SLITS MEASUREMENT OF EMITTANCE ON TTF

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Abstract

The proposed TeV Superconducting Linear Accelerator (TESLA) is a 30km long electron/positron collider. The TESLA Test Facility (TTF) currently under construction is an ideal accelerator to drive a SASE FEL. Small beam emittance, especially beam size at the interaction point of such a linear collider has to be achieved with high average beam power. The Free Electron Laser at the TESLA Test Facility (TTF FEL)[1] is based on the principle of self amplified spontaneous emission (SASE), which requires that the beam has as low as a few π mm mrad normalized transverse emittance at GeV energy levels. A precise emittance measurement on the TTF is therefore very important. Provision methods of measurement are pepper pot [2] or slits. During TTF commissioning, the radio frequency photoinjector delivering multiple bunches requires a fast beam diagnostic system. Our work is aimed at building a fast beam image acquisition system. This paper describes the beam image acquisition system, image processing, analysis and emittance calculation. The implementation of communication between remote medm display screen and a local MFC program is presented.

1 INTRODUCTION

For the TESLA Test Facility (TTF), two RF photoninjectors [3] need to be tested. The first one is the Fermilab gun, which delivers a high charge (8nC) per microbunch at a repetition rate of 1 MHz to test the behavior of the superconducting cavities with the beam structure foreseen for the TESLA linac. The second one is FEL gun, which delivers only 1 nC per microbunch, at 9 MHz, but with a normalized transverse emittance as low as 2 mm mrad. The latter will be used to test the possibility to generate and preserve the quality of a very low emittance beam, needed for a high luminosity linear collider, and will be used as an injector for a single pass UV FEL based on the SASE amplification process.

In both cases the measurement of the transverse beam emittance at the gun exit is of fundamental importance. Due to the large space charge effects, the traditional method of measuring the beam profile as a function of the strength of a focusing element is not applicable, only the pepper-pot/slits technique may be used, and, in particular for the low emittance case with very small holes have to be used. Two commonly used emittance measurement methods [4] are slits and pepper pot. The former is a one dimensional emittance measurement device and the latter is a two dimensional one. For our purpose, a pepperpot is installed at TTF beam line. The beam image after the pepperpot is recorded by means of an optical transition radiation (OTR) screen read out by a CCD camera. For the image processing, we built an image acquisition system, which consists of a PC with a PULSAR board and the CCD camera.

2 EMITTANCE FORMULA FOR SLITS MEASUREMENT

A typical setup for the slit measurement is shown in the figure 1. The incident beam comes from left. The beam is transformed into small bunchlets through the slits. x is the slit plate coordinate and X is that for the OTR screen. Slits length runs perpendicularly to the paper. The intensity of beamlet spots on the screen is directly proportional to the number of particles in the beamlets, which hit the screen. We use two coordinates to locate the beamlets: one for the slit (x), the other for the screen (X). Their origins do not need to be aligned, but they are assumed to have the same unit. It is also assumed that the size of the slits to be all the same and very small compared to the beam size. Our goal is to find an emittance formula (ε_x) which employs only geometrical parameters of the slits and the spots on the screen, that is, slit position (x_{sj}), mean position of spots on screen ($\overline{X}_j$), and rms size of spots on screen (σ_j).

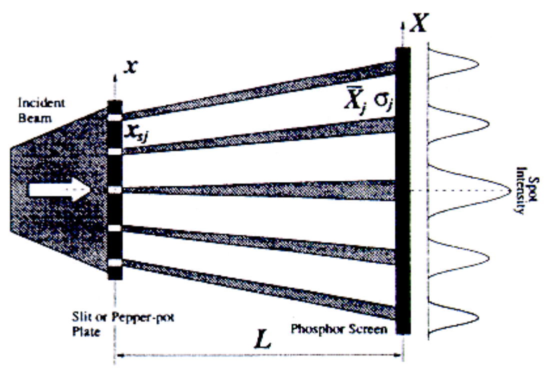

Figure 1: Typical setup for emittance measurement

rms emittance is defined by

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

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With

$$< x^2 > \equiv \frac{1}{N}\sum_{i=0}^{N}(x_i - \overline{x})^2, \quad \overline{x} \equiv \frac{1}{N}\sum^{N} x_i ,$$

$$< xx' > \equiv \frac{1}{N}\sum_{i}^{N}(x_i - \overline{x})(x_i' - \overline{x}').$$

Here, N is total number of particles behind the slit. x_i' is defined in figure 2 $x_i' \equiv \frac{X - x_i}{L}$

The term $< xx' >^2$ reflect a correlation between x and x' which occurs, for instance, when the beam is either converging (e.g., after passing through a lens) or diverging (e.g., after passing through a waist); it is zero at the waist of an ideal uniform beam.

