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Abstract

The National Ignition Facility[1-9] (NIF) in Livermore, California, is the world's highest-energy laser fusion system and one of the premier large scale scientific projects in the United States. The system is designed to setup and fire a laser shot to a fusion ignition or high energy density target at rates up to a shot every 4 hours. NIF has 192 laser beams delivering up to 1.8 MJ of energy to a ~2 mm target that is planned to produce >100 billion atm of pressure and temperatures of >100 million degrees centigrade. NIF is housed in a ten-story building footprint the size of three football fields as shown in Fig. 1. Commissioning was recently completed and NIF will be formally dedicated at Lawrence Livermore National Laboratory on May 29, 2009. The control system has 60,000 hardware controls points and employs 2 million lines of control system code. The control room has highly automated equipment setup prior to firing laser system shots. This automation has a data driven implementation that is conducive to dynamic modification and optimization depending on the shot goals defined by the end user experimenters. NIF has extensive facility machine history and infrastructure maintenance workflow tools both under development and deployed. An extensive operational tools suite has been developed to support facility operations including experimental shot setup, machine readiness, machine health and safety, and machine history. The following paragraphs discuss the current state and future upgrades to these four categories of operational tools.

EXPERIMENTAL SHOT SETUP

Experiments are setup in a web based Campaign Management Tool (CMT) that allows end use principal investigators to define facility technical goals with a high degree of flexibility. For example, a full 192 beam NIF shot with targets and diagnostics contains approximately 10,000 experimental input definitions required for automated machine setup prior to firing a shot such as laser energies or target diagnostic aim points. These can be defined in grouped blocks or down to the individual component level at the discretion of the principal investigator. This experimental input deck then flows through analysis tools to define derived setup parameters and verify that machine safety limits are not exceeded. At this point the experiment is electronically “ready” to be conducted. Prior to beginning the shot, analysis can then performed on the facility readiness to conduct this experiment (physical configuration) and schedule optimization can be performed to minimize the maintenance impact of performing this experiment. When the experimental shot setup process is started, the shot cycle setup model is dynamically defined through turning on and off approximately 20,000 macrosteps, or pieces of automated work scope, that define the shot cycle setup model. This dynamic model functionality is designed to optimize the operational execution of the shot cycle. The shot setup process flow and examples of the tools which perform the facility readiness analysis, optimization, and results visualization will be presented.

MACHINE READINESS

Once an experimental shot setup is defined, the facility physical and commissioning readiness can be assessed against the current status of the facility. This collection of web based tools is essential for the facility operations team to have an effective means of evaluating the next steps in reconfiguring the facility for the next experiment. The central element of this system is the Configuration Checker which takes the experimental plan converts it to physical configuration requirements and compares it to the installation and commissioning status of the facility. Both general and specific physical configurations are verified. For example if a special user optic is required, then the required optic part number and installation orientation is compared to that installed in the facility. From there a list of discrepancies is generated for operations which is graphically displayed as go, no go for shot for each beamline. Drill down capability, to required facility reconfigurations, and list generation of required work scope is automated. NIF consists of more than 6,000 Line Replaceable Units (LRUs) that within a group or type can be interchangeably replaced for ease of maintenance. The installation and commissioning status of LRUs is color coded and graphically displayed on a standard beaming format which is organized by LRU type and location. In addition to LRU readiness there is a Restriction Manager which records and classifies any operational restrictions which may be placed by the engineering or operations organizations on a functional sub-system or component. Restrictions are categorized by type which includes conditional use, do not use, or out of service for maintenance. Restrictions are further categorized by location in the system which implies which laser beamlines and beam end use locations are affected. Conditional use restrictions contain additional information about temporary energy and power limitations that are below the full performance envelope of the machine. An automated algorithm compares the experimental shot requirements with these categorized restrictions to produce a list of any restrictions that apply to the planned experiment.

MACHINE HEALTH AND SAFETY

NIF has performed an extensive Failure Modes and Effects Analysis that has defined machine safety control points or devices in the system. These devices have specific machine safety requirements, such as required position, reservations and verifications at shot time. Virtually all critical devices are automatically positioned and verified by the shot cycle control software, but it was determined that an independent engineered status verification method was required that adds an additional layer of protection given the complexity of the NIF system. This status verifier system directly interrogates the device level control hardware separate from supervisory or status and control aggregation levels and compares their positions and status with a predetermined set of device requirements that is independent derived with simplified logic from shot setup requirements. The status of this verification is provided in a rolled up graphical format with drill down capability to the device level. Higher level processes such as closed loop alignments or voltage profile monitoring are fed to a central alerts framework and displayed by an Alerts Manager. This alerts manager categorizes the alerts by subsystem and provides a mechanism for retaining, acknowledging, and clearing alerts. This provides flexibility to operations to monitor in an organized way for alerts that are new, latent, and false alarms. Examples of these machine health and safety applications will be presented and discussed.

