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STATUS OF THE NATIONAL IGNITION FACILITY (NIF) INTEGRATED COMPUTER CONTROL AND INFORMATION SYSTEMS*

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Abstract

The National Ignition Facility (NIF) is the world's largest and most energetic laser experimental facility with 192 beams capable of delivering 1.8 megajoules of 500-terawatt ultraviolet laser energy to a target. The energy, temperatures and pressures capable of being generated on the NIF allow scientists the ability to generate conditions similar to the center of the sun and explore the physics of planetary interiors, supernovae, black holes and thermonuclear burn. This year concludes a very successful multi-year plan of optimizations to the control & information systems and operational processes to increase the quantity of experimental target shots conducted in the facility. In addition, many new system control and diagnostic capabilities have been commissioned for operational use to maximize the scientific value produced. With NIF expecting to be operational for greater than 20 years focus has also been placed on optimizing the software processes to improve the sustainability of the control system. This talk will report on the current status of each of these areas in support of the wide variety of experiments being conducted in the facility.

INTRODUCTION

The National Ignition Facility (NIF) [1] provides a scientific center for the study of inertial confinement fusion (ICF) and matter at extreme energy densities and pressures [2]. Each NIF experiment, or shot cycle, is managed by the Integrated Computer Control System (ICCS) [3], which uses a scalable software architecture running code on more than 2000 front end processors, embedded controllers and supervisory servers. The NIF control system operates laser and industrial controls hardware containing 66,000 control points (e.g. motors, calorimeters, etc) to ensure that all NIF's 192 laser pulses arrive at a target within 30 picoseconds of each other, are aligned to a pointing accuracy of less than 50 microns, and orchestrate a host of diagnostic equipment collecting experimental data in a few billionths of a second. Every NIF shot cycle [4] consists of approximately 1.6 million sequenced control point operations, such as beam path alignment, pulse shaping and diagnostic configuration and each cycle is typically conducted within 4-8 hours depending on the experiment complexity.

NIF has been a 24x7 operational facility since 2009 and has supported the advancement of understanding in various fields of study such as High Energy Density (HED) experiments for Stockpile Stewardship, Inertial Confinement Fusion (ICF), National Security Applications and Discovery Science. The facility and control system advancement has continued since becoming operational and many significant changes over occurred to increase its capabilities and efficiency since last reporting [5]. A summarization of the most recent enhancements is detailed in the following paper.

CONTROL SYSTEM STATUS

NIF Shot Rate Improvements

Over a two-year period, starting in 2014, the NIF facility and control system embarked on a large focused activity to improve the efficiency of shot operations with a goal to increase the number of shots performed annually thereby maximizing the experimental value obtained, all while keeping a flat funding level. Two significant goals of the activities were defined; 300 target shots in fiscal year 2015, and 400 target shots in fiscal year 2016, the latter goal representing greater than a 100% increase over the volume performed in 2014

Through a series of systems engineering analysis studies, optimizations were identified [6] and implemented in the areas of improved experiment scheduling, formalizing a 24x5 shot week and increasing the number of weeks utilized for shots during the year (by 10% to 44 weeks), and control system and operational process enhancements to reduce the shot cycle activity durations.

All optimizations have now been implemented and the results obtained (fig. 1) highlight that both goals were exceeded. As of August 2017, the facility is also on track for exceeding the fiscal year 400 target shot goal again (completes end September 2017). NIF also achieved another milestone in August this year when it successfully completed the 2000th target shot since becoming operational. The improvements made are now institutionalized and we believe that the capability to conduct similar annual target shots rates is sustainable.

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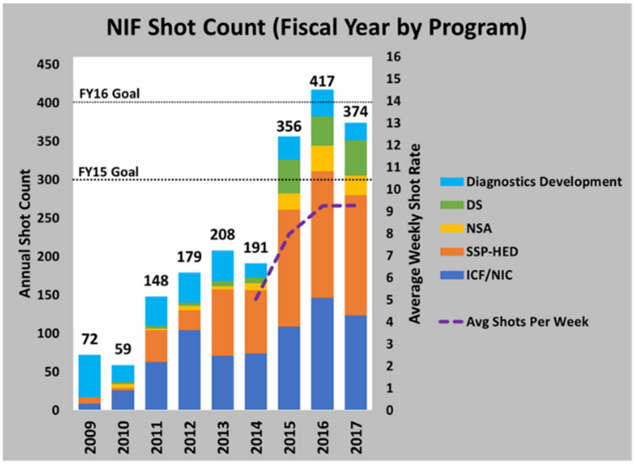

Figure 1: NIF target shot count and rates, by major program, since operational.