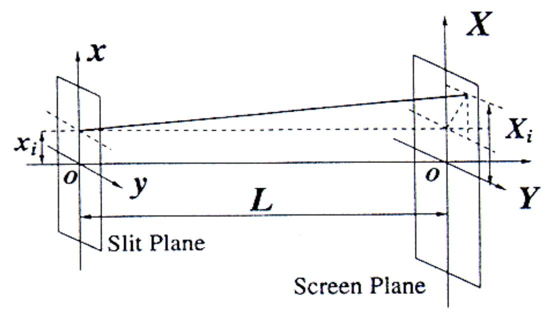

Figure 2: Illustration of x_i'. L is the distance between the slit plate and the screen.

According the above mode, the final derivation formula is as follows:

$$\varepsilon^2{}_x \approx \frac{1}{N^2}\left\{\left[\sum_{j=1}^{p} n_j (x_{sj} - \overline{x})^2\right]\left[\sum_{j=1}^{p}\left[n_j \sigma_{x_j'}{}^2 + n_j(\overline{x_j'} - \overline{x}')^2\right]\right] - \left[\sum_{j=1}^{p} n_j x_{sj} x_j' - N\overline{x}\overline{x}'\right]^2\right\}$$

Slit positions and beamlet spot parameters express all the terms in the formula on the screen. Specifically, they are

x_{sj} : j-th slit's position;

P: total number of slits;

n_j : number of particles passing through j-th slit and hitting the screen. This is a practical weighting of spot intensity;

$\overline{x}$: mean position of all beamlets;

x_j' : mean divergence of j-th beamlet;

$\overline{x}'$: mean divergence of all beamlets;

$\sigma_{x_j'}$: rms divergence of j-th beamlet.

3 THE ARCHITECTURE OF THE SLITS MEASUREMENT SYSTEM ON TTF

The slit measurement system is shown in figure 3. It consists of a pepperpot, OTR screen, CCD camera and a PC with PULSAR board. The electrons come out from the gun and are accelerated through the capture cavity.

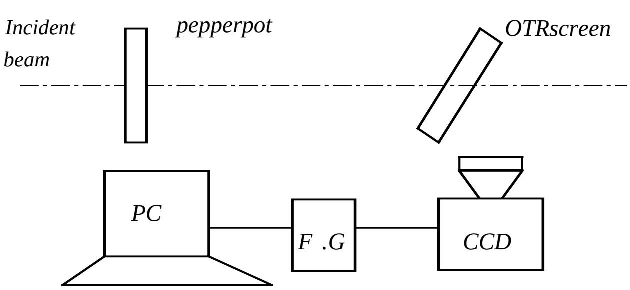

Figure3: Schematic map of the image acquisition system

The beam transferred into beamlets after the slits that hit the OTR screen. The pepper pot is installed after the capture cavity. The slits are mounted inside the pepper pot. Some parameters are shown in the table 1. Along the beam line, the three OTR screens are installed in three different positions, which are 385mm, 2198mm, 2805mm distances from the pepper pot. During tests, we only use the nearest screen downstream of the pepper pot.

Table 1: The parameters of the slits

The height of the slits	Half of the screen has 1 mm the other half has 0.5mm
The depth of the slits	1mm
The distance between the slits	50 μ m
The number of the slits	10
The direction of the slits	Horizontal

The CCD camera is a CCIR (PAL) mono camera 768*572. The video output signal from the camera is connected to the MATROX Pulsar board in a PC. The Matrox Pulsar board is a single-slot PCI frame grabber that features an on-board grab, display capabilities, and real-time transfers to Host memory. It features a 2-Mbyte image frame buffer, and a 2-Mbyte graphics overlay (VGA) frame buffer for non-destructive overlay capabilities. It is capable of 8-bit digitization at up to 45MHz. It has four analog software-selectable input channels and a trigger input channel. The main advantage of the OTR screen is the absolute linearity with the beam intensity and the prompt time response.

