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INVESTIGATION OF OTHER OPERATING POINTS FOR THE RCA STREAK TUBE IN THE LAWRENCE LIVERMORE NATIONAL LABORATORY STREAK CAMERA

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Investigation of other operating points for the RCA streak tube in the Lawrence Livermore National Laboratory streak camera

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Abstract

The RCA streak tube can be operated satisfactorily at voltages other than those we have been using for nearly ten years.

Our soft x-ray streak camera uses the RCA C73435 streak tube body fitted with a removable x-ray cathode. The front of the streak tube is exposed to the vacuum of an experimental chamber, which is not entirely under the control of a streak camera operator. Occasionally, the vacuum becomes poor enough to cause corona and arcing from the cathode to the chamber wall. The corona problem is more difficult because the dimensions of the x-ray camera body are smaller than for the optical camera body. Therefore, we investigated the effects on camera performance of decreasing the accelerating voltage at the cathode from the customary 17 kV. Several operating points were evaluated and 12 kV cathode-to-anode with 5 kV cathode-to-grid were selected for more detailed investigation. Transverse spatial resolution and dynamic range were found to be essentially the same as at our normal operating point of 17 kV for the cathode and 2500 V on the grid. Magnification, sweep linearity and absolute sensitivity changed as expected. In the course of the investigation, we measured the dynamic range with our CCD readout system. The effect of coulomb repulsion at the crossover point was also measured and found not to affect dynamic range.

Introduction

Optical and x-ray streak camera performance, reliability, and understanding are important to the success of our laser fusion program. To this end, several tests have been performed and are reported upon herein. Our soft x-ray camera system (shown schematically with the CCD readout in Figure 1) is operated with the cathode exposed to the target chamber vacuum, as shown in Figure 2. If the pressure rises in the chamber with the camera

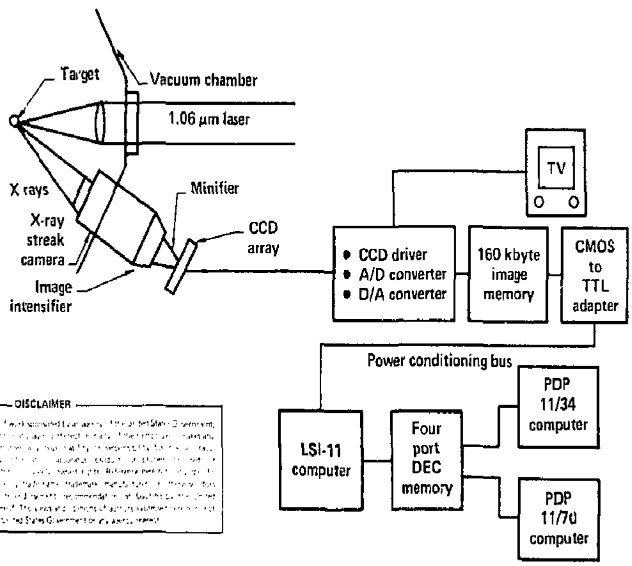


Figure 1. Soft x-ray streak camera system with CCD readout.

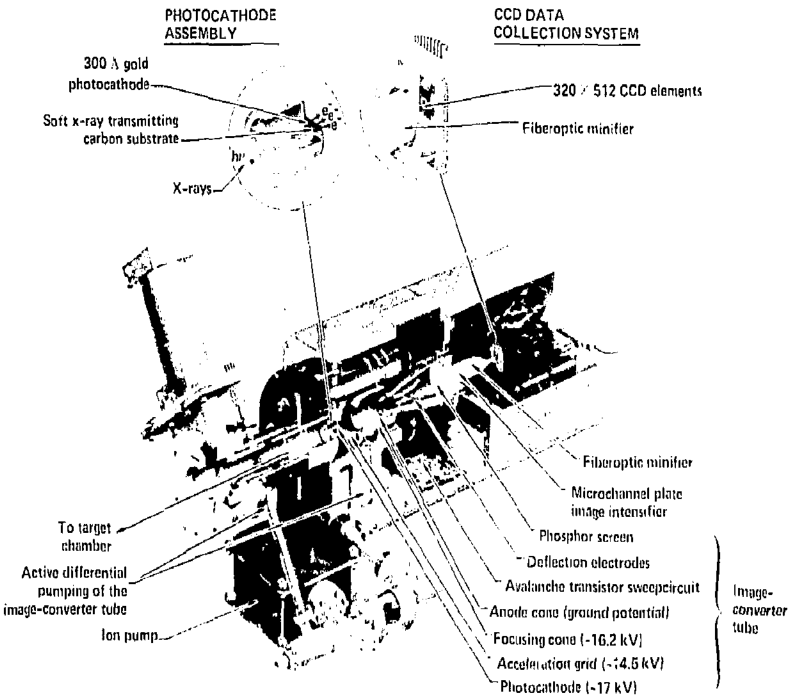


Figure 2. Cutaway of soft x-ray camera, including CCD readout system.

