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EMITTANCE MEASUREMENTS AT FAST FACILITY*

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Abstract

The electron linac at the Fermilab Accelerator Science and Technology (FAST) facility has recently been commissioned. It has demonstrated generation of an electron beam with a highly flexible parameter space in terms of number of bunches, bunch energy, charge and bunch length etc, suitable for a variety of accelerator science and beam physics experiments. Its primary role will be as an injector for the upcoming Integrable Opticsl Test Accelerator (IOTA), but it also offers an opportunity to carry out linac-based studies such as, e.g., generation of flat beam and intense gamma ray beam through inverse Compton scattering. Measurement of the beam emittance in particular is of critical importance for these and a number of techniques such as multi-slit and quadruple-scan methods have been implemented to characterize it. An online emittance measurement has been developed based on the multi-slit method to provide an immediate emittance measurement with minimum beam interruption to allow for beam optimization as a part of other studies. In this report we present initial results from the emittance studies using this tool in the low energy beamline.

INTRODUCTION

The electron linac at FAST [1] has recently been commissioned to its design energy of 300 MeV. [2] It will soon serve as the injector for the IOTA ring. Initially designed as a test of the ILC SRF technololgy, the parameter space of this linac is highly adaptable in terms of bunch currents, energy and bunch structure, making it an ideal accelerator for beamline-based studies and experiments in beam physics, including an intense gamma ray experiment based on inverse Compton scattering (ICS) planned in the next two years. [3]

The linac consists of an L-band rf photocathode (PC) gun that generates a 5-MeV beam of electrons with a 3-MHz micropulse repetition rate. Two TESLA-style cavities accelerate this beam up to 50 MeV in the low-energy linac, followed by an 8-cavity TESLA-style, ILC-type cryomodule (CM) capable of accelerating the beam with average energy gain of 31.5 MeV per cavity for a total beam energy of up to 300 MeV. Beam is then either transported to the high energy absorber (HEA), or be delivered to the IOTA ring at 150 MeV starting with the commissioning run scheduled to start in Summer of 2018. Both low- and high-energy beam lines are equipped with an array of diagnostics including beam position monitors, wall current monitor, and beam imaging stations to monitor beam parameters during tuning, operation and studies.

Beam emittance in particular is of critical importance for both commissioning of the IOTA ring as well as operation of the ICS and other experiments. (In this paper the emittance normally means RMS emittance unless specifically defined.) In order to measure the emittance of the beam quickly and accurately a real-time emittance measurement has been developed based on a multi-slit method [4] in the low-energy beamline. In addition to the emittance, this method provides Twiss parameters that may be used in beamline simulation programs to properly match with low energy beamline lattice to the CM. Emittance of the high-energy beam is measured with standard quad scan approach. In this report we present results from emittance studies using both methods during the 2017 300 MeV beam commissioning run (Fig. 1).

MEASUREMENT METHOD

The utility of a multi-slit transverse emittance measurement was demonstrated at the Fermilab A0 photoinjector [5]. In the A0 prototype the emittance measurement was divided into two steps. First the beam size was measured at a given position with an OTR foil. The foil was then extracted and a multi-slit mask was then inserted in the same plane. The masked beam propagated downstream to another monitoring station a known distance away, this one using Ce:YAG crystal, and an analysis of the beam

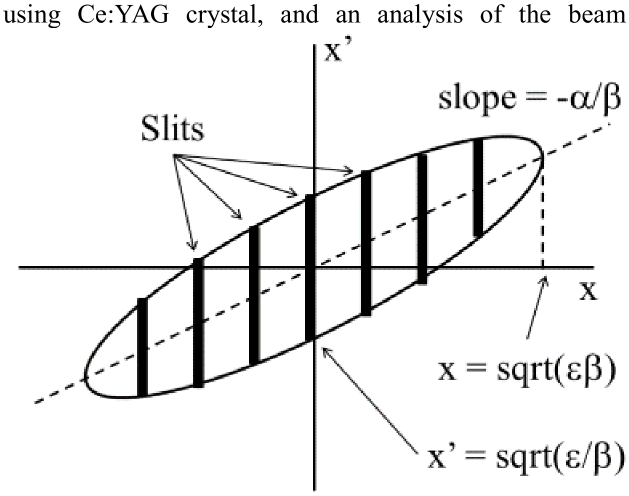

Figure 1: Diagram showing parametrization of phase space ellipse relevant to multi-slit technique.

