UPGRADE DESIGN OF KU-FEL DRIVER LINAC USING PHOTO-CATHODE RF-GUN

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Abstract

Upgrade design of KU-FEL driver linac has been carried out to obtain a stable oscillation in the infrared FEL. The existing 4.5-cell thermionic RF gun will be operated with a photocathode to enhance the FEL gain. The numerical evaluation of beam properties is carried out from gun to FEL by using PARMELA and TDA3D. The evaluated peak current is 4 times and the expected FEL gain is 10 times as high as those with the thermionic cathode. A 1.6-cell photocathode RF gun dedicated to photocathode operation is also examined to obtain an excellent electron beam. Expected FEL gain is more than 2 times as high as the gain with the 4.5-cell photocathode RF gun.

INTRODUCTION

An infrared FEL (4-13 μm) facility for energy science is under construction at the Institute of Advanced Energy, Kyoto University[1]. The electron beam of 30 MeV has been successfully accelerated by a linac system which consists of a 4.5-cell thermionic RF gun, a 'dog-leg' transport system, a 3m s-band linac, and a 180-degree arc for bunch compression[2]. Figure 1 shows the schematic view of the linac system which includes the upgrade plan view. To reduce the back-bombardment effect in the 4.5-cell RF gun, several attempts have been made, and the macro pulse duration of 3 μs has been achieved[3]. However, there still needs several efforts are needed to extend the macro pulse duration to reach the FEL saturation[4]. Upgrade from the present thermionic RF gun to a photocathode RF gun is one of promising ways, because a photocathode RF gun is free from back-bombardment. Thus, a design work for the system upgrade of the linac system from gun to FEL has been performed. At first, we evaluate the beam parameters of the existing 4.5-cell RF gun which is operated as a photocathode. Then the FEL gain is compared with the original design. Next, the beam parameter and the FEL gain with a 1.6-cell photocathode RF gun are also evaluated.

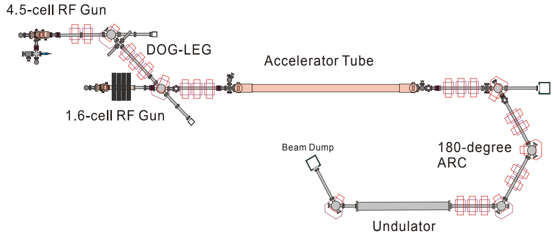

Fig. 1 Schematic view of the KU-FEL driver linac.

4.5-CELL RF GUN

The 4.5-cell RF gun has been used for a thermionic cathode in the original system[4] and successfully generated several hundred mA, 10 MeV electron beam[5]. The maximum electric field at the cathode surface is 32 MV which is limited by 7 MW output power of the RF source. We fixed the maximum electric field to be 32 MV during the calculation. The driver laser assumed here is a picosecond UV laser, i.e. the SHI type one[6,7], whose beam profile is 0.7 mm at the cathode surface and the pulse duration is 6.0 ps. The Gaussian shapes are also assumed both for the transverse(1mm cut-off) and for the longitudinal(12 ps cut-off) distribution to simplify the

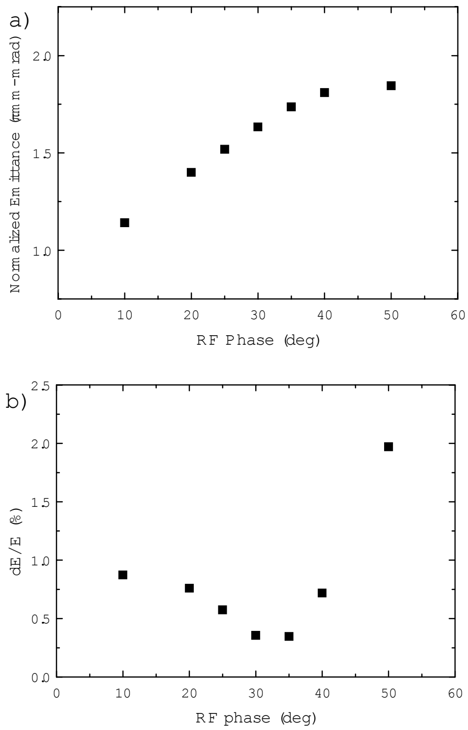

Fig.2 Transverse RMS emittance(a) and energy spread(b) of the electron beam from the gun as a function of the laser injection timing.

