Transverse Emittance Measurement of KAERI Linac with Thick Lens Quadrupole Scan

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2RC THz Pump X-ray Probe

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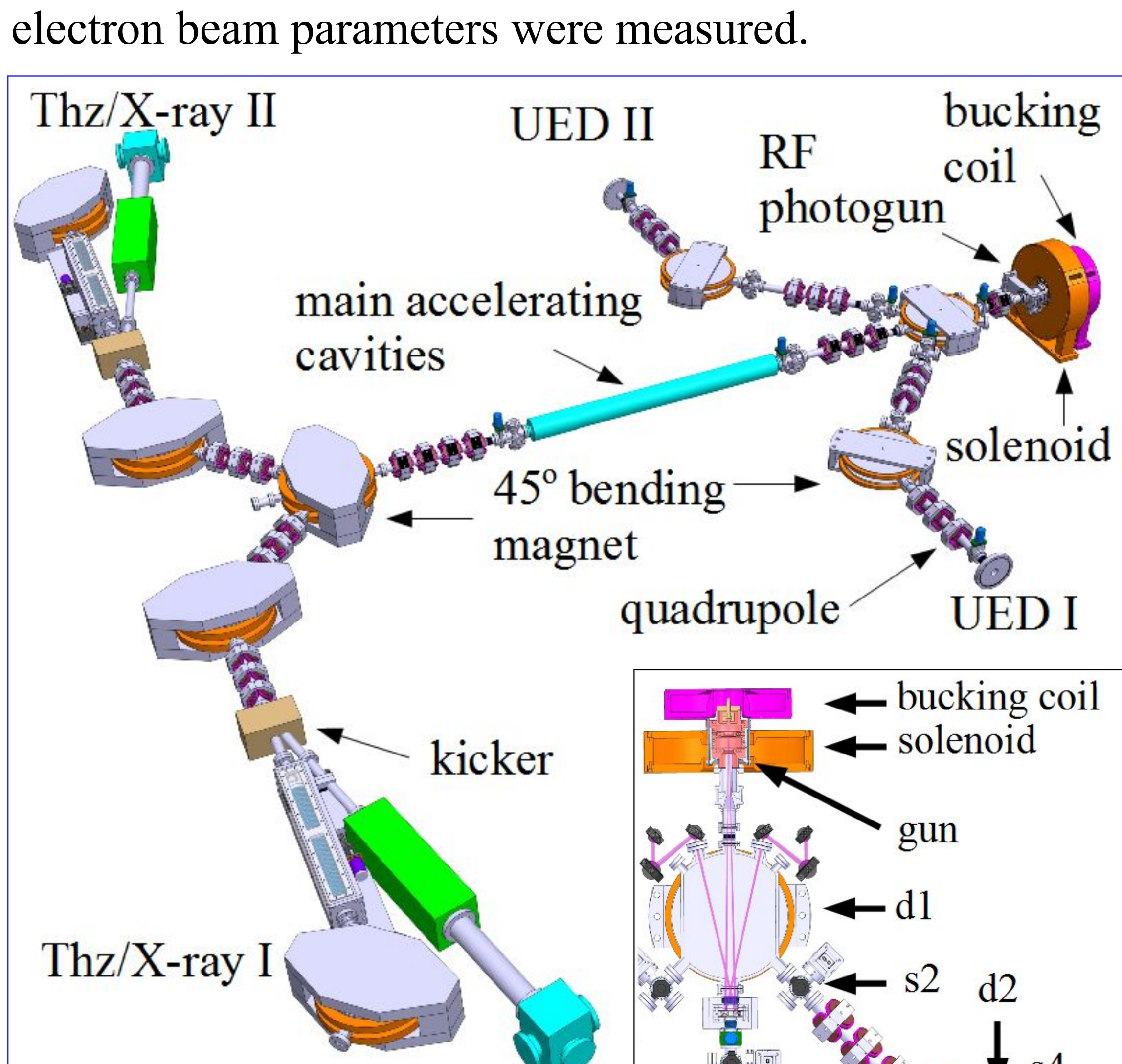
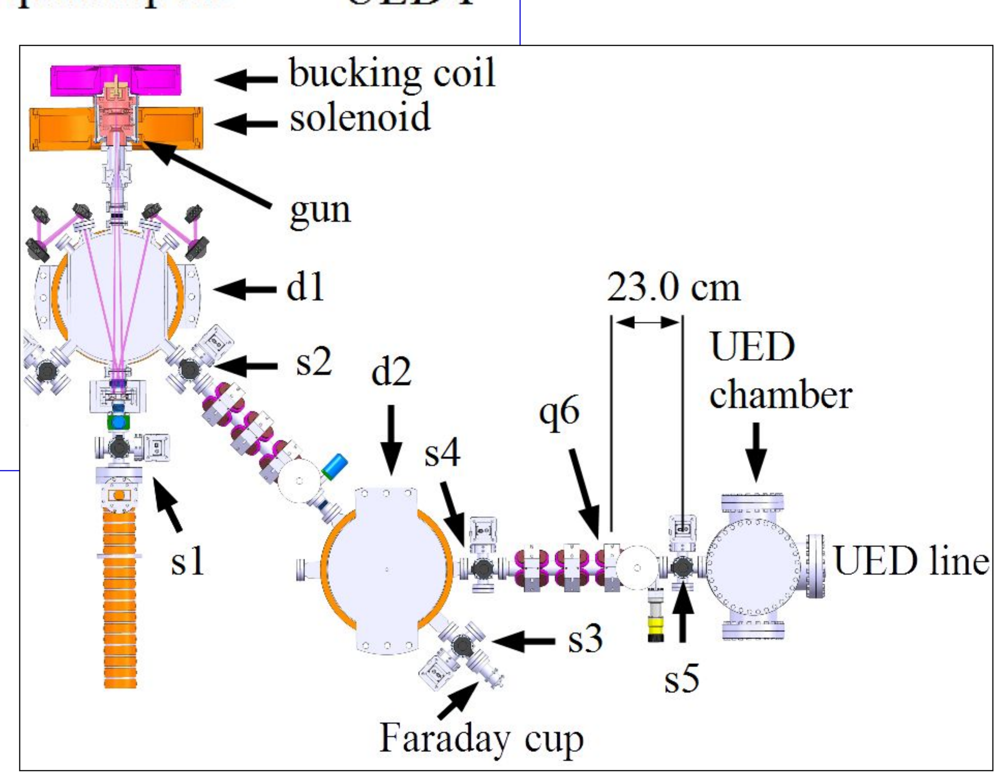
1. Introduction

