PHOTO-ELECTRON BEAM DIAGNOSTICS USING TOMOGRAPHY TECHNIQUE

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Abstract

It is very important to measure a density-distribution of electron beam in transverse and longitudinal phase space for accelerator operation and many applications. A photo-cathode rf-gun is capable of not only controlling the transverse emittance of electron beam, but also longitudinal emittance changing laser profile on the cathode and the input rf parameters for the rf-gun cavities. The transverse phase space distribution of photoelectron beam was observed at the Accelerating Test Facility in KEK (KEK-ATF) using tomography technique. Using the tomography technique, the transverse phase space distribution is measured without assumptions of shape of phase space distribution such as Gaussian distribution. The distribution of an electron beam in a transverse phase space was reconstructed from the measured transverse profiles of the electron beam using a screen monitor. We describe the principle of tomography technique, the experimental set-up at KEK-ATF and preliminary results of the beam test in this paper. Longitudinal tomography measurements also briefly described including the beam test result at Brookhaven National Laboratory (BNL) [1].

1 INTRODUCTION

Electron bunches with low emittance in both transverse and longitudinal are required in linear colliders, single-pass X-ray FEL, second-generation laser accelerator and many other applications. Producing and measuring the high quality electron bunches is one of the most active areas in beam physics R&D [2]. Photo-cathode rf-gun has emerged as the capable of producing high-brightness electron bunch to drive X-ray FEL and second-generation laser accelerators. Performance of rf-gun strongly depends not only rf parameters but also laser parameters. Especially, the laser profile on the photo-cathode has strong effects on the transverse emittance of the photo-electron beam.

Until now, many beam diagnostic methods have been developed to measure electron beam characteristics. For the transverse phase space distribution of electron beam, a waist scan method with quadrupole magnets and a multiple scan method are widely used in accelerator physics. In these measurements, we assume that an electron bunch has Gaussian density-distribution. In an injector part of accelerators, electron beams are usually not Gaussian. Especially, transverse characteristics of photo-electron beam generated by photo-cathode rf-gun depends on laser profile on the cathode. Therefore it is very useful to measure the density-distribution in phase space without assumptions of initial distribution.

The transverse tomography technique developed at BNL Accelerator Test Facility (BNL-ATF) is one of the tools for transverse phase space characterization [3][4]. We also applied the same technique to photo-electron transverse characterization at KEK-ATF. We performed first experiment at the injector part of KEK-ATF linac using an s-band photo cathode rf-gun. On the other hand, we implemented longitudinal tomography technique at the Brookhaven Accelerator Test Facility (ATF) to study the photo-electron beam longitudinal phase space.

2 PRINCIPLE OF TRNSEVERSE TOMOGRAPHY

The tomography technique is widely used in the medical imaging community for diagnostics, brain function studies and many other applications. Similar technique was employed for both transverse [3] [4] and longitudinal [1][5] phase space characterization of electron beam. The two-dimensional image can be reconstructed from its one-dimensional projections (Figure 1) using tomographic technique. For electron beam's phase reconstruction, the measured distribution in the physical space can be regard as a projection of the phase space distribution. The projection axis can be rotated changing the beam optics.

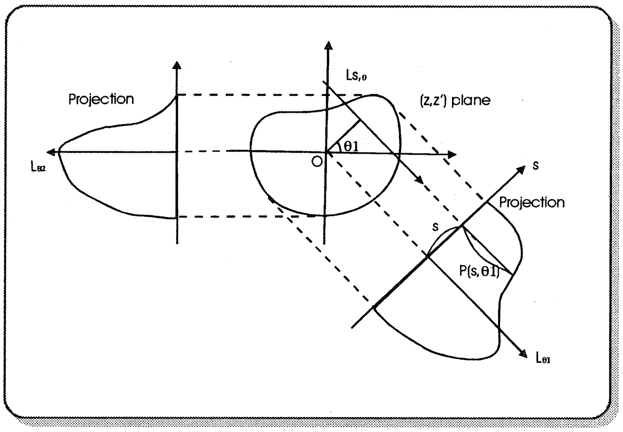

Figure 1 Principle of tomographic imaging

For the transverse phase space tomography, the electron beam profiles were measured using a phosphorescent screen monitor. In order to take the independent projection of electron beam in phase space, the electron beam was rotated in the phase space varying strength of quadrupole magnets (shown in Figure 2).