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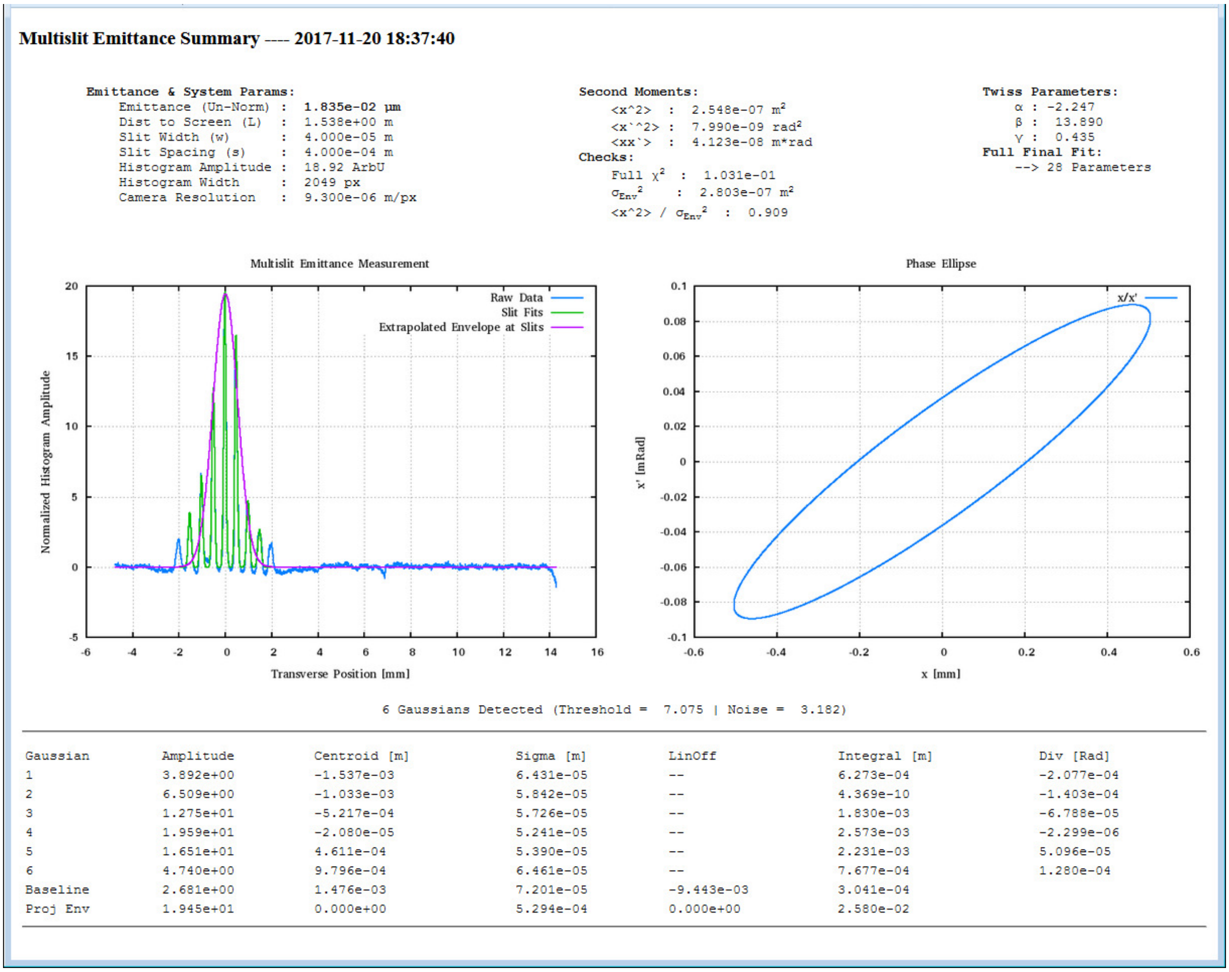

Gaussian	Amplitude	Centroid [m]	Sigma [m]	LinOff	Integral [m]	Div [Rad]
1	3.892e+00	-1.537e-03	6.431e-05	--	6.273e-04	-2.077e-04
2	6.509e+00	-1.033e-03	5.842e-05	--	4.369e-10	-1.403e-04
3	1.275e+01	-5.217e-04	5.726e-05	--	1.830e-03	-6.788e-05
4	1.959e+01	-2.080e-05	5.241e-05	--	2.573e-03	-2.299e-06
5	1.651e+01	4.611e-04	5.390e-05	--	2.231e-03	5.096e-05
6	4.740e+00	9.796e-04	6.461e-05	--	7.677e-04	1.280e-04
Baseline	2.681e+00	1.476e-03	7.201e-05	-9.443e-03	3.041e-04	
Proj Env	1.945e+01	0.000e+00	5.294e-04	0.000e+00	2.580e-02	

Figure 2: An example of the multi-slit Python measurement routine output, generated with each call of the routine. Final beam parameters are displayed on the top while the histogram of the slit image is shown in the left with fitted peak and fitted beam envelop information at the slit location. The phase ellipse is displayed on the right side.

divergence was performed using this image, the known beam size at the slits and the drift distance. Both the OTR foil and YAG crystal were oriented normal to the beam and light from the beam was diverted to respective cameras each by a 45° mirror. With the beam size and divergence information the beam transverse emittance was calculated. In our previous setup all the information was processed in a MATLAB graphical user interface (GUI). [5] Although this 2-step approach provides a simple emittance calculation there was room for improvement, principally in its need of images from two locations for the calculation and the need for user input in the GUI, which relied on user identification of each peak location, extending the analysis process for each measurement dramatically.

