ROSS Performance Optimization

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I. Abstract

An inertial confinement fusion implosion driven by the OMEGA laser takes place over a span of approximately one nanosecond. To study the physics of the implosion on OMEGA, a streak camera with subnanosecond time resolution, good spatial resolution, and high dynamic range is necessary. The Rochester Optical Streak System (ROSS) is able to make measurements with 1% accuracy using its Optical Calibration Module (OCM). Software scripts have been written to optimize the alignment and focus of the camera using the OCM. Because the P510 streak tube has a slot accelerator and a single electrostatic lens, it will have optimal temporal and spatial foci at different focus voltages. A common mode voltage (CMV) added to the deflection plate voltage allows the plates to act as an additional electrostatic lens, while still retaining deflection capabilities. This technique focuses a P510 tube simultaneously in both the temporal and spatial dimensions. A script has been written to determine the optimal CMV and resulting focus voltage for the ROSS with a P510 tube. Additionally, the performance of low voltage photocathode extraction fields has been measured and agrees with electron optics code predictions. The low field power supply doubles the usable photocathode

area and will be used in photon-starved experiments.

II. Background

The ROSS[1] is a streak system capable of being calibrated to within 1% accuracy.[2] The ROSS achieves this calibration via its OCM which is a self-contained calibration unit. The OCM contains fiber optic inputs, a fiber optic head, a flat field illumination head, a patterned reticle, a flip-in mirror to switch between calibration and input, an Offner mirror that images the input or calibration onto the streak tube window, and controlling electronics. For this project, the flat field illuminator, the patterned reticle, and the free space input (as shown in Fig. 1) were utilized to create a calibrated image. The goals of this project were to use program scripts to simultaneously focus the camera in the temporal and spatial directions using a P510 streak tube[3], and to test the effects of a

