LLNL-CONF-644257

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September 26, 2013

ICALEPCS 2013
San Francisco, CA, United States
October 6, 2013 through October 11, 2013

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AUTOMATIC ALIGNMENT OF THE ADVANCED RADIOGRAPHIC CAPABILITY FOR THE NATIONAL IGNITION FACILITY*

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Abstract

Experiments and operation of the National Ignition Facility (NIF) will soon benefit from a new, high-energy x-ray (60 – 200 keV), radiography diagnostic [1]. To generate these x-rays, in the summer of 2014, NIF will be deploying the Advanced Radiographic Capability (ARC) which is designed to generate precise, high-energy short-pulses, amplified through a NIF beamline, and aimed at backlighter filaments near ignition targets. The alignment precision for ARC is an important element in the success of this enhancement. A key challenge for the ARC automatic alignment (AA) process lies in implementing the new alignment capabilities without disturbing the existing operations of NIF. Any risks that may occur by the addition of the ARC system are mitigated through careful design and control of the ARC/AA interfaces. In this paper, we will describe some of the new ARC alignments, the ARC Split Beam Injector (SBI) and ARC Compressor. The SBI combines two independent ARC beams into a single NIF beam before being aligned and injected into the main NIF amplifier chain. After main amplification, the pulsewidths are compressed in the ARC compressor vessel and aimed at backlighter targets in the NIF target chamber. Alignment verification of the compressor grating will be critical to ensuring the ARC pulses meet their design specifications.

ARC OVERVIEW

For ARC, the normal NIF shot light from the master oscillator room (MOR) is replaced with a pair of pulses which are chirped (change in frequency over time as shown in Figure 1). These pulses are injected into the Dual Regenerative Amplifiers and, subsequently the pair of Gaussian beams are propagated into the Split Beam Injector (SBI) package (see Figure 2) producing two “beamlets” within the standard NIF beam aperture. The ARC SBI light is then injected into one of the forty-eight Pre-Amplifier Modules (PAMs), where an ARC waveplate is inserted at the Multi-Pass Amplifier (MPA) input [2,3,4]. Hardware changes to the existing PAM and Main Laser (ML) amplifier are limited to allow the main components of the laser to be operated and conventional alignment to be maintained when ARC is not in use. Both the conventional PAM and ARC PAM amplify the MOR pulse energy to the Joule level before it is distributed to four beamlines. The energy of each beamline is further amplified to the kilojoule level in the main laser amplifiers before it is directed to the target chamber. When configured for ARC, at the end of each ML, the light will be redirected, via an insertable mirror carriage, into the ARC compressor vessel and aimed at backlighter filaments or other targets in the NIF target chamber.

When the ARC beamline enhancement is complete, each ARC beamline could be used to produce two high-energy beamlets that can be independently pointed within the target chamber and independently timed to provide spatially and temporally resolved radiographs. When ARC is completed on 4 beamlines, ARC will be able to produce eight independent spatially and/or temporally distributed pulses.

Typical operations for the completed ARC system will illuminate multiple backlighters. As an example, an experiment setup for using ARC would use timed sequence pulses on backlighters to produce six independent temporally separated pulses, with the timing between pulses being evenly spaced at 500 ps. This example setup requires the use of three beamlines each split into A and B ARC pulses. The timing offset for the example ARC pulses requires the adjustment of a trombone style mirror assembly in two of the three beamlines used for ARC pulses. The delay of each pulse is set by translating the “elbow” of the trombone. Next, the second beamline will be set to be 1 ns longer than the first. The third beam line will be adjusted to be 1 ns longer than the second and 2 ns longer than the first. The movement of the trombones, for these large temporal shifts, will affect the optical path length, which will change alignment and wave front adjustments, see reference [5] and [6] for details on trombone operation and wave front control.

