Study on Effect of Asymmetric RF-gun on Electron Beam Properties

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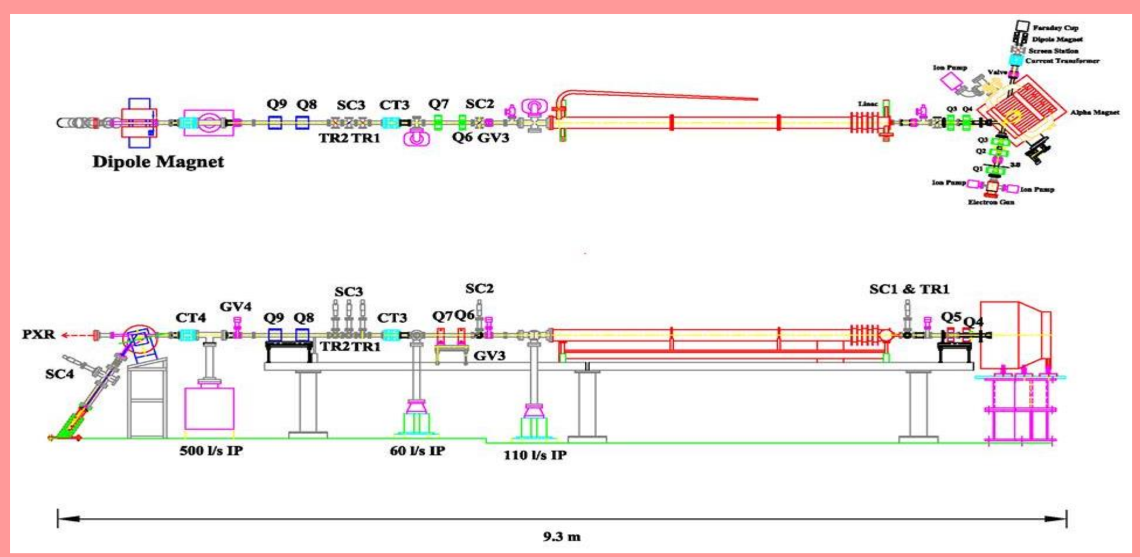
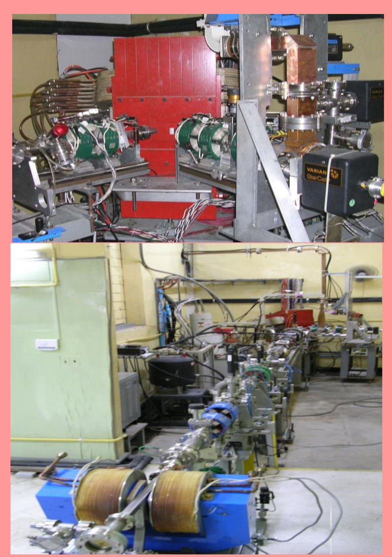
Abstract

The electron source of the linear accelerator system at the Plasma and Beam Physics Research Facility, Chiang Mai University, is a thermionic cathode RF-gun. The gun is a standing wave structure composing of two S-band accelerating cells and a side-coupling cavity. The 2856 MHz RF wave is transmitted from the klystron to the gun through a rectangular waveguide input-port. Both RF input-port and the side-coupling cavity are the cause of asymmetric electromagnetic field distribution inside the gun. To investigate the effect of the asymmetric fields on electron properties, beam dynamic simulations are performed by using the computer codes PARMELA and ELEGANT. The input 2D and 3D field distributions of the RF-gun for PARMELA simulations are obtained from the RF modeling programs SUPERFISH 7.19 and CST Microwave Studio 2012. An electron bunch of 250,000 macro-particles with a total charge 0.91 nC per RF period are tracked through the fields inside the RF-gun with radial and longitudinal meshes of 0.25 mm and 44.4 μm, respectively. The beam with a maximum kinetic energy of 2.63 MeV and a total bunch charge of 0.21 nC is achieved at the gun exit. The output beam from the asymmetric gun has asymmetric transverse shape with the emittance value higher than the beam from the symmetric gun. The problems can be enlarged when the beam is transported from the gun through the whole accelerator system, which consists of an alpha magnet, a travelling wave linac, magnet elements and related beam diagnostic components. The code ELEGANT is then used to track the particles from the gun exit to the experimental station. Energy slits inside the alpha magnet vacuum chamber is used to filter the electrons with kinetic energies of lower than 1.58 MeV. Study results show that the alpha magnet with a gradient of 360 G/cm provides the minimum energy spread. The beam produced from the asymmetric RF-gun has higher energy spread at the experimental station than the symmetric one.

