Electron Beam Properties from a Compact Seeded Terahertz FEL Amplifier at Kyoto University

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Abstract

A compact seeded Terahertz FEL amplifier is started construction at the Institute of Advanced Energy, Kyoto University, Japan. The system consists of a 1.6 cell BNL type S-Band photocathode RF-gun, a magnetic bunch compressor in form of a chicane, triplet quadrupole magnets and a short planar undulator. Electron beams from the photocathode RF-gun were measured and compared with the PARMELA simulation results. Numerical and experimental studies on the contribution of the space charge effect were carried out. By using the RF power of 9 MW, the RF phase of 40 degree, the laser pulse energy of 20 μJ and the solenoid magnet current of 135 A, the electron beam with a bunch charge of 50 pC, a beam energy of around 5 MeV and an RMS emittance of 6-8 mm-mrad was achieved.

Introduction

The Institute of Advance Energy has developed the compact seeded THz-FEL (IR-FEL) amplifier. The system was designed to be simple, compact and economical aimed to use in scientific researches. The system consists of a 1.6 cell BNL type S-Band photocathode RF-gun, a magnetic bunch compressor in form of a chicane, triplet quadrupole magnets and a short planar undulator. The photocathode RF-gun succeeded to generate the first beam in May, 2015. The electron beam properties, i.e. an bunch charge, an beam energy and a transverse beam emittance from the RF-gun were measured and compared with the PARMELA simulation results.

Photocathode RF-gun
- Effective length of the half-cell : 3.4135 cm
- Effective length of the full-cell : 9.0405 cm
- Resonant frequency : 2856 MHz
- Maximum repetition rate : 10 Hz
- Microwave pulse duration : ~ 2 μs
- Cathode material : Copper
- Operating temperature : 30º C

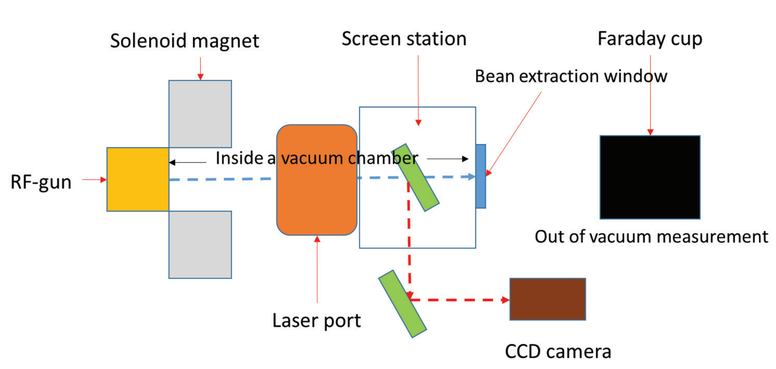
Drive laser system
- Laser media : Nd:YVO_4
- Laser wavelength : 266 nm
- Pulse length at FWHM : 8 ps
- Maximum laser pulse energy : 200 μJ
- Repetition rate of macro-pulse : 89.25 MHz
- Laser components : 2 amplifier, beam stabilizers and SHG-FHG

Electron bunch charge

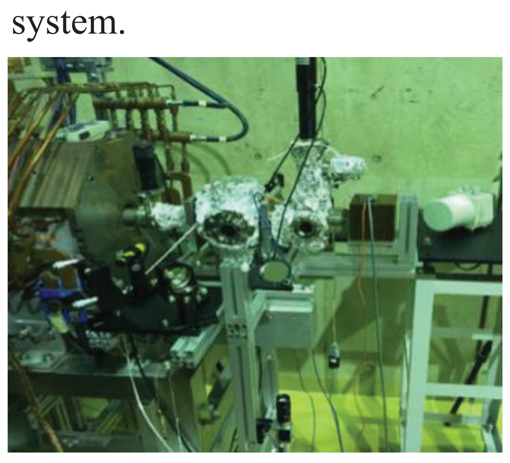
The electron beam is observed by using a Faraday cup, which is located outside of the vacuum chamber. The cup is made of graphite for absorbing the beam by using the in air measurement technique. The electron bunch charge is obtained by using an equation

