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ABSTRACT

To improve the symmetry of x-ray drive on indirectly driven ICF capsules, we have increased the accuracy of operating procedures and diagnostics on the Nova laser. Precision Nova operations includes routine precision power balance to within 10% rms in the "foot" and 5% rms in the peak of shaped pulses, beam synchronization to within 10 ps rms, and pointing of the beams onto targets to within 35 μm rms. We have also added a "fail-safe chirp" system to avoid Stimulated Brillouin Scattering (SBS) in optical components during high energy shots.

KEYWORDS: pointing, power balance, Nova, synchronization, SBS

1. INTRODUCTION

When Nova was built in the mid-1980's, the capability of operating the laser with high levels of precision was not considered important. As it became clear that precision pointing and power balance were important even for indirectly driven capsules, a team was formed to develop the necessary procedures that utilize mostly existing hardware. In 1993, the Precision Nova team[1] reported successful demonstrations of their goals; power balance among the ten beamlines to within 10% rms in the "foot" and 5% rms in the peak of shaped 3ω pulses with total energies exceeding 40 kJ, beam synchronization to within 10 ps rms, and pointing of the beams onto targets to within 30 μm rms. This article describes recent diagnostics improvements and current procedures on the nearly 25% of the shots on the Nova laser that require precision pointing and power balance.

2. PRECISION POINTING

The accuracy with which we place beams on target is determined by imaging x-rays from a planar target illuminated with 100 ps laser pulses with one axial pinhole camera on each side of the target chamber.[2] The targets used for these calibration shots contain a pattern of 10 μm diameter holes which serve as points to which the laser operators aim the beams as well as spatial fiducials for data analysis. The images (Fig. 1) are recorded on film and digitized. A computer code is used to convert the film density data to incident laser irradiance, then determine the location of the features in the image.

The image analