

DEVELOPMENT OF AN AUTOMATIC MATLAB BASED EMITTANCE MEASUREMENT TOOL FOR IAC ACCELERATORS

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Abstract

At the Idaho Accelerator Center (IAC) of Idaho State University [1], we have been operating nine low energy accelerators. To optimize those accelerators properly, we have to measure the transverse beam emittance. We installed an Optical Transition Radiation (OTR) screen and a prosilica GigE GC1290 digital CCD camera [2] in the beamline of an S-band linear accelerator to measure the transverse beam emittance with the quadrupole scan method. From the images of the digital CCD camera, the transverse beam profile on the OTR screen can be acquired. We have developed MATLAB codes that can extract the transverse beam size and estimate the transverse beam emittance. This paper describes the developed MATLAB program and an automatic emittance measurement tool, which is based on EPICS, MATLAB Channel Access (MCA), and MATLAB.

INTRODUCTION

It is important to measure the traverse beam emittance in accelerators for optics matching in a beamline and to judge the beam quality. Though there are many ways to measure transverse emittance, the quadrupole scan method was used to measure the emittance at the High Repetition Rate Linear accelerator (HRRL) at the IAC [3–5]. To measure the emittance of the IAC HRRL accelerator, an EPICS, MCA, and MATLAB based automatic emittance measurement tool was developed as shown in Fig. 1.

EPICS is the most popular control software in accelerator community, whereas MCA is an extension of EPICS to transfer data between equipments and MATLAB [6]. To control the current of the TDK-Lambda ZUP magnet power supply and the shutter of the Prosilica GigE CCD camera simultaneously, several MCA commands are used in MATLAB codes, and beam images are automatically captured by MATLAB codes during the scanning of the quadrupole magnet current. All these processes can be controlled with MATLAB codes by changing the current of the power supply, hence magnetic field of the quadrupole and by taking corresponding beam images at each quadrupole scanning step. By using MCA commands, MATLAB codes can get values of the quadrupole strength and beam images. Then, they are used to extract beam sizes and to estimate transverse beam emittance in MATLAB codes. These are all fully automatized processes controlled by MATLAB codes to measure the transverse beam emittance.

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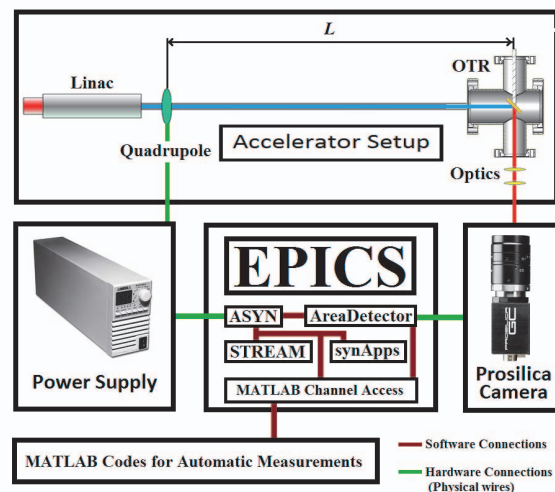


Figure 1: The schematic layout of the IAC automatic emittance measurement system.

QUADRUPLE SCAN METHOD

Setup for Measurements

As shown in Fig. 1, the quadrupole scan method for the emittance measurement uses a quadrupole and a screen to find a correlation between strength of the quadrupole and beam size on the screen. From this correlation and the second order polynomial fitting, we can extract the transverse beam emittance. This is accomplished by changing the quadrupole normalized strength k , which can be done by changing the current of the magnet power supply.

When the electron beam hits an OTR screen, an optical transition radiation will be generated from the screen, which is located at a 3.1 m long distance L from the center of the scanning quadrupole. The OTR screen is vertically mounted on an actuator arm and sits with an angle of 45 degree with respect to the beam direction, and there is a quartz crystal window that allows the radiation light from the OTR to pass through to the CCD camera. The camera has a lens system to transfer the light from the OTR screen to the CCD camera [4]. By capturing the image of the radiation light with a CCD camera, we can obtain the transverse beam profile, rms beam size, and beam emittance.

The process for the emittance measurement starts with subtracting the background, which is an image of the noises due to dark current and other sources, such as stray light. By subtracting the background, the beam image becomes more clear as shown in Fig. 2. Then the horizontal and

vertical projections of the image are used to find rms beam size as shown in Fig. 3.

