Effect of film development on uniformity and modulation transfer function of the gated/fast x-ray imagers data

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We have been investigating the different phenomena that affect the modulation transfer function response of the gated x-ray imagers and fast x-ray imagers that we use to record subnanosecond x-ray images at different laser facilities. As part of that investigation, we noticed that there is definite nonuniformity to the recorded images, even when the incident radiation was uniform. After a significant effort to track down that effect we found that the automatic developing processors, which process the film along the length of the roll, cause the effect. Manual development, which depends primarily on transverse agitation in the developer, and automatic processors that do not use a feed mechanism but emulate this agitation, do not introduce such artifacts. We recommend that for absolutely critical missions, such as target symmetry measurements, certain automatic machines should not be used. [DOI: 10.1063/1.1310585]

I. INTRODUCTION

Gated multichannel plates (MCPs) made up of a stack of millions of tubes, are useful for detecting x-ray radiation and for amplifying the number of electrons released by such a radiation for recording purposes.[1,2] These MCPs have been used in a number of instruments, such as the gated x-ray imagers (GXIs) and fast x-ray imagers (FXIs) etc.,[3,4] for detecting and imaging the spatial structures in laser generated plasmas with high temporal resolution. These instruments have been used to measure the uniformity of the drive and the structure of shocks in inertial fusion capsules.[1] To that effect, significant efforts have been expended to measure the spatial resolution of such instruments and to flat field them in order to subtract nonlinear gains that exist across the fields of view of these detectors.[5,6] However, in addition to the resolution of the recording medium, the spatial structure of such MCPs, the low quantum efficiency of the photocathodes used, the coupling of the electrons to the phosphor, and the coupling of the phosphor light to the recording medium, all contribute significantly to the resolution of the recorded data. One of the areas that did not receive attention is the effect of film processing on the measured flat fielding data. In this article we outline the results we found and we make specific recommendations.

II. PROCESS

For most of our work we used a GXI already built and described previously.[2] For this study we used film recording, although we also studied charge coupled device camera responses and will publish those results separately. We used an electron bombardment x-ray source for all these studies, and calibrated the source size and radiance using a 4 mm diam SiLi detector placed 44 cm from the source. The source spot was elliptical in shape and about 1 mm$\times$2 mm in size. The source was a sealed KEVEX unit that emits about 1.34×10^{11} photons/s/amp/sr through a combination of a 250 μm Zr and a 75 μm iron filters at the molybdenum 17.5 keV photon energy using a 35 kV accelerating potential. We placed the x-ray source about 82.3 cm from the gated MCP detector face, and attenuated the x rays such that the rate of arrival of x rays is less than 1 photon per MCP tube per second. Zirconium and iron filters with 250 and 75 μm thickness, respectively, were used to attenuate and filter the source, thus ensuring that the rate of two photons arriving simultaneously during the gain/transit time of the MCP is much less than 1%.[7] We checked the uniformity of the illumination by placing x-ray film in front of the MCP and recording the illumination pattern.

Continuous wedges were recorded on the film before developing and were used to linearize the film response. At Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL) we developed the film using a Hope500 with a roller transport for automatic developing. We used unstabled-base Kodak T-Max 3200 film. T-Max Developer was used at film strength for 7 min at 75 F. The stabled-base Kodak Instrumentation Film 2484 Estar was developed using Kodak D-19FS film strength for 6 min at 26.9 °C. At the Laboratory for Laser Energetics (LLE) a JOBO processor using a LLE standard development for TMAX 3200 was used. The following steps are used for processing Kodak T-Max 3200 film in a rotary (JOBO ATL2000) processor at 24 °C ($\pm$0.1) @ 50 rpm (with short rinses in-between chemistries). After preheating in an ambient water bath (30 s) and presoaking for 2 min in tap water, the film was developed with a T-MAX developer for 7.5 min then stopped with a Kodak Indicator Stop Bath for 30 s. The film was next fixed in a Kodak rapid fix for 7 min, followed by a first water wash for 1 min in tap water and then 2 min in Heico Perma wash. Finally the film was washed in tap water

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again for 3 min, Kodak Photo-flo, and then de-ionized water before it was dried.

