THE ADVANCED RADIOGRAPHIC CAPABILITY, A MAJOR UPGRADE OF THE COMPUTER CONTROLS FOR THE NATIONAL IGNITION FACILITY

G. Brunton, C. Marshall, L. Lagin, G. Tietbohl, B. Fishler, J. Fisher, B. Horowitz, D. Mathisen, D. Maloy, D. McGuigan, M. Paul, P Ludwigsen, L. Kegelmeyer, C. Estes, G. Bowers, J. Matone, K. Wilhelmsen, R. S. Roberts, A. Barnes, S. Glenn
Lawrence Livermore National Laboratory, Livermore, California USA

Abstract

The Advanced Radiographic Capability (ARC) currently under development for the National Ignition Facility (NIF) will provide short (1-50 picoseconds) ultra high power (>1 Petawatt) laser pulses used for a variety of diagnostic purposes on NIF ranging from a high energy x-ray pulse source for backlighter imaging to an experimental platform for fast-ignition. A single NIF Quad (4 beams) is being upgraded to support experimentally driven, autonomous operations using either ARC or existing NIF pulses. Using its own seed oscillator, ARC generates short, wide bandwidth pulses that propagate down the existing NIF beamlines for amplification before being redirected through large aperture gratings that perform chirped pulse compression, generating a series of high-intensity pulses within the target chamber. This significant effort to integrate the ARC adds 70% additional control points to the existing NIF Quad and will be deployed in several phases over the coming year. This talk discusses some new unique ARC software controls used for short pulse operation on NIF and integration techniques being used to expedite deployment of this new diagnostic.

INTRODUCTION

The National Ignition Facility (NIF) laser system [1] provides a scientific center for the study of inertial confinement fusion (ICF) and matter at extreme energy densities and pressures. Dynamic x-ray radiography of an ICF implosion is a core requirement for analyzing performance of an ignition experiment [2]. The NIF is currently integrating the Advanced Radiographic Capability (ARC) system [3] which is designed to deliver short-pulse kilo-Joule laser pulses for X-ray backlighting of NIF fusion capsules. The ARC will provide NIF with eight Petawatt-class high-intensity beamlines with controllable delays that will add the ability to measure target fuel compression through multi-frame X-ray image acquisitions. This very large-scale enhancement requires many system updates to the existing NIF, including major controls development, and all integration must be performed while causing minimal disruption to continued NIF shot operations. This paper describes on overview of the ARC system and the Integrated Computer Control System (ICCS) [4] development and integration techniques used to deliver this important new laser capability. Figure 1 depicts a simulation of the x-ray radiography expected from the ARC.

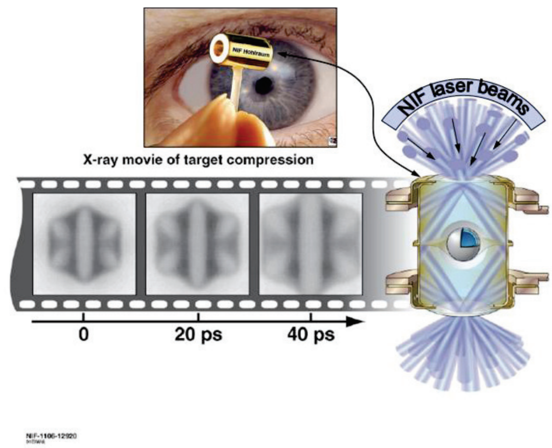

Figure 1: Simulated example of ARC x-ray radiography.

THE ADVANCED RADIOGRAPHIC CAPABILITY

The ARC is integrated on an existing quad of NIF beamlines to facilitate reuse of the existing NIF main amplification system. To protect the NIF main laser optic system from the ARC high peak power, short pulse, operation the ARC pulses must be stretched prior to amplification and subsequently recompressed before focusing the pulse on its target. This stretching and recompression is achieved using a series of small (front end) and large (target area) aperture gratings. Figure 2 below shows the generation and propagation of an ARC short pulse through the existing NIF amplifier chain.

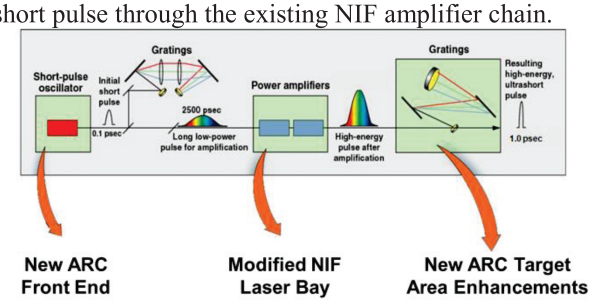

Figure 2: ARC short pulse generation and beamline propagation.

Each of the eight ARC pulses can be independently aligned to different backlighter targets. To produce eight pulses from a quad of NIF beamlines, each beamline contains 2 ARC pulses (beamlets) that are configurable

ISBN 978-3-95450-139-7

with independent temporal characteristics. This independence provides the ability to obtain a pulsed-backlighter source and facilitate the multi-frame x-ray image acquisitions. Figure 3 shows the ARC beamlets configuration in a NIF beam aperture and an example of the temporal configuration of the ARC pulses in relation to the primary NIF pulses.

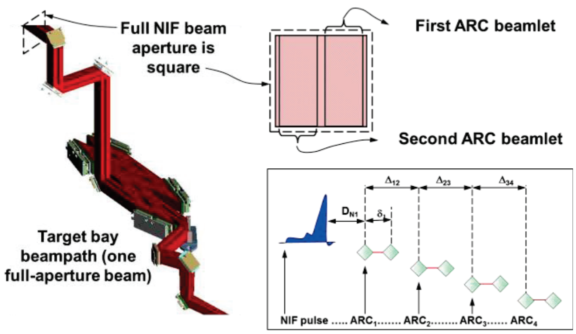

Figure 3: ARC beamlet configuration and timing.

The modified NIF quad will support either ARC (short pulse) or NIF (long pulse) operations and can autonomously reconfigure itself between these two modes based on experimental requirements. Figure 4 shows the NIF target area with the integration of the ARC pulse compressors and its relation to the existing NIF beamlines. The ARC beam pick-off box allows for redirection of ARC pulses into the large aperture pulse compressors. These pick-off stages are motorized and configured by the ICCS control software to perform this automated reconfiguration in the target area between ARC or NIF experiments.

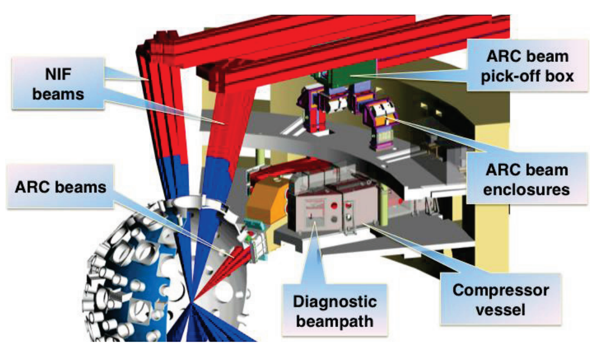

Figure 4: ARC system integration with NIF target area.

Significant modifications are also required to the front end of the laser system to allow both NIF and ARC operations on a single quad. Figure 5 below shows a block diagram overview of the NIF and ARC pulse generation in the Master Oscillator system and selection of the mode of operation in the multi-pass amplifier section of the existing pre-amplifier module (PAM). The pre-amplifier transport system (PABTS) has also added motorized encoded trombones allowing the control of ARC pulse-to-pulse timing.

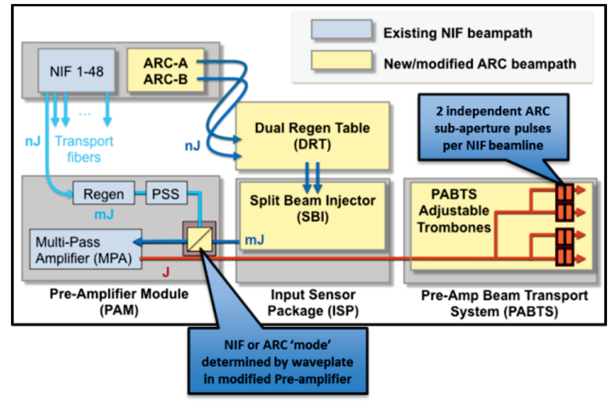

Figure 5: ARC 'front-end' system modifications.

