A Low Cost Time Resolved Spot Diagnostic for Flash X-ray Machines

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ABSTRACT

AWE has embarked on a programme to develop an improved intense electron beam diode for flash x-ray radiography machines. In order to understand the performance of the diode and to validate computer modelling codes, there is a requirement to obtain time resolved x-ray spot size and position data during the 50 ns electron beam pulse.

A simple, low cost, time resolved spot diagnostic has been designed in collaboration with Photek Limited. The system is based around number of identical, single frame, fast gating intensified CCD camera modules viewing a very fast organic scintillator. Each camera has an independent internal delay generator and a microchannel plate intensifier (MCP) capable of gate widths down to 1 ns. The complete system is battery driven and controlled remotely via optical fibres to provide electrical isolation and reduce Electro Magnetic Interference (EMI) susceptibility.

An initial four frame system (easily extendable to 8 frames and beyond) has been developed and deployed successfully on one of AWE's flash x-ray machines.

Keywords: ICCD, Flash X-ray, Microchannel Plate, Organic Scintialltor

INTRODUCTION

AWE has a requirement for transmission radiography of dense, explosively driven objects. In order to provide optimum beam penetration of the object, high energy flash x-ray machines are used. A programme of work is currently underway to improve the design and performance of these machines. Time resolved x-ray spot size and position information during the 50 ns x-ray pulse would provide invaluable data to verify electron beam diode behaviour and indicate modelling and diode improvements.

CAMERA DESIGN ISSUES

Camera design requirements were to provide a robust, simple to operate and portable system with adequate sensitivity (governed by the photocathode efficiency) and a gate time of approximately 1 ns.

The high electron beam energy of the x-ray machines (several MeV) coupled with the high currents (tens of kA) necessary to produce the required dose levels (a few hundred R at a metre) implies an extreme electro-magnetic (EM) environment. To minimise EMI susceptibility, the cameras are capable of being operated from internal batteries and all input and outputs are via optical fibres.

While it would have been possible to use a beam splitter and multiple camera heads, it was decided that it would add to system flexibility to make the cameras as small as possible, so that they could be stacked together – 2 x 2, 3 x 3 etc. with their own individual objectives lens and iris. Photek designed and developed a new ultra-fast ICCD camera to meet these general requirements. Designated ICNSGC, (Intensified Camera Nano Second Gating Controller) the camera modules are 111 mm square, including a substantial battery pack, on-board timing electronics and fibre optic interfaces.

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A block diagram of the camera is shown in Figure 1 and highlights the four main modules of the camera; the intensifier and CCD module, gating control module, digital interface module and the power management module.

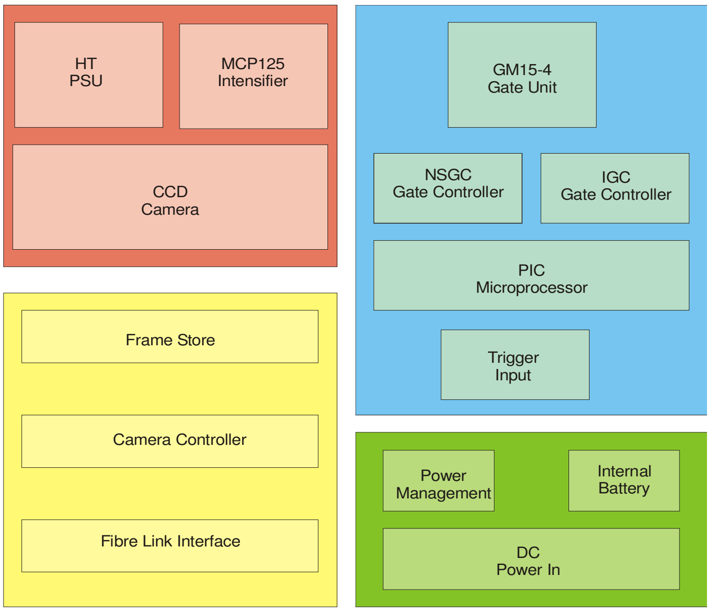

Fig. 1. ICNSGC Block

INTENSIFIER AND CCD MODULE

A 25 mm diameter microchannel plate intensifier (MCPI) is used to provide a gain of up to 1000 W/W as well as gating. The phosphor screen output from the image intensifier is coupled to a 768 x 576 pixel Sony ICX083AL CCD sensor by a reducing fibre optic taper. To achieve useful time resolved data, gating times of ~2 ns were required. In order to meet this requirement, the image intensifiers use conventional semi-transparent metal under layers. Cathode sensitivity is reduced by about 50% when using these under layers. However, initial AWE calculations indicated that sufficient system sensitivity would be obtained with a photocathode efficiency of 5-10%. Shorter exposure times could be achieved with mesh under layer and a faster pulse generator, however, all cameras easily met AWE requirements, consistent with the 1.4 ns decay time of the BC422 organic scintillator [1].

GATING CONTROL MODULE

Both exposure time and internal camera delay can be set in 250 ps steps initiated from an external trigger using a parallel delay line technique. (NSPG Mode) Although the jitter on these settings could (in principal) have been ± one step, it proved difficult to achieve better than ± two steps (500 ps). The timing jitter achieved was nominally 1 ns, or better. The maximum gate time achievable with this degree of precision is 1 µs. For longer gate times and delays, a 100 MHz clock system is built into the camera, enabling exposures between 1 µs and 20 ms to be set-up in 10 ns increments. (IGC mode) Obviously, the timing jitter is also degraded, to ± 10 ns, with this type of control system.

Inherent delay inside the camera, from receipt of trigger to camera shutter open is 160 ns. Longer delays can be programmed from the PC.

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Each camera has a trigger monitor output which can be used to identify precisely when each gate unit fires. Figure 2 show the trigger monitor outputs from four cameras each with different exposure times. Figure 3 shows a 2 ns FWHM intensifier gate pulse generated by the NSPG pulse generator. Jitter is measured at 400 ps in the NSPG mode and 10ns in the IGC mode. Figures 4 and 5 show histograms of the jitter performance.

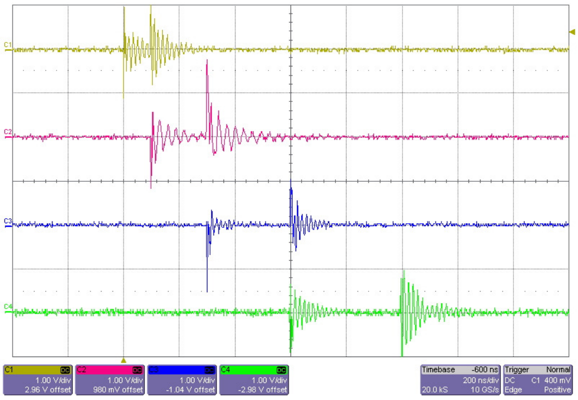

Fig. 2. Gate monitor output from four cameras

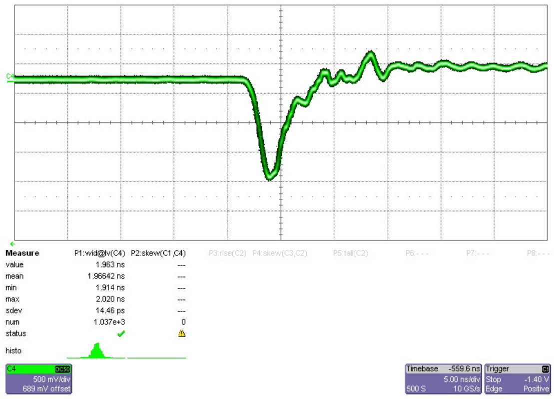

Fig.3 2 ns FWHM intensifier gate Pulse

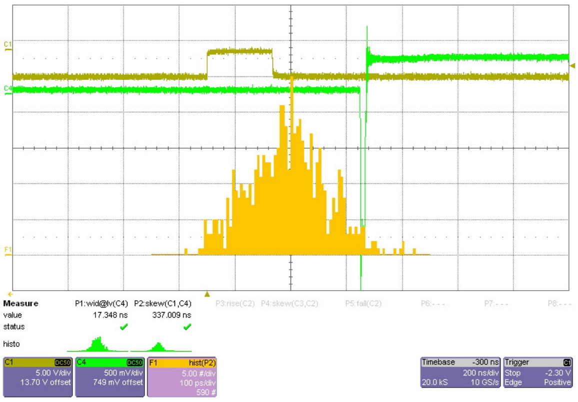

Fig. 4. NSPG gating mode (100 ps/div)