Split Beam Injector (SBI)

To setup for ARC light pulse propagation, changes in hardware will be made with automated devices. The SBI will be configured to allow transmission of the ARC

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

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pulses by opening shutters in the Dual Regenerative Amplifier cavities (from their normal NIF operating position of closed) and setting the waveplates for full pulse transmission. A waveplate in the PAM MPA will also be inserted to allow for the transmission of all ARC pulses. The ARC beams from the SBI will then be aligned with the NIF beam using a camera in the input sensor package (ISP). See reference [7] for an overview of the NIF ISP. All automatic alignment and verification image collection, for the SBI, will be done with the ISP.

The alignment of the SBI and PAM for ARC pulse propagation is similar to the normal NIF operations. The polarizer mirrors (Pol in Figure 2) are the same mirrors, but uses different images for alignment feedback. The main difference between ARC SBI alignment and PAM alignment is the addition of the SBI (see Figure 2) at the MPA input.

The SBI is the initial alignment stage for ARC. The SBI creates an A and B ARC beam to propagate through the PAM and ML. Within the SBI, these independent beam inputs necessitate the addition of a new co-pointing adjustment to ensure the A and B beams propagate collinearly (mirror SM5 in Figure 3). In addition, ARC alignment requires the replacement of the initial beam source alignment with two independent light sources adjustments (mirrors SBS1 and SM7 in Figure 3).

Alignment of ARC from ML Pick-Off

As of August 2013, the alignment of ARC after ML pick-off is still under development. The plan for the first step in ARC target area alignment is the insertion of a corner cube at the planned position of the pickoff mirrors in the ML beampath (see Figure 4). This corner cube is positioned in the middle the two steering mirrors A and B. The Light from the ML is bounced off this corner cube back to an alignment sensor in the ML. Using the information from this reflected light, the ML output mirror is positioned to center the beam on these corner cubes. This alignment process is similar to the NIF alignment of the final output assembly [8].

Next, the ARC light is passed through the ARC beam enclosure to the compressor vessel and diagnostic beampath. After the pick-off mirror, there are 34 new alignment adjustments and alignment verifications. Discussion of a few select parts follows.

Compressor Vessel

The compressor is where the amplified laser pulse is compressed in time to a 1 pico-second pulse. At the output of the ML, both A and B beam paths are an expanded long pulses with changing wavelength. This long pulse is compressed to a short pulse using four gratings. The compression is done by making the optical path of the early part of the spectrum longer than the later parts

The alignment of the compressor vessel is done by survey at atmospheric pressure. Sensors on each grading record the alignment position. The plan is to recreate the alignment position at atmospheric pressure when the chamber is at vacuum. Each grating has 3 positioning motors and a tilt sensor, where tilt is a vector rotation around the gravity axis. Two laser spots, each at different frequency, are reflected off a grating and recorded on a camera. The reflective spots measure the position of each mirror perpendicular to gravity and the tilt sensor measures tilt. After the compressor vessel is put at vacuum, the measure alignment positions at atmosphere are restored.

Back Lighter Target Alignment

Currently, the NIF target chamber has three positioners, two target positioners and a separate target alignment sensor [8]. The back lighter will be mounted on an extension from the target. The target and backlighter will be mounted on one of the target positioner. A camera will be mounted on the other target positioner. This camera is referred to as the ‘Active Target’. The ‘Active Target’ is positioned at a pre-determined backlighter position using the target alignment sensor. With the ‘Active Target’, the focus and position of the ARC beam can be measured and adjusted. The baseline requirement for the back lighter target is a 10 µm x 60 µm gold wire. Modeling suggests ARC may be able to achieve 25µm RMS pointing accuracy to the backlighter target.

SUMMARY

Experiments and operation of the NIF will soon utilize the ARC system. The addition of ARC continues to be a complex process, necessitating the addition of 42 new alignment and verification steps per beamline. The alignment precision for ARC is an important element in the success of the added capability. The new alignment capability must be implemented without disturbing the existing operations of NIF. Based on the current schedule, a single ARC beam will be available for experimentation the summer of 2014.