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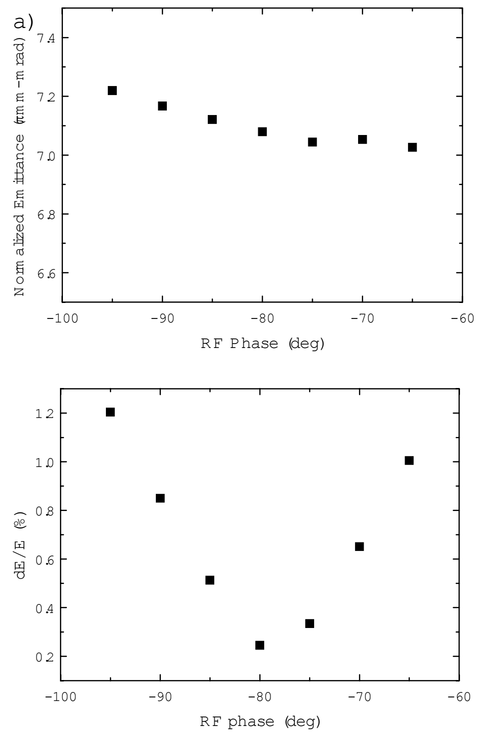

Fig.3 Transverse RMS emittance(a) and energy spread(b) of the electron beam from accelerator tube.

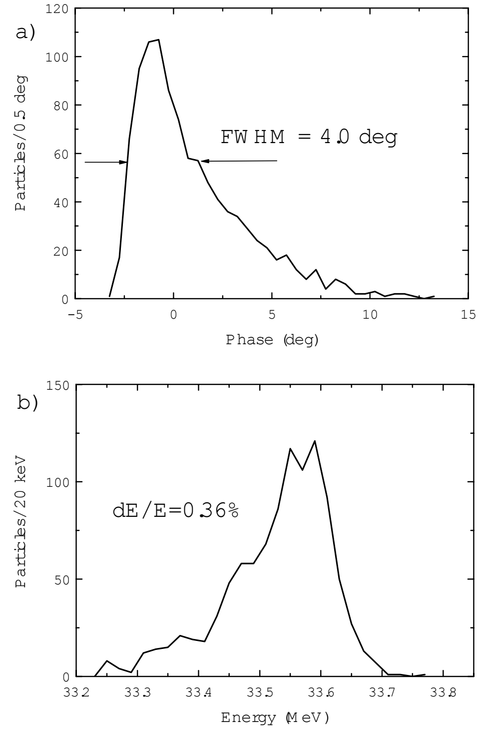

Fig.4 Phase(a) and energy(b) spectrum at the entrance of the undulator.

calculation. Figure 2 shows the transverse RMS emittance(a) and energy spread(b) of the electron beam from the gun as a function of the laser injection timing. PARMELA is used for calculations. It is clear that the electron beam with the transverse RMS emittance below 2 πmm-mrad and the energy spread below 1% can be expected with the 4.5-cell photocathode RF gun. On the other hand, the transverse RMS emittance of 4 πmm-mrad and the energy spread of 22% have been calculated with the thermionic RF gun[4]. The beam charge of 250 pC, which is obtained with normal operation in the existing gun, is assumed. The laser timing of 30 degree, where the best energy spread is obtained in fig.1, is used for the following calculations.

It should be noted that the thermionic RF-gun needs an energy compressor and/or an energy filter for its' broad energy distribution. Therefore, the original design of the linac system employs a 'dog-leg' transport system for the energy filter[4]. Although, we can omit this section for the photocathode RF gun for its' narrow energy spread, we will keep the 'dog-leg' section for the thermionic operation of the RF-gun which is preferable for experiments which need high total power beam. We may omit the 180-degree arc section because of a short bunch beam from the photocathode RF-gun. However, since we are planning to extend our system to the energy recovery one for the future[8], we will keep the 180-degree arc in this calculation, too. The beam transport system is designed by TRACE3D to satisfy the achromatic condition in 'dog-leg'. Figure 3 shows the transverse RMS emittance(a) and energy spread(b) from the accelerator tube as a function of the RF-phase of the accelerator tube. It is clear that the transverse emittance is almost constant (-7 πmm-mrad), although the energy spread varies with the RF-phase. The smallest energy spread, 0.2%, is obtained with -80 degree which is used in the following calculations. We found that the transverse emittance is mainly enlarged by the 'dog-leg' section.

The achromatic 180-degree arc section is set both for the matching condition of the undulator parameter and for the bunch compression condition with matrix element, R56, by using TRACE3D. The phase spectrum and the energy spectrum at the entrance of the undulator are shown in figure 4. Consequently, a beam with peak current of 150 A and an energy spread of 0.36% beam can be generated by using the 4.5 cell photocathode RF gun. The normalized emittance is calculated to be 7.0 πmm-mrad in horizontal and 11 πmm-mrad in vertical. On the other hand, a beam with 40 A peak current and 0.4 % energy spread beam with a normalized emittance of 11 πmm-mrad in horizontal and 10 πmm-mrad in vertical has been obtained with the thermionic RF gun[4]. As a result, almost 4 times large peak current can be expected with the photocathode RF-gun. However, the beam emittance and the energy spread are not so improved from those of thermionic system. The main reason of this emittance

Table 1 Main parameter of the undulator

Period	40 mm
Number of period	40
Total length	1600 mm
Gap	26-56 mm
K value	0.95-0.17

growth is a slight difference between PARMELA and TRACE3D.

