2-D LOW ENERGY ELECTRON BEAM PROFILE MEASUREMENT BASED ON COMPUTER TOMOGRAPHY ALGORITHM WITH MULTI-WIRE SCANNER*

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Abstract

A new method for low energy electron beam profile measurement is advanced, which presents a full 2-D beam profile distribution other than the traditional 2-D beam profile distribution given by 1-D vertical and horizontal beam profiles. The method is based on the CT (Computer Tomography) algorithm. Multiple sets of 1-D beam profile projection data are obtained by rotating the multi-wire scanner. Then a 2-D beam profile is reconstructed from these projections with CT algorithm. The principle of this method is presented. An experimental setup was designed and the experimental results are analyzed in detail.

INTRODUCTION

Low energy electron beam profile measurement is of great significance since the initial emittance of the injector or electron gun can be indirectly obtained from it, which determines the emittance of the whole electron beam of an accelerator. The research work for several types of Electron guns is currently carried out in department of engineering physics, Tsinghua University, where the beam profile and initial emittance measurements for the electron guns are required. Thus a new method for 2-D beam profile measurement for electron gun based on CT algorithm with rotating multi-wire scanner is advanced, and an experiment setup has been designed to verify the method.

The 2-D beam profile measurement based on CT algorithm with rotating multi-wire scanner is developed from the combination of computer tomography and multi-wire scanner technology. A mechanism is introduced to rotate the multi-wire scanner. Multiple sets of 1-D beam profile projections can be acquired while rotating the scanner. A 2-D beam profile distribution will be reconstructed with CT algorithm from the projections. This method can present a full 2-D beam profile distribution other than the traditional 2-D beam profile distribution given by 1-D vertical and horizontal beam profiles. But there is no time resolution when the projections in various angles are not obtained synchronously.

THEORY

Computer tomography, the technology for slice image reconstruction from multiple sets of 1-D slice projections, is widely used in medicine, astrology, nondestructive examination, geology and so on. The basic physical principle of CT is that when X rays penetrate an object, the change of X ray intensity reflects the information concerning the attenuating coefficients of it[1], which is shown in equation (1), where I_1 denotes the intensity of X ray source, I_2 denotes the intensity of the X ray attenuated by the object, $\mu(x, y)$ denotes the attenuating coefficient distribution function of the object and L is the integral route. The central slice theorem and the Radon transform[1] give the mathematical possibility and basic realization method for extracting the 2-D slice distribution information from 1-D projections, and many CT algorithms has been developed from them.

$$\int_L \mu(x,y)dl = \ln(\frac{I_1}{I_2}) \tag{1}$$

The main wire signal of the multiple wire scanner is the deposited electron current generated by the interaction of a low energy electron beam and the wire. The current I is proportional to the primary electron beam, and can be described by equation (2), where $Q(x, y)$ is the charge distribution function of beam profile, L is the integral route and t is the time parameter.

$$I = \int_L Q(x,y)dl / t \tag{2}$$

The analogy between equation (1) and (2) gives the possibility to introduce the CT algorithm into the 2-D beam profile measurement with multi-wire scanner (Figure 1). Let the beam profile denote the slice image to be reconstructed, wires denote X rays, and then rotate the wire scanner to get multiple sets of 1-D beam profile projections in the multiple angles. The whole measurement setup resembles a CT machine. The principle of 2-D beam profile measurement based on the CT algorithm with rotating multi-wire scanner is as follows: in an initial angle, one set of beam profile projections can be obtained by using a multi-wire scanner with the wire interval D; then rotate the scanner one step angle $\Delta\theta$ ahead to get a second set of projection; the rest may be deduced by analogy. When the scanner has been

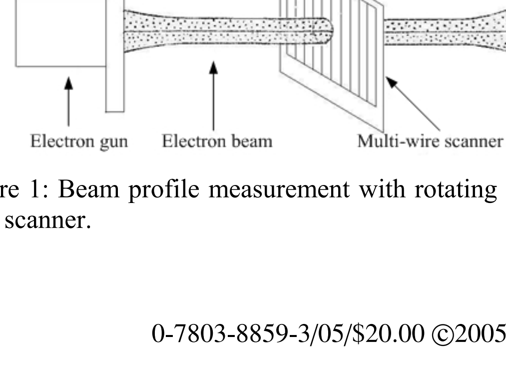

Figure 1: Beam profile measurement with rotating multi-wire scanner.