For performing a modulation transfer function measurement we placed two strips of 9 mil thick razor blade with a knife edge on each near the MCP surface. We thus have a well-defined region across the MCP of width 7 mm, in the middle of the MCP strips. This region is too narrow for MCP gain effects to be significant, but allows a large region to record the wing response of the MCP for a straight edge illumination. We immediately noticed that there is a left right asymmetry in the recorded signal. Such nonuniformities were observed before and were assumed to be constant and dependent on the gains of the MCPs.[8] Techniques were used to correct such nonuniformities of response from the data. We suspected that there may be other sources for the nonuniformity of the recorded signals; either the x rays were nonuniform, or that there is a left right asymmetry in the gain of the MCP, or that the slits were not the same thickness, or that the slits scattered x rays differently. After eliminating each of these effects we came to the then ''ridiculous'' conclusion that the film processing is to blame. As it turns out this is related to the ''adjacency effect''[9] in film development. The film density in a given region is not only a function of the exposure in that region, but may depend on the exposure in adjacent regions. The depletion of developer chemicals in a region will effect development nearby if there is not enough agitation or flow to maintain a constant, uniform sufficient developer concentration.

Two types of film used in the inertial confinement fusion program were used in this study: Kodak 2484 and T-MAX 3200. These films are well matched to the blue light emission and decay time of the P-11 phosphor.[2] TMAX, is used more because it has higher resolution, and 2484, being less sensitive to static electricity, prevalent at Los Alamos, and more useful for archival purposes, since it does not shrink in time. To prove the depletion effect, we processed six sets of film. In each set one film was processed with the leader first, another with the trailer first, and the third film was processed by hand. Two of the sets each used three rolls of 2484 film; one set processed at LANL and another at LLNL. The next four sets each used three rolls of TMAX-3200 film, and each was exposed under identical conditions, with one set sent to LLNL, one set sent to LLE, one set developed locally at the Trident laser facility, and one set developed locally at the Plasma Physics photo shop. Each film had the following format; a continuous P-11 wedge, an exposure at 700 V, an exposure at 800 V, an exposure at 900 V, and in some cases a P-11 step wedge rotated at 180° relative to the other wedge. The exposure time was 60 s for each image using the molybdenum 17.4 keVK_α line and a gold photocathode. The P-11 step wedge is a calibrated wedge used with a 47B Blue Wratten Gel filter that adjusts the light output from the Xe flashlamp in the sensitometer source to approximate the spectral emission from the P-11 phosphor used at the fiber-optic output faceplate of the MCP. In each of these sets, one roll was developed with the trailer first into the automatic processor, one roll developed with the trailer last into the automatic processor, and one set developed manually. The LLNL film was digitized at Bechtel-Nevada, LANL bldg. 87 PDS processor, and at LLNL. We did not notice a major difference between the LANL bldg. 87 film processor and the Trident film processor results, thus indicating reasonable repeatability within LANL. Thus in the following we will not distinguish among the LANL results individually, but will refer only to the film and processor types.

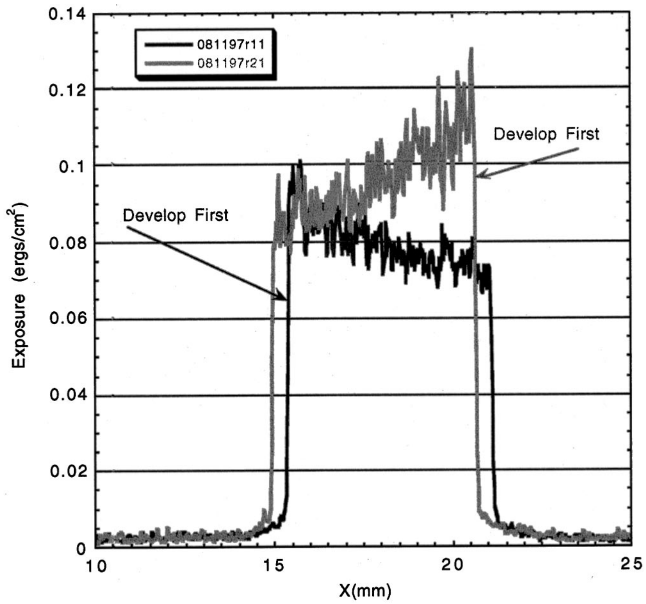

FIG. 1. Slit apertured exposure with 2484 film: MCP voltage 850 V, 3 kV phosphor, LANL developed.

III. RESULTS

The results are shown in the attached figures. Figure 1 shows a typical result for 2484 film. The exposure in erg/cm^2 is calculated from the wedge, but has not been absolutely calibrated. The horizontal axis is shifted between the two scans in order to show the response of the edges. In each of the two scans we found that the region which is fed to the processor first gets developed to a higher exposure level, and that the nonuniform region extends over at least 5 mm! In Fig. 2 we show the effect of increasing the gain of the system to get higher exposures. The voltages listed are the voltages across the MCP wafer. Again, we find development to a higher exposure level where the high exposure region first enters the developer, followed by a lower exposure level due to developer depletion. The effect seems to depend on the exposure level of the film. The hand developed film shows little of the effect. At the higher gains, where the exposure level is highest, the effect is most severe.