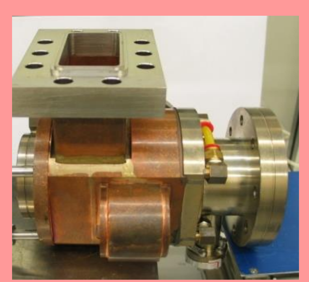
Introduction and Methodology

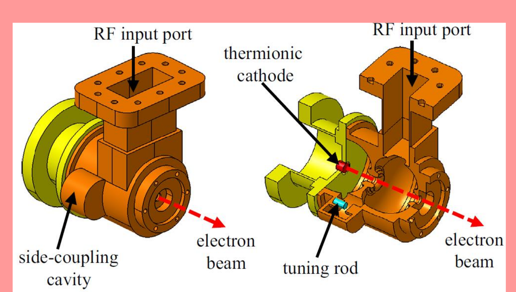
The electron linear accelerator system at PBP consists of a thermionic cathode RF electron gun, an alpha magnet as a magnetic bunch compressor, a travelling wave linac, magnets elements and various beam diagnostic systems. The accelerator is used to produce electron beams with short bunch length for generation of THZ radiation.

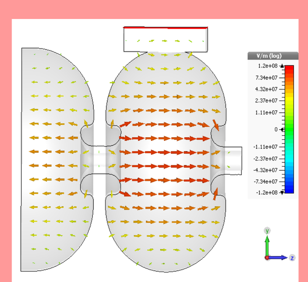


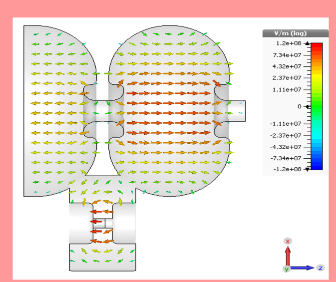


The RF-gun has asymmetric shape due to opening ports for the RF-input waveguide and the side-coupling cavity. This leads to asymmetric EM field distribution inside the gun.

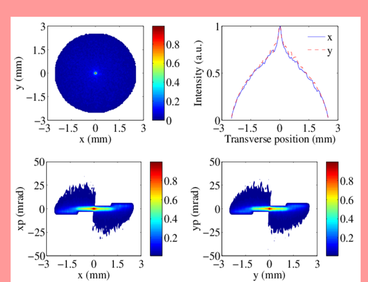


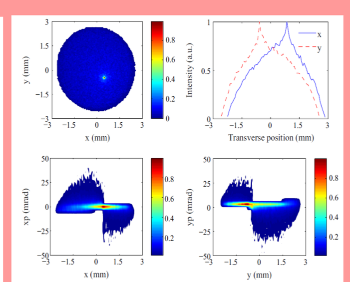


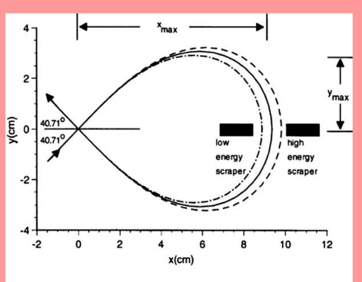


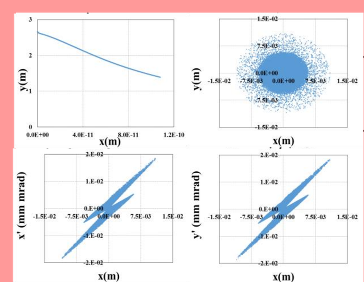


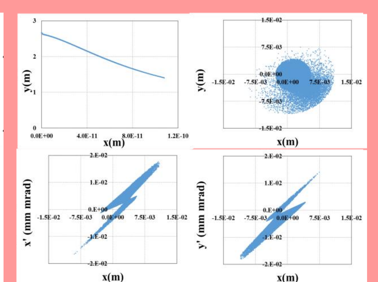
Asymmetric EM fields inside the RF-gun affect transverse properties of electron beam. The beam has asymmetric shape and may deviate and hits the vacuum pipe wall, when it travels from the RF-gun exit through the beam transport line.


