PULSED POWER DRIVEN FLASH X-RAY SOURCES FOR THE HYDRUS PROJECT AT AWE

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Abstract

The Hydrus project will provide an enhancement of the flash radiographic diagnostics available in the Hydrodynamics Department at AWE as part of new facilities for hydrodynamics research. The X-ray sources for the experiments carried out at AWE are provided by focused electron beam diodes driven by pulsed power accelerators. A design for a 10 cell IVA (Induction Voltage Adder) has been completed by L3 Communications Pulse Sciences [1] for AWE and three such machines are about to be manufactured to provide the main radiographic capability in the new facility. Research currently being conducted by AWE and international collaborators aims to also develop improved electron beam diodes to meet the requirements for higher radiographic resolution being demanded. The short term radiographic requirements have been demonstrated with a Self Magnetic Pinch Diode [2] driven by the RITS 6 accelerator at SNL [5].

Other experiments performed at AWE require a softer X-ray spectrum and hence a lower voltage pulsed power driver, two of which will be provided in a second area of the same facility. It has been determined that the optimum radiographic source will have a sub-100 ns pulse , a diameter of 1 mm or less, an X-ray dose of at least 15R at 1 metre and an X-ray spectrum end point energy of 1-1.5 MeV. An electron beam diode that has demonstrated performance of this order is the plasma filled rod pinch [3] driven by the Gamble II accelerator at NRL.

In order to deliver these improved radiographic sources into AWE, a significant increase in internal Pulsed Power capability is required. This uplift represents a significant investment to ensure that AWE has the capability to operate, maintain and improve radiographic sources well into the future. A further 30 pulsed power scientists, engineers and technicians will be recruited over the next few years.

I. INTRODUCTION

The Pulsed Power Group at AWE is involved in a major uplift of the hydrodynamics diagnostic capability for supporting stewardship of the UK nuclear deterrent stockpile. While the current facilities for flash radiography of hydrodynamics experiments at AWE are world class in terms of their performance [8] the aim in the new and refurbished facilities will be to improve even further on that capability. The majority of future trials will be conducted in the new facility to be built as part of the Hydrus project. Improved Pulsed Power machines and E-beam diodes are being developed to provide the enhanced flash X-ray sources required both for this project and to meet longer term goals.

A Pulsed Power strategy has been developed to deliver the necessary capability to achieve not only these aims but also the application of Pulsed Power to other nuclear weapon problems e.g. materials and shock physics.

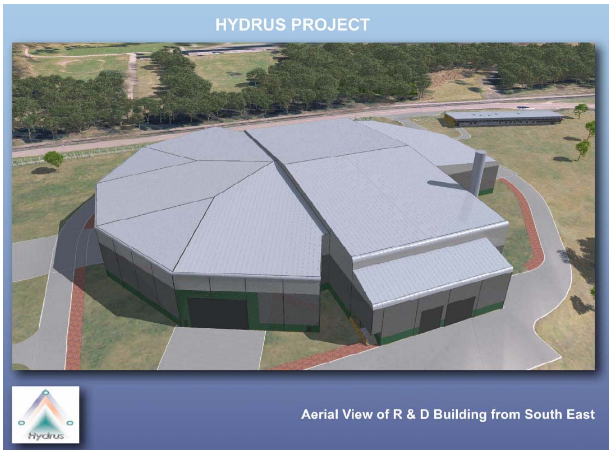

Figure 1. The Hydrus Facility

II. PROJECT HYDRUS

The Hydrus project will provide an integrated facility (Fig. 1) with a hardened structure for hydrodynamics experiments and with a range of diagnostics but principally 3 axis radiography of thick objects in one chamber and 2 axis radiography of thin objects in the other. The 3 axis chamber will have three IVA machines (Figs. 2 & 3) designed for AWE by L3-Communications Pulse Sciences Division. The two axis chamber (Fig. 4) for thin object radiography will have two lower voltage pulsed power machines (LVPPMs) for which contracts for design and manufacture are yet to be placed.