high voltage on, corona discharge or arcing can occur. The corona is accentuated by closer spacing in the smaller chassis of the x-ray camera as compared to the optical camera, and the corona sometimes triggers the camera's avalanche transistor sweep circuit. To reduce the corona we investigated reducing the high voltage in the streak tube. The effect on camera performance is the subject of this paper. For a description of our camera and its operation, see References 1 and 2.

Optical and x-ray cameras use the s[illegible] RCA type C73435A streak tube and the electronics are also identical. We chose the optic[illegible] camera for the following tests because of the easier availability of an input source.

Resolution vs voltage

Data supplied to us through the courtesy of RCA (Figure 3[3]), indicated that resolution would be improved by raising the grid-1 voltage and possibly by lowering the cathode-anode voltage. (The data for Figure 3 were taken under static conditions without an intensifier.) Therefore, we measured static spatial resolution at several cathode-anode and grid-1-to-cathode (grid) voltages by imaging a test pattern (a section of the standard, U.S. Air Force, 1951, resolution test pattern) onto the cathode. We used a white light source with a 1.06-μm bandpass interference filter. "Limiting" resolution was determined with a microscope at the microchannel intensifier output. Table 1 shows the results. For a cathode voltage of 12 kV and grid voltage of 4560 V (nominally 5 kV) the resolution appeared to be slightly better than at the other test points and, therefore, this point was chosen for subsequent evaluation.

Dynamic range

It is important that streak camera output intensity be a linear representation of the input photon intensity. Also, the range of this linearity must be adequate to permit input

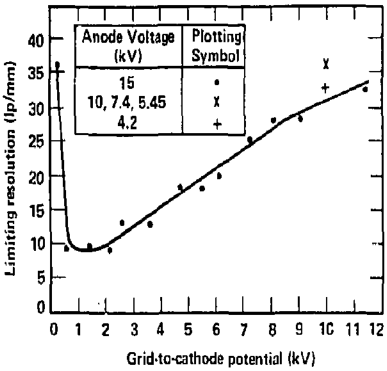


Figure 3. Static resolution vs grid voltage for the RCA C73435 streak tube (courtesy of RCA).

Table 1. Resolution vs cathode and grid voltages.

Cathode-to-anode voltage (-kV)	Grid 1-to-cathode voltage (kV)	Focus grid-to-cathode voltage (volts)	Resolution at cathode (lp/mm)
17.0	2.5	770	10
14.8	2.41	680	11.4
14.8	4.56	200	11.4
12.04	2.54	420	11.4
12.02	4.56	200	>11.4
10.01	2.5	300	11.4
10.01	4.58	140	11.4

amplitude variations to occur. The upper limit of this "dynamic range" is defined here as the intensity at which streak camera output pulse width is broadened by 20%, using as a reference either the widths of lower-intensity pulses or the width as measured by a second camera known to be operating within the linear range. The lower limit is set by the noise level of the recording system, usually film. Complete details are given in References 4 and 5.

Dynamic range was measured at the 17-kV operating point and again at the 12-kV point. Royal X-Pan film processed to an ASA 2000 speed was used. The results are shown in Figure 4. The dynamic range is nearly equal for both tests and is adequate for our application.

Transverse Resolution

The dynamic spatial resolution transverse to the sweep direction was measured by streaking the output of a 150-ps glass etalon with 90% reflective surfaces, illuminated by

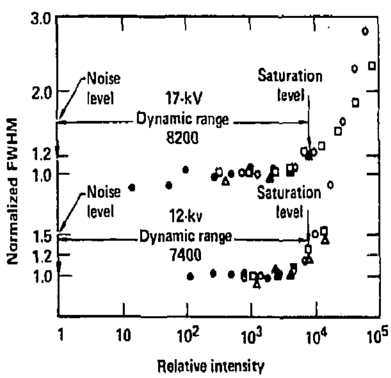


Figure 4. Dynamic range at 17 kV and at 12 kV.