The expected FEL gain is calculated with the evaluated electron beam parameters by using TDA3D. The undulator parameter used is shown in table 1. We assumed that the Rayleigh length and the position of the beam waist are fixed at centre of the undulator, 0.8 m. K parameter, 0.95, is also fixed. The calculated FEL gain in wavelength of 6.86 μm is 310% with the electron beam generated with the 4.5-cell photocathode RF gun. On the other hand, the FEL gain with the 4.5-cell thermionic RF gun is 32% at the same conditions as in the photocathode. Consequently, the expected FEL gain with the 4.5-cell photocathode RF gun is almost 10 times as high as that with the original design. This enhancement in FEL gain is mainly due to the enhancement of the peak current. The round-trip development of the FEL gain is also calculated by using modified TDA3D code assuming 10% loss per round-trip. The result shows that the gain saturation can be observed from about 35 round-trips, 0.4 μs. Here we assume the optical cavity length of 3.78 m which is adjusted to the mode-lock frequency of the laser, 79.34 MHz. On the other hand, 175 round-trips is required for the thermionic RF gun. As a result, the FEL saturation will be easily achieved and stable FEL will be expected by the 4.5-cell photocathode.

1.6-CELL RF GUN

Although the existing 4.5-cell RF gun can be operated both as a photocathode and as a thermionic one, as shown in previous section, the estimated emittance is enlarged by the ‘dog-leg’ beam transport system. However, the thermionic operation is still preferable for a high total charge operation. Thus we plan to introduce a new RF gun dedicated to the photocathode operation into our system to obtain an excellent electron beam. The BNL type 1.6-cell photocathode RF gun, which is widely used for generation of a high brightness electron beam[9] and 1 πmm-mrad with 1 nC electron beam has been generated, is presently considered as a photocathode RF gun. As is shown in figure 1, the 1.6-cell photo-cathode RF gun will be placed just upstream of the accelerator tube. The RF system will be shared with the existing RF gun.

The beam evaluation for the 1.6-cell RF gun is also carried out with the maximum electric field of 100 MV at the cathode surface. Figure 5 shows the transverse RMS emittance(a) and energy spread(b) of the electron beam from the RF gun as a function of the laser injection timing. It is clear that the transverse RMS emittance of 1.5 πmm-mrad and energy spread of 0.25% can be generated at the 30 degree. These values are almost same

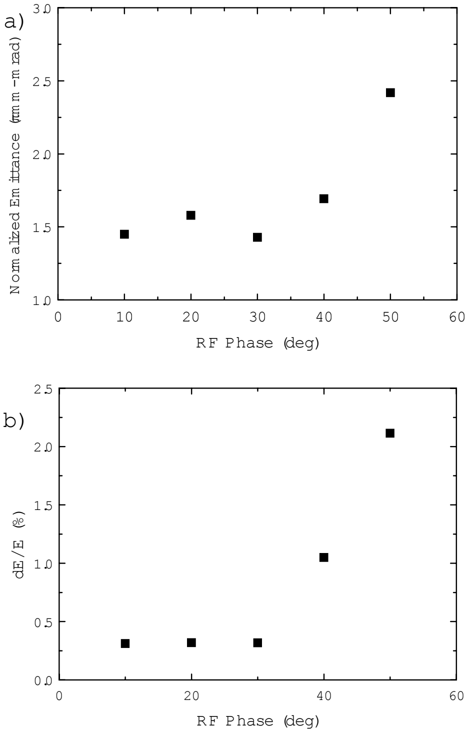

Fig.5 Transverse RMS emittance(a) and energy spread(b) of the electron beam from the gun as a function of the laser injection timing.

as the 4.5-cell photocathode RF gun. The solenoid field for the emittance compensation[10] is also taken into account. The solenoid field used is the same geometric configuration of reference[11]. The field distribution is calculated by using POISSON. We choose the maximum field of 1800 Gauss, where the smallest transverse emittance, 2.4 πmm-mrad, is obtained from the accelerator tube. Figure 6 shows the transverse RMS emittance(a) and energy spread(b) of the electron beam from the accelerator tube as a function of RF phase of the accelerator tube. RF-phase of 65 degree, where the smallest energy spread is obtained in figure 6, is used in the successive calculations. It should be noted that the transverse emittance slightly growths in the solenoid field and further optimization of the solenoid field will be required for our configuration. Figure 7 shows the phase spectrum and the energy spectrum at the entrance of the undulator with a matched 180-degree arc which also works as a bunch compressor. Finally, a peak current of 180 A and an energy spread of 0.31% electron beam can be generated by the 1.6-cell photocathode RF gun. The normalized emittance is calculated to be 10 πmm-mrad in horizontal and 1.7 πmm-mrad in vertical. Consequently, by using 1.6-cell photocathode RF gun, we can expect an improved transverse emittance and a higher peak current electron beam.than that from 4.5-cell photocathode RF gun.

