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TITLE: FAST FRAMING CAMERA WITH INDEPENDENT FRAME ADJUSTMENTS

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AUTHOR(S): G. Kyrala
J. McGurn
J. Calligan
J. Pallone

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Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FAST FRAMING CAMERA WITH INDEPENDENT FRAME ADJUSTMENTS

George A. Kyrala and John S. McGurn

Los Alamos National Laboratory, P.O. Box 1663, MS E526, Los Alamos, New Mexico 87545

Joe Calligan and Jim Pallone

EG&G, Los Alamos, NM 87544

Abstract

We have designed, built and tested a fast framing camera that works in the visible and short infrared region of the spectrum, from 300 nm to 850 nm. The camera has four separate channels. Each framing channel has its own individual trigger input and individually adjustable framing gate width. Each channel is spatially separate from the other channels as well, thus allowing for complete independence among the four channels. The output from the four channels in the camera is recorded on one piece of 4" by 5" sheet of film. Each channel has a circular recording format with a useful diameter of 18 mm. The channels are positioned on the corners of a square with a center to center spacing of 4.45 cm (1.75"). The camera utilizes commercially available gated intensified Microchannel-plate tubes. The camera contains its own power supply and gating circuits. It required four gating inputs (12 volts). The electronics occupy a volume of 27 cm X 33 cm X 14 cm. The framing part occupies a volume of 21 cm X 25 cm X 5 cm. Characteristics of the camera, such as: framing times, spatial modulation transfer functions, gate delay, and uniformity were studied utilizing a 35 picosecond long blue light pulse, generated by a nitrogen-pumped dye-laser system. A pulsed semiconductor laser at 820 nm was used as well for the setup.

Motivation

Many of the experiments that are performed at the Los Alamos National Laboratory require framing camera pictures of the events with time resolutions of between few 100 nanoseconds and few nanoseconds. However, many of those experiments are conducted on time scales where the events of interest do not occur at equally spaced, nor uniformly distributed, time spans. In addition the events do not necessarily occur with the same time duration. Thus in many situations we are faced with the task of resolving what happens at the initiation of an event, or phenomena, more frequently than at the end of the event and with higher time resolution (i.e. smaller framing time). Of course there are other cases where the reverse situation is true, such as in imploding foil systems which tend to accelerate slowly to higher and higher velocities until the foil implodes on axis. The commercially available cameras take pictures with equal time exposures and at periodic instances in time. Thus one of our most important motivation was to construct such a camera with the modest goal of four frames, each being independently adjustable, with the constraint of recording on the same one sheet of film.

Parameter Restrictions

While building individually gated separate intensified microchannel plate image intensified camera (MCPII) would have been completely feasible, alignment, power supply, and recording requirements would have been prohibitive since individual recording optics is required. It would have been equally cumbersome, since a large box would have to be built. At the beginning of the design cycle we restricted ourself to the use of the off-the-shelf equipment and technologies, the recording on one piece of film, the complete enclosure of all the system in a compact well shielded EMI package. Further, we decided on completely characterizing the system before actual use. No control or adjustment knobs were allowed to be accessible at the outside of the camera, save for pulse length adjustment through various lengths of coaxial cable, thus preserving any calibration settings and conditions.

Approach

We decided to use standard microchannel plates which are available from different manufacturers. Quick delivery dictated the choice. In addition we decided to accept, for our initial choice, non premium tubes which may have some defects. We were lucky in that the tubes we received did not have any initial blemishes that we could distinguish, at least in our initial testing. The first choice were 18 mm diameter tubes manufactured by the VARO corporation model No. 5722 with an s-20 photocathode, a p-20 phosphor, a glass faceplate, and fiber optic output coupling windows. Although we knew that low resistivity photocathodes would have considerably lower gating times, the manufacturing of such photocathodes reliably, consistently and inexpensively is not feasible at the present time. Thus the VARO tubes purchased did not have low resistivity photocathodes. In keeping with the principle of simplicity and speed of execution, it was decided not to add any optical system in front of the camera as part of the camera. (It is our experience that few scientists like other scientists optical systems anyway). We hoped that a few front end optical systems will be built to accommodate specific needs for different experiments.