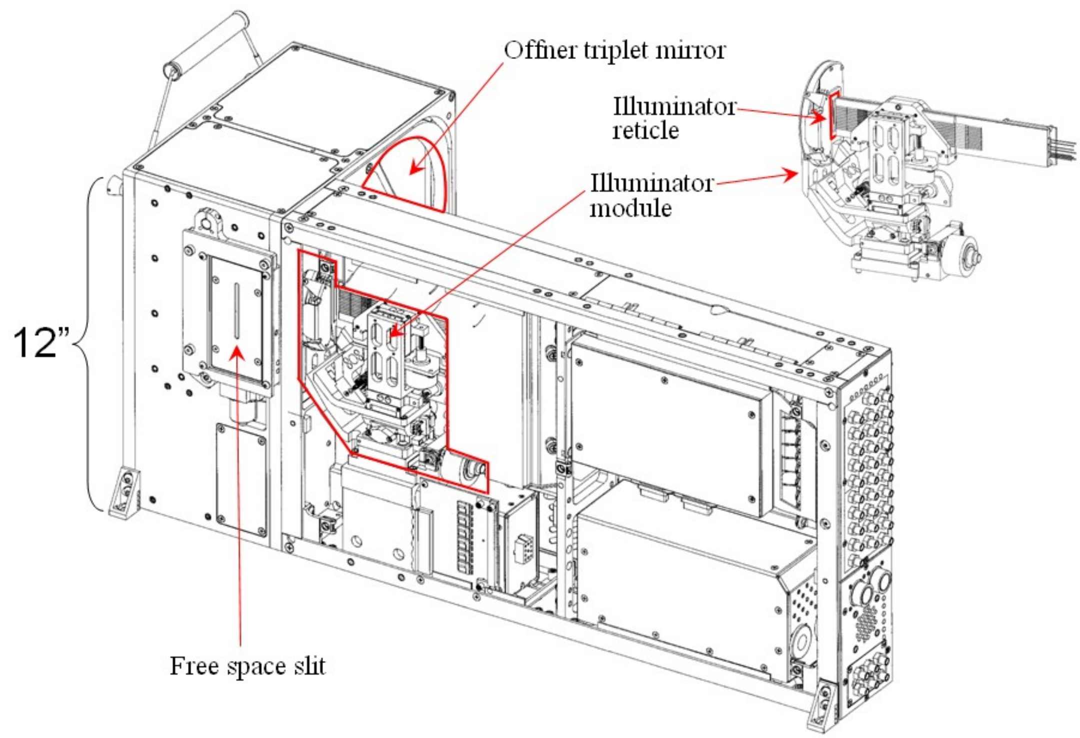

Fig. 1: The ROSS OCM and illumination module. The OCM is used to calibrate the streak camera to within 1% accuracy. The flat field illumination and fiber optic module has been separated for clarity.

low-field power supply (LFPS) on the light capturing abilities of the ROSS. The focusing program would help capture more accurate images with the P510 tube, and the LFPS would allow minute amounts of light to be measured for photon-starved experiments.

III. Problem

1. Focus Voltage Optimization

The problem with P510 streak tubes is that they contain a single tubular electrostatic lens. This lens will thus only focus the image in the time and space direction equally. This would not be a problem if the electrons did not need to be accelerated by an electric field. The P510 tube uses a slot accelerating plate (shown in Fig. 2) to speed up the electrons, typically with 2500 Volts between the cathode and the slot plate. Figure 2 illustrates how the fringing effects of the slot cause the electric field to bend in the time direction causing the virtual focus to be behind the cathode. Because the virtual focus is on the cathode in the space direction, the P510 tube focuses best in the time direction at a

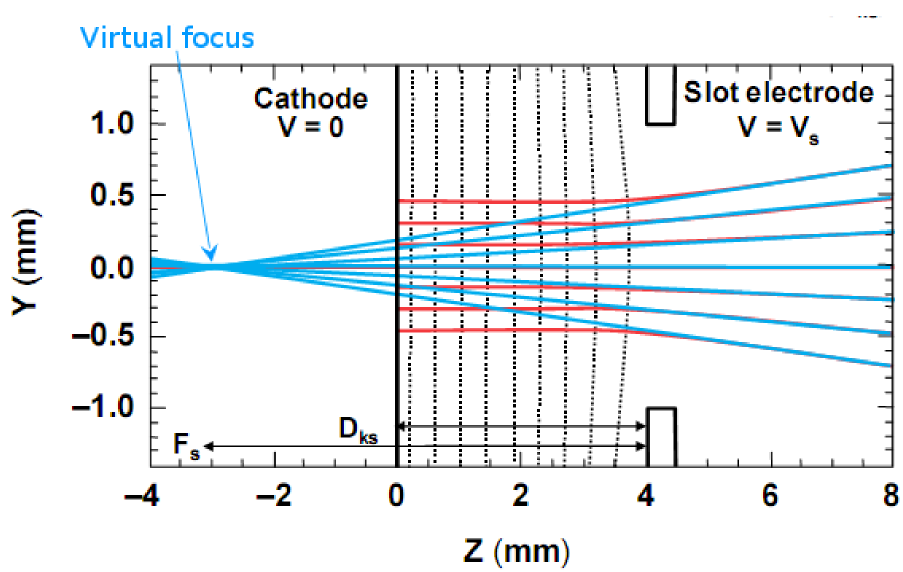

Fig. 2: Electron optics ray trace of slot accelerator. The virtual focus is behind the cathode a distance F_s due to fringing effects that result from using a slot accelerator.

different focus voltage than it focuses in the space direction.

Without any other corrections to fix this problem, the streak camera will have the smallest full-width at half maximum (FWHM) at one focus voltage and the best spatial contrast at another focus voltage. Scientists utilizing the P510 streak tube for past experiments have picked which was better for the experiment (spatial or temporal focus) or just decided that between the two voltages was "good enough." This project succeeded in creating a program that uses a CMV to focus the P510 streak tube simultaneously in the spatial and temporal directions.