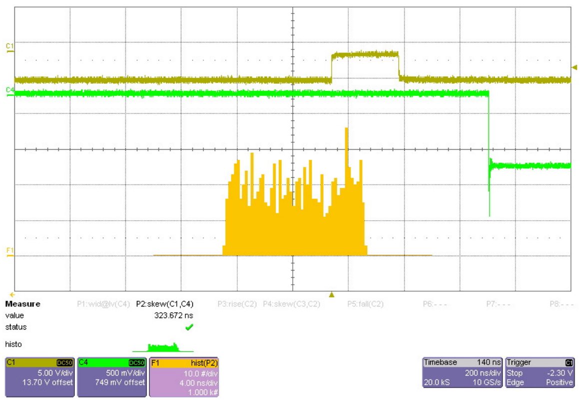

Fig.5 IGC gating mode (4 ns/div)

DIGITAL INTERFACE MODULE

The system supports a novel “ring” technology enabling up to 254 cameras to be cascaded together dramatically reducing the cabling and computer interface requirements. Each camera has its own 8 bit address code to identify itself to other cameras and the PC. The output from one camera feeds into the next in the sequence with only two cables connecting to the PC interface

A pre trigger pulse (>20 ms in advance of the gate trigger) is required to arm the CCD camera. Full video data including sync and black level pedestals are six times over sampled to 10 bits accuracy and is stored in a 2 Mb frame buffer. Once data has been captured the PC may request image data from any of the cameras currently in the ring. The software on the PC computer detects synch and black level from the raw video data and assembles the data into a 768 x 576 pixel image The 6X over sampling allows accurate detection of sync pulses and allows six digitised data values to be

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averaged for each pixel thus improving the signal to noise ratio (SNR) of the resulting image. The same fibre optic interface allows commands to be sent from the PC computer to set exposure, delay and gain of the intensifier.

As each camera has a built-in frame store, any number of camera images can be read sequentially to the host PC, which can be up to 200 metres away.

POWER MANAGEMENT

The EMI radiation inevitably associated with the use of high energy flash x-ray generators causes havoc with electronic systems (such as cameras and computers) located in proximity. To help reduce interference one of the design possibilities was to house the cameras within a Faraday cage. For this to work successfully, it was decided that the all interfaces to the camera would be via fibre optic cables and that the camera would be capable of operating from an internal battery supply. Prior to taking an exposure, the system is switched from mains power to battery operation. Relays are used to isolate external power supplies. The cameras operate for up to 40 minutes from a fully charged set of batteries. Once the PC has acquired the image the camera automatically switches back to external power.

SYSTEM CONFIGURATION

Figure 6 shows the four frame system configuration. The very fast organic scintillator, Bicron type BC422, converts incident x-rays into light. This light is focused onto the ICNSGC photocathode via an entrance lens. A mirror is used such that the sensitive CCD and MCP can be placed outside of the direct x-ray beam.

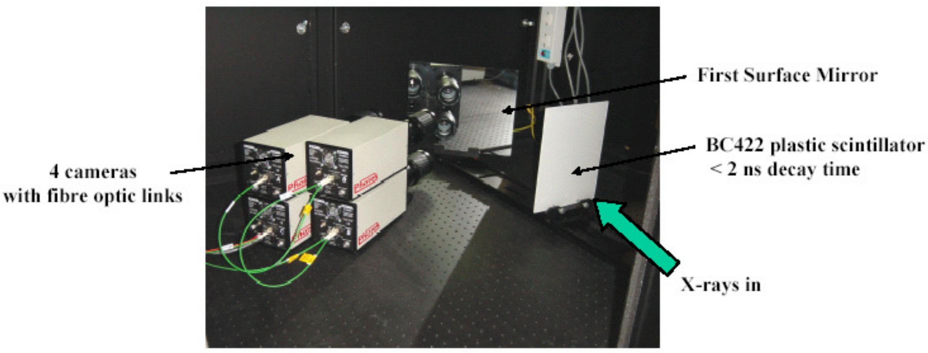

Fig. 6. Camera System Configuration

Flash x-ray machine spot size can be determined from an image encoded by a 2D rolled ‘knife edge’. This edge spread image can be analysed to produce line spread and modulation transfer function (LSF and MTF) data as required.