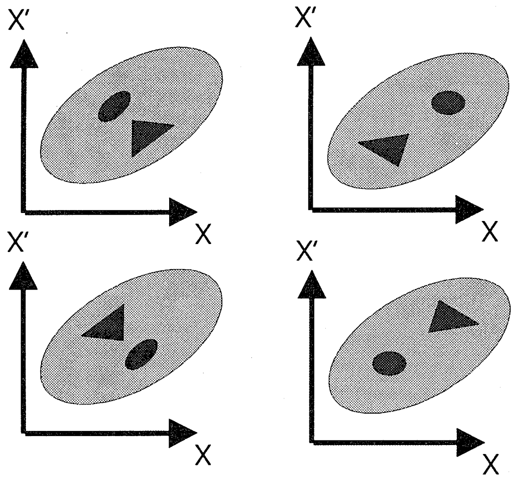

Figure 2 Changing rotation angle in phase space using quadrupole magnets

As an electron bunch goes through a beam line, the transverse coordinates (x_0, x'_0) of electrons are transformed in the following way

$$\begin{pmatrix}x\\x'\end{pmatrix} = M\cdot\begin{pmatrix}x_0\\x_0'\end{pmatrix} = \begin{pmatrix}M_{11}x_0+M_{12}x_0'\\M_{21}x_0+M_{22}x_0'\end{pmatrix} = \begin{pmatrix}A(x_0\cos\theta + x_0'\sin\theta)\\M_{21}x_0+M_{22}x_0'\end{pmatrix} \qquad (1)$$

,where M is transfer matrix from the initial point to the screen monitor, A is the transversal stretching factor and θ is the rotation angle in the transverse phase space.

3 TRANSVERSE TOMOGRAPHY STUDIES AT KEK-ATF

3.1 Experimental Setup

The KEK-ATF was constructed in the KEK Assembly Hall for linear collider R&D. The purpose of KEK-ATF is to develop an extremely low emittance multi-bunch beam. This is an essential requirement for getting high collision luminosity in future linear collider. In 2001 summer, beam test of the s-band photo-cathode rf-gun developed at BNL [6] was performed at the injector part of KEK-ATF to investigate a possibility of photo-cathode rf-gun as an electron source of linear colliders.

Figure 3 shows the layout of the injector part of the ATF accelerator system which is composed of a s-band photo-cathode rf gun, a 3-m long s-band accelerating structure, an energy analysing section and beam diagnostic tools such as beam profile monitor, beam position monitor (BPM) and so on. In the measurement of transverse density-distribution, the rotation of the angle in the phase space was done changing the currents of three quadrupole magnets (QA1L, QA2L, QA3L) and the beam profile was measured using the screen monitor (MS5L). Basically the rotating angle of density-distribution in phase space should cover more than 180 degrees. But in this beam test we used only three quadrupole magnets, therefore the rotating angle of density-distribution was limited in some range (about 140 degrees) with constant value of the transversal stretching factor (A).

In this measurement, beam energy of photoelectron beam was 65 MeV and bunch charge was about 1.2~1.8 nC at the measurement point of beam profile. Nd-YLF laser (UV; λ = 262 nm) was used for the irradiation laser of photo-cathode. Transverse shape on the cathode was made to be a circle using a prism and the length was ~10 ps (FWHM).

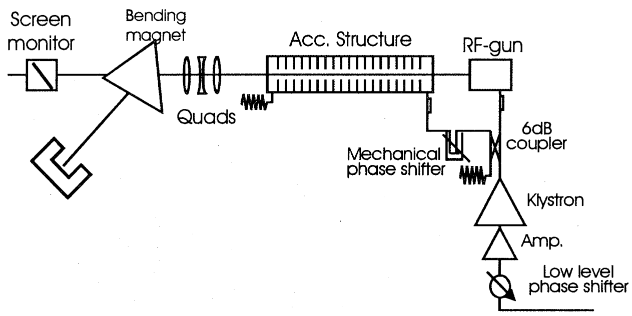

Figure 3 Experimental setup at KEK-ATF injector part

3.2 Data Taking and Analysis

We prepared 24 current settings of the quadrupole magnets to rotate the density-distribution in phase space using SAD code [7]. Step of the rotating angle was about 5 degrees and the total covered angle was 140 degrees.

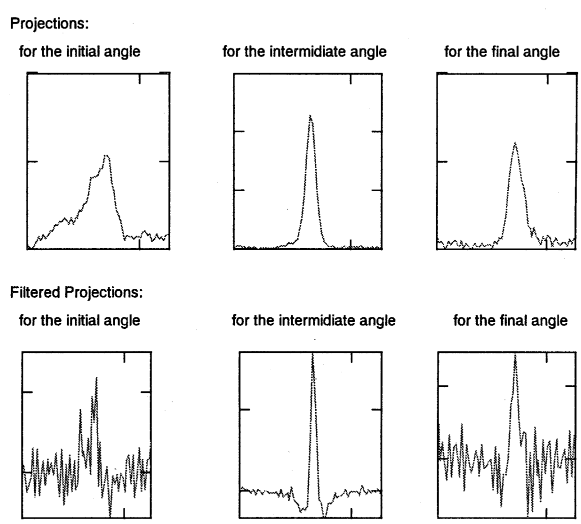

Figure 4 Examples of projection and filtered projection at different rotation angle