2. Power Supply Comparison

The other objective of this project was to test the effect of using a low-field power supply (LFPS) that would provide 1/5 of the 2500 V normally used between the cathode and the slot with a high-field power supply (HFPS). The reason for using this lower voltage is to allow more of the light to reach the CCD from the cathode. Figure 3 shows a trace of the LFPS on the left and the HFPS on the right. Expression 1 shows the electron optic equivalent of the index of refraction, which is calculated with respect to voltage.

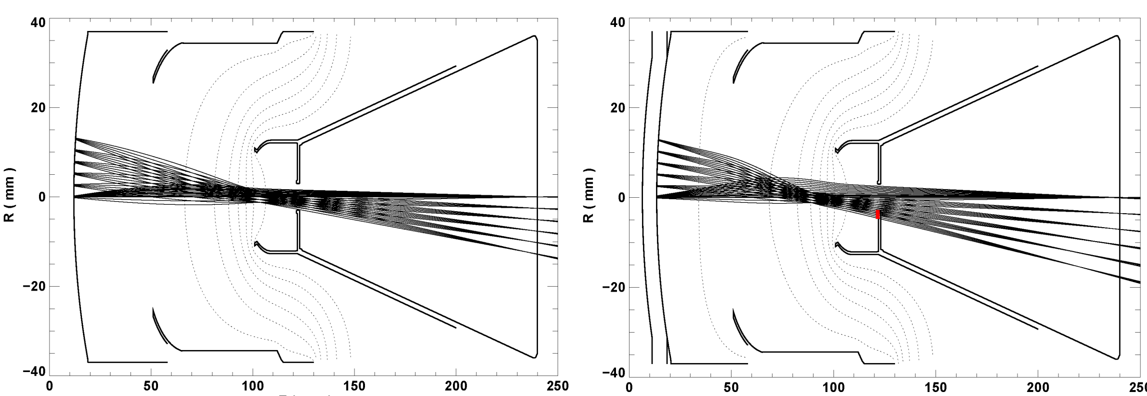

Fig. 3: Ray traces for low field (V_{ks}=500 V) and high field (V_{ks}=2500 V) power supplies, respectively. More light reaches the cathode with an LFPS because more light is allowed through the anode aperture. The red line shows the part of the anode that blocks rays as a result of using the HFPS.

$$\sqrt{V\left(1+\frac{eV}{2\mathrm{mc}^2}\right)} \quad (1)$$

This expression includes $[eV/2mc^2]^{1/2}$ which corrects for relativistic effects if the electrons are traveling close to the speed of light. Because the electrons in the P510 are not close to relativistic speeds, we can ignore this term. Thus the expression just becomes $\sqrt{V}$. This means that if you decrease voltage, the light is refracted less by the electrostatic lens and more light passes through the anode aperture. The the lower accelerating voltage provided by the LFPS decreases the index of refraction of the slot accelerator and lowers the magnification of the image, allowing more light to pass through the anode aperture. The HFPS causes some of the light to be blocked by the anode aperture. Photon starved experiments need the extra light that gets through the anode aperture.

IV. Methods

1. Focus Voltage Optimization

To optimize the focus voltage, a program was written that added a CMV on to the deflection plates. For this calibration, a flat field illumination from the OCM was used to create a pattern with 5 or 10 line pairs per millimeter (LP/mm) vertically. The program adds a certain negative CMV to the deflection plates in order to repel the electrons and focus them in the time direction independent of the spatial direction. The program then scans across a range of focus voltages while measuring FWHM and contrast, as shown in Figure 4. It fits a Gaussian to the contrast curve to find the maximum and a parabola to the FWHM curve to find the minimum. These points indicate the best spatial and temporal focus, respectively. The program measures the difference between the two focus