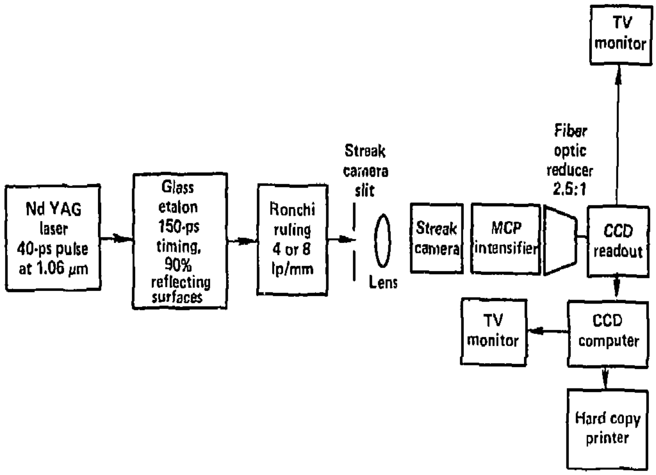


Figure 5. Schematic of the experimental setup for transverse resolution testing.

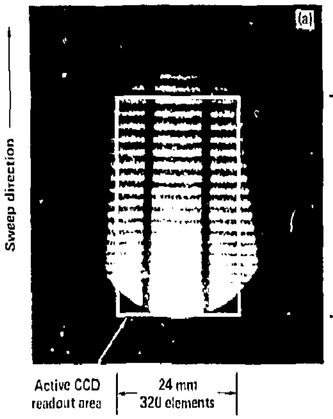
a single 40-ps pulse from a NdYag laser at 1.06 μm. The experimental setup is shown schematically in Figure 5. The slit was set at 400 μm for all tests, and a Ronchi ruling (alternate dark and light bars, equally spaced and sized) was positioned before the slit and aligned parallel to the sweep direction. Hard copy line-outs were taken and analyzed for modulation depth at several places on the output surface of the intensifier. A typical readout is shown in Figure 6. Figure 6 (a) shows the rectangular area readout by the CCD through its fiber optic minifier superimposed on a typical polaroid film recording of the streak camera output at the 17-kV operating point. The image was divided into the nine sectors shown in (b) as overlaid on the TV monitor display of the entire CCD readout with the camera at the 12-kV operating point. Symmetry permitted reduction to the four unique sectors labeled I through IV. The dark line is due to a bad element on this particular CCD and is not typical. In (c) the lineout of line 185 of (b) is shown. The dark areas or big dips are images of 1.6-mm wide strips of tape placed 8.5 mm apart on the streak tube cathode. The tape strips were placed to determine horizontal magnification at the various operating points. The modulation was caused by a Ronchi ruling of 3.3 line pair per mm. An example of the peak, valley and base points used to determine modulation depth is shown. The results of the test are presented in Table 2 in the form of modulation depth for 3.3 and 6.7 line pairs per mm. Differences in the data between the 17 kV (2500 V grid) and 12 kV (4600 V grid) cases are small and the two cases can be considered identical, within experimental error.

Magnification

Horizontal (transverse) magnification was determined by the spacing of images of the tape on the cathode, as mentioned above, to be 1.2 at 17 kV and 1.6 at 12 kV. The grid in the RCA tube is composed of horizontal wires 5 mm apart and 7.2 mm from the cathode.[6] A strong negative electron lens is formed in the vertical direction by the electric field from these wires, resulting in a vertical magnification significantly less than one. With

Table 2. Modulation depth (%) at various locations on the output. Data spread is ±7 percentage points at the edge (Areas I, III and IV) and ±5 percentage points at the center (Area II).

