SYDOR TECHNOLOGIES

COMPLEX MEASUREMENTS—CRITICAL RESULTS

Pulse Dilation: Overview of Techniques & Applications

INTRODUCTION

Background: Inertial Confinement Fusion

During Inertial Confinement Fusion (ICF) experiments, a small fuel capsule containing Deuterium and Tritium is compressed and then heated by radiation to create pressures and temperatures capable of initiating the fusion process. The radiation is either directly or indirectly created by numerous pulsed terawatt lasers and experiments (shots) last on the order of tens of nanoseconds, ultimately ending with capsule destruction. In order to optimize the various steps in the implosion process (pulsed power, laser-drive, hohlraum-based indirect drive) scientists need to be able to analyze data from multiple sources during each shot. The ability to analyze with high time resolution is critical for comparison of experiments with models. Two informative parameters for fusion experiments include the symmetry of the implosion and the implosion velocity.

Many diagnostics used at ICF facilities rely on the conversion of an input photon image into an electron image at a photo-cathode. The input image may be formed either by X-rays or lower energy photons and the resulting electron image can be gated or deflected rapidly by the application of electrical signals. This allows the temporal evolution of the input image to be extracted. The resulting swept or gated image may be amplified by an MCP and then recorded using a solid state detector, such as a CCD with or without a phosphor, or a film paired with a phosphor. ICF experiments have high neutron and gamma ray yields, reducing the SNR of many diagnostics and making others unusable. Ruggedized diagnostics require fast, high voltage switching to achieve high time resolution, and common x-ray imaging diagnostics provide time resolution around 30-100 picoseconds (ps) in these environments [1,2,3].

Implementation

To assist with the improvement of the temporal resolution requirements of ICF experiments, Kentech has developed novel pulsers for implementation in various diagnostics to provide pulse-dilation capabilities. The use of pulse-dilation to enhance time resolution, which is essentially the opposite of bunching in particle accelerators, was first proposed in the 1970's [4]. The use of this in an imaging system was proposed more recently and has been exploited in several high-speed imaging and detection systems [5,6]. This technique dilates a photoelectron bunch inside a diagnostic, essentially creating a temporal magnification of the signal carried by photoelectrons. As well as contributing to the electron optical design, Kentech has developed programmable high voltage pulse shaping techniques and has built pulsers for pulse-dilation instruments in use at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory and the OMEGA laser at the Laboratory for Laser Energetics. This technology has been applied on three key diagnostics—the DIlation X-ray Imager (DIXI) [7], the Single Line of Sight (SLOS) X-ray detector [8] and the Pulse Dilation Photomultiplier Tube (PD-PMT) [9]. Figure 1 details an overview of the pulse dilation technique as applied to DIXI in which an X-ray exposure time of 10 ps has been demonstrated.

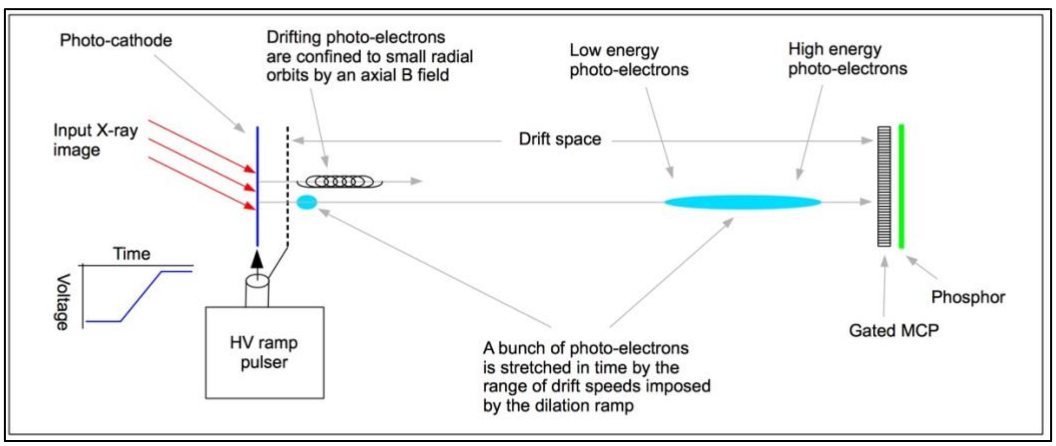

Figure 1: Cartoon of pulse dilation technique [4,5,6]. Incident x-rays generate electrons on a photocathode. A non-linear voltage pulse accelerates electrons with a time-dependent ramp. Electrons linearly spread through the drift space, creating a magnification of up to 50x.