Figures 3, 4, and 5 show the data for the TMAX 3200 film developed at LANL, LLNL, and LLE, respectively. The depletion effect is again more noticeable at higher gain, and more dramatic than for the 2484 film. However hand developing the film has a much smaller effect. If we define a measure of the linearity as a percent nonlinearity per mm of distance, then the hand developing gives the best linearity, usually less than 2%/mm, while the automatic processors give values as large as 5% for the TMAX-3200 film. The measured values for the hand developing were random in nature and did not correlate with a direction on film, thus

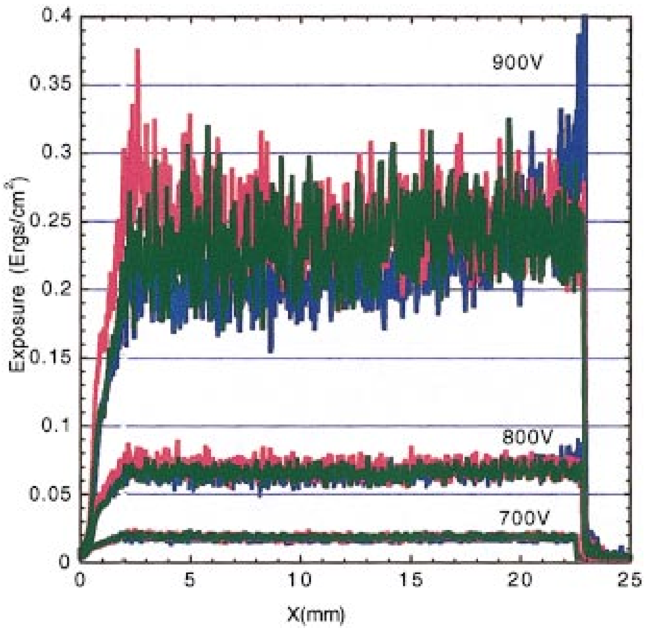

FIG. 2. (Color) Slit apertured exposure with 2484 film: MCP voltage 700 V, 800 V, and 900 V, 3 kV phosphor, LANL developed: (blue) leader first, (red) leader last, and (green) hand developed.

representing the best uniformity. Slight variations may occur due to the nonuniformities in the gain of the MCP. The 2484 film shows a similar behavior, but with a slightly better measure, especially at lower exposure. Notice that in all cases hand developing is best, but that there is a difference in the film density among the three labs for presumably identical exposures.

We tried to quantify some of these numbers to put the results in perspective. We used the leader-first developed film for the measurement. We define the signal as the rms average across the slit, and the percent uniformity as the

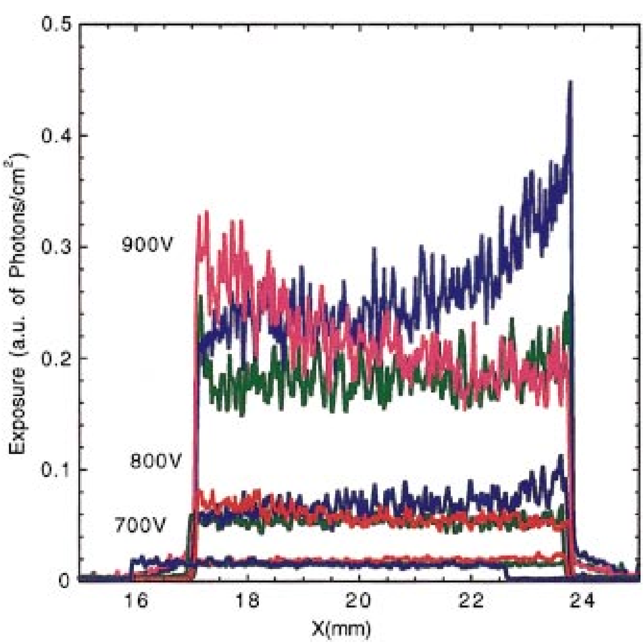

FIG. 3. (Color) Slit apertured exposure with T-3200 film: MCP voltage 700 V, 800 V, and 900 V, 3 kV phosphor, LANL developed: (blue) leader first, (red) leader last, and (green) hand developed.