New Control and Diagnostic Capabilities

One of the current focus areas for the National Ignition Facility is an acceleration of the study of Inertial Confinement Fusion (ICF) [7], a key mission of the facility. Results from recent ICF experimentation have been positive with a recent 20% increase in neutron yield measured (fig.2) including the first demonstration of alpha-heating (self-sustaining) and approaching the ‘burning plasma’ regime.

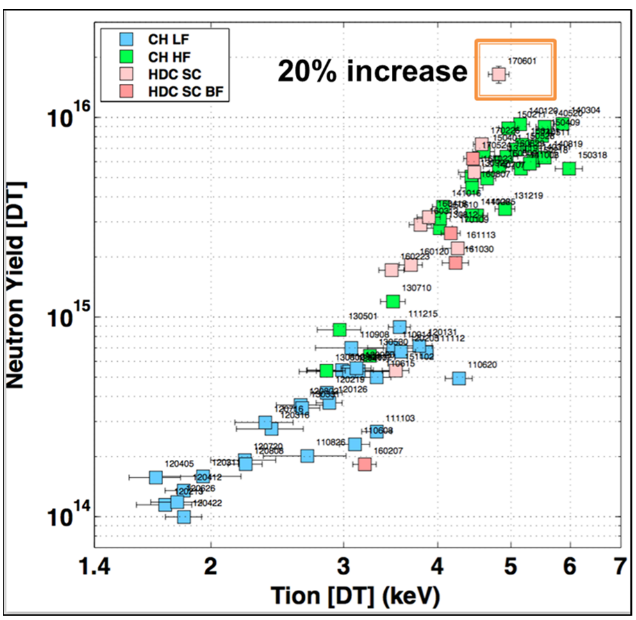

Figure 2: NIF ICF target experiment yield vs energy by platform.

ICF target experimentation requires the exclusive use of the only NIF target positioner capable of growing cryogenically cooled deuterium-tritium (DT) layers (CryoTARPOS) on the target capsule. As the process of target layer growth can take days this limited the number of non-layered experiments on the only other NIF target positioner available (TARPOS)

To accelerate the ICF study while also increasing the NIF shot rate two additional positioners have been added to the facility capabilities since the last report. To maximize the value obtained from these new positioners they were designed to be dual-function allowing use as either a target or diagnostic positioner. The first of these Target and Diagnostic Manipulators (TanDM) has been in use since late 2016 (fig. 3) and is allowing significant flexibility in experiment scheduling, and increased operational efficiency, by facilitating experiment preparation to be alternated between it and the non-layering target positioner (TARPOS), while allowing exclusive availability of CryoTARPOS for layered experimentation preparations. The second TanDM positioner was moved into the NIF facility earlier this calendar year and is currently going through its controls commissioning phase and is expected to be available for operational use, with an initial focus on diagnostic manipulation, by the end of the calendar year. The completion of the second TanDM will be the tenth target chamber manipulator for NIF, which are used for a variety of purposes during shot and maintenance operations, from alignment of the shot targets and diagnostic instruments to damage inspection of all final optics.

Figure 3: First of two new dual (target or diagnostic) positioners being prepared for a NIF shot.

Precision alignment of diagnostic positioners has traditionally been performed using an opposed port alignment system (OPAS) [8] and the chamber interior viewing system (CIVS). These camera-based systems are used by skilled alignment operators and rely on visual features and overlaid graphical images to assist with human measurements. Alignments using this approach achieve high accuracy despite variations in visual features caused by lighting conditions, past shot debris, and radiation-induced artifacts on the video camera sensors. Although effective, manual alignment consumes an operator for up to one hour during each shot. Due to the narrow imaging field of view required for operation of this system each diagnostic positioner requires its own OPAS.

To improve diagnostic alignment accuracy, repeatability, reduce maintenance and increase operational efficiency a new alignment system has been deployed [9] [10] (fig. 4).

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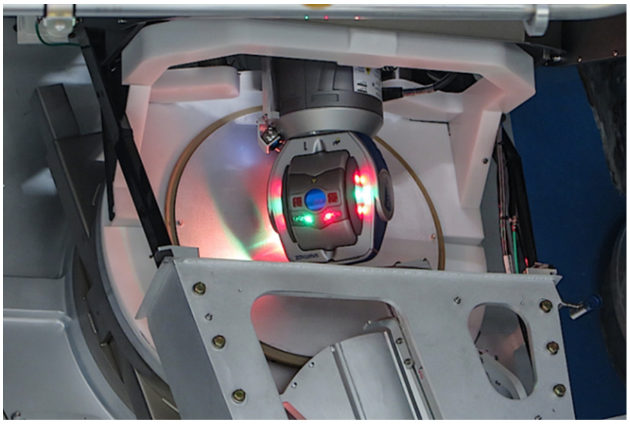

Figure 4: The ATLAS mounted on the NIF target chamber port performing self-calibration operation.