$$Q = \int I(t)dt = \frac{1}{R}\int U(t)dt,$$

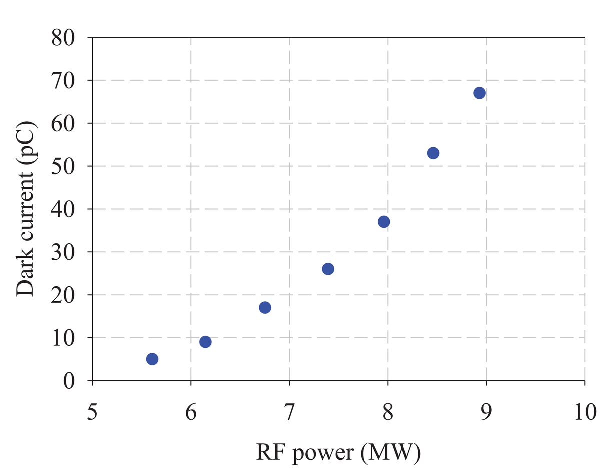
where $U(t)$ is the measured voltage observed by the oscilloscope and R is a resistance of the measurement system.



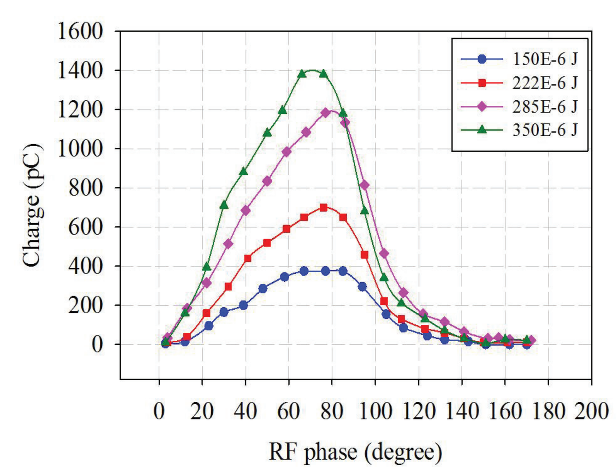
Layout of the electron bunch charge measurement (out of vacuum measurement).



The photograph of experimental set up for electron bunch charge measurement.



Relationship between the dark current and the RF powers.



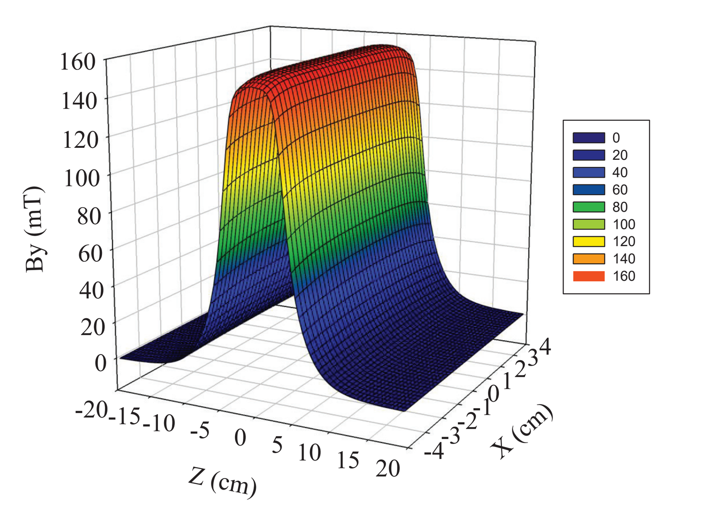
Electron bunch charges dependence on the RF phases and the drive laser pulse energies.