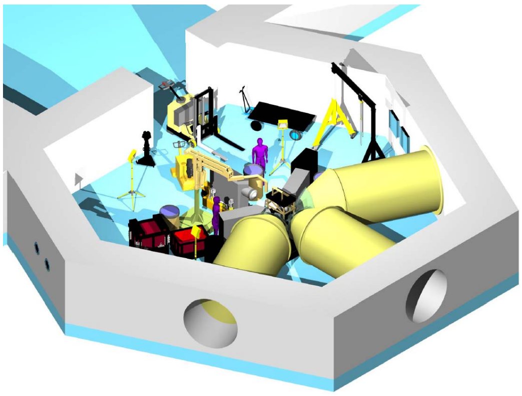

Figure 2. The 3 view chamber.

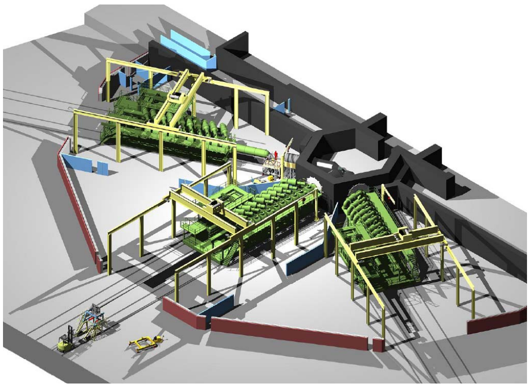

Figure 3. The IVA Halls.

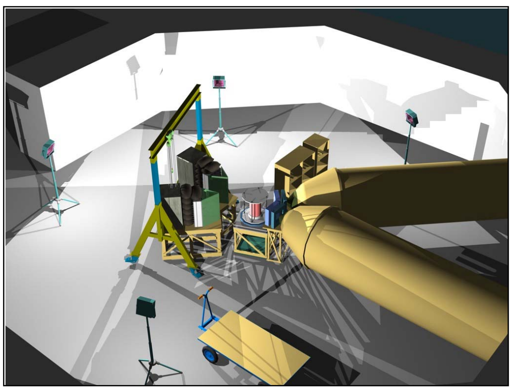

Figure 4. The two view chamber.

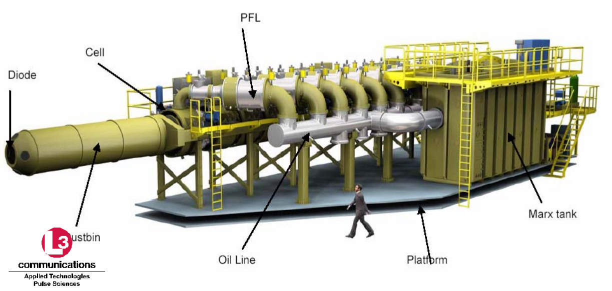

Figure 5. The IVA designed for AWE by L3-Communications Pulse Sciences Division.

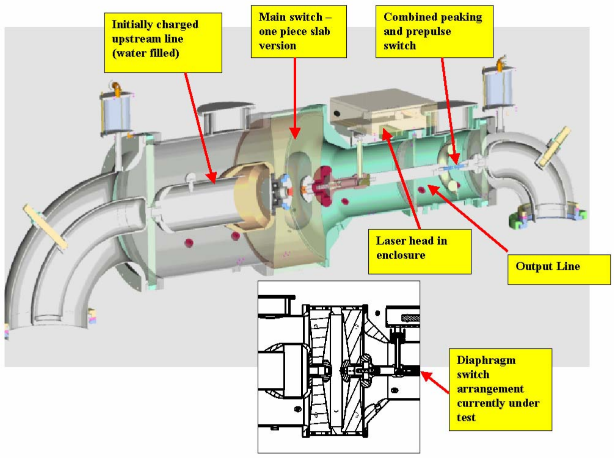

Figure 6. The Pulse Forming Line for the IVA showing two alternative switch options.