ACKNOWLEDGEMENT

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

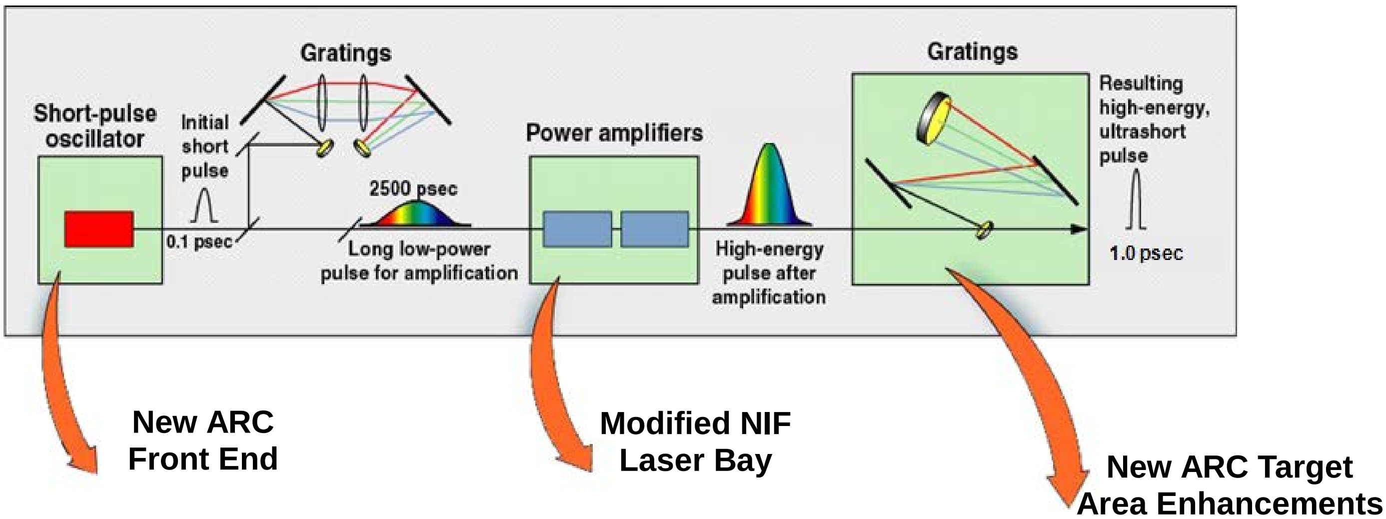

Figure 1. Overview of the ARC operation including injection of a long pulse with an expanded spectrum input. Next, the long pulse is amplified through NIF Laser Bay, and finally, recompressed into a 1 pico-second pulse using gratings. There are actually more gratings in ARC then depicted in diagram, which was simplified for illustration only.