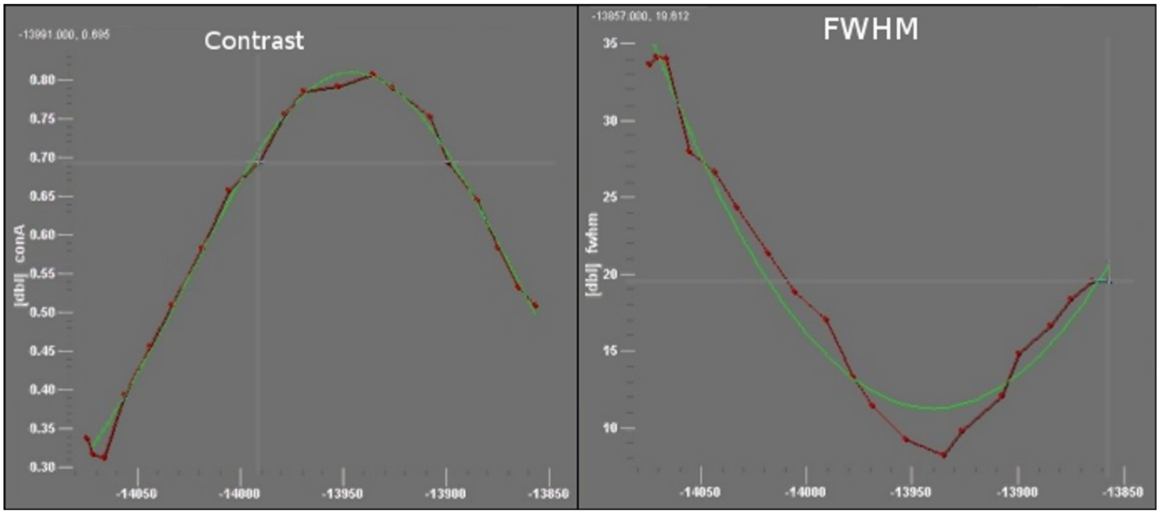

Fig. 4: Contrast vs. Focus Voltage and FWHM vs. Focus Voltage. The program fits a Gaussian and a parabola to the contrast and FWHM data, respectively.

voltages and plots that to another graph. Every cycle of the program adds more negative charge to the deflection plates and should bring the difference in focus voltage through zero. The final plot (CMV vs. distance between spatial and temporal focus optimums) is fit with a line regression and the x-intercept is calculated as the CMV that will bring simultaneous temporal and spatial focus. The program then rescans for the optimum focus voltage by setting the CMV at the calculated optimum and reports the results to the user.

2. Power Supply Comparison

To compare the effects of low and high acceleration field power supplies, the camera was first run through a series of tests using the existing HFPS and later, this was swapped out for the LFPS. The spatial magnification and sweet spot width (the width of the usable cathode), were measured. Line spread functions (optimal temporal focus), spatial focus (paraxial and off-axis), and dual focus with a CMV were optimized.

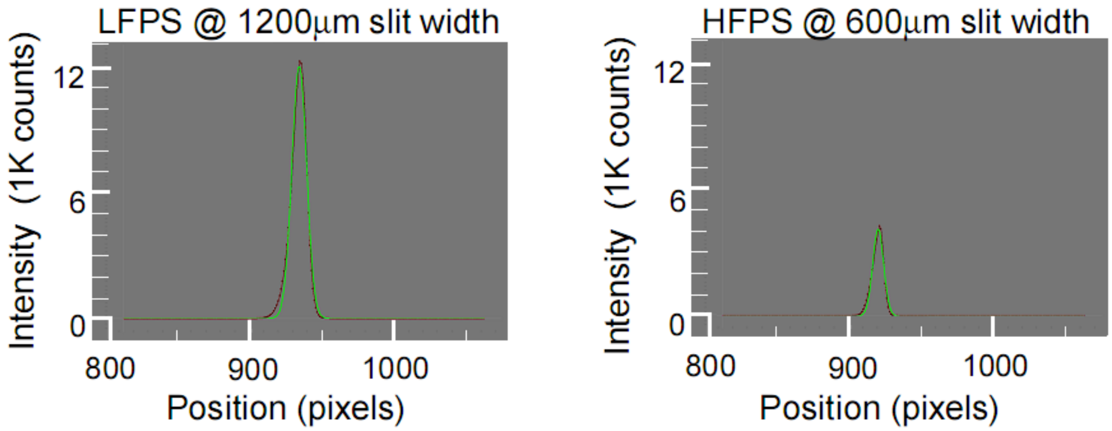

Fig. 5: Comparison of LFPS and HFPS photoelectron throughput. The photoelectron throughput is the FWHM (in μm) times the intensity of the image.