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rotated for M steps, $M*\Delta\theta=180°$, the measurement is finished. The 2-D image of the beam profile can be reconstructed from the multiple sets of projections by using the CT algorithm. Here filtered back projection algorithm[2] is chosen since it is easy to understand and directly realized.

Theoretically an undistorted image of 2-D beam profile can be reconstructed. But in fact, the spatial resolution is determined by D and $\Delta\theta$ due to the actual size limitations of them. The maximum spatial frequency $B=(2D)^{-1}$[1]. In this method, proper spatial resolution can be reached by a suitable value for D and with precise mechanical structure design and construction.

EXPERIMENTAL SETUP

An initial experimental setup was designed to verify the 2-D beam profile measurement method (Figure 2). The multi-wire scanner is a piece of printed circuit board with 20 copper wires soldered on it. The wire diameter is 100μm and the interval between wires is 1mm. The scanner is mounted on a rotating metal base driven by a stepping-motor. The base has two limit switches to check the position of the scanner.

A special signal transmitting circuit board was designed for motor control and wire signal acquisition. It has several functions: 1) it transmits motor control signal from the parallel port of PC to the motor driver and check the status of the limit switches in the rotating base; 2) it processes the wire signals and transmits them through two 16-channel multiplexers to a PCI data acquisition card PCI9810 in PC; 3) it transmits the pulse synchronous signal to the AD card for triggering.

The schematic of the measurement circuit is shown in Figure 3. Each wire is connected with a 110 ohm resistor of which the other end is connected to ground. The wire signal for measurement is the resistor voltage, which is transmitted by the multiplexer and sent to the data acquisition card.

RESULTS AND DISCUSSION

A first experiment of beam profile measurement with this method was accomplished and some exciting results were obtained. The experiment was carried out on the experimental electron gun beam measurement platform in department of engineering physics, Tsinghua University. The electron beam energy is 10keV, peak current about 300mA, and pulse frequency 30Hz. The multi-wire scanner was mounted in the beam line and was positioned at 25mm distance from the anode of the electron gun.