4 SOFTWARE IMPLEMENTATION

The Matrox Pulsar is programmed using MIL-Lite, the C development library for Windows NT. The user interface shown in figure 4 is implemented using visual C/C++ with MFC. The program has the following functionality: continuous grabbing of an image into the allocated windows, stop grabbing, saving and opening, emittance calculation and emittance value display in the current windows. We also use EPICS to implement the communication between the medm screen and local MFC program shown in figure 5. The medm screen is a client,

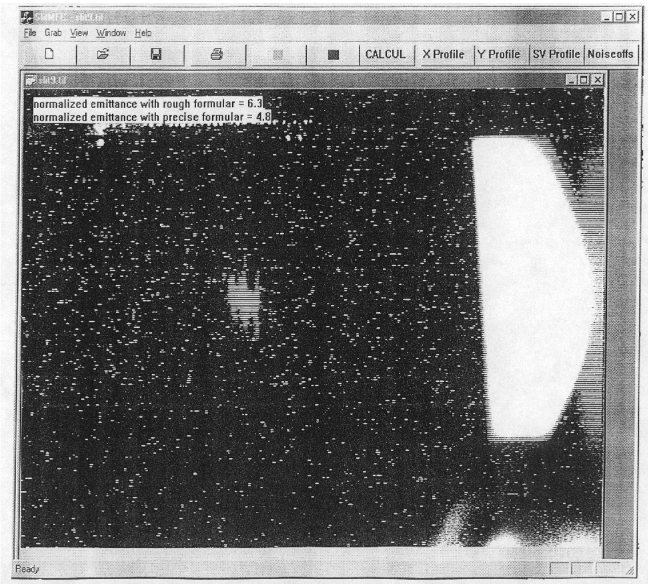

Figure 4: Local MFC program user interface

but the local MFC program is a server. The emittance value and profile dates are put into IOC channels by the local program. Emittance value and image profile can be displayed on the medm screen by EPICS channel access. From the medm screen, you can also send some commands to MFC program by the channel access. The remote commands such as startGrab, stopGab and calculation are downloaded into IOC channels by EPICS. The local program is responsible for monitoring the related channels, and then makes appropriate actions.

5 THE RESULT OF THE SLITS MEASUREMENT

In the slit measurement, we measured the emittance with diffirent bunch charges, 1 or 8 nC. With same bunch charge, we also measured the emittance at different solenoid settings. The result of the measurement is still in evaluation, however, preliminary results are as follows: For a 1 nC beam the transverse emittance is of the order of 5 to 8 mm mrad depending on the solenoid field settings. For a 8 nC beam, the transverse emittance is about between 10 to 12 mm mrad.

Performing a measurement of emittance with slits on TTF, it was proved that this set of image acquisition system is applicable and works well.

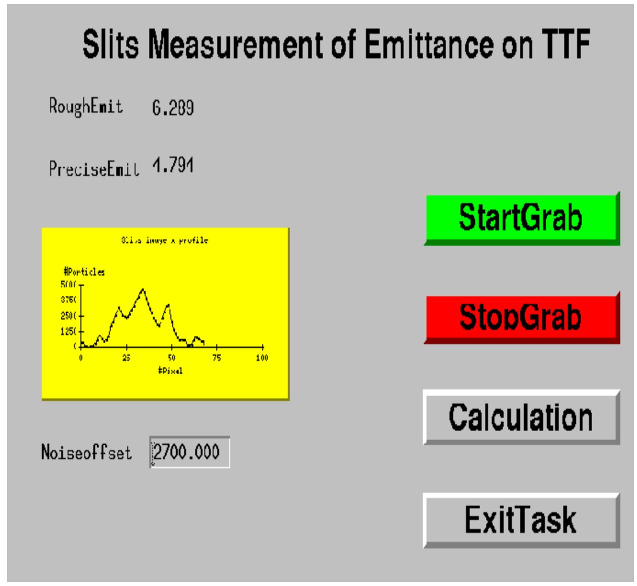

Figure 5: Remote medm screen

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