BEAM PARAMETER MEASUREMENT AFTER RELOCATION OF S-BAND LINEAR ACCELERATOR

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Abstract

Ultrashort electron bunches have been applied in many scientific fields including accelerator physics and radiation chemistry. Pulse radiolysis is one of the most powerful tools in radiation chemistry, which is a pump-probe measurement using an electron bunch and a laser pulse. Our laboratory aims to generate electron bunches with durations of less-than femtoseconds using an S-band linear accelerator (linac) at Osaka University in order to improve the time resolution of the pulse radiolysis system. Recently, the linac system has been relocated for expanding application using ultrashort electron bunches. In this study, the parameters of electron bunches generated from the relocated linac system were simulated using General Particle Tracer (GPT) code.

INTRODUCTION

Ultrashort electron bunches with bunch lengths of femtoseconds and attoseconds are demanded for physical application in accelerator science such as free-electron lasers [1], laser-Compton scattering x-ray sources [2] and terahertz-light sources based on coherent radiation [3]. Additionally, the ultrashort electron bunches play an important role in pulse radiolysis, which is one of the most powerful tools in radiation chemistry to investigate ultrafast phenomena induced by electron bunches. Usually, the pulse radiolysis uses an electron bunch as a pump source to generate transient species in sample material, and the time resolution of the system strongly depends on the bunch length of the electron bunch. Thus, improvement of the time resolution of the pulse radiolysis has been expected to observe ultrafast phenomena occurred in less-than picoseconds. So far, much effort has been paid to improve the time resolution, and the best time resolution of 240 fs was achieved using 100-fs electron bunches generated from a laser photocathode RF gun linac and a magnetic bunch compressor at Osaka University in 2011[4]. Recently, generation of ultrashort electron bunches with bunch length of less-than 100 fs is one of the key topics to improve the time resolution of the pulse radiolysis system. Hitherto, less-than 10-fs electron bunches were generated using the linac system of Osaka University [5,6]. The bunch lengths of the ultrashort electron bunches were diagnosed on basis of an autocorrelation of coherent transition radiation emitted from the electron bunches using a Michelson interferometer [5,6].

In the present situation, the linac system at Osaka University was relocated and was made some modification like establishment of new beam lines in as shown in Fig. 1. This linac system was mainly composed of three sections: a photocathode RF gun with a copper cathode, an S-band acceleration cavity and an achromatic arc-type magnetic bunch compressor. The photocathode is irradiated by a 266-nm femtosecond laser pulse of the third harmonic of a Ti:sapphire femtosecond laser with a regenerative amplifier (Tsunami with Spitfire, Spectra Physics). The generated electron bunch is accelerated at ~4 MeV at the exit of the gun. The solenoid is mounted at the exit of the gun for emittance compensation. The electron bunch is accelerated by the RF electric field inside the 2-m long S-band traveling wave linac. The maximum energy of the electron bunch at the exit of the linac is ~40 MeV, and the electron bunch is energy-correlated inside the cavity for bunch compression using the achromatic arc-type magnetic bunch compressor. The bunch compressor is composed of two bending magnets, four quadrupole magnets and two sextupole magnets. The sextupole magnets in the compressor served to compensate for the second-order effect due to the fringing fields of the magnets, which will cause bunch length growth because of the nonlinear transformation of the energy-phase correlation. The fundamental structure of the relocated linac is almost same with the conventional linac system [5,6], but two quadrupled magnets was installed after linac exit and there is a drift space for future installation of an RF cavity for precise energy-phase correlation. Since the arrangement of the linac system was slightly modified, the beam tracking simulation using General Particle Tracer (GPT) [7] was carried out for scanning beam parameters to generate ultrashort electron bunches in this study. This paper explains the details of beam tracking simulation.

SETUP FOR SIMULATION

In this study, beam tracking simulation for the relocated linac system as shown in Fig. 1 was carried out to search optimum beam parameters for bunch compression. The GPT code was used for the beam tracking simulation with space charge effect. Poisson/superfish code [8] was also used for calculation of electromagnetic fields of the photocathode RF gun, the solenoid magnet and the S-band traveling wave linac, and the results of the calculation were adopted as the field maps for the GPT calculation. The field map of the linac was duplicated by superimposing the field maps of the standing wave structures with two different boundary conditions (magnetic and electric short-circuit surfaces) because the fiels map of the standing wave can only be calculated using the superfish code and we cannot directly calculate the traveling wave using it [8,9].

Figure 2 shows the field map and the longitudinal electric field at the centre of the cavity of the photocathode RF gun calculated using the superfish code. The resonant frequency was fixed to be 2856 MHz and the field balance of the cavity was adjusted to be 1:1 in the half cell and the full

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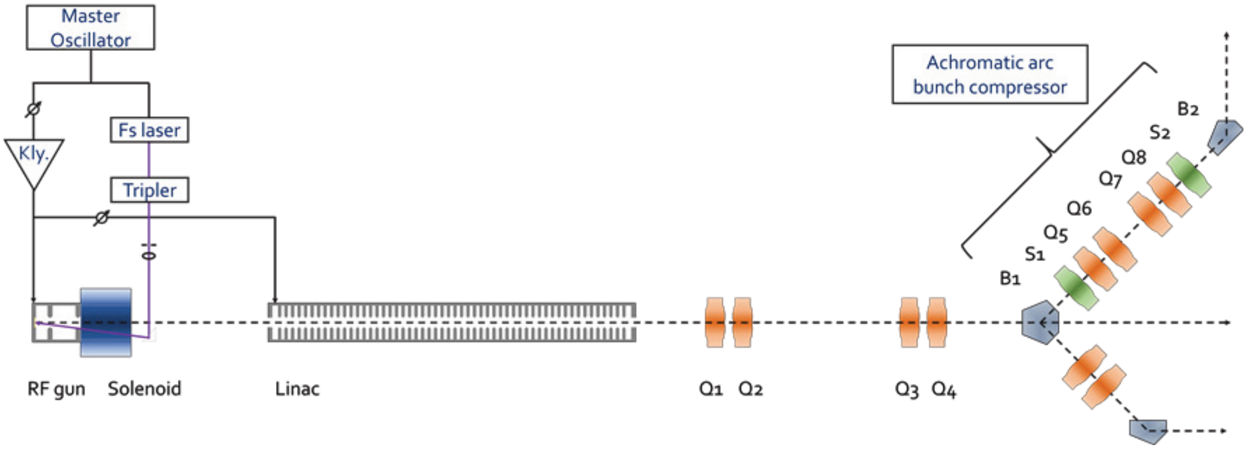

Figure 1: Schematic diagram of a laser photocathode RF gun linac and a magnetic bunch compressor. B, Q and S denote a bending magnet, a quadrupole magnet and a sextupole magnet, respectively.

cell. In the GPT calculation, the field strength was multiplied by an enhancement factor for setting the maximum beam energy to 4 MeV at the exit of the gun.

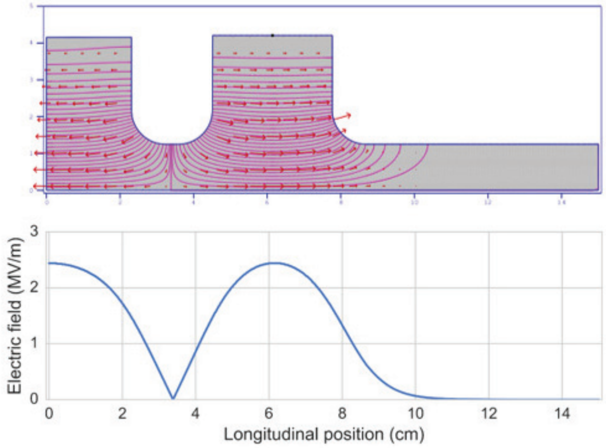

Figure 2: Field map and longitudinal electric field at the centre of the cavity.

RESULT AND DISCUSSION

Simulation of Photocathode RF Gun

First of all, the GPT simulation of the photocathode RF gun was carried out to find out a trend of beam parameters to achieve shorter electron bunch at the exit of the gun. The beam parameters at the exit of the photocathode RF gun are important to obtain low-transverse emittance and short electron bunches, which are necessary for generation of ultrashort electron bunches using the bunch compressor.

Figure 3 shows the dependence of the bunch length on the RF phase of the gun and laser spot size of the UV pulse that irradiates the cathode and table 1 lists the summary of parameters of the simulation. The calculation included space-charge effect and the number of macro particles was set to 5000 particles from the view point of the computation time. As listed in table 1, the bunch charge, the field strength of the solenoid and the initial laser pulse width were fixed to be 1 pC, 0.1 T and 100 fs in rms, respectively. The screen position was set to be 1-m ahead the cathode surface that was near the linac entrance. As a result, the electron bunches with the bunch lengths of the several tens of femtoseconds were able to be obtained by optimizing the laser spot sizes and utilizing compression effect due to the RF electric fields.

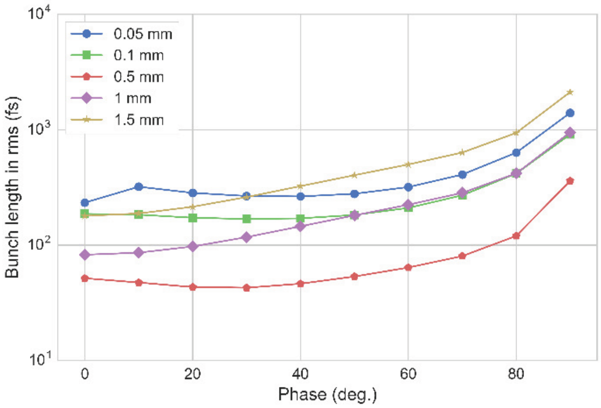

Figure 3: Dependence of bunch lengths on the RF phases of the gun and laser spot sizes. Each value shown in the legend denotes the laser spot size in rms.

Table 1: Summary of Simulation Parameters

Parameters	Value
Number of macro particles	5000
Bunch charge (pC)	1
Laser pulse width in rms (fs)	100
Laser spot size (mm)	0.05 - 1.5
Work function of copper (eV)	0.26
Space charge effect	3Dmesh
RF phase(deg.)	0-90
Magnetic field of solenoid magnet (T)	0.1
Position of screen (m)	1

However, the shape of the longitudinal phase space distribution sometimes seemed to be distorted due to the space charge effect in the case that the bunch length was the several tens of femtoseconds.

Simulation of Whole Linac System

First of all, the beam trajectory was checked before adjustment of the parameters of the linac components like the magnets. Since the electron bunches travelled a correct trajectory, optimization of the beam parameters was carried out. The criteria for the optimization was selected as the bunch length in rms at a position which was 150 mm away from the bending magnet (B2) and the normalized transverse emittance, and the GPT built-in solver was used to optimize the parameters in this research.

Figure 4 shows longitudinal phase space distributions at four different positions: (a) the gun exit, (b) the linac exit, (c) the middle plane of the bunch compressor and (d) the exit of the bunch compressor. The simulation parameters were listed in table 2. As mentioned above, the longitudinal phase space at the exit of the gun was seemed to be distorted due to the space charge effect because this distortion of the phase space did not occur when the simulation was performed without the space charge calculation. The distortion caused the nonlinear energy-phase correlation of the longitudinal phase space at the position of the exit of the bunch compressor, and it increased the bunch length of the compressed electron bunches. In this case, the final bunch length in rms was 7.15 fs. This was a typical result and the optimization has not been completed yet, but it indicated that generation of less-than several femtosecond electron bunches was possible using this linac system. The optimization of the parameters will be performed to achieve the shortest electron bunches in the future.

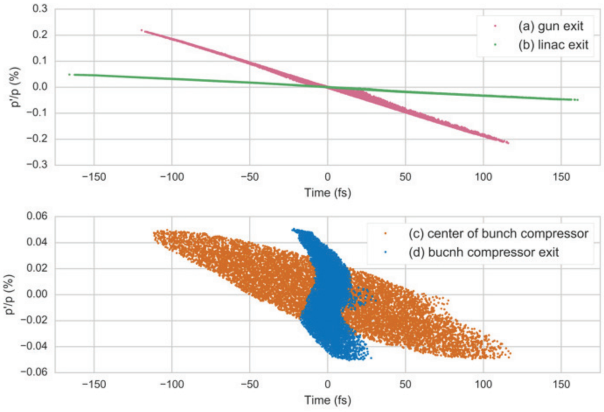

Figure 4: Longitudinal phase space at four different positions: (a) the gun exit (pink), (b) the linac exit (green), (c) the middle plane of the bunch compressor (orange) and (d) the exit of the bunch compressor (blue). The final bunch length was 7.15 fs in rms at the condition of the bunch charge of 0.1 pC.

Table 2: Summary of Parameters for Simulation of the Whole Linac System

Parameters	Value
Number of macro particles	10000
Bunch charge (pC)	0.1
Laser pulse width in rms (fs)	100
Laser spot size (mm)	0.1
Work function of copper (eV)	2.6
space charge effect	3Dmesh
RF phase of gun (deg.)	30
RF phase of linac (deg.)	120
Magnetic field of solenoid magnet (T)	0.12
Magnetic field of Q1 and Q2 (T/m)	1.1
Magnetic field of Q3 and Q4 (T/m)	3.3
Magnetic field of Q5 and Q8 (T/m)	2.9
Magnetic field of Q6 and Q7 (T/m)	0.9
Magnetic field of S1 and S2(T/m2)	5.4

CONCLUSION

In this research, the GPT simulation was carried out for scanning the conditions for generation of ultrashort electron bunches using the relocated linac system. The optimization of the simulation parameters has not been completed yet, but the result of simulation indicated the possibility of generation of several femtosecond electron bunches. In the future, a precise optimization of the simulation parameters will be performed to generate <1-fs electron bunches.

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