Design

The framing camera was made up of two physical parts (see photos Figures 1, 2, and 3). The first part consisted of the power supply and the gating circuits. The second part consisted of the electro-optic elements themselves, and the film plate holder. Each of the four intensifier tubes had its own gating circuit, Figure 4, but shared the power supply circuit. Each tube was separately gateable with its own trigger source. The tube was gated differently from the regular gating circuits. Usually the gating pulse was negative and was applied to the photocathode of the intensified MCP. The MCP was biased off so that no signal was allowed to reach the phosphor. An alternative method was used in this system. The gating signal was a positive pulse which was fed to the input electrode of the channel-plate with the photocathode tied to the signal ground. The gating pulser was a 50 ohm device and will drive the channel plate without noticeable drop in the applied volt gate voltage for at least 100 ns. The measured drop was less than 2 percent at 100 ns after application of the 150 volt gate pulse. The pulse width was controlled by varying the length of an RG-223 coaxial cable attached to the gating pulser of each tube. The minimum gating width was determined by the capacitance of the gating circuit plus the minimum length of coaxial cable that attached it to the BNC connector on the outside of the framing camera. This was measured to be .9 ns FWHM. The input trigger pulse requirement was a fast rising pulse (+5 to +20 volts) with a rise time < 50 ns, fed separately to each trigger circuit. We have never experienced any coupling between separate trigger channels. The four intensified MCPs were held in a common aluminum holder plate that also held the separate electrical feed throughs (see Figure 2). The same plate also held a standard film camera pack for 4 by 5 inch film. The camera back, see Figure 3, had to be modified slightly to hold the film firmly, against the multichannel plate fiberoptic output window. We experienced enough variation in the thickness among the different channel plates and in the parallelism among their output and input faceplates that we decided not to put any precision on the machining of the holder, but to account for that variation by having a pressure pad behind the film to push the film firmly on each faceplate. This served our purposes well, and kept all four faceplates in good contact with the film. The lower package was constructed with good EMI shielding techniques, so that no false triggers would occur due to EMI noise such as would be encountered in pulsed power machine and capacitor banks. All openings were closed with very closely spaced holding bolts. The camera's physical design was such that it would be coupled nicely to regular optical tables with 1/4-20 bolt holes equally spaced at 1 inch intervals. Each tube was mounted in the same aluminum frame. Each tube had provisions to mount its own camera lens. We tend to use standard TV lenses since their format, their small size, and focal length match the present configuration well. Thus c-mount grooves were machined into the aluminum block in front of the MCPs.

Testing

Two test setups were used. The first setup is shown schematically in Figure 4. It was used to measure the gating time and gating behaviour of the framing camera. The second setup is shown schematically in Figure 5. It was used to measure the modulation transfer function, the resolution, and the dynamic range of the intensified gated MCPs. In all tests we used 2484 film to record the images from the tubes. The film was then digitized with 14 μm x 14 μm resolution.

Gating properties: The test setup used a short pulse nitrogen laser (500 ps FWHM) to pump a R590 dye laser. When the pump laser was operated at the lowest power necessary for the dye laser to lase, the output pulse was roughly 35 ps FWHM, and operated at the peak fluorescence radiation of the dye, 570 nm. The laser pulse contained some fluorescence from the dye. Thus we used an inexpensive interference wedge monochromator with very narrow input slits to clean up the laser beam. The monochromator was placed at the largest optical distance from the laser. The combination served many purposes simultaneously; first since the fluorescence tend to have a broad angular distribution while the laser beam divergence was small, few tens of microradians, little of the fluorescent radiation entered the monochromator. Second the monochromator bandwidth was set at few nm which cut down even further on the fluorescence from the laser and the optical elements in between. Third, since the monochromator had very small apertures, it operated in conjunction with the nonachromatic lens before it as a sort of spatial filter cleaning up the mode structure in the beam before it illuminated the photocathode of the intensified MCPs. A small amount of light output from the monochromator was split off and sampled through a fiber optic cable by a fast 30 ps/mm resolution streak camera. The fiber optics acted as a further time delay in the optical path. A part of the laser pulse was split-off early in the optical path to the camera, and was used to trigger a silicon photodiode avalanche circuit combination. This electric trigger was suitably divided, delayed and attenuated; then used to trigger the framing and the streak cameras. A very long optical path was used on purpose. This allowed sufficient time to overcome the streak camera trigger delay, and allowed us to vary and measure all the time delays electronically using a Los Alamos National Laboratory built, 10 picosecond resolution, analog delay box. A typical output of the measurements is shown in the photograph of Figure 6. Shown are a sequence of pictures taken as the delay between the electric and the optical pulse was varied. No length of external coaxial cable was attached to the gating circuit. Thus the case represents the shortest inherent gating behaviour of that particular intensified MCP. One sees the tube starts gated off, then the gated open region starts to propagate radially in, finally the whole tube is gated on. On shutoff the tube turns off at the circumference and again the gated-off region propagates radially inward. The measured gating on-time (or framing time) is 3 ns². The time difference between the frames is 1 ns, and one can see that frame (a) and frame (d) correspond to the same region being on and off respectively. The width of the on to off region is a rough measure of the laser pulse width, 55 ps in that particular frame (a), convolved with the rise time of the system. The front moves at a speed of 9 mm in 2 ns. The front width is roughly 1 mm, corresponding to a

convolved risetime of .22 ns. Using quadratures to add the risetime and the FWHM of the laser pulse, the actual on-risetime and decay-time are roughly 210 ps. Similar studies were performed on all the intensified gated MCPs. We found that two tubes had 2.5 ns gating time, while the other two had 3 and 4 ns gating times respectively. We should note that the gated output of the different MCPs were additive, in the sense that adding a length of cable to the no-cable configuration, added an incremental on-time equal to twice the electric transit length of the cable.