Beam at the exit of symmetric gun.

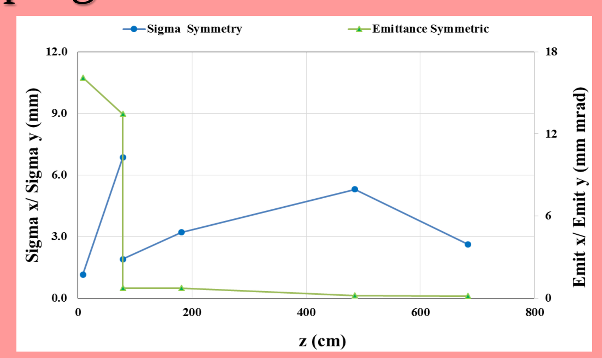

Beam at the exit of asymmetric gun.

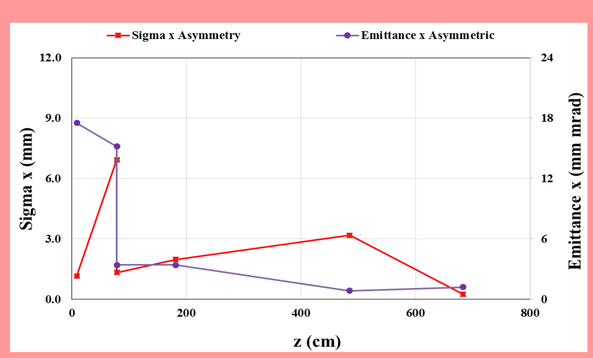

Electron trajectories inside the alpha magnet.

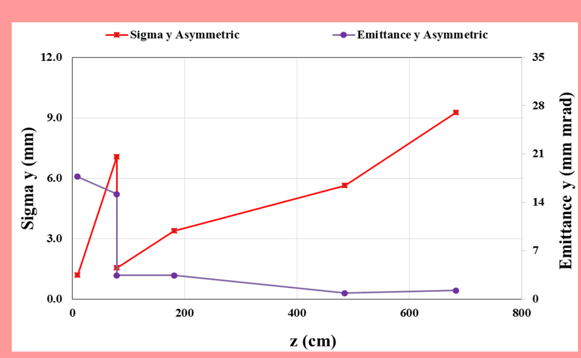

Beam at the α-magnet vertex for the symmetric gun.


Beam at the α-magnet vertex for the asymmetric gun.

Beam dynamic simulations were performed to study behavior electrons by using the programs PARMELA and ELEGANT.

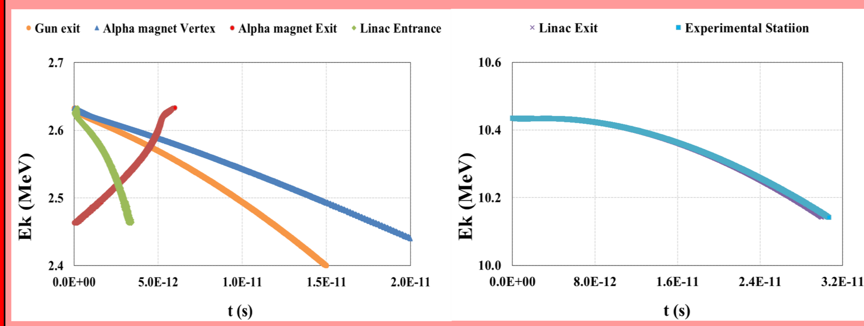

Beam evolution from the gun exit to the α-magnet vertex for symmetric gun.

