calculations.

beam emittance is zero on the cathode surface. The result shown in Figure 4 suggests that, for the burst mode beam extraction at 2 A, the beam emittance can be reduced by approximately 20 % if the wehnelt shape is optimized, though at the expense of considerable growth in the full bunch mode operation.

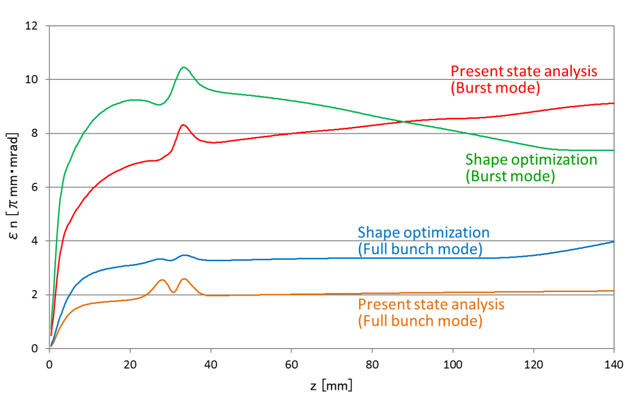

Figure 4: Comparison of the emittances estimated in the simulations for the different wehnelt shapes in each operation mode.

CONCLUSION

The simulation for the high current burst mode beam extraction at LEBRA suggested that the focusing effect of the present gun wehnelt electrode is so weak that the beam size was considerably increased at the position of the first magnetic lens in the linac injector line. The simulation also suggested that the electron beam emittance can be reduced by 20 % by adjusting the angle of the slope of the wehnelt electrode, which is desirable for the improvement in the beam transparency and the acceleration efficiency in the linac.

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