Electron beam energy

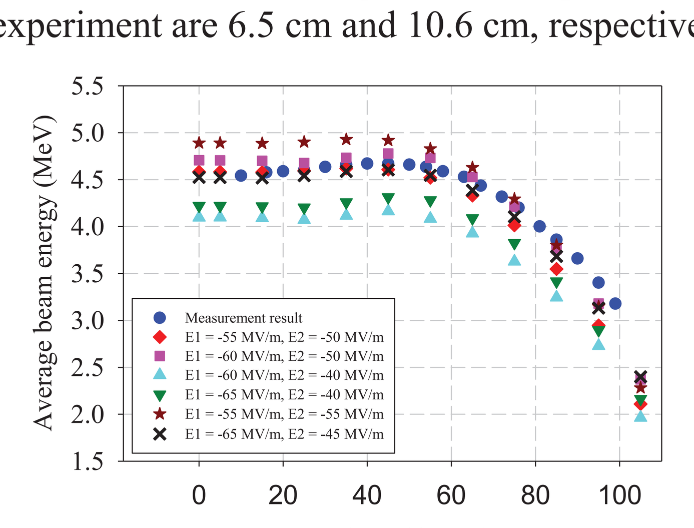
When the electron beam travelling pass a dispersive region of the dipole magnet, which has the magnetic field perpendicular to a traveling path of the beam, the magnetic field acts on the electron beam related to the beam energy as

$$\frac{1}{\rho[m]} = \frac{0.2998 B_0[Tesla]}{\beta E_{total}[GeV]}.$$

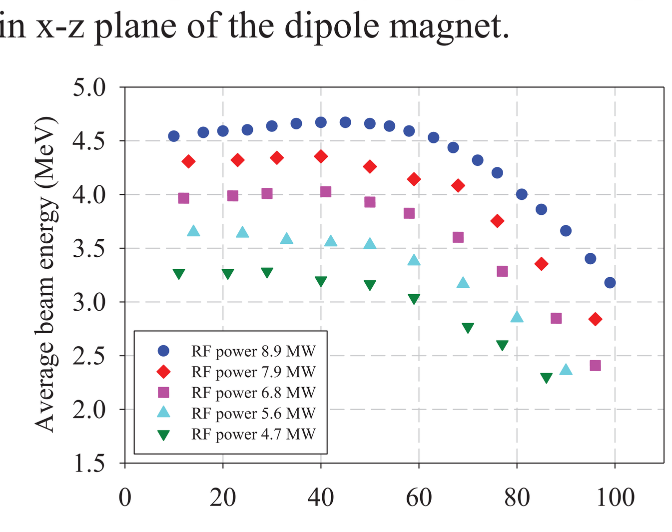
The electrons with difference energies bend in the dispersive region with difference radii. A geometry length and an effective length of the dipole magnet in this experiment are 6.5 cm and 10.6 cm, respectively.



Relationship between By component and positions in x-z plane of the dipole magnet.



Beam energy dependence on the RF phase. The blue plots in this figure are the measurement results and other plots are the example of simulation results.



Measurement results of the beam energy dependence on the RF phase and the RF power.

Beam emittance

Beam emittance is an important quantity for evaluation of the transverse electron beam quality. The emittance is correlated to area or volume of the phase space diagram, which is occupied by the electrons. The emittance are defined as

$$\varepsilon_x = \sqrt{<x^2><x'^2> - <xx'>^2},$$

and

$$\varepsilon_y = \sqrt{<y^2><y'^2> - <yy'>^2}.$$

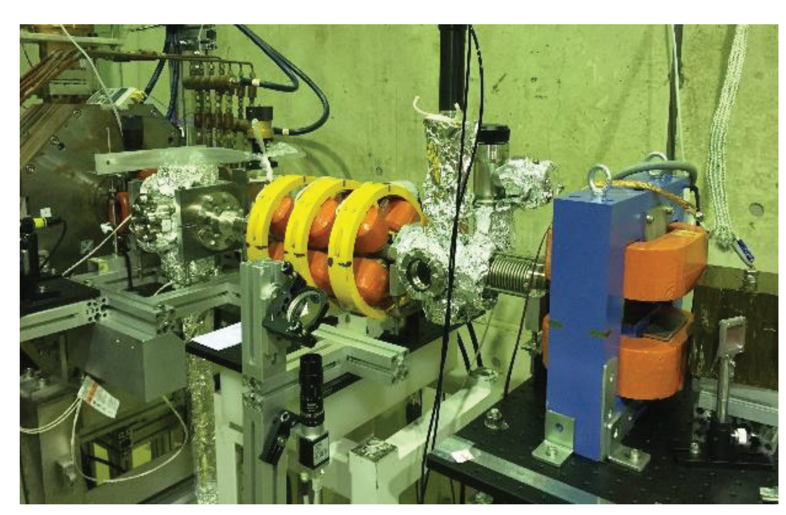
Measurement system is prepared in form of a quadrupole scan method with a thin lens approximation. A focal length of the quadrupole is given by following this equation