V. Results

The focus optimization program successfully optimized the temporal and spatial focus using a CMV. The contrast was raised and the FWHM lowered by using a CMV. This method gets better image results than just taking halfway between the optimal spatial and temporal focus voltages. For the 5 LP/mm slits, the contrast stayed around 93% with FWHM only increasing about 6.35 μm when focused optimally using a CMV. For the 10 LP/mm slits, the contrast remained close to 78% with FWHM similarly close. These changes are from optimizing solely based upon either contrast or FWHM. The use of a CMV effectively optimized the focus voltage to optimize both temporal and spatial resolution.

Additionally, many tests were run to see the effect of using an LFPS with the ROSS camera. These tests demonstrated many of the expected differences between using HF and LF power supplies. For example, the sweet spot width for the LFPS was 1,193 μm, compared to only 603 μm for the HFPS. The reduction of the acceleration voltage from 2500 V to 500 V should have theoretically allowed for 2.236 times the sweet spot width due to reduced index of refraction, and the actual ratio is about 1.978. Also, the photoelectron throughput (Intensity times FWHM) was about 4.34 times greater for the LFPS than for the HFPS, as shown in figure 5. However, the LFPS showed drawbacks that result from increased light throughput, mainly reduced temporal and spatial resolution. While the HFPS does offer superior spatial and temporal resolution, running the ROSS with an LFPS allows more than four times the photoelectron throughput to reach the cathode. This increased throughput is necessary for photon-starved experiments.

VI. Future Work

There is the possibility for future work to continue improving the program, to help improve the programming interface, and to help implement the program for use in scientific experiments. Currently, the program for optimizing CMV has to scan through a range of focus voltages and take around 20 exposures to find the distance between the two optimum voltages. It has to do a cycle of 20 exposures for at least five possible CMVs to create the linear regression to optimize the CMV. Finally, it has to find the optimal focus voltage that corresponds to the optimal CMV. This whole process is very time consuming if done fully. The program can be sped up by limiting the cycles or exposures, or increasing the bin size for the images captured, but these speed compensations hurt the accuracy of the results. Future work could be done to find the best compromise between program speed and program accuracy.

Additionally, the programming interface for the ROSS is fairly limited. The interface could be made more user friendly for scientists. Also, the interface limited this project from doing an inverted Gaussian fit of the FWHM. This feature would increase the program's accuracy. Finally, both the CMV program and the LFPS need to be implemented for experiments. Additional work would make the ROSS more easily usable by experimenters and more flexible.

VII. Conclusion

The aim of this project was to write software scripts which would automatically focus the ROSS with a P510 streak tube in both temporal and spatial directions, and to test the ability of a low field power supply to increase sensitivity of the camera for photon starved experiments. The software scripts effectively were able to focus the ROSS in both the temporal and spatial directions using a single focus voltage together with a single common mode voltage on the deflection plates. The LFPS was able to increase photoelectron throughput and usable photocathode width. Future work may help improve and implement these programs for use in scientific experiments. These programs will increase the utility and usability of ROSS camera systems by calibrating simultaneous temporal and spatial focus and by increasing the sensitivity of the ROSS for photon starved experiments.

VIII. Acknowledgments

I would like to thank Robert Boni, Dr. Paul Jaanimagi, and Matt Millecchia for the time that they invested in my project. I know that this experience helped me to gain valuable knowledge and skills that will help me excel in the future, and that I could not have completed this project without their help and guidance. Also, I would like to thank Dr. Stephen Craxton for admitting me to this program. I learned more about working in a real world research environment, and I gained experience presenting and writing for a technical or non-technical audience.

IX. References

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