Hardware: Kentech Pulser

In order to produce a constant temporal magnification a shaped ramp potential must be applied to the photo-cathode. The Kentech pulser combines a number of high-speed voltage step pulses, each with programmable delay and amplitude, in order to shape the final voltage rise. This shaping is adjustable on a timescale of 100 ps and programmable fast rising pulses can be generated at an amplitude of >3 kV. This shaping plus low trigger jitter is important for maintaining constant temporal magnification and detector timing and has led to the exceptional temporal performance of the SLOS and PD-PMT instruments.

Brief descriptions of the three diagnostics in which pulse dilation has been implemented are presented.

DILATION X-RAY IMAGER (DIXI)

Figure 2: DIXI installed at the National Ignition Facility [10].

The DIXI, seen in Figure 2, is an X-ray imager capturing a sequence of short duration X-ray images formed by an array of pinholes. In this first implementation of a pulse dilation X-ray framing camera, multiple images from the pinhole array are formed in different positions on each of four photo-cathode strips. A high potential on the cathode accelerates electrons which then drift through the device and a gated MCP at the rear captures electrons which arrive at a particular time with respect to the initial X-ray exposure. This effectively forms an energy selector as the energy of a drifting electron determines its arrival time and this drift energy may be chosen by setting the MCP gate delay.

The Kentech dilation pulser produces four ramp signals which are propagated across each of the four cathode strips. The time at which any given part of the photo-cathode reaches the chosen drift energy determines the time at which a frame is captured so the combination of transit time along each cathode strip and different pulser delays between each strip allows a sequence of very short exposure images to be captured [7]. The DIXI has been used to stretch an input signal by a factor of up to 50x. This maps a 10 ps input signal to a 500 ps electron bunch at the fast gated MCP, so producing the 10 ps gate. The MCP output is converted to light at a phosphor, coupled to a relatively slow CCD camera and the resulting output image can be mapped back to the signal at the photo-cathode to yield a super-fast X-ray 'movie'.

SINGLE LINE OF SIGHT (SLOS)

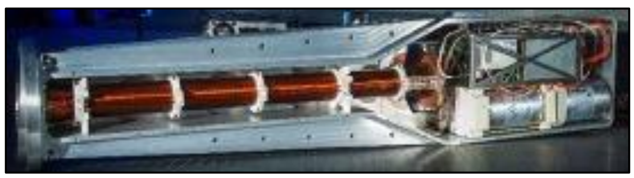

Figure 3: A side view of a fully-assembled SLOS imager prior to implementation at the OMEGA laser [8].

The SLOS detector, shown in Figure 3, operates with a similar technique as DIXI, but it is able to record multiple snapshots from the same line of sight, avoiding the introduction of parallax between recorded images (a major issue for back lit objects). SLOS benefits from an electron sensitive burst-mode CMOS hybrid image sensor (hCMOS) developed at Sandia National Laboratory by hybridizing silicon photodiode wafers to readout integrated wafers [8,11,12]. The hCMOS is able to capture multiple frames of data, but it has a limited gate speed of ~1 ns. The Kentech dilation pulser stretches time at the photo-cathode by a factor of ~20 which has successfully been used in combination with the hCMOS sensor to allow the SLOS camera to capture short exposure images 100 ps apart. As the SLOS captures signal on a single line of sight, requiring only one image formed at its photocathode, it is important that the image gating is spatially invariant across the photocathode. To accomplish this a dilation pulser was built to produce two counter-propagating linear ramp signals at the photocathode to produce a substantially uniform voltage history across the whole photocathode. In order to record data with a uniform dilation factor, however, non-linear ramps are required. The programmability of the photocathode ramp shape allows the temporal magnification to be held constant throughout the exposure time. The SLOS magnification was selected to allow a constant dilation factor with an approximately spatially invariant gate along the photocathode [8].

PULSE-DILATION PHOTOMULTIPLIER TUBE (PD-PMT)

Figure 4: A side view of the detector component of a PD-PMT [13].

The implementation of pulse dilation on a photomultiplier tube to form the PD-PMT, as pictured in Figure 4, required modifications to the electron optics within the PMT envelope. A long (~0.5 m) drift section is introduced between the photocathode and the MCP and an axial magnetic field is applied to confine the drifting and dilating electron signal to a sufficiently tight enough radius to overlap with the MCP at the end of the drift section. Spatial invariance across the photocathode is achieved with multiple feed points around the photocathode. The stretched electrical output signal is recorded on an oscilloscope. The temporal magnification can be set in the range 2 - 40 via the programmable ramp pulse shaping provided by a Kentech dilation pulser. This system has demonstrated a temporal resolution of <15 ps for a 400 ps duration optical signal at the photocathode [9,14].

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