MACHINE HISTORY

NIF has provided for an extensive machine history archiving and data visualization of component level history. The Machine History Database includes the Shot Setup requirements, change management history of those requirements, optics damage inspection, and laser diagnostics archive. This data is available to be visualized with a web based suite of GUIs that organizes and displays the information both in raw format as well as processed or analyzed. This is achieved by archiving of device positions or capturing images on every shot and plotting the long term trending of device data for facility predictive maintenance. In addition, the long term trending of subsystem efficiency or performance is recorded as part of the shot control framework. The duration of macrosteps are measured and recorded for each of shots conducted on the facility. The analysis of these trends and blocks allows for optimization of the shot cycle or machine turn on model as facility conditions evolves.

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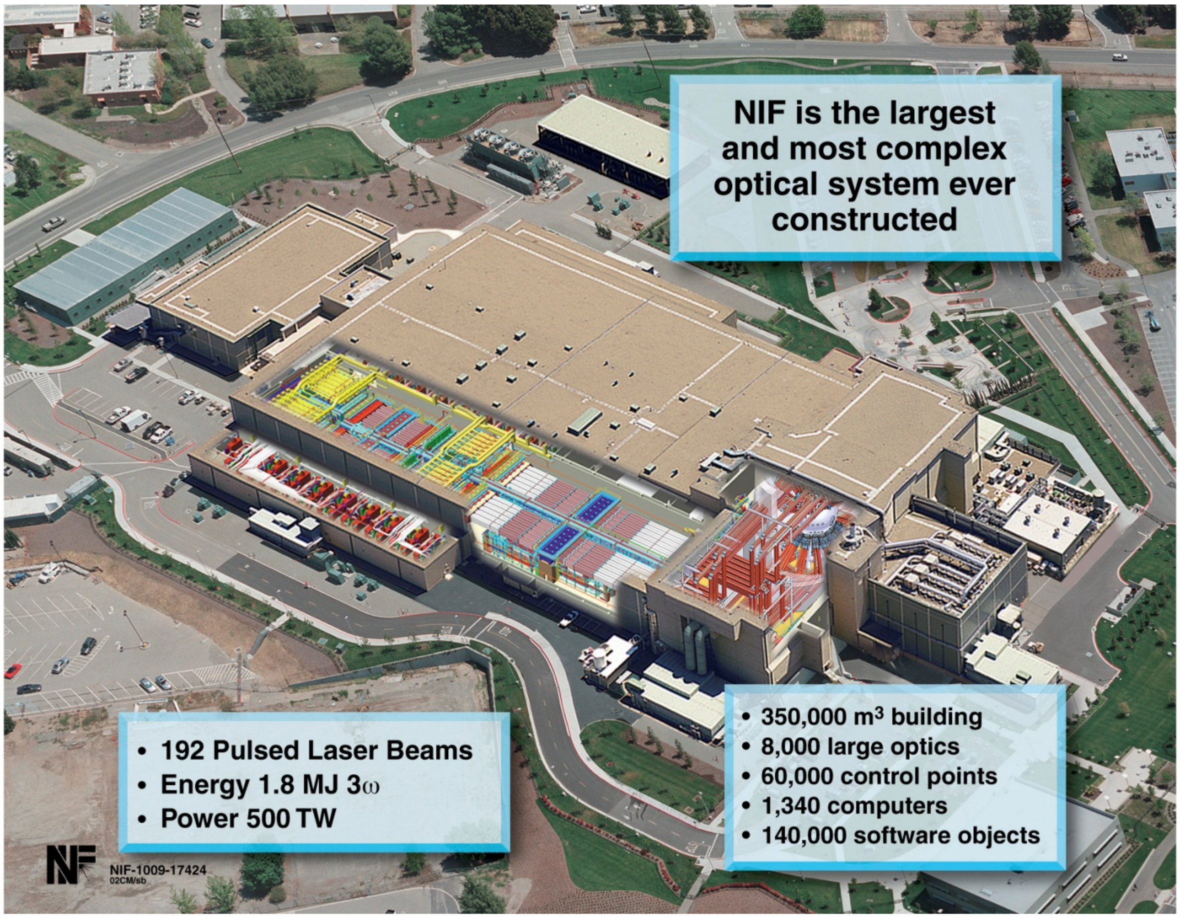

Figure 1: The National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL) in Livermore California is the world's first megaJoule laser facility now conducting experiments for the National Ignition Campaign.