SPATIAL RESOLUTION

The optical image is transferred to the camera using a 28 – 200 mm zoom lens allowing flexibility of camera position relative to the scintillator. At an optical magnification of 0.1, the system MTF corresponds to 10% for 1.7 mm features, and 50% for 5 mm features, at the scintillator, respectively.

The system sensitivity is limited by the need to use a fast organic scintillator, which has a small cross section for high energy photons. The system spatial resolution is also limited by energy spread within the scintillator and a thickness of 3 mm was chosen to achieve a balance between sensitivity and resolution. A large radiographic magnification (Y/X), of typically 4 – 10 is used to minimize the effects of detector resolution.

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EXPERIMENTS AT THE EROS AWE FACILITY

The camera system has been used to successfully image a self magnetic pinch diode shot on the EROS facility at AWE. EROS is a 5 MV, 14 Ohm driver delivering typical spot sizes of 3 - 4 mm with a dose of about 80 R at a metre in ~50 ns. Figure 8 shows the experimental set up.

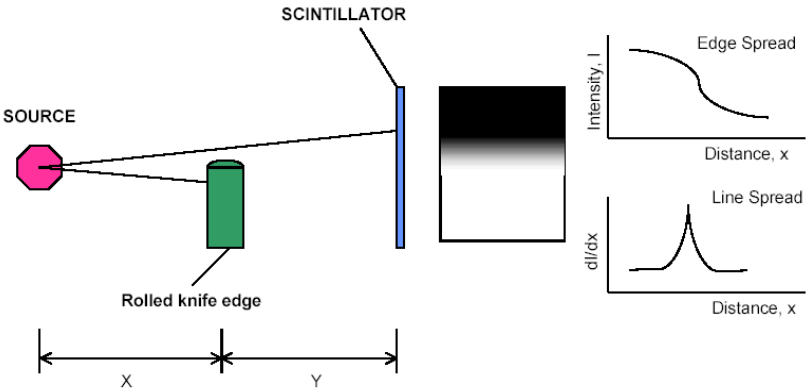

Fig. 7. Spot Size Measurements

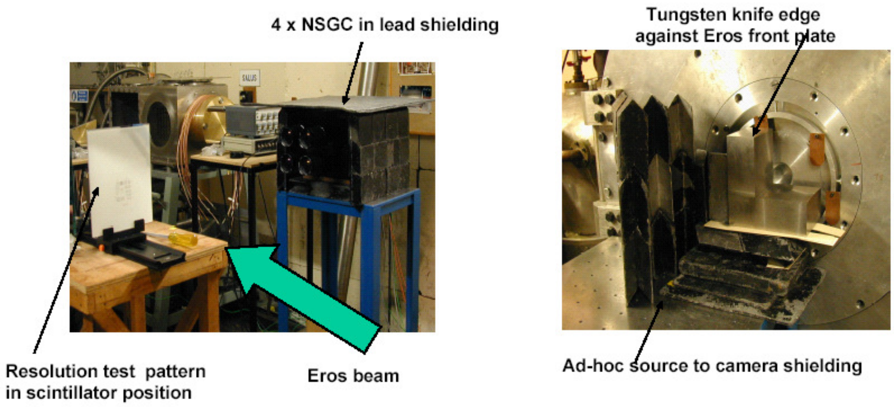

Fig. 8. EROS Experimental Set Up

EMP/EMI has been well suppressed however, substantial lead shielding around the cameras is required to minimise the effects of scattered x-rays on the sensitive CCD and MCP.

Figure 9 shows three 4 ns gated images with a 15 ns separation obtained from a self magnetic pinch diode fielded on EROS Shot 34007, together with an integrated exposure (Camera A). Figure 10 shows the camera gate times relative to the recorded x-ray pulse.