Anode voltage (kV)	3.3 lp/mm				6.7 lp/mm			
	Area				Area			
	I	II	III	IV	I	II	III	IV
17	30	35	33	35	17	18	26	26
12	34	34	35	37	16	22	28	28



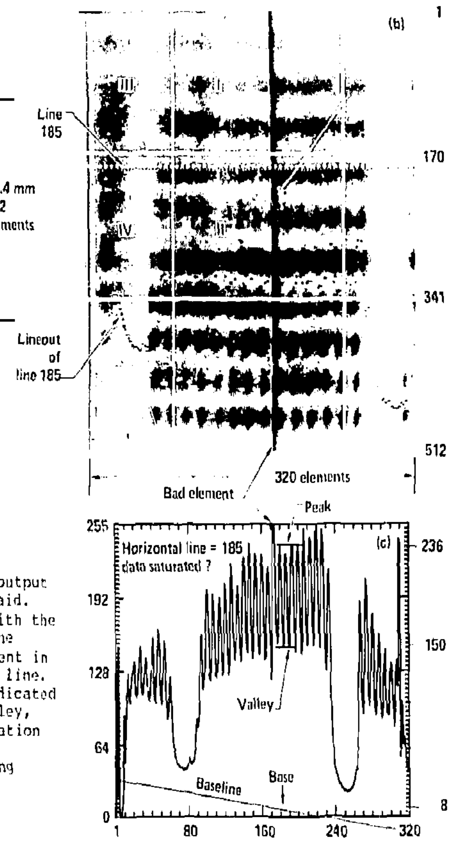


Figure 6. CCD readout. (a) shows the output on film with the CCD readout area overlaid. (b) shows the TV monitor presentation with the areas I thru IV identified as used in the transverse resolution test. A bad element in this CCD array caused the dark vertical line. (c) shows the lineout of line 185 as indicated in (b) and points out typical peak, valley, and base values used to calculate modulation depth for Table 2. The baseline slants because of an improperly adjusted shading compensator.

a vertical magnification of 0.1, for example, a 400-µm slit should be 40 µm wide at the phosphor. However, aberrations in the electron focusing lens limit the minimum spot size to about 175 µm at the phosphor screen for input slit widths of from 2.5 to over 400 µm.[5] Therefore, vertical magnification (in the sweep direction) was determined statically by monitoring the position of the centroid of the slit image on the phosphor output as the slit was scanned in the streak direction across the cathode between two grid wires. Magnification here is defined as the change in the position of the centroid of the image on the screen, divided by the corresponding change in position of the slit image at the cathode. Figure 7 shows the results for the two test conditions. At 17 kV vertical magnification dips below 0.1 at one point, while at 12 kV it dips below 0.075.

Sweep linearity

The CCD system was used to measure sweep linearity. The experimental setup was similar to that of Figure 4, except that the Ronchi ruling was not needed. A record of the etalon pulse train was used. The CCD computer system calculated and stored the location of, and the distances between, the peaks of the pulses for several laser shots. The system used the etalon timing to calculate and plot sweep rate vs position, as shown in Figure 8, at 17 kV (a) and 12 kV (b). The sweep is linear within ± 15.6% over 80% of the output for 17 kV and within ± 12% for 12 kV over the same area. Moving the curves in Figure 8 to the left by optimizing the sweep bias, as is normally done, would improve the linearity to 11.6% and 6.5%, respectively.

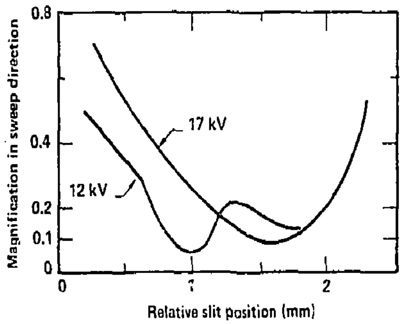


Figure 7. Magnification in the sweep direction vs slit position on the cathode.

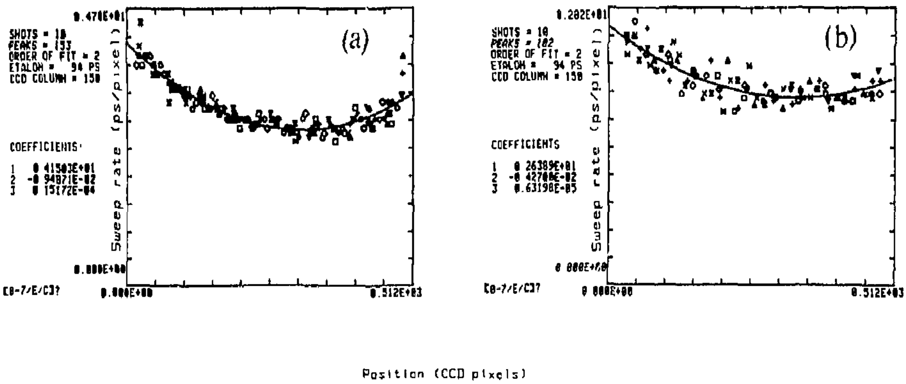


Figure 8. Sweep vs output position for (a) 17 kV, and (b) 12 kV.