ARC SOFTWARE CONTROLS

Integrating the ARC into NIF represents a very large scale system and software controls enhancement. On the single NIF quad ARC is being installed, the number of control points being added total 860, equating to a 70% growth in the control point volume over the existing NIF. Figure 6 shows a NIF system overview highlighting the number of additional controls required for each ARC system.

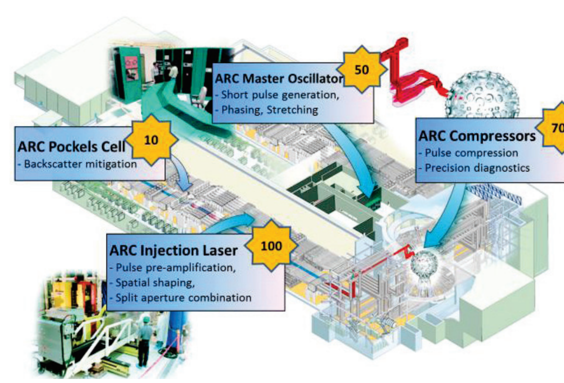

Figure 6: New ARC control points by NIF system.

Controls Architecture

Although ARC represents a significant control system enhancement, major focus has been given throughout the system design phase to leveraging existing control types. This reuse strategy has led to significant acceleration of the deployment schedule. New control point instances of existing software can be deployed simply by defining database specifications for the component. Interconnection of all distributed components is implemented over a Common Object Broker (CORBA) middleware [5].

Leveraging existing control software in the design of ARC has greatly reduced the overall deployment cost of the software project. Of all the new control points only 15% represent new or modified software components, all of which represent specialized controls hardware necessary for short pulse control or diagnostic analysis. This limited set of additions and modifications has also greatly reduced the qualification period required for the ARC manual controls.

ISBN 978-3-95450-139-7

Pulse Timing Coordination

Timing of the ARC pulses to the existing NIF pulses is a critical feature of the new control system.

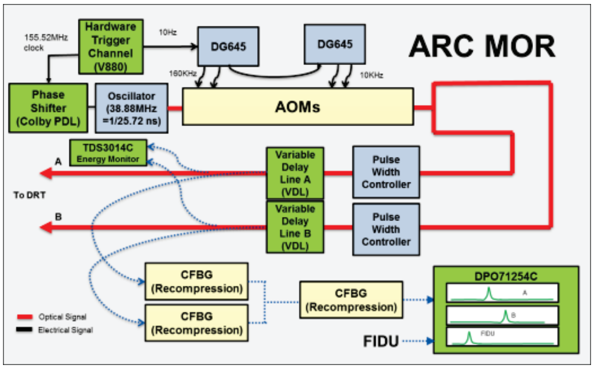

Figure 7: ARC timing control system overview

Using a series of closed loop control algorithms, the ARC pulses will be temporally adjusted to an arbitrary delay relative to the NIF pulse with an accuracy of 5 pico-seconds. Figure 7 depicts the ARC front end timing control system with the system components used in the control loop highlighted in green.

Achieving this high timing accuracy requires orchestrating a number of coarse and fine adjustments in a series of control loops. Coarse timing is performed by adjustment of an electrical trigger and programmable delay line to gate the required ARC pulse in a pair of acousto-optic modulators (AOMs). Fine timing is performed by adjustment of an optical variable delay line (VDL) for each of the ARC beamlets. As the final step in the close loop adjustments, the gate trigger is optimized for pre-pulse extinction using an energy digitizer for feedback.