III. IVA AND DIODE FOR CORE-PUNCH RADIOGRAPHY

The IVA machines (Fig. 5) for deep penetration radiography have ten modules each comprising an induction cell connected to the output of a PFL (Pulse Forming Line) shown in Fig. 6. The induction cells are threaded by a stalk forming a MITL. The design has benefited from the previous experience of Sandia National Lab. and L3 Pulse Sciences in building the RITS prototype radiographic IVA on which experiments are currently being carried out to develop the diode for the Hydrus deep penetration radiographic sources [5]. The original baseline design was intended to drive a high impedance (~300 Ohms) paraxial diode at 14 MV via a 120 Ohm MITL. However, the lower impedance (~ 40 Ohms) SMP (Self magnetic Pinch) diode (Fig. 7) has, at ~ 6 MV, demonstrated better radiographic performance. The short term goal for the thick object experimental sources are 250 R at 1 metre with a 2.75 mm diameter spot for one class of experiments and 600R at 1 metre with a 5 mm spot, or equivalent, for another. The first of these requirements has already been shown to be achievable with the SMP diode by collaborative AWE/SNL/NRL experiments [5, 10]. It has been shown by further modelling of the radiographic chain that an equivalent source to the 600 R, 5mm spot originally specified would be 350 R at 1 metre with a 2.75 mm spot size [9]. This performance has already been demonstrated with the SMP diode and so it has been chosen as the sole diode for the short term. The baseline 10 cell, 10 PFL IVA can be configured to drive this diode at the voltage required by using a lower impedance (80 Ohm) MITL. If the dose from the SMP continues to increase as predicted by MCNP with validation up to 6.5MV (Fig. 8) [4], it will also be a candidate for meeting the long term goals for radiographic performance beyond the scope of the Hydrus project. Flexibilities incorporated in the IVA design would allow it to be upgraded to drive the the SMP diode to the higher voltages required in the longer term.

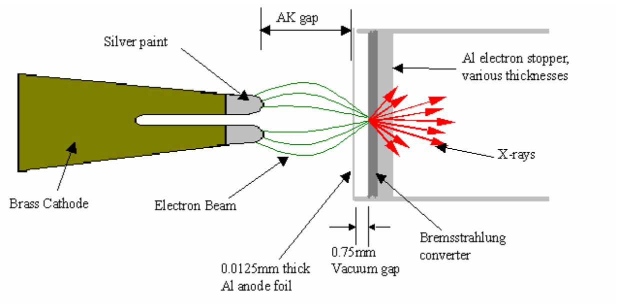

Figure 7. The SMP diode.

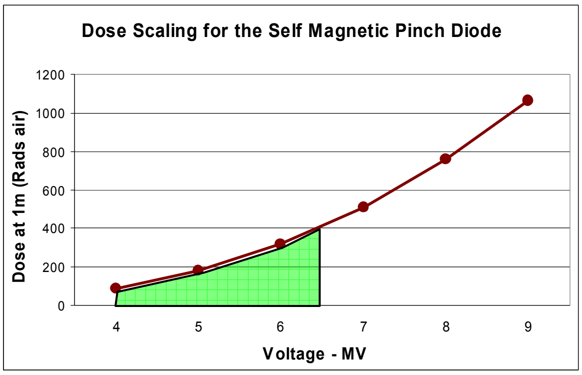

Figure 8. Predicted SMP Dose Scaling, The shaded area shows experimental validation

IV. LVPPM MACHINE AND DIODE

The requirements for thin object radiography led to a specification for the X-ray source which is best met by the Plasma Filled Rod Pinch (PFRP) Diode developed by NRL [3] on their Gamble II machine (Fig. 9), delivering up to 2 MV at the diode. A water PFL connects to a transit time isolating section which was until recently (see below) a transmission line transformer, at the end of which is the vacuum section containing the diode, negating the need for a MITL. The transit time isolator is a small enough diameter to fit in a "sting" to allow a small source to object distance within a large diameter firing chamber. Therefore a low voltage pulsed power machine (LVPPM) of equivalent performance to Gamble II and with a similar front end geometry would meet the requirements for a pulsed power driver to drive the PFRP, provided that the necessary vacuum pumping, plasma injection hardware, collimation and alignment systems can be arranged within the geometrical constraints of the chamber sting.

Experiments on Gamble II (Fig. 10) with the PFRP diode have produced a dose of ~20 R at 1 metre with a sub 1 mm diameter spot and a Bremsstrahlung spectrum end point energy in the 1 – 1.5 MeV band, which together meet the system requirements determined as a result of forward modelling of typical radiographic experiments [6]. Consistency of the output of the PFRP diode was also demonstrated although for a limited number of shots to date [7]. It has also been shown on Gamble II that the tapered transit time isolator originally fitted to the machine can be replaced with a simpler straight 3 Ohm line without affecting the PFRP performance significantly [7].