$$f[m] = \frac{1}{k[m^{-2}]l[m]},$$

where k is the strength of the magnet and l is the effective length of the magnet, which is related to

$$k = \frac{0.2998 G[T/m]}{p[GeV/c]},$$

where G is a gradient of the quadrupole magnet and p is a momentum of the electron.



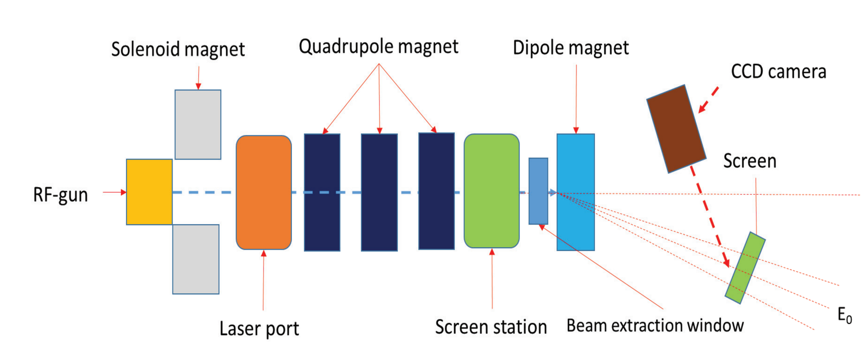
Experimental set up to measure the beam energy and the beam emittance. The system consists of three quadrupole magnets, a dipole magnet, a fluorescence screen and two CCD cameras.

An effective length of the quadrupole magnet in this experiment is 55 mm. The momentum is related to

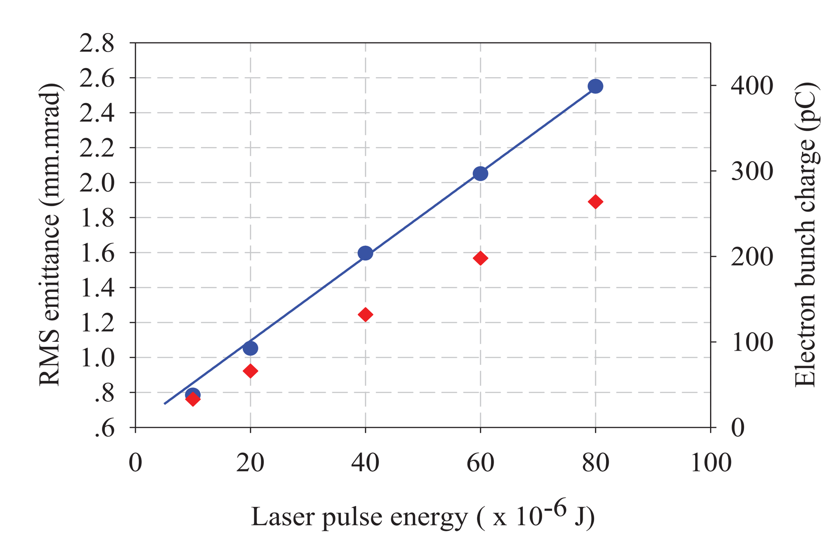
$$cp = \beta E_{total},$$

where c is a velocity of light, $\beta = v/c$ and E is a total energy of the electron

