

IMAGING

INTRODUCTION:

Imaging is a powerful tool for diagnosing the beam. The conversion of beam density information to light reveals not only the size, shape, and centering of the beam, but also its detailed structure. This information is essential for beam steering and matching. Furthermore, beam imaging forms the basis of a number of diagnostics such as quadrupole scans, pepper-pots, and tomographic phase-space mapping.

OBJECTIVE:

In this experiment we will project a beam onto a phosphor screen, capture the light through a CCD camera, and record the resulting images under different conditions in the gun, and for different gun apertures and magnet strengths. We will also use Image processing software in MATLAB to clean up the images and derive quantitative information about the beam. In the process, we will learn about pinholes (the basis of pepper-pot phase space mappers), about beam optics and using a solenoid lens to create an image of a mask.

BACKGROUND:

Lecture on Imaging by Rami Kishek.

EQUIPMENT:

(see Experimental Station Data Sheet)

Notes:

The diameter of the visible part of the screens in all 3 stations is 1.25"
For the LSE station you can monitor the beam current at all times. Do so.

PROCEDURE:

Familiarization and Calibration:

1. Familiarize with the equipment: camera, mirror, lens, XCAP software, etc.
2. [Assistance Required] Open Gate Valve.
3. Turn on gun High Voltage at recommended value.
4. Turn on solenoid power supply and set the current at 5.5 A.
5. Look at screen, can you see beam?
6. Turn on XCAP Software (clear buffers if error). Experiment with XCAP settings and set the mode to "external Trigger" and the timing to "Single Tap, 12-bit", and exposure to "fast". Also experiment with frame integration (Capture -> Frame Average).

7. Adjust camera/mirror until screen is fully visible in XCAP window.
8. Set offset to zero, then adjust gain until peak intensity inside beam is just below saturation. Display a profile to check saturation.
9. Adjust lens focus until beam is sharp. Turn room lights off and on, then over the lens with a black cloth. Does anything happen to the image background?
10. Turn the High Voltage off. Increase the gain of the camera until the screen edges are clearly visible. Save the photo in your folder on the desktop as 8 bit bmp with the filename: Group#_Calibration.bmp, where # is your group number.
11. Draw a circle to fit the screen edges (Draw -> Circle). Record the Screen Center and the Screen Size in pixels.

Bias Voltage Scans:

12. Turn the High Voltage back on to recommended value. Check $I_{\text{SOL}} = 5.5 \text{ A}$
13. Set the gun BIAS Voltage to 15, 20, 25, 30 V, and save each photo as 8-bit bmp with the name Group#_23mA_??V.bmp where ?? is the Bias voltage.
14. [Assistance Required] Turn off HV/ Change Apertures/Turn on HV
15. With assistance for changing apertures, repeat bias voltage scans for 7 mA, pencil, and 5-beamlet beams, saving all photos.

Pinhole Aperture:

16. For pencil beam (0.25 mm radius pinhole aperture), perform the BIAS voltage scan with the solenoid current set to zero. You may have to use frame integration. As in a pepper-pot emittance meter, the image of a beam emerging from a pinhole aperture corresponds to the beam velocity space in the aperture plane. A scan of that pinhole aperture is a method for phase-space reconstruction.

5-beamlet Aperture:

17. The 5-beamlet aperture is a mask with 5 holes allowing separate but interacting beamlets to emerge. For this beam, in addition to the BIAS voltage scan at a solenoid current of 5.5 A, scan the solenoid current while observing the beam. At what solenoid current does a near-perfect image of the beam occur? Record I_{SOL} and the beam image.
18. [Assistance Required] Turn off HV/ Close Gate Valve/Lift IC1/ Open Gate Valve/Turn on HV
19. Use the Bergoz coil to measure the beam current for the 5 beamlet aperture. Record the flat-top current. Observe the current waveform as a function of BIAS voltage.
20. Turn off HV. If doing quad scan, set up camera on IC2 of UMER.
21. [Assistance Required] Close Gate Valve.

ANALYSIS / QUESTIONS:

1. Copy all your photos to processing computer
2. Look over `PhotoProcess.m` code and understand the different sections
3. Select one photo for practice. Edit the top of the file to handle it.
4. Using the program to process the photo, experiment with the threshold level, median filtering and filter size, while recording the integrated intensity, x/y beam centroids, x/y beam radii, and rotation angle. What are the optimal settings for this photo?
5. Repeat for other, qualitatively different photos, such as one with a halo, one with 5-beamlets, and one with a pinhole aperture.
6. Process the remaining photos at each photo's optimal settings. Tabulate the results for all beams.
7. From the photos of the pinhole beam with zero solenoid current, estimate the emittance of the UMER pencil beam. The radius of that aperture is 0.25 mm. Assume no correlation between configuration and velocity space.
8. What is the rotation angle of the 5-beamlet image? Can you predict it knowing the solenoid current and geometry?
9. For the 5-beamlet beam, try to estimate the emittance as follows: Calculate the generalized perveance from the current and energy. Assume the image forms $\frac{1}{2}$ a betatron wavelength (with space charge) away from the aperture. Also assume the average beam radius over the entire distance from the gun to the screen is approximately equal to the beam radius on the screen. Take advantage of the following relationships:

$$k_o^2 a = \frac{K}{a} + \frac{\epsilon^2}{a^3}$$

$$k^2 \equiv k_o^2 - \frac{K}{a^2},$$

$$\lambda = 2\pi/k$$

10. What thresholds did you select and why?
11. How does the bias voltage affect the beam halo? Why?
12. Experiment with color-coding a photo with a halo using the code `Colorcode.m`