The expected FEL gain can be calculated with the numerical evaluation. The undulator parameter used is the same as 4.5-cell RF gun (table 1) except for the FEL wavelength, because the electron energy(28 MeV) is different from that of 4.5-cell photocathode system(34 MeV). The calculated FEL gain in wavelength of 9.8 μm is 810%. On the other hand, the FEL gain with the 4.5-cell photocathode RF gun is calculated to be 320%. It should be noted that the same electron beam parameter as in the previous section is used for the 4.5-cell photocathode RF gun except for the beam energy. More than 2 times larger FEL gain will be obtained with the 1.6-cell photocathode RF gun. This enhancement in FEL gain is both due to the enhancement of the peak current and improvement in the transverse emittance. The round-trip development of the FEL gain is also calculated as the same manner as the previous section. The result shows that the gain saturation can be observed from about 10 round-trips. As a result, the FEL gain will be further enhanced by using the 1.6-cell photocathode RF gun.

CONCLUSION

Upgrade design of KU-FEL driver linac has been carried out to obtain a saturated FEL in the infrared region. The existing 4.5-cell thermionic RF gun will be operated with a photocathode. The numerical evaluation is carried out from gun to FEL by using PARMELA and TDA3D codes. The expected FEL gain is 10 times larger than that of original system. A 1.6-cell photocathode RF gun dedicated to photocathode operation is also considered to obtain an excellent electron beam. The FEL gain with the 1.6-cell photocathode RF gun is more than 2 times as high as that with the 4.5-cell photocathode RF gun. Further studies are needed to optimize the final upgrade design both for the photocathode operation and for the thermionic cathode operation which is still attractive for high average current.

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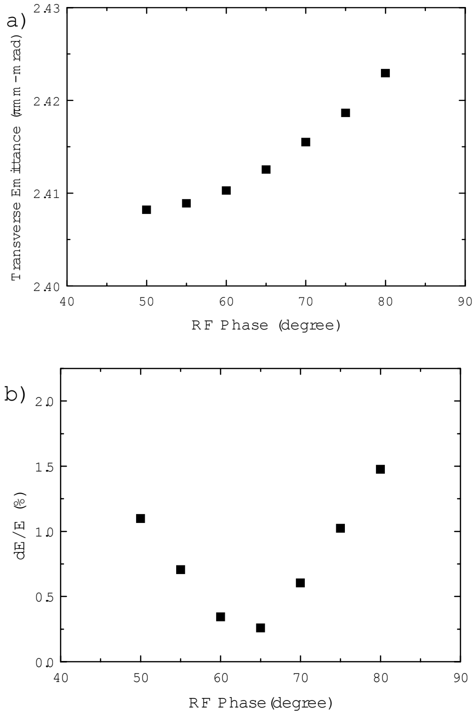

Fig.6 Transverse RMS emittance(a) and energy spread(b) of the electron beam from the accelerator tube.

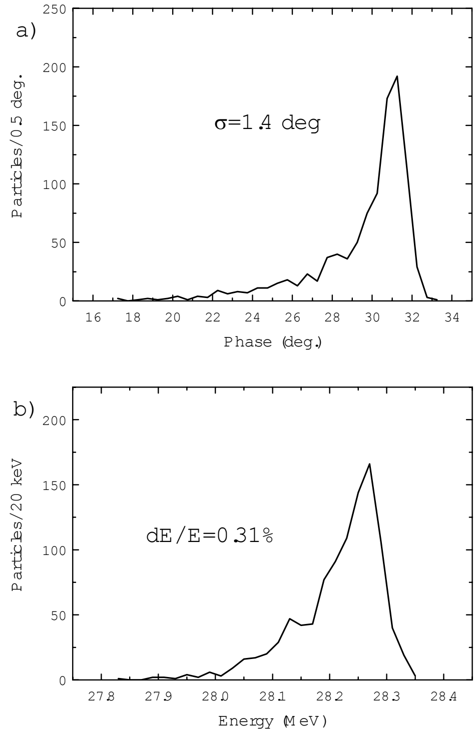

Fig.7 Phase(a) and energy(b) spectrum at the entrance of the undulator.