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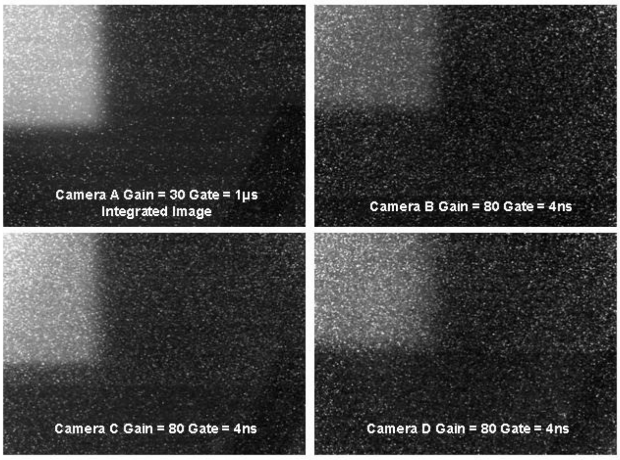

Fig. 9. Images from a 2D rolled knife edge at EROS Shot 34007

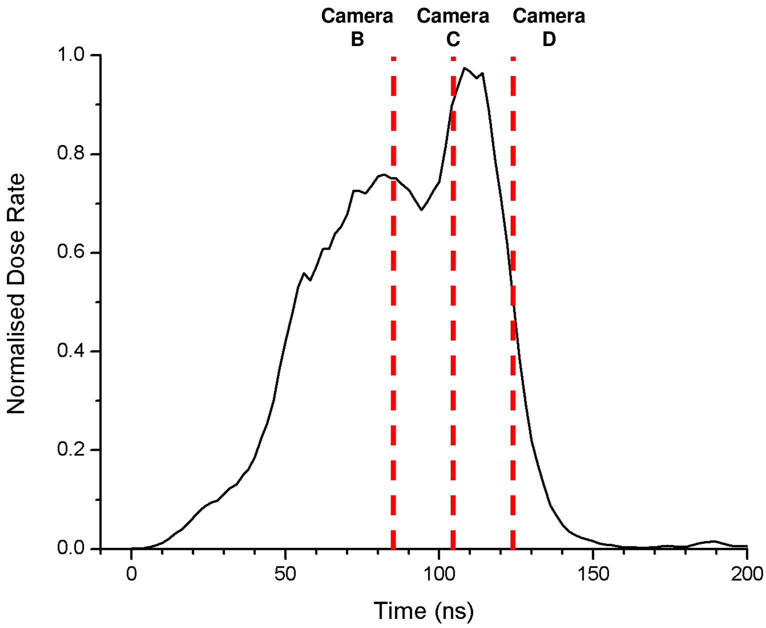

Fig. 10. Camera gate times relative to x-ray output.

These images were subsequently corrected for camera and scintillator non-uniformities. Fiducials were used in the field of view so that the source position could be accurately monitored for each time resolved image. The line spread data shown in Figure 5 was obtained by differentiating the edge spread data from each image. This limited data suggests that whilst the x-ray spot dimensions are asymmetric, there is a fairly consistent spot size and position during the pulse.

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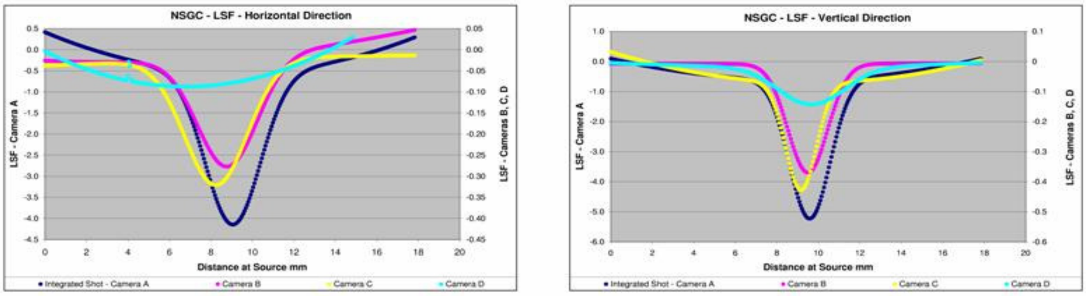

Fig. 11 Line Spread Data from EROS Shot 34007

SUMMARY

A relatively low cost time resolved spot diagnostic for use in flash x-ray machine research at AWE has been developed. Battery operation and fibre optic connections reduce electro magnetic interference from high power x-ray machines. The system is modular allowing easy integration of up to 254 cameras. Each camera is capable of gating times down to 1 ns. Initial measurements at the EROS flash x-ray facility at AWE has provided useful time resolved data. This system will become an invaluable diagnostic in the verification of intense electron beam diode behaviour.

REFERENCES

[1] Scintillation Products – Organic Scintillators. Saint-Gobain Crystals and Detectors. 2001.

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