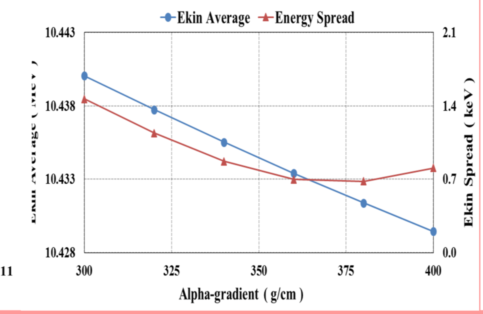


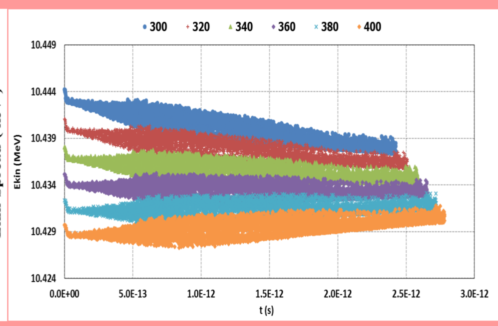

Beam evolution from the gun exit to the α-magnet vertex for asymmetric gun.

Simulation Results

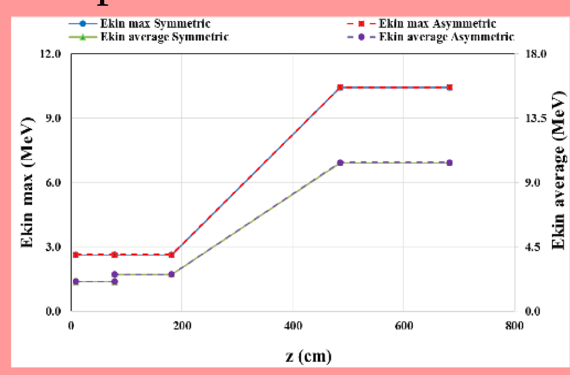
The α-magnet is an important component, which has effect on longitudinal position of electrons in the bunch. Its gradient was varied to investigate the influence on the electron bunch length. Study results show that the α-magnet with high gradients leads to over compression of the energy-time distribution at the experimental station. In contrast, the α-magnet with low gradients cannot compress the electron bunch with high kinetic energy part. Therefore, the optimization of the α-magnet gradient is necessary. Study results show that the α-magnet with a gradient of 360 G/cm provides the minimum energy spread with the bunch length comparable to other gradients in the range of 300-400 G/cm.

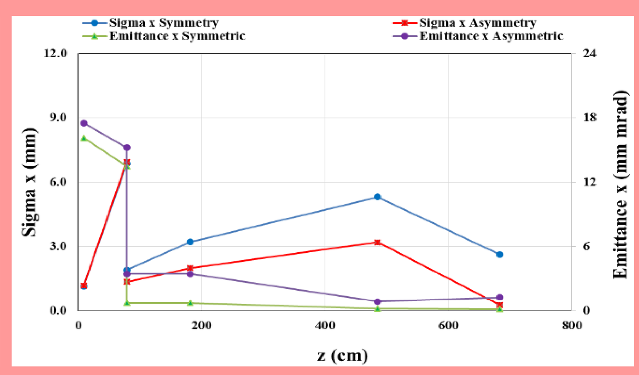

Energy-time distributions at various locations in the beam line.

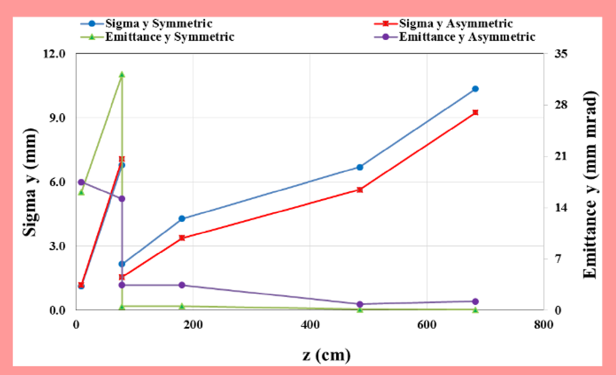

Average kinetic energy and energy spread of electron bunch at the experimental station as a function of α-magnet gradient


Energy-time distribution at the experimental station for the α-magnet gradients of 300-400 G/cm.