Laser Diagnostic Controls

Operationally qualifying the ARC system requires many aspects of the short pulse to be verified. To allow these verifications to be performed and continuously monitored on each ARC shot a comprehensive suite of short pulse diagnostics are being integrated into the system. Due to the specialized equipment used for short pulse operation a significant control system development has been required for this area. Figure 8 shows the diagnostic suite in offline qualification and shows the pulse characteristics that the package verifies.

Figure 8: ARC laser diagnostic system overview

Conducting Automated NIF and ARC Shots

All NIF experiments are performed with the support of the experiment automation system [6]. This software layer implements a workflow automation model to:

- Acquire campaign shot goals from laser physics model
- Perform automatic alignment and wavefront correction
- Configure diagnostics and laser performance settings
- Perform critical device verifications
- Conduct shot countdown
- Assess shot outcome and archive shot data

Most laser shots are conducted within a 4-8 hour window with minimal operational input. The shot automation software is based on a data driven workflow engine within a state machine model. The model breaks a shot cycle into numerous operational phases. Each phase is populated with workflow nodes ("macro steps") that perform well defined, reusable, automated activities (i.e. read goals, pulse shaping, energy calibration, etc.). The campaign goals are used to autonomously reconfigure the system based on experimental needs. It is this data-driven flexibility that has facilitated the integration of ARC shots into the workflow automation with minimal software framework modifications.

Throughout the conduct of a shot cycle operations staff receive constant feedback on the state of shot and alerts and events communicate if the system has detected any off-normal conditions that require operational attention.

INTEGRATION AND QUALIFICATION

As ARC is a very large system modification, off-line qualification is critical to minimize risk prior to deployment. The software design and implementation of every control point in NIF has both a 'real' and emulated equivalent. The emulated software component closely mirrors the behavior of the 'real' hardware device. Off-line integration and formal QA environments qualify all software modifications prior to deployment.

ARC has also established several other offline facilities that have been used to qualify the integration of both the software and the system to further reduce the deployment risk in fielding ARC into NIF. Much of this qualification has now been completed and the project is transitioning to the deployment phase.

PROJECT STATUS

Deployment of the ARC system is well underway with most of the front end (MOR, DRT, SBI) already installed and undergoing extensive commissioning. The full-aperture pick-off mechanism and compressor vessels are installed and optic alignment has commenced. Over 60% of the software controls necessary for ARC have been deployed to NIF and the remainder are scheduled to be deployed in over the next few months.

ISBN 978-3-95450-139-7

The first shot automation support will be deployed this fall and will support conducting ARC laser shots to qualify the front end of ARC. ARC target experiments are expected to commence by mid-2014.

CONCLUSION

In this paper, the software and system modifications required integrate the Advanced Radiographic Capability (ARC) into NIF are discussed. Rapid controls deployment is facilitated by this extensible, database-driven, object-oriented control system, which meets all the system requirements presently defined for current and future ARC and NIF experiments.

ACKNOWLEDGEMENT

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-CONF-644266.

REFERENCES

[1] E. I. Moses, "Overview of the National Ignition Facility", Fusion Science and Technology 54, pp. 361-366 (2008).

[2] J. D. Lindl, et al, "The US ICF Ignition Program and the Inertial Fusion Energy Program", *30th EPS Conference on Controlled Fusion and Plasma Physics*, St. Petersburg, Russia, 2003.

[3] J. K. Crane, et al, "Progress on Converting a NIF Quad to Eight, Petawatt Beams for Advanced Radiography", *IFSA 2009, San Francisco, United States, 2009.*

[4] P.J. Van Arsdall, et al "National Ignition Facility Integrated Computer Control System", *Third Annual International Conference on Solid State Lasers for Application (SSLA) to Inertial Confinement Fusion (ICF)*, Monterey, CA, 1998.

[5] E. Stout, et al, "CORBA-Based Distributed Software Framework for the NIF Integrated Computer Control System", *Sixth IAEA Technical Meeting on Control, Data Acquisition and Remote Participation for Fusion Research, Inuyama, Japan, 2007*

[6] L. Lagin, et al, "Shot Automation for the National Ignition Facility", *ICALEPCS 2005, Genvea, Switzerland, 2005.*

ISBN 978-3-95450-139-7