The UED (Ultrafast Electron Diffraction) beamline of KAERI (Korea Atomic Energy Research Institute) WCI (World Class Institute) Center has been completed and successfully commissioned. Transverse emittance of the electron beam was measured at the entrance of the UED chamber with the quad scan method. In this method, larger drift distance between the quad and screen is preferable due to the better thin lens approximation. For a space charge dominated beam however, the growth of the beam size in the drift space cannot be ignored due to the space charge force. We mitigated this growth by introducing quadrupole scan with short drift and without thin lens approximation. We shall discuss the measurement process and results.

2. Thick Lens Quadrupole Scan at KAERI

The RF photogun of KAERI WCI Center is designed to generate sub-picosecond electron bunches with energy around 3 MeV. The beam can be delivered to UED experiments or can be further accelerated up to 20-30~MeV by the main accelerating cavity for X-ray/THz pump and probe experiments as shown in the figugre below. The UED section of beamline is designed to supply electron bunches with 0.1 ps length, 1 pC charge, and nominal energy of 3 MeV by bending and bunching the beam from the gun using a ninety degree achromatic bend [1]. The UED section has been successfully commissioned recently and electron beam parameters were measured.





Left: KAERI linac layout;
Right: Quadruple scan setup.

In thin lens approximation is satisfied when $\sqrt{k}L \ll 1$. Here k is quad strength and L is quad effective length. quad is viewed as a thin focusing/de-focusing lens. In quadrupole scanning method, for a better thin lens approximation k is kept small while the drift distance between the quad and screen is set as large as possible (few meters). But a space charge dominated beam pass through a long drift will experience emittance growth due to the space charge force [2]. This growth can be mitigated by shortening drift length and extracting emittance without using thin lens approximation. In our case, drift length is 23 cm.

2. Thick Lens Quadrupole Scan

quad transfer matrix — drift transfer matrix — total transfer matrix

$$Q=\begin{pmatrix} \cos\sqrt{k}L & \frac{1}{\sqrt{k}}\sin\sqrt{k}L \\ -\sqrt{k}\sin\sqrt{k}L & \cos\sqrt{k}L \end{pmatrix} \qquad S=\begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}=\begin{pmatrix} 1 & l \\ 0 & 1 \end{pmatrix} \qquad M=SQ=\begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix}$$

Here, l is the drift length, L is the effective length of the quad, and k is the quad strength. The beam matrix at the screen is related to the beam matrix of the quadrupole using the similarity transformation [3].

$$\sigma_{screen}=M\sigma_{quad}M^T, \text{ where } \sigma=\begin{pmatrix} \sigma_x^2 & \sigma_{xx'} \\ \sigma_{xx'} & \sigma_{x'}^2 \end{pmatrix}.$$

σ_{screen} can be expressed as the function of the matrix elements m_{11} and m_{12} as