The new advanced tracking laser alignment system (ATLAS) uses a commercial laser tracker system [11], mounted on the exterior of the NIF target chamber viewport, to precisely measure the location of a diagnostic positioner by correlating reflected signals from a reflector mounted on the diagnostic snout inside the target chamber. The tracker system measures the reflected light and analyzes the distance and angle to the reflector, providing a three-dimensional point location. The ATLAS measures a group of reflectors attached at strategic locations on the diagnostic snout, from which a six-dimensional position is computed (x, y, z, pitch, yaw, and roll). From the resulting measured location, the positioner is adjusted, in a feedback loop, so that the diagnostic is aligned with the desired view of the target. With the wide field of view afforded to the ATLAS system (fig. 5) a single tracker can be used to align multiple positioners significantly reducing the system maintenance required, and all TanDM diagnostic alignments exclusively use ATLAS as no OPAS system has been implemented for these positioners. The ATLAS control system has now been fully commissioned and integrated into operational use with results having consistently bettered the required alignment tolerance of 500 micrometers. Further analysis is currently being conducted to explore expanded use of the system including potentially target alignments.

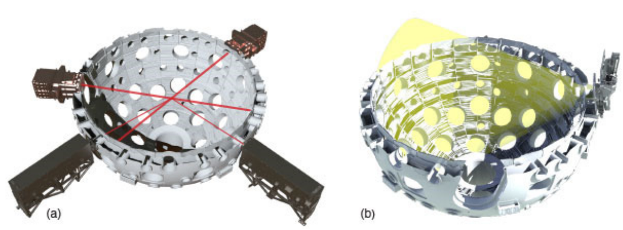

Figure 5: (a) the existing opposed port alignment system, (b) the wide field of view of the new ATLAS.

In addition to operational efficiency enhancements, several new and enhanced target diagnostics have been added to the facility capabilities in support of furthering research for the primary mission areas of HED and ICF. The first performance qualification data (fig. 6) has been obtained from the Advanced Radiographic Capability (ARC) system [12] since recently updating the front-end laser control system to improve the image contrast obtained from the x-ray radiographs. The system is current being optimized in conjunction with the development of the complex HED target platform it is initially being used to support.

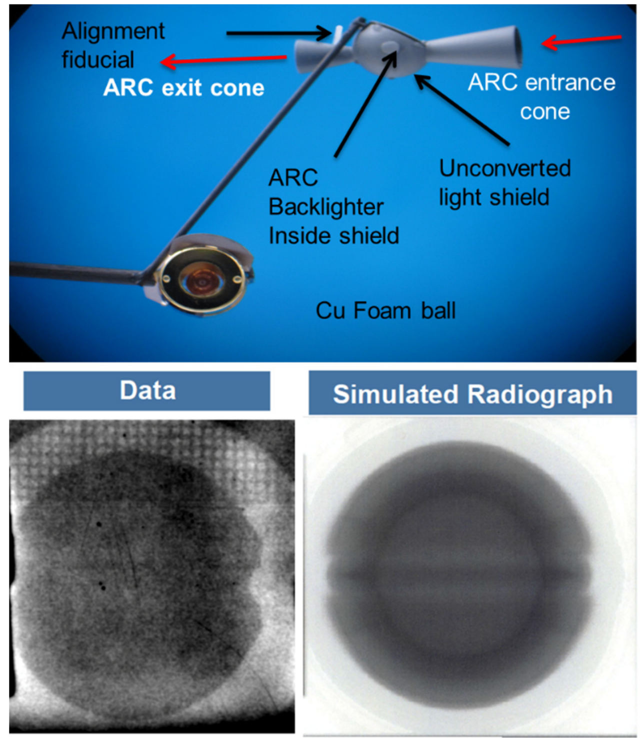

Figure 6: An example experimental target and ARC backlighting target, with actual and simulated radiograph imagery obtained from recent experimentation.

Controls have also recently been developed and commissioned for 48 new neutron activation detectors (RTNAD) that will improve the understanding of ICF target implosion symmetry. Each of the detectors are symmetrically placed around the NIF target chamber and activate a Zirconium cap on each detector from the neutrons generated from the ICF shot. Each RTNAD digiBASE-E gamma spectrometer measures the neutron decay from the Zr material over the subsequent hours after the shot. Through post-processing the resultant emission signals and stitching this around the geometric locations of each detector the symmetry of each target experiment can be reconstructed (fig. 7) and will be used to fine tune the energy balance to improve the implosion symmetry.