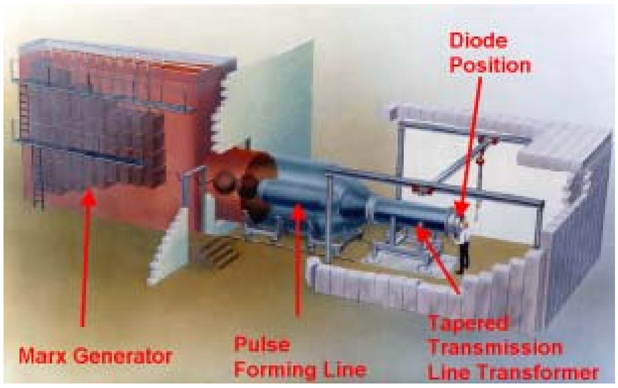

Figure 9. NRL's Gamble II Accelerator.

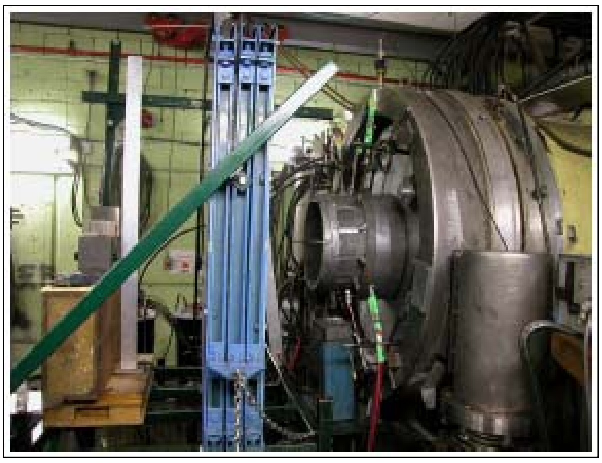

Figure 10. Gamble II PFRP Diode test facility

V. LONG TERM GOALS

The performance requirement for thin object radiography is likely to be met by the PFRP diode without any significant further development and a pulsed power driver of equivalent performance to Gamble II.

However there is a long term requirement to improve the performance of the core-punch radiographic sources to a level equivalent to having five axes each with 1000 R at 1 metre and a 2 mm spot. All aspects of the radiographic chain are being researched in an attempt to achieve this performance. An aggressive programme of diode development is continuing involving collaboration with partners including US labs and UK Universities. Achieving the long term goal may require further investment in facilities or the upgrade of the IVA accelerators.

VI. PULSED POWER GROUP GROWTH AND STRATEGY

In order to meet the forthcoming needs of AWE to build and run new facilities as well as maintaining and enhancing current facilities the complement of people – scientist, engineers and technicians - employed in the pulsed power field will be more than doubled in the next few years.

AWE aims to become a respected centre of excellence for pulsed power design with a flexible and innovative approach at the cutting edge of this technology in order to deliver solutions to nuclear weapon stewardship problems. While providing near term radiographic solutions a comprehensive capability will be developed in the longer term to tackle more wide ranging problems. This work and the uplift in resources, both in terms of people and facilities, will provide a stimulating environment to nurture an innovative and flexible team approach and involving partnerships with external research and manufacturing organisations all geared to achieving successful outcomes to the projects which will be tackled.

VII. SUMMARY

The Hydrus project is intended, in the next decade, to provide AWE with a world class multi-chamber, multi-axis Hydrodynamics experimental facility. Progress is being made in the development of improved radiographic sources to provide the key diagnostics for the experiments that will be carried out there. To support these future developments and other possible challenges there is a strategy to expand the capabilities of the Pulsed Power Group at AWE.

VIII. ACKNOWLEDGEMENTS

The authors would like to thank the numerous people who are contributing to the work mentioned here – both those at AWE and at partner organisations including SNL, L3 Pulse Sciences, NRL, National Security Technologies, LLNL, LANL, Voss Scientific, CEA, Imperial College and Strathclyde University.

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