Relative sensitivity

The camera was operated statically using a lamp in a similar setup to that for the Resolution-vs-Voltage test, and outputs were obtained at 17 kV and at 12 kV. The magnification difference at these two operating points produced different line widths of the image for the two cases, so the integral of the area under the curve was used for the comparison. Assuming a phosphor dead layer voltage of 5 kV, the intensity ratios or relative sensitivities should be 1.71 to 1. We measured 1.75 to 1 using the CCD readout system.

Dynamic range and the crossover

For some time, it has been speculated that the upper limit of the dynamic range of a streak tube could be affected by space charge at the "crossover" point. This is the point where electrons from opposite sides of the cathode cross on their journey to the screen. If there is a significant space charge effect, the image of a short pulse would be broadened for high intensity levels at this point.

In order to investigate this space charge effect for the RCA tube (at 17 kV), we measured the dynamic range of the camera with the slit apertured to 2.5 mm in the spatial direction. (See References 4 and 5 for the definition of dynamic range and for test description details.) We repeated the test with the slit aperture increased to 12 mm and 19 mm. The data are presented in Figure 9. We see less than a 50% change in the saturation point intensity (20% broadening of the pulse width), instead of the 8:1 ratio expected if space charge were responsible for limiting dynamic range. In fact, the observed change could be explained by the normal experimental errors of this type of measurement. It is clear that, for the RCA tube, space charge broadening at the crossover is not significant.

CCD dynamic range

Normally, the 8-bit dynamic range of our CCD streak camera readout system[7,9] is exceeded before the streak camera saturates. Consequently, we can not determine how close to camera saturation the CCD system is operating. This limitation is unimportant unless an operator wishes to reduce the intensifier gain in order to realize a possible improvement in noise level or to control the camera's input sensitivity--an asset for the soft x-ray camera. Therefore, we performed several dynamic range tests using the CCD readout, while we varied the intensifier gain from the maximum of 20 000 to 1 000. At a gain of 3 000 camera saturation occurred within the dynamic range of the CCD. The data are shown in Figure 10, plotted on the curve of the camera alone as taken on hard film. The arrows show

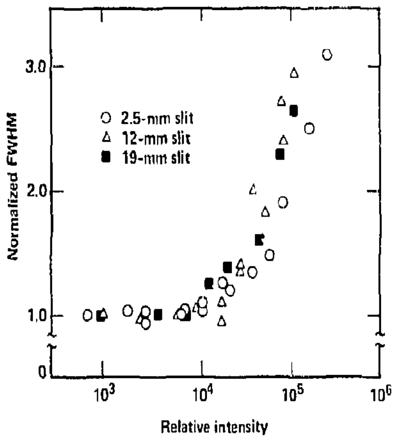


Figure 9. Dynamic range vs slit length for slits of 2.5, 12, and 19 mm.

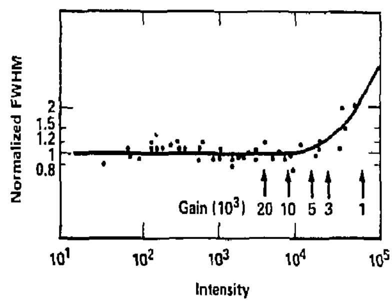


Figure 10. Dynamic range with the CCD readout indicated at several intensifier gain settings, plotted on a curve for the camera alone.

the relative streak camera input intensity for the CCD system saturation level (256 counts) at the indicated intensifier gain. Dynamic linearity is preserved as long as the intensifier gain is above 5 000, permitting a reduction factor of 4 below maximum gain if desired. However, these data were taken on only one camera and several variables, such as spectral matching factors, CCD sensitivity, and streak tube characteristics, make it necessary to measure the minimum usable intensifier gain for each camera system.

Conclusion

During this investigation we have documented many characteristics not previously recorded, such as dynamic range with the CCD readout, magnification, and transverse resolution. We have shown that it is possible to operate our streak cameras at 12 kV accelerating voltage without detracting from performance. In order to realize the benefits of this new operating point, such as better sweep linearity and lower corona potential, we have started procurement of an adjustable high voltage supply to cover an accelerating voltage range of 12 to 17 kV and a grid voltage range of 2.5 to 5 kV.

Acknowledgment

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