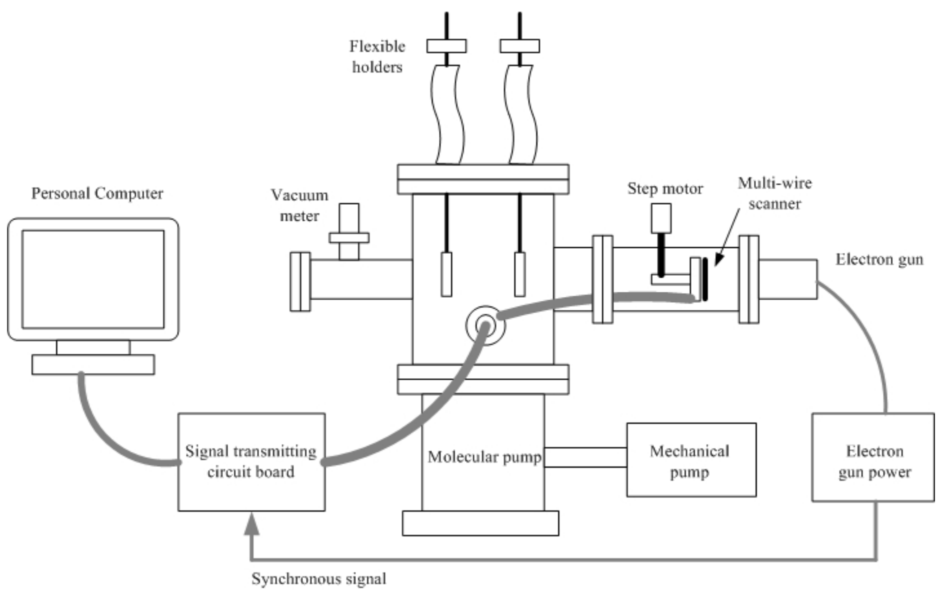

Figure 2: Schematic view of the experimental setup.

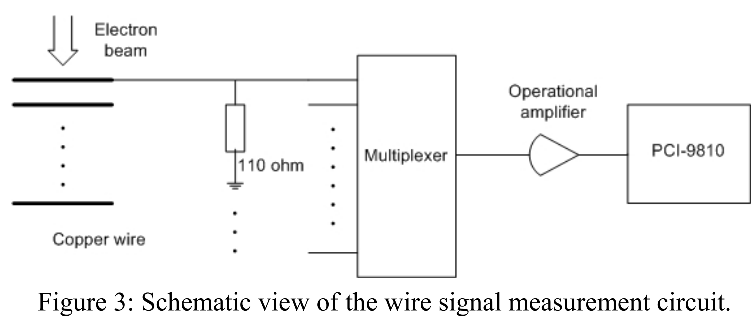

Figure 3: Schematic view of the wire signal measurement circuit.

The reconstructed image of the beam profile is shown in Figure 4. A full 2-D beam profile is presented. The size of the image is 20mm*20mm, which is the size of the measurement window. As is shown, the diameter of the beam profile is about 6 mm and the profile is a bit hollow, the outer intensity is greater than the inner inside.

Masks with parallel slits were introduced in front of the scanner to verify the spatial resolution. Two types are applied and one's width and spacing interval are 1mm, the other 2mm. Experimental results are shown in figure 5 and figure 6. Obviously 1 mm spatial resolution is obtained.

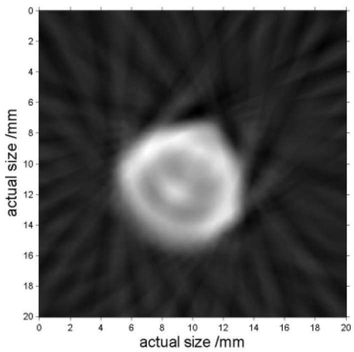

Figure 4: 2-D beam profile reconstructed.

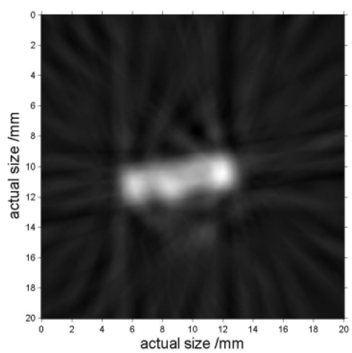

Figure 5: Beam profile reconstructed with mask (slit width 2mm).

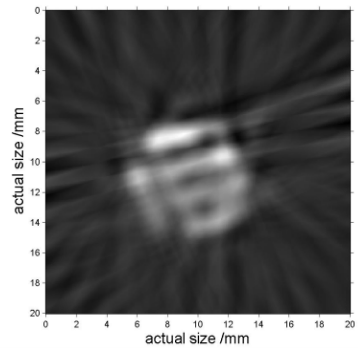

Figure 6: Beam profile reconstructed with mask(slit width 1mm).

CONCLUSIONS

A new method for low energy electron beam measurement is developed and primary experimental results prove the practicability of the method. More research work will be done to improve the experimental results and apply this method to other beams for emittance measurements.

REFERENCES

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[2] Gabor T. Herman, "Image Reconstruction from Projections", Academic Press, New York, U.S.A, 1980, p. 118-145.