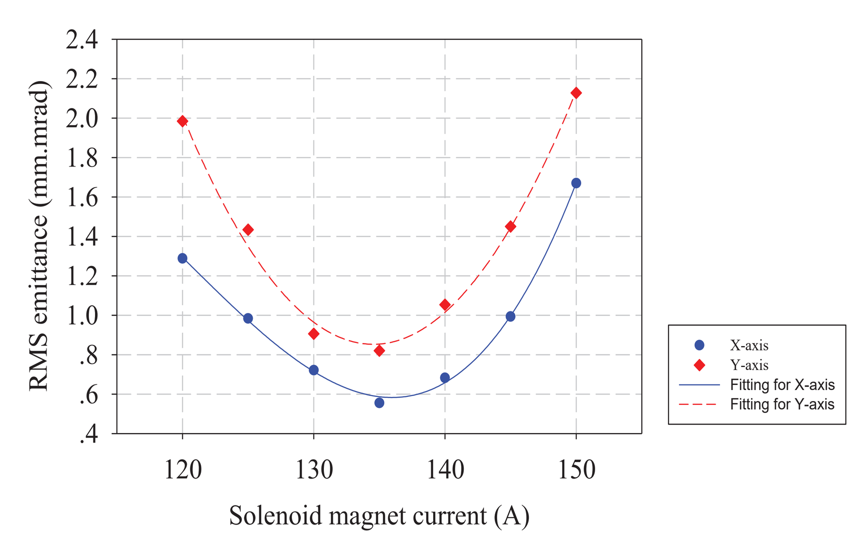
Unfortunately, we did not have enough time to prepare in vacuum measurement, the beam energy measurement for beam emittance measurement has been performed with the in air measurement.



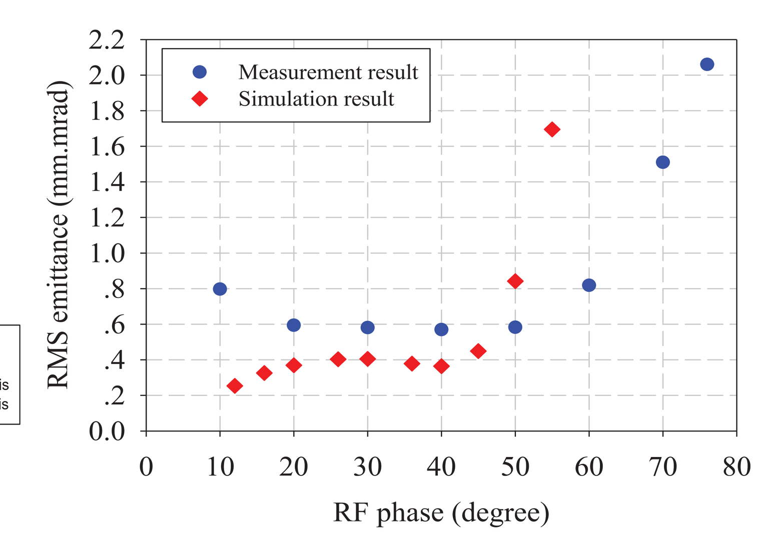
Layout of the beam emittance measurement system. The beam profile measurement part is in vacuum measurement but the dispersive part to measure the energy is the in air.



The beam emittances dependence on the bunch charges and the drive laser pulse energies by using the RF power of 9 MW, the RF phase of 40 degree and the solenoid current of 130 Ampere.



The beam emittances dependence on the solenoid magnet currents by using the RF power of 9 MW, the RF phase of 40 degree, the bunch charge of 50 pC and the drive laser pulse energy of 20 μJ.



The beam emittances dependence on the RF phases by using the RF power of 9 MW, bunch charge of 50 pC and the solenoid current of 135 A.

Conclusion and outlook

The numerical and experimental studies on the contribution of the electron beam properties have been carried out. Result of the investigation show that the electron beam with a bunch charge of 50 pC, a beam energy of around 5 MeV and an RMS emittance of 6-8 mm-mrad can be obtained by using the RF power of 9 MW, the RF phase of 40 degree, the laser pulse energy of 20 μJ and the solenoid magnet current of 135 A. Further investigation will be performed in order to improve the quality of the RF-gun, the measurement systems and calculation methods for the better performance of the 1.6 cell BNL type photocathode RF-gun.

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