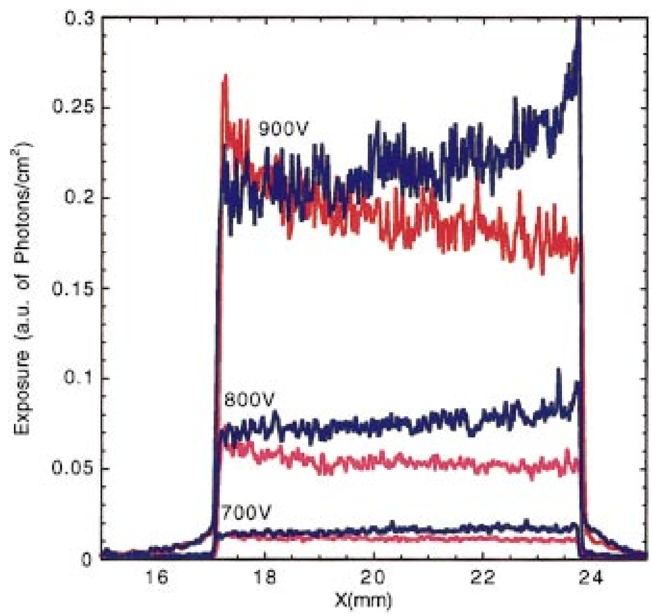

FIG. 4. (Color) Slit apertured exposure with T-3200 film: MCP voltage 700 V, 800 V, and 900 V, 3 kV phosphor, LLNL developed: (blue) leader first, (red) leader last.

slope from one edge of the slit to the other edge.

The results, shown in Table I, point to a possible problem with some previous measurements of symmetry and uniformity of illumination. If film was not developed by hand, then the GXI and FXI measurements have possible errors up to 5%/mm in the image plane. If a magnification of 8× was used, this error due to film development translates to 4%/100 μm in the source (object) plane. We believe that unless adjacency effects due to the development process of the film are avoided, results requiring uniform film development may be suspect.

The results for the gain are also valuable. For all the

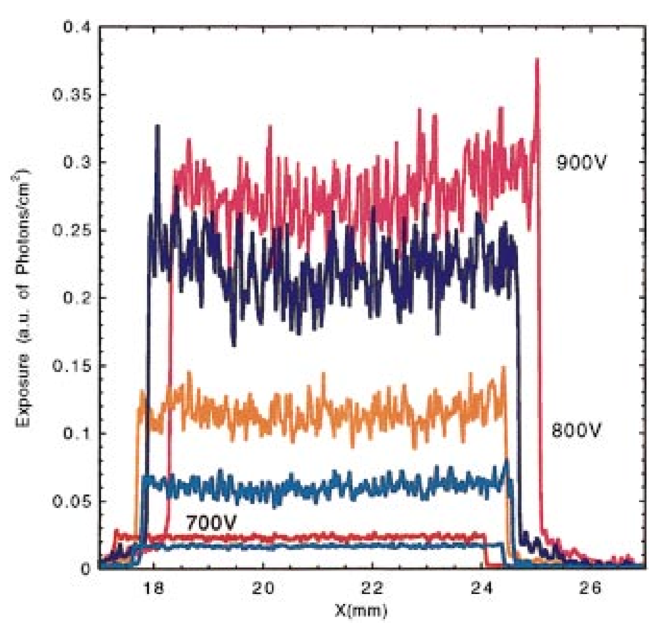

FIG. 5. (Color) Slit apertured exposure with T-3200 film: MCP voltage 700 V, 800 V, and 900 V, 3 kV. LLE developed, leader not relevant, colors give an idea of repeatability.

TABLE I. Summary of the measured response of the film at the three labs for different films. The voltage is the voltage across the MCP. The third column identifies the departure from linearity across the image, and the last column shows the perceived change in gain per 100 V increase across the MCP.

	Voltage	%/mm	Signal	Gain/100 V
TMAX-3200 LANL	700	3.1	.02	1
	800	4.1	.06	3
	900	5.6	.215	3.6
TMAX-3200 LLNL	700	2.8	.017	1
	800	2.5	.075	4.4
	900	4.4	.225	3.0
TMAX-3200 LLE	700	2.11	.019	1
	800	1.08	.13	6.8
	900	2.04	.28	2.2
2484 LANL	700	1.7	.019	1
	800	3.6	.07	3.7
	900	4.0	.25	3.6

films, except the LLE developed film that showed the largest spread, the gain per 100 V increase across the MCP was 3.5 ± 0.5 showing the nonsaturation in the system as measured. Also the different films gave about the same average number of erg/cm^2 of illumination at each gain.

These results have a significant impact on measuring MTF using film. A nonuniform recording or processing modifies the MTF that is recorded at long wavelengths, precisely the region where one has trouble with background. Any results without film development calibration are also affected at long scale lengths, with the effect dependent on film exposure.

IV. CONCLUSION

Since film is still used at many laser facilities to record the output from x-ray instruments, careful attention to the film processing is a necessary part of ensuring accurate measurements of spatially dependent information. Our observation suggests that one not use film unless one calibrates the system in the mode to be used. If one has to use film and wants to get quantitative irradiance data, as some experiments require, then they should not use automatic developing machines unless they are of the kind that emulates hand developing, or better yet develop manually, and be patient while it is developed.

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