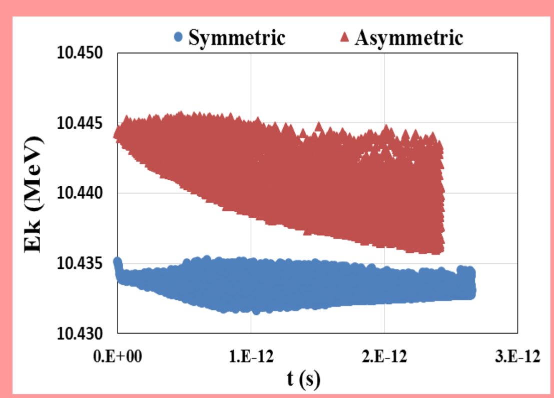
Beam dynamic simulations were performed to study the evolution of both symmetric and asymmetric electron bunches from the gun exit through the whole accelerator system by using the program ELEGANT with 2nd-order transport matrices. Comparison results reveal that the maximum and average kinetic energies of both cases are comparable while the transverse beam sizes and emittance values are different.


Maximum and average kinetic energy of electron bunch along the beam line.

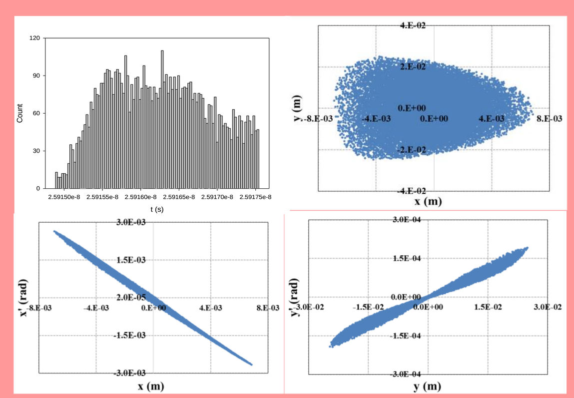

Horizontal beam transverse size and emittance of electron bunch along the beam line.

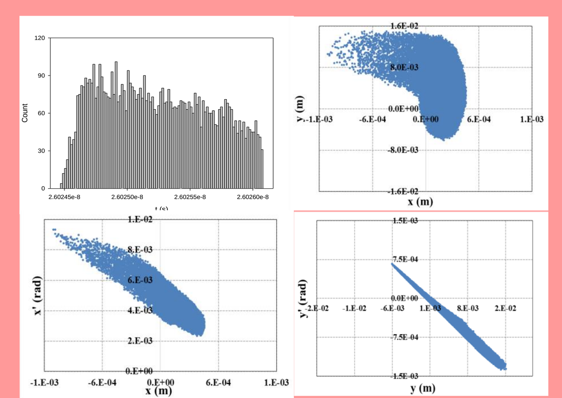

Vertical beam transverse size and emittance of electron bunch along the beam line.

Energy-time distributions, longitudinal histograms, transverse beam distributions and phase spaces for the beams from symmetric and asymmetric RF-guns at the experimental station are compared. The results show that the beams from symmetric gun has lower energy spread and better beam **transverse** shape.



Energy-time distributions at the experimental station.


Beam (head of bunch) at the experimental station for symmetric beam from the gun.


Beam (head of bunch) at the experimental station for asymmetric beam from the gun.

Conclusion

The dynamic studies of electron beams in the PBP-CMU linac system were conducted for the cases of symmetric and asymmetric RF-gun field distributions in the RF-gun. Magnetic field strengths of all quadrupole magnets were optimized to achieve the appropriate beam transverse size at the experimental station. The results show that the optimal alpha-magnet gradient is 360 G/cm. The beam produced from the symmetric RF-gun has lower energy spread and better beam transverse shape than the asymmetric RF-gun. Results of the optimal condition are concluded in the following table.

Parameters	Symmetric gun	Asymmetric gun
Beam size X (m)	2.97	0.13
Beam size Y (m)	10.93	9.42
Emittance X (mm mrad)	0.21	0.63
Emittance Y (mm mrad)	0.09	0.18
Ekin max (MeV)	10.435	10.446
Ekin average (MeV)	10.433	10.441
Energy spread (keV)	0.699	2.314
FWHM bunch length (ps)	1.9	1.3

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