At each current setting of quadrupole magnets, beam profile data was taken using the HAMAMATSU image data acquisition system. In this data taking, the projected data to the horizontal and vertical axis (X, Y) were saved as 16-bit digitising number. Using Filtered Back-Projection method with the Ramachandran-Lakshminarayanan filter function [8], we reconstructed the phase space distribution from these filtered projections. Figure 4 shows example of projection data and filtered projections at different rotating angles. We measured the transverse density-distribution of electron beam for different laser profiles on the cathode of rf-gun, one is a Gaussian laser intensity profile and another is a non-Gaussian laser intensity profile cutting the tail of the Gausian distribution using 2 mm iris.

3.3 Experimental Results and Discussion

Figure 5 shows the reconstructed image of electron beam density-distribution in transverse phase space at just upstream of the first quadrupole magnet. From two reconstructed images in Figure 5, we can observe the difference at the part of beam hallows. It should come from the difference of the initial laser intensity profile on the cathode.

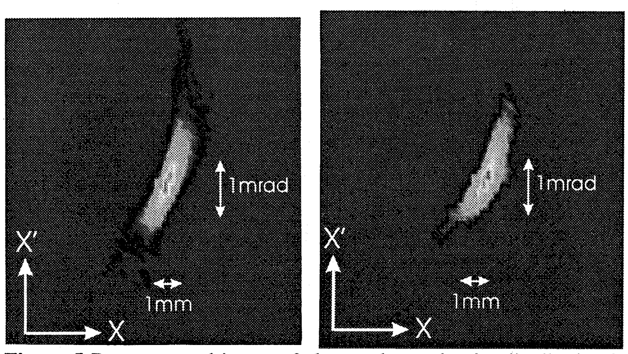

Figure 5 Reconstructed image of electron beam density-distribution in transverse phase space at just upstream of quadrupole magnets. (left; Gaussian laser intensity profile, right; Tail cut Gaussian laser intensity profile using 2mm iris)

In this measurement, we neglected errors of strength of quadrupole magnets. They directly affect the rotating angles and the transversal stretches and the reconstructed density-distribution in phase space. As next step, it is necessary to estimate the effects of the errors. On the other hand, to get a fine reconstructed image of density-distribution, a wide range and precise of image acquisition system is required.

3 LOGITUDINAL TOMOGRAPHY

Similar tomography technique can be applied to the measurement of longitudinal density-distribution. For the longitudinal phase space, the magnetic dispersion section and the off-phase accelerating structure is used to rotate the density-distribution (Figure 6). Final energy distribution is measured using spectrometer, and longitudinal distribution of initial electron bunch is revealed from this measured final energy distributions.

We have performed the measurement of longitudinal emittance using tomography technique as function of bunch charge (space charge) and rf-gun phase at BNL-ATF [1]. We have controlled the energy of irradiate laser for the cathode of the rf-gun to change the bunch charge from 50 pC to 250 pC at the constant rf-gun phase. From this measurement, the longitudinal emittance was evaluated to be roughly proportional to the bunch charge.

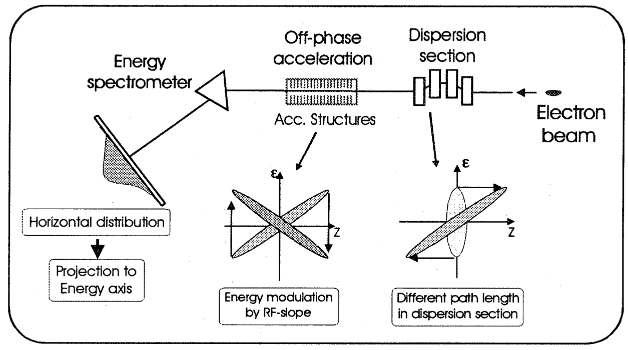

Figure 6 Transformation of longitudinal phase space distribution using the dispersion section and the off-phase accelerating structure.

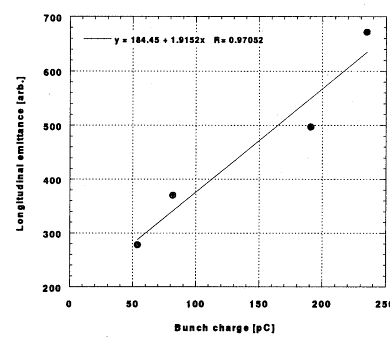

Figure 7 Bunch charge vs longitudinal emittance

4 CONCLUSION

We performed the density-distribution measurement using the tomography technique for photo-electron beam. The tomography technique was very useful to measure the density-distribution of electron beam without assumption of initial density shape. To get high accuracy of the measurement, we will give attention the data taking system and reconstruction algorism of tomography technique such as filter function.

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