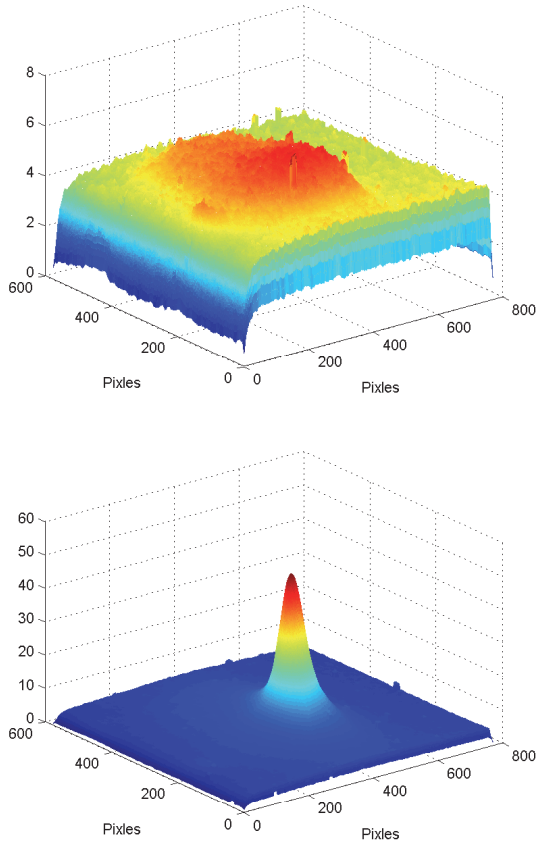


Figure 2: (top) the background of an image without the beam, (bottom) the beam image after the background subtraction.

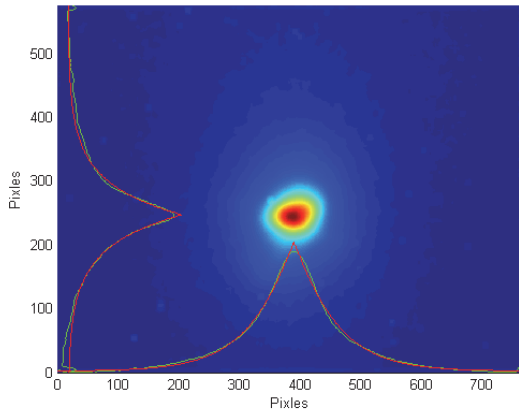


Figure 3: The beam profile image after the background subtraction and its horizontal and vertical projections with the Super-Gaussian fitting.

Since our beam profile is the Lorentzian shape, the reg-

ular Gaussian fitting does not work to extract beam size. Therefore we used the Super-Gaussian function to get the correct beam size as shown in Fig. 3, where green and red lines display the measured image data and its fitting, respectively. After taking ten images continuously for a given quadrupole current value, these images were averaged to get a more precise beam size. These background subtraction and image averaging processes were done until the quadrupole scanning was completely finished.

Since the raw data of camera does not supply a real physical dimension on the beam size, a calibration is required to get the real beam size. From known distances between screen holders, the calibrations between camera pixels and the physical distances were made in the horizontal and vertical planes. As summarized in Table 1, these calibrations provide the physical units such as μm for our beam size. During the quadrupole scanning, after assuming the thin lens approximation, the correlation between σ_s^2 and kL_q can be given by

$$\sigma_s^2 = A(kL_q)^2 - 2AB(kL_q) + (C + AB^2), \quad (1)$$

where σ_s is the rms beam size on the screen, $L_q = 0.15 \text{ m}$ is the quadrupole length, k is the normalized quadrupole strength, A , B , and C are coefficients which can be found from the second order polynomial fitting. Then, the unnormalized geometrical emittance ϵ can be defined as

$$\epsilon = \sqrt{AC}/L^2. \quad (2)$$

Therefore, we can extract the emittance and the twiss parameters (α and β) by performing the second order polynomial fitting after plotting σ_s^2 versus kL_q [3–5,7] as shown in Fig. 4.

Measured Emittance

The main parameters of the HRRL accelerator during the quadrupole scanning and the results afterwards are summarized in Table 1. Its estimated normalized horizontal and vertical emittances are $\epsilon_{nx} = 12.02 \pm 0.376 \mu\text{m}$ and $\epsilon_{ny} = 9.13 \pm 0.286 \mu\text{m}$, respectively.