Resolution: The setup shown in Figure 7 was used for this study. A strobe light was used as light source. The duration of the light source was a few microseconds. The strobe output was focused on a diffuser which illuminated a resolution chart or a bar chart. After attenuation by neutral density filters the resolution chart was imaged at the input photocathode of the intensified MCPTs using a long focal length lens ($f=126$ mm). The measured resolution was very dependent on the input intensity. When we optimized the input light intensity the measured resolution was independent of the gating pulse width and was very close to the static resolution of 4.5 lpm. The resolution was slightly better at the edge of the MCPT than at the center. The photograph in Figure 6 is a poor reproduction of the Air Force resolution chart measured with a demagnification of .7 using the tube shown in Figure 8, with minimum gating time.

Dynamic Range: The dynamic range in intensity was studied using the setup shown schematically in Figure 7. A bar chart was used. It had eleven steps of intensity transmission. The steps were spaced by 0.2 ND starting at 0 ND and ending at 2.0 ND. Two patterns rotated 180 degrees from each others were used, thus allowing for simultaneous coverage of all the bands in the chart on one frame. A typical output is shown in the photographs reproduced in Figure 9. The gating time for the figure was 12 ns. The light was kept fixed, and the bar chart was attenuated using other ND filters. Under optimum light conditions for a given gate width we measure a dynamic range for intensity recording of better than 100. This is a combination of film and intensified MCP dynamic range. The gain of the MCP was kept fixed at roughly 10,000. The same MCP exhibited reasonable recording reciprocity, see Table 1. A 0.3 ND change corresponds to an intensity change of a factor of two, which is roughly the change in the gating time. Under marginal light it is expected that the dynamic range for recording would be less than a hundred, but probably better than 40. Note from the Figure 9 that a lot of light was leaking through the gated MCPT. The quoted on:off leakthrough was $10^6:1$. Remembering that the strobe light remains on for 10 microseconds while the gating time was 15 ns, the quoted number seems to be a little optimistic, since an ND of 3.0 was needed to match the leakthrough to the saturation intensity. The measured on:off ratio is more like 6.6×10^5 .

Table 1.

shot sequence number	45	54	53
ND required	1.0	1.3	1.6
gate time (ns)	3.0	15	27

Summary

In this paper we have described the construction of a four frame gated intensified multichannel plate framing camera. We gave the motivation and application for the present framing camera. We have also discussed the method and apparatus used to test and characterize the camera. Briefly the camera had separate MCPs that shared the same chassis and film, but had separate independent gating circuits. The MCP resolution and on:off transmission ratio did not change significantly from the static case. The minimum gating on-time was measured to be 3 nanoseconds with a rise and decay times of 220 picoseconds. The resolution was roughly 7.5 line pairs per millimeter, and the intensity dynamic range was about 100. The camera occupied a space of 27 by 33 by 14 cm. The recording was on standard 10 cm by 12.5 cm (4 by 5 inch) film. Provisions were made for the input optics to be separately adjustable, and utilized standard TV camera equipment and format.

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Figure 1. A photograph of the internals of the framing camera showing the power supplies and the gating circuits. The back of the film holder is shown at the top of the photograph.

Figure 2. The front view of the framing camera. The four MCPs are shown with the TV lenses attached, but covered. The coaxial cables carry the gating pulses. The other cables carry the high voltage bias.

Figure 3. Rear view of the framing camera. The photographic plate holder is removed to show the high voltage potting of the MCPs tubes.

Figure 4. A diagram of the pulse gating and biasing circuits. The high voltage dividers, the gating pulse generators, and high voltage power supply are packaged separately from the MCPs. The biasing voltages are connected to the MCPs by short leads of high voltage cables. The gating pulses are connected by coaxial cables.

Figure 5. A schematic layout of the test apparatus used to measure the framing times reported in this paper. The optical path from the laser to the MCPs was made very long compared to the camera trigger time delays in order that all delays be measured electrically using our high resolution (10 ps) delay boxes.

Figure 8. The resolution measurement for the same MCP tube as in Figure 6. The gate time was measured at 15 ns. The measured resolution was 4.5 l pm.

Figure 6. Shutter sequence of closure. The separation, or delay, between the consecutive frames is 1 ns. The open region is light, the cut-off region is dark. The inferred gating on-time is 3 ns.

Figure 9. The dynamic range response of the MCP tube with 15 ns measured gating time. The step wedge had 0.2 ND per step. The attenuator used in front of the step wedge had neutral density values of 0, 0.3, 0.6, and 1.0 for cases a, b, c, d, respectively.

Figure 7. A schematic diagram of the setup used to test for resolution and or dynamic range. An Air Force resolution chart or bar chart was used for the respective measurement.