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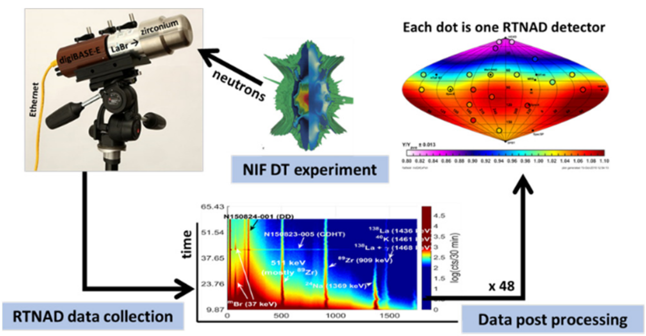

Figure 7: Control and data processing overview for the RTNAD diagnostic detectors.

These two diagnostics represent a small fraction of the capabilities added to the NIF diagnostic inventory as we continue to expand the array of the primary diagnostic types available to the experimental programs; neutron/gamma, x-ray and optical. A significant effort in optimizing the efficiency of diagnostic setup and configuration has also performed and remote filter and attenuation controls have been added to the frequently used diagnostics to reduce the reconfiguration time of these between experiments. Further diagnostic efficiency optimizations are also planned in the coming year and include commencement of the replacement of film based imaging diagnostics with neutron hardened CMOS controls.

Control System Sustainability

As the NIF is expected to continue to expand its capabilities as an operational facility for greater than the next 20 years, it is critical that the controls infrastructure and development processes can sustain this evolution while maintaining high operational availability. Many of the developments that have recently occurred required significant development and integration efforts to be successful and carried significant risk to the ongoing operation of the facility had appropriate levels of engineering rigor not existed. Although the original control system development processes are largely in place [12], like the control system hardware and software evolutions, we have continued to evaluate and optimize them to ensure they are appropriate for the phase of the project lifecycle [13]

Over the past several years significant effort has been spent to consolidate and virtualize the controls platforms [14] and migrate the 3.5 million lines of control system software from Ada95 to Java. This activity is expected to complete in the next 2 years and has been very successful to date. In conjunction with each component migration we chose to require the implementation of a comprehensive unit and integration test suite to be developed. This strategy has provided three primary benefits for the facility; 1) documents the existing component expected behavior, providing a comprehensive test suite to validate the reimplementation to the original, 2) provides a more efficient and extensive requalification platform on which to evaluate future modifications, and 3) accelerates the on-boarding new employees which is inevitable over the lifetime of the project support period.

Building on early experiences into control system health and performance insight gained using data analytic techniques [15], we have continued to expand our use of the Splunk® toolkit beyond rudimentary log file analysis. Comprehensive information dashboards for control system monitoring and alerting, historical shot cycle metrics of execution patterns used for identifying optimization options and component performance trending for prediction of component failure are a few examples of increased value the framework has been extended to provide [16].

Future Work

The NIF continues to expand both its laser and diagnostic capabilities and the upcoming two years continue in a similar vein. A new target diagnostic, the 5ω Optical Thomson Scattering diagnostic (OTS), is being built and commissioned to improve the understanding of NIF hohlraum physics by analyzing plasma density effects around the target at shot time using a deep-UV probe beam. This system requires a large-scale control system enhancement to support the additional laser beamline required to provide the necessary energy levels for the probe. The laser system is currently under construction with the system expecting to be operational during FY19.

In addition to continued target diagnostic capability expansion the upcoming year will also continue work on the evaluation of increasing the laser energy and power from NIF's 1.8MJ, 500TW NIF baseline specification. Improvements in optic processing techniques have already commenced and recent experimentation on a single quad (4 NIF beams) have successfully increased the energy above 2.1MJ (full NIF equivalent). No explicit power and energy goals have yet been set, however in preparation for continued advancement the NIF's Precision Diagnostic System (PDS), providing a broad range of 1ω, 2ω and 3ω laser diagnostics used to tune and qualify NIF to the original baseline, will be recommissioned and modernized. Significant control system development is required for the PDS system and strategies for the most effective and efficient approach are currently being analyzed.

To facilitate continued capability additions while maintaining a high annual shot rate we will also be commencing a second phase of efficiency improvements in the coming two years. The goal of the project is to further reduce the current shot to shot duration by one third. Systems analysis is presently ongoing and the primary focus of the improvements will be in the areas of increased parallelization of laser setup activities and increased automation of the target and diagnostic alignment processes.

CONCLUSION

The NIF control system is a critical component for effectively and efficiency continuing to perform target experimentation in support of the advancement of various physical areas of study. Having proven itself for a sustainable 24x7 operation of the facility the initial phase of shot rate improvements has been successfully completed and all

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goals met or exceeded, all while maintaining a flat funding level. Concurrently with these upgrades, many new diagnostic capabilities have been deployed and commissioned for operational use further expanding the experimental value being achieved. In addition, major control system modernizations are close to completion and positions the facility in an excellent position to sustain the facility for the next 20 years.

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