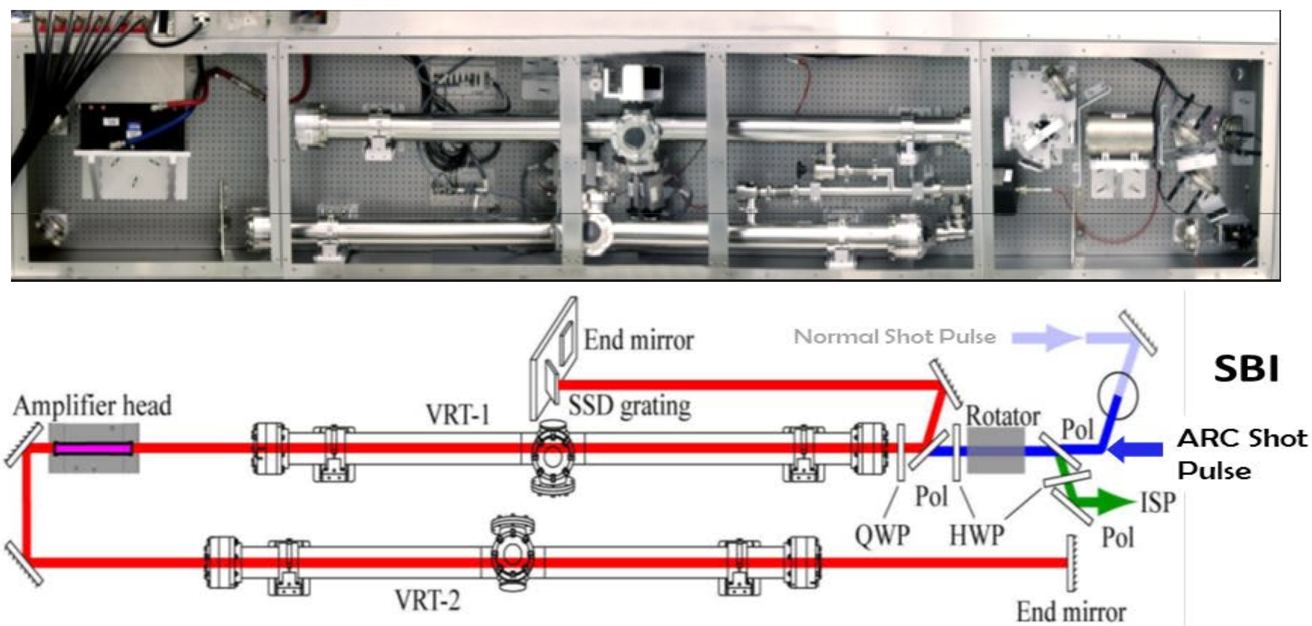

Figure 2. Overview of the PAM Multi-Pass Amplifier (MPA) geometry. Following the Regenerative Amplifier stage and beam shaping module, the light is injected (blue) through a Faraday rotator into the four-pass amplifier circuit (red). The upper Vacuum Relay Telescope (VRT-1) images the shaped beam onto the flashlamp pumped rod. The lower Vacuum Relay Telescope (VRT-2) images the beam onto a displaced end mirror to avoid spatial hole burning and pulse shape distortion on the second pass. A QWP enables two more passes through the rod after reflecting off a choice of end mirror or SSD grating (at the Littrow angle) in the upper leg.

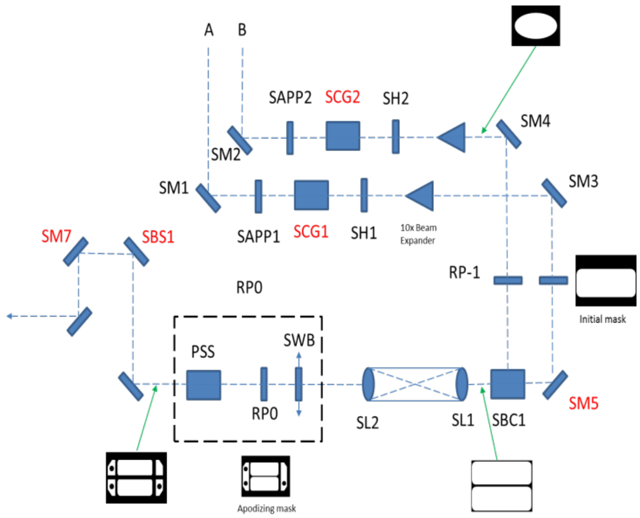

Figure 3: Schematic of relevant automated alignment components of the ARC SBI.

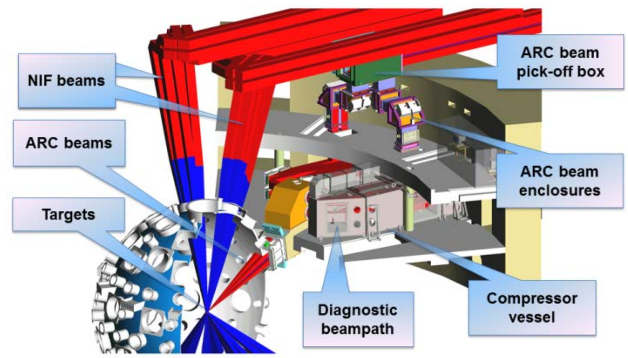

Figure 4: ARC beams are pick-off of beamlines for ML with an insertable mirror. Picked off beams are aligned through the ARC Beam enclosure, thought the compression vessel to diagnostics and targets in the target chamber.

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