Table 1: Measured Parameters during Quadrupole Scan

Parameter	Unit	Value
RF frequency	MHz	2855
RF macropulse length (FWHM)	ns	200
single bunch charge	pC	14.5
energy	MeV	14
horizontal pixel calibration factor	$\mu\text{m}/\text{pixel}$	43.1
vertical pixel calibration factor	$\mu\text{m}/\text{pixel}$	42.2
normalized x-emittance ϵ_{nx}	μm	12.02
normalized y-emittance ϵ_{ny}	μm	9.13
horizontal α -function		1.465
vertical α -function		0.651
horizontal β -function	m	0.659
vertical β -function	m	0.516

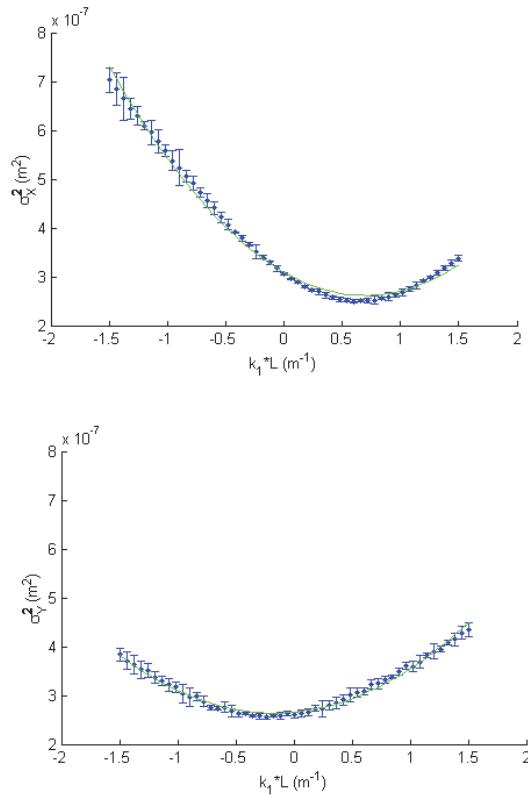


Figure 4: Horizontal (top) and vertical (bottom) 2nd order polynomial plots fitted for the emittance measurement.

MCA & AUTOMATIC MEASUREMENTS

EPICS is the most popular control software in accelerator community and can control all aspects of accelerator operation. Our automatic emittance measurement tool uses two EPICS extensions, AreaDetector for proper camera function and MCA for interaction between the equipment and MATLAB. The main commands of MCA to open the desired channels between the equipment and MATLAB, to read information, and to rewrite Process Variables (PV's) are MCAOPEN, MCAGET and MCAPUT. An example of the MCA and MATLAB code is following [6];

```
CameraAcquire=MCAOPEN('13PS1:cam1:Acquire');
AcquireData=MCAGET(CameraAcquire);
MCAPUT(CameraAcquire,1);
MCACLOSE(CameraAcquire);
```

where '13PS1:cam1:Acquire' is the PV name to control the camera shutter. The MCAGET will retrieve the status on the PV of the camera shutter. If the CameraAcquire is 0, then the camera shutter is closed. However if the CameraAcquire value is 1, then the shutter is open, and the camera starts taking images. The MCAPUT will write values into the PV, such as 1 or 0 for shutter open or shutter closed, and the MCACLOSE will close the

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channel of the PV's [6]. By using these MCA commands in MATLAB codes, the emittance measurement system will automatically collect data from the camera and the magnet power supply as shown in Fig. 5.

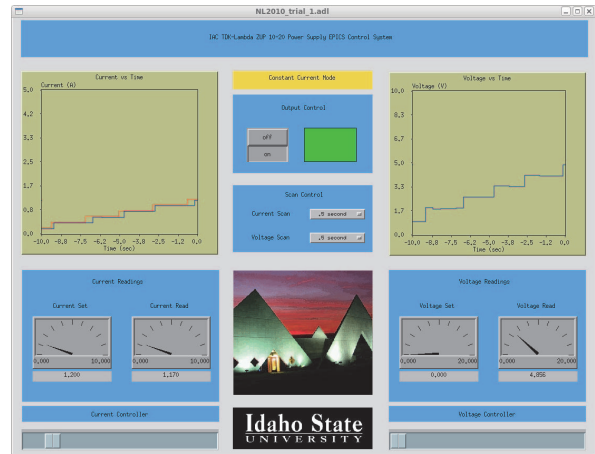


Figure 5: Power supply current and camera being controlled by MCA through MATLAB program.

SUMMARY

To measure the transverse beam emittance of the IAC accelerators, we developed an EPICS, MCA, and MATLAB based automatic emittance measurement tool. By using the automatic tool, we successfully measured the emittance of the IAC HRRL accelerator and dramatically reduced the measurement time, as well as human based data processing error. We expect that this MATLAB program can be used to measure the emittance of any IAC accelerator. We would also like to give our sincere thanks to Dr. Mark Rivers of APS for his advice and guidance on AreaDetector and MCA. In addition, we would like to thank Dr. Kukhee Kim and Dr. Henrik Loos of SLAC for their strong interest and encouragement in this project.

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