The multi-slit measurement at FAST improved upon this technique dramatically by using knowledge of the slit geometry to project back from the viewing screen and determine the incident beam profile at the slits. This allows a single step measurement, requiring only insertion of the slits and the downstream viewing screen according to [4]. Implementation of online peak-picking and data analysis allow for data acquisition and evaluation to provide an emittance measurement on the time scale of the nominal macropulse repetition rate of 1 Hz. The Python routine is also easily launched and run alongside the Accelerator Control Language (ACL) and native Accelerator Controls Network (ACNET) applications, allowing for better coordination of the measurement, allowing for coordination of the measurement with other tasks to minimize interruption of beam operations. For example, an ACL routine might insert the slit mask and viewing screen, launch the emittance measurement, and then extract the slit mask and screen again upon completion. Other ACL routines have been used to run the emittance measurement code at each breakpoint in beamline parameter scans (e.g. gun phase).

Both vertical and horizontal slit masks were used in commissioning the system. Vertical slits provide horizontal (x) profiles, which allow measurement of the horizontal transverse emittance while horizontal slits likewise allow measurement of the vertical transverse emittances. The python code reads the appropriate histogram according to a command line argument, along with various other run-time parameters and options. On initialization, the Python routine collects histograms, averaging them together according to the user-specified option. The python code then attempts to determine the number of peaks from the

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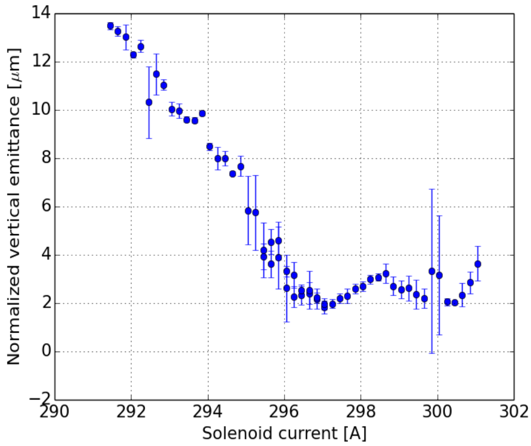

Figure 3: Emittance at 250pC vs gun solenoid scan data. All data shown was collected real time and re-evaluated offline. During this scan main and bucking solenoid is kept in a fixed ratio to minimize magnetic field at the photocathode.

histogram and performs gaussian fits to each of these. All information is output to a webpage for display and archived for future reference, including re-fitting the same data with different run-time parameters (e.g. adjusting the threshold).

The archived file includes the composite histogram profile with all averaging performed on collection, the resulting graphs, and the webpage output shown in Figure 2 (i.e. Twiss, gaussian fit, and other relevant measurement parameters). The Python routine also places the measured beam emittance into an ACNET device that may be used for plotting and datalogging, further integrating the measurement into the controls network as shown in Figure 3 and allowing for further implementation in studies and controls regimes including machine learning with accelerator controls. [6]

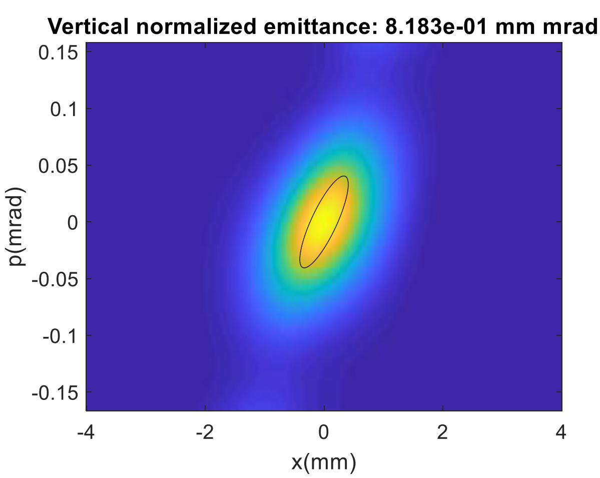

Figure 4: Phase diagram from a one-shot multi-slit measurement for 100pC beam. The black circle is drawn from Twiss parameters calculated in the measurement. The intensity map was drawn with interpolation of the measured data.

MEASUREMENT RESULT

A typical vertical multi-slit emittance measurement for a charge of 100pC at 43 MeV in the low energy beamline is shown in Figure 4. The unnormalized emittance in this instance is 9.5e-3 mm mrad and the normalized emittance of 0.82mm mrad. This measured value is slightly larger than the measurement performed with a quad scan under the same conditions that day. The measured horizontal emittance on the same day yields a value 20% lower than the vertical emittance. The reason for this is still being investigated, but is most likely due to the non-symmetrical shape of the UV laser profile on the photocathode. [7]

CONCLUSION

In summary a Python based, real-time emittance monitor has been commissioned for emittance measurements in the FAST low-energy 50 MeV electron beamline. The measured emittance and calculated Twiss parameters have been used for commissioning of the 150-300MeV high-energy beamline. The normalized emittance was found to be on the order of 1mm mrad for 100pC bunch charge at the nominal beam energy.

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