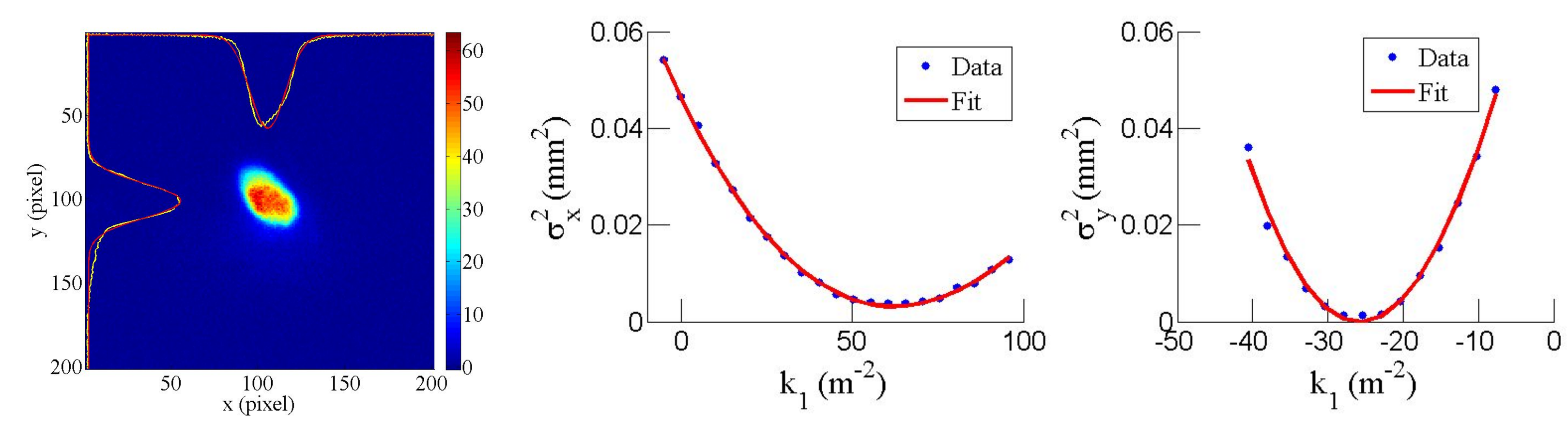
$$\sigma^2_{screen,x}=\sigma_{11}\left(m_{11}+m_{12}\frac{\sigma_{12}}{\sigma_{11}}\right)^2+m_{12}^2\frac{\varepsilon^2_{q,x}}{\sigma_{11}},$$

$$m_{11}=S_{11}\cos\sqrt{k}L-S_{12}\sqrt{k}\sin\sqrt{k}L,$$

$$m_{12}=S_{11}\frac{1}{\sqrt{k}}\sin\sqrt{k}L+S_{12}\cos\sqrt{k}L.$$

3. Experiment and Results

The emittance measurement was performed by changing the quadrupole current, which changes quad strength k, and measuring the corresponding beam image on the view screen. The measured two-dimensional beam image was projected along the image's abscissa and ordinate axes. The rms value is extracted by fitting Gaussian distribution to the beam projection. Measurements of σ_s^2 *vs* k_1 is then fit using the function in above equation to determine the emittance and the Twiss parameters.



Left: Beam profile observed on phosphor screen when q6 is off.
center/right: Squares of rms beamsize *vs* quad strength, σ_s^2 *vs* k_1, and fit using thick lens equation for horizontal/vertical beam projection.

Table 1: Emittance Measurement Results

Parameter	Unit	Value
normalized emittance $\varepsilon_{n,x}$	mm·mrad	0.23 ± 0.03
normalized emittance $\varepsilon_{n,y}$	mm·mrad	0.42 ± 0.07
β_x-function	m	0.63 ± 0.10
β_y-function	m	5.5 ± 1.6
α_x-function	rad	0.9 ± 1.1
α_y-function	rad	0.23 ± 0.03
bunch charge	pC	1.12 ± 0.03
total energy E	MeV	3.26
relative energy spread $\Delta E/E$	%	0.32

The vertical emittance is significantly larger than horizontal one. One possible reason is vertical beam size reached its waist during the scanning and couldn't be focused further. However, the fitting curve follows smaller vertically minimum beamsize as can be seen in the above figure. We plan to perform a test by beginning the quad scan with a with larger vertical size instead of round shape.

4. Conclusion

We have used quadrupole scanning method with thick lens equation to measure the beam emittance of the WCI cetner UED Linac at the KAERI. The horizontal/vertical emittance was measured to be 0.23±0.03/0.42 ± 0.07 mm·mrad for 1.12 ± 0.03 pC bunch charge. The vertical emittance is significantly larger than horizontal one. We plan to conduct further investigation on this matter. We also plan to measure emittance *vs* charge in the near future and compare emittances obtained with and without thin lens approximations as charge grow.

Acknowledgment

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