Co-timing UV and IR laser pulses on the OMEGA EP Laser System

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ABSTRACT

Independently managing the timing of individual beams so they all arrive at the target within 10 ps of the time specified by the principal investigator is crucial to the success of experiments on the OMEGA EP Laser System. A streak camera is used to observe the x rays emitted when the laser beams strike a gold target, while an optical streak camera is used to measure the UV pulses. Correlating the signal on the two instruments gives a timing accuracy of 10 ps for the short-pulse IR beams and 20 ps for the long-pulse UV beams.

1. INTRODUCTION

The OMEGA EP Laser System at the University of Rochester's Laboratory for Laser Energetics (LLE) is a four-beam, kilojoule-class laser system.[1] The four beams can be configured to produce different pulse shapes with durations ranging from 100 ps to 10 ns and energies up to 10 kJ with a wavelength of 351 nm. Nd:glass amplifiers are used to amplify the optical pulse with a gain peak at 1053 nm. The IR light is converted to the UV via nonlinear optical tripling in two KDP crystals.[2] In additional configurations of OMEGA EP, up to two of the beams may propagate to the target chamber without being converted to the UV. Instead, the IR light passes through a grating compressor[3] and is delivered to the target as a 1- to 100-ps Gaussian pulse with up to 1 kJ of optical energy. The users of this facility can perform experiments where the beams arrive at the target with adjustable relative delays. For OMEGA EP the tolerances on these timings are specified to be 25 ps for both the short-pulse IR beams and the long-pulse UV beams.

If two pulse shapes are identical, a simple overlap would suffice for timing where any feature of the pulse (e.g., the peak or the 50% threshold on the rising edge) can be used for alignment as in shown in Fig. 1(a).

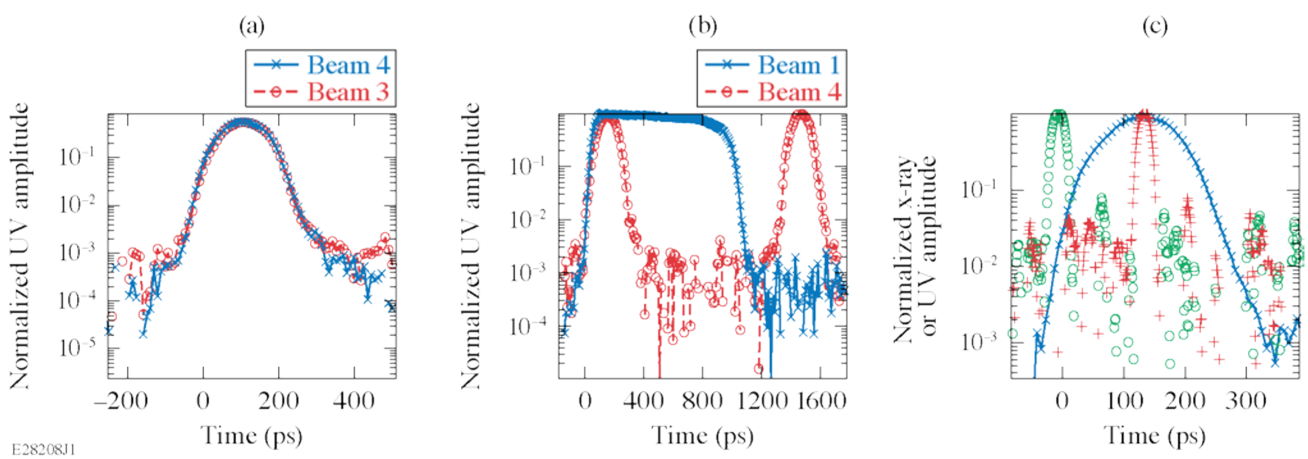

Figure 1. (a) The temporal alignment of two UV pulses with identical shapes. Any point can be used for the alignment. (b) Two dissimilar UV pulse shapes must be aligned by matching equal normalized amplitude points on the rising edge. (c) The UV (blue ×'s) and IR (green circles) are timed such that the peak of the IR pulse coincide with the 2% point of the UV pulse. An alternative timing where the peaks coincide is shown by the red crosses. This timing is not applicable with all UV shapes.

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As soon as the pulse shapes differ, which is the typical case with OMEGA EP shots, the situation becomes more complicated. A 1-ns square pulse does not have an unambiguous peak. Figure 1(b) illustrates that two dissimilar UV pulse shapes are aligned by matching the point on the rising edge, which is 2% of the peak intensity of that pulse. In the UV streak cameras used for these measurements,[4] the 2% point is well above the noise floor, leading to reliable and repeatable timing measurements. When OMEGA EP is configured to run with both IR and UV pulses, we encounter the problem that the different wavelengths cannot be viewed with a single instrument that has sufficient bandwidth to resolve both optical pulse shapes. At 1053 nm, very few instruments can resolve temporal structure on a 1- to 10-ps pulse. Figure 1(c) illustrates the timing of the 100-ps UV pulse with the x rays generated by a 10-ps IR pulse. Two alternative timing are shown for the IR pulse. The red crosses show the peak of the IR pulse at the peak of the 100-ps UV Gaussian. The green circles show the peak of the IR pulse coinciding with the 2% point on the leading edge of the UV pulse. The green circles illustrate the actual timing on shot.

Given that alternative timing schemes are possible, the OMEGA EP Laser System has adopted the following conventions for co-timing the various beam configurations. UV pulses are considered to be co-timed when the points on the rising edge, corresponding to the 2% level of the peak, reach the target simultaneously. For the IR beams, co-timing means that the peak of the Gaussian pulse shape arrives at the target simultaneously, regardless of the width of the pulses. When both IR and UV pulses are co-timed, the peak of the IR Gaussian is aligned with the 2% point on the rising edge of the UV pulse. Of course, any of the beams can be mistimed to produce the arrival times desired by the principal investigator, but the mistimings are always specified relative to the timed definitions.

This paper describes a system for verifying and maintaining the timing of the OMEGA EP Laser System. The optical pulses are recorded on streak cameras and photodiodes. The arrival times at the target chamber are determined by having the optical pulses strike a gold-coated sheet of plastic at target chamber center (TCC). The x rays generated by the optical beams striking the target are monitored with a streak camera as shown in Fig. 2. The relative timings of the beams are then adjusted to achieve the specified co-timing conditions.

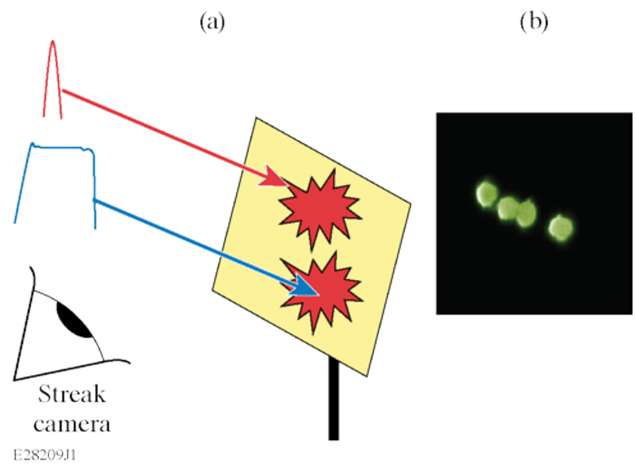

Figure 2. (a) The optical pulses, both UV and IR, are timed by observing the simultaneous temporal histories of the x ray generated when the pulse strikes a gold target. (b) A time-integrated x-ray pinhole camera image of a target being illuminated by four UV beams.

2. METHODOLOGY

The co-timing system begins by recording the UV pulse shapes on an optical streak camera similar to the one described in Ref. 1. The four UV beams can be spatially multiplexed onto the S-20 photocathode of the streak camera. The UV signals are derived from a pickoff in each beamline before it enters the target chamber and are transported to the camera via a high-bandwidth, UV optical fiber.[5] The signals arrive at the streak cameras arbitrarily but at deterministic and reproducible times resulting from the optical-path differences from the pickoff. The time base of the camera is calibrated by illuminating a portion of the photocathode with a 2-GHz optical comb pulse that establishes the number of picoseconds per pixel across the streak-camera image. In general, the sweep is not uniform in time, and the variations in the comb pulse are used to remove the temporal irregularities. Also recorded on the streak camera is an eight-pulse, 1.8-GHz comb pulse tied to the master clock of the OMEGA EP Laser System. This fiducial links the measured optical pulse to the outputs of the other diagnostics on the system, thereby enabling one to convert the relative timings measured on the streak camera into absolute system times.

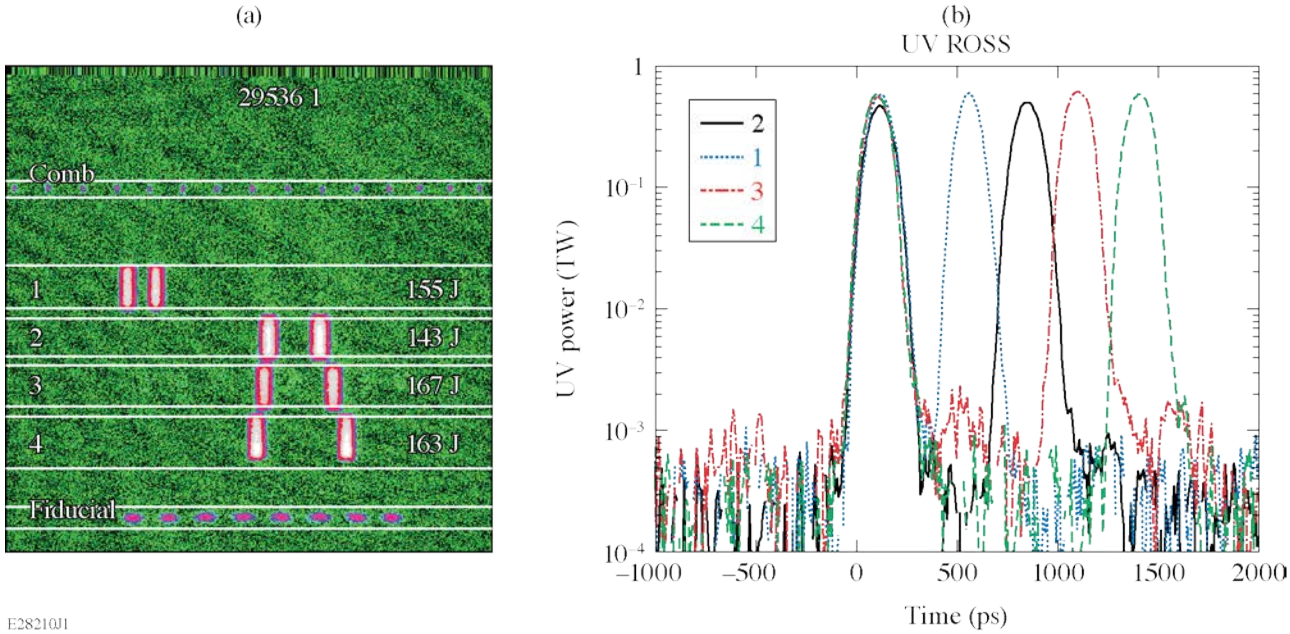

Figure 3. (a) The raw image from the UV streak cameras showing the four double-Gaussian pulse shapes and the two timing comb pulses. (b) The integrated lineouts of the four beams with the calibrated temporal alignment applied.

When taking system timing shots, the UV pulse shapes are always a series of two Gaussian pulses that serve a number of purposes: First, the peaks of the UV pulses can be easily correlated with peaks of the corresponding x-ray pulses. Second, as will be discussed later, the x-ray peaks that they generate can be used to absolutely calibrate the time base of the x-ray streak camera. Finally, since there is noise on both the x-ray and optical streak cameras, trying to pick a single point on a waveform is problematic. It is easy, however, to fit a Gaussian to both the measured UV and x-ray pulses. The parameters of those fits can be used to determine the temporal positions of both the peak and the 2% point on the rising edge. Effectively, we are averaging about 20 data points to determine those positions.[6] This is particularly important in the x rays where the 2% point is at or below the noise floor of the data, as shown in Fig. 1(c). The UV timing shots set the timing among the four beams. When the short-pulse IR timing shots are taken, at least one long-pulse UV is also fired, setting the IR timing relative to all the other UV beams. Since the short-pulse IR beams do not have the same flexible pulse-shaping capabilities as the UV beams and are assumed to be Gaussian, there is no need to precisely measure the IR pulses on a streak camera. A low bandwidth measurement with a photodiode and an oscilloscope is all that is necessary to simply establish a temporal offset with respect to the fiducial. However, all of these optical measurements, derived from pickoffs, do not convey any information about the arrival times at TCC. The arrival times at TCC are determined by x rays measured on the streak camera.

The PJX x-ray streak camera, developed at LLE,[7] allows for an x-ray pulse measurement with picosecond time resolution and can be mounted in a ten-inch-manipulator (TIM) directly on the OMEGA EP target chamber. Figure 4 shows the output image of the PJX streak camera for the two different timing configurations.

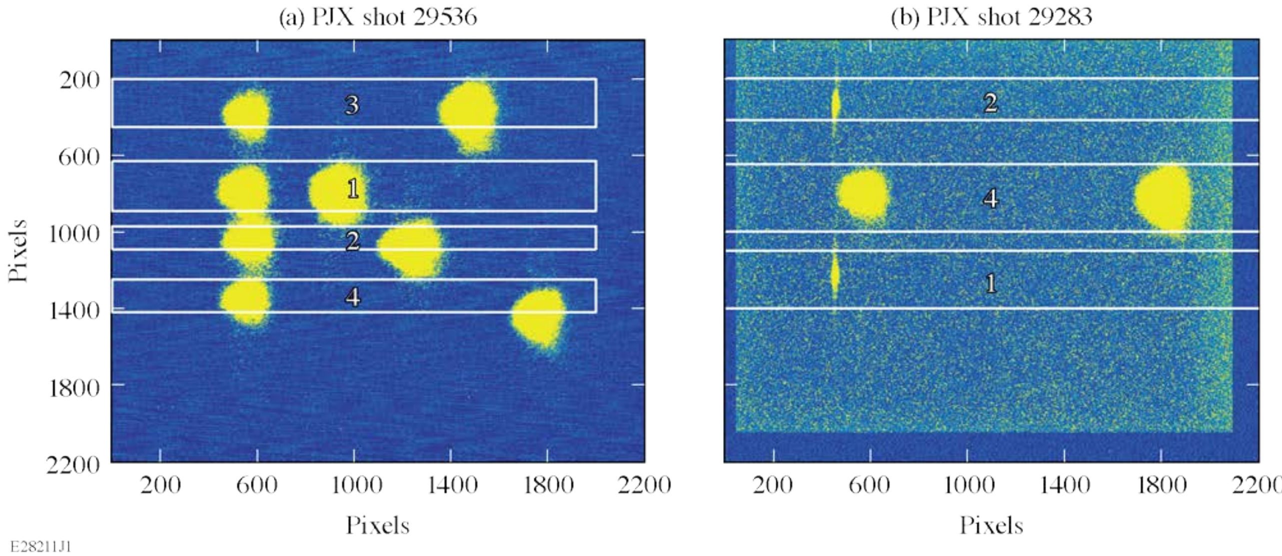

Figure 4. (a) The x-ray streak-camera image of a four-beam, long-pulse shot showing eight pulses from the four beams. (b) Two short-pulse IR beams and one UV beam strike the target. The temporal calibration is ~1 ps per pixel.

If the system is properly co-timed, the leading x-ray image of each of the four UV beams, shown in Fig. 4(a) should align in the temporal (vertical) direction. In the short-pulse to long-pulse configuration, shown in Fig. 4(b), the peaks of the two short-pulse beams should align with the 2% point on the leading edge of the long-pulse UV beam. Exact timing at the picosecond level requires a quantitative analysis of these images.

Notice in Fig. 4 that there are no timing fiducials. Those fiducials are in the visible portion for the electromagnetic spectrum and cannot excite an electron from the x-ray photocathode. Instead the UV beams define the time base and act as the timing fiducial. A lineout of each beam is produced by integrating vertically over the boxes in Fig. 4. Then the peaks of the eight x-ray pulses in Fig. 4(a) can be associated with the UV peaks in Fig. 3(b). The separations between the peaks establish the number of picoseconds per pixel across the image. The anchor point between Figs. 3(a) and 4 is the first peak of Beamline 4; that peak is timed by definition. The 2% point on the rising edge before that UV peak is defined to be the zero of both images. The peaks of the UV and x-ray pulses are assumed to be coincident in time. The discrete picosecond-per-pixel data are extended to the entire horizontal axis by using a spline fit. Integrating that fit produces the time base, and the anchor point specified above is used to set the zero of the time axis.

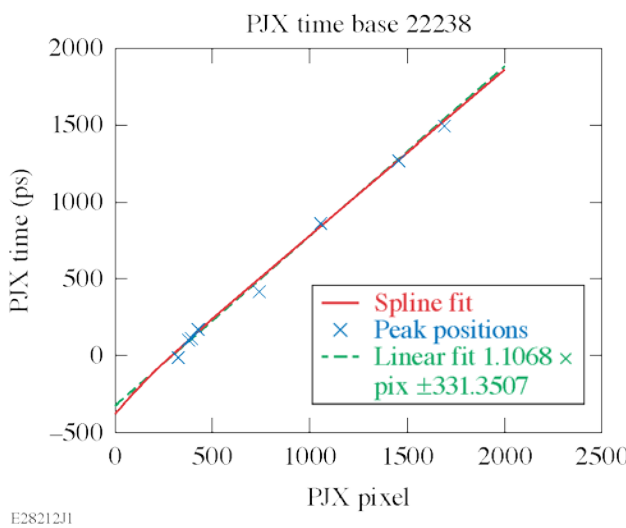

Figure 5. The time base generated by long-pulse UV timing.

The target consists of a 25-μm-thick, 3-mm × 3-mm sheet of polyimide coated with 0.5 μm of gold. As seen in Fig. 1(b) the beams are spatially distributed in a line across the target. The extent of the line is dictated by the field of view of the PJX x-ray streak camera and the need to separate spots by at least their respective diameters. From the image in Fig. 1(b), a lineout through the spots indicates that the diameters are ~200 μm. The total energy in each UV beam is ~170 J, giving ~85 J in each of the two 100-ps Gaussians; therefore the total intensity is ~5×10^{15} W/cm^2. At this intensity, at 351 nm, the temporal profile of the x-ray pulse matches that of the UV pulse as seen in Fig. 6. The x-ray temporal pulse shape matches the measured UV pulse shape. At intensities below 10^{14} W/cm^2, the emitted x rays typically follow the UV power to the 3.4 power.[8] When the UV optical power is raised to 3.4 power, the power-law conversion obviously does not match the x-ray temporal profile. This is advantageous in processing the data because when the x-ray and UV peaks are aligned, the 2% points on the leading edge, which are the actual timing points, are also aligned.

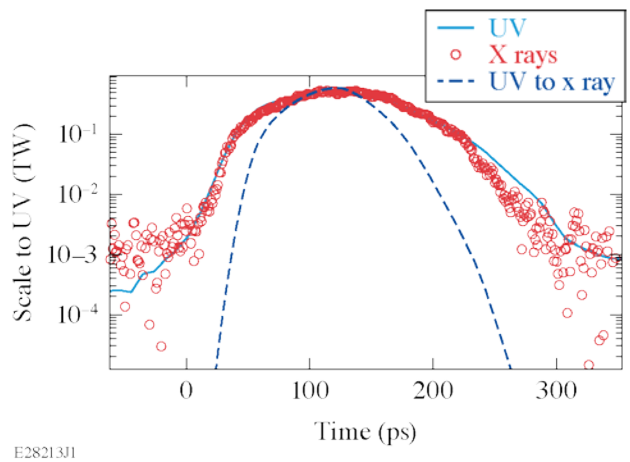

Figure 6. The x-ray temporal pulse shape (red circles) matches the measured UV pulse shape (solid blue line). The dashed blue line is the UV optical power raised to 3.4 power, which is typical of UV to x-ray conversion at lower powers and obviously does not match the x ray at these intensities.

This is particularly important when timing the short-pulse beams. The IR pulses are treated differently. The shortest pulse duration, 1 ps, is at or below the resolution limit of the PJX streak camera, so the timing campaigns operate with IR pulse durations of 10 ps at best focus of the laser system. No sub-structure can be discerned in the x rays generated by the IR pulses. The IR x-ray data are simply fitted with a Gaussian to find the peak. It is worthwhile to note that in Fig. 1(c) the 2% point on the IR-generated x ray is at or below the noise floor, making that point inaccessible.

3. RESULTS AND CONCLUSIONS

The UV-to-UV and UV-to-IR timing campaigns are run every three months, typically with a three-month separation between the two types of campaigns. The typical variations are less than the 20 ps, which is actually better than the current OMEGA EP timing specification of 25 ps for all beams. Therefore the OMEGA EP Laser System maintains a beam-to-beam timing of 20 ps by simultaneously measuring the optical pulse and the x rays generated when that optical pulse strikes a gold target. By operating in a high-intensity regime, the x ray's pulse shape closely tracks the optical pulse, which facilitates the timing.

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