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# Generation of Ultrashort Electron Bunches

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## Abstract

Abstract Abstract The generation of high-brightness ultrashort electron bunches is currently a research direction for electron linear accelerators. Both conventional accelerators and plasma-based accelerators can produce ultrashort (sub-picosecond) bunches. This paper briefly describes an accelerator facility for generating ultrashort electron bunches and presents simulation studies.

## Full Text

## Study on the Generation of Ultra-Short Electron Bunches

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The generation of high-brightness ultra-short electron bunches is a key research direction in linear electron accelerators. Both conventional accelerators and plasma-based accelerators can produce ultra-short (sub-picosecond) bunches. This paper briefly describes an accelerator device designed for generating ultra-short electron bunches and presents corresponding simulation studies.

**Keywords:** ultra-short electron bunch, bunch compression

## 1. Introduction

With the development of laser plasma accelerators and free electron laser facilities, the generation of ultra-short electron bunches has become an urgent necessity. Compared with conventional DC thermionic cathode electron guns, photocathode electron guns represent an advanced generation of electron sources. The BNL 1.6-cell standing-wave photocathode electron gun commonly used in major laboratories can produce electron bunches of approximately 10 picoseconds. However, due to severe bunch lengthening effects in photocathode electron guns, it is difficult to directly generate sub-picosecond bunches in the gun itself. Consequently, bunch compressors are typically employed to generate ultra-short electron bunches.

This paper presents simulation studies of an S-band ultra-short electron bunch generation device [1,2] (see Figure 1). The device consists of a BNL-type S-band photocathode electron gun, S-band accelerating structure, solenoid, focusing coils, and a bunch compressor.

Figure 1. Schematic diagram of the ultra-short electron bunch generation device [Figure 2: see original paper].

## 2. Basic Theory of Bunch Compression [3]

Bunch compression technology is widely used in free electron laser facilities and linear colliders to obtain short bunches with high peak current. Compression typically employs magnetic techniques, consisting of an accelerating section and a magnetic compressor. In the accelerating section, the acceleration phase is offset from the peak acceleration phase, causing the bunch to develop a position-dependent coherent energy spread. Particles with different energies then travel different path lengths through the magnetic compressor, thereby compressing the bunch.

In linear theory, the dependencies of position and energy spread are respectively:

where R56 is the first-order momentum compaction factor,  is the relative energy spread, z and z0 are the positions of particles relative to the bunch center after and before compression, respectively, and a is the first-order energy-position correlation factor (chirp).

Assuming an uncorrelated initial bunch distribution (where $\langle L \rangle$ denotes averaging over the bunch), the relationship between bunch lengths before and after compression is:

In the above equation, $R56 \cdot a$ is a small quantity. When $|R56 \cdot a| > 0$, this corresponds to the compression regime, which is the fundamental principle of bunch compression.

## 3. Accelerator Device and Numerical Simulation Study

The device consists of a BNL-type S-band photocathode electron gun, S-band accelerating structure, and bunch compressor.

### 3.1 Photocathode Electron Gun Parameters

The main parameters of the photocathode electron gun are listed in Table 1.

Table 1 . Photocathode electron gun parameters - Cathode surface peak field strength: 100 MV/m - Electron beam energy at gun exit: ~5 MeV - Electron beam charge: [value not specified] - Energy spread at gun exit: 2% rms - Electron beam repetition rate: 10 Hz - RF pulse length: ~3 µs - RF peak power: 15 MW - Number of gun cells: 1.6 - Gun length: 0.168 m - Cathode material:

Cu(Mg) - Laser spot size: 1.0 mm - Laser wavelength: 266 nm - Laser pulse energy: 10 µJ - Laser pulse duration: 0.55 µs

### 3.2 Accelerating Structure

The accelerating structure consists of 61 cells operating in the 3/2  mode. The main parameters of the accelerator tube are listed in Table 2.

Table 2 . Typical parameters of the S-band traveling wave accelerator tube - Frequency: 2856 MHz - Structure type: Constant gradient - Length: 2.09 m - Shunt impedance: 57 MΩ/m - Attenuation: 0.57 dB - Filling time: 0.02 µs - Beam energy: [value not specified] - Energy spread: 0.03% - Pulse duration: 0.55 µs

### 3.3 Magnetic Compressor

The main parameters of the magnetic compressor are listed in Table 3.

Table 3 . Main parameters of the magnetic compressor - Electron bunch energy: [value not specified] - Electron bunch energy spread (rms): [value not specified] - Bunch length compression ratio (rms): [value not specified] - Total length (from 1st to 4th dipole magnet): [value not specified] - Projected length between 1st and 2nd (3rd and 4th) dipole magnets: [value not specified] - Projected length between 2nd and 3rd dipole magnets: [value not specified] - Effective length of dipole magnets: [value not specified] - Dipole magnet bending angle: [value not specified] - CSR emittance growth: [value not specified]

Four quadrupole magnets are placed before the compressor for matching between the accelerator tube and the magnetic compressor.

### 3.4 Simulation Setup and Results

We simulated the device using PARMELA. PARMELA [4] is a multi-particle PIC code that considers space charge effects and is widely recognized in the field. The version of PARMELA used does not account for Coherent Synchrotron Radiation (CSR) effects, so the emittance growth obtained is smaller than in reality. Edge field effects were included in the simulations.

The laser parameters used in the simulation are listed in Table 4.

Table 4 . Typical laser parameters - Laser wavelength: 266 nm - Laser pulse energy: 20 µJ - Laser pulse duration: 0.7 ps - Laser transverse distribution: uniform

The bunch is compressed from 10 ps to less than 1 ps, with a normalized emittance growth of approximately 0.1 mm · mrad in the compressor.

The main parameters of the accelerator for ultra-short bunch generation are listed in Table 5.

Table 5 . Main accelerator parameters - Beam energy: 15 MeV - Bunch length: $< 1$ ps - Normalized emittance: 3.1 mm · mrad

The normalized emittance evolution is shown in Figure 2, and the longitudinal distribution of the ultra-short electron bunch is shown in Figure 3.

Figure 2. Normalized emittance evolution plot.

Figure 3. Longitudinal distribution of the ultra-short electron bunch.

## 4. Conclusion

This paper presents simulation studies of an S-band ultra-short electron bunch generation accelerator. The generated bunches can be used for external injection studies in plasma accelerators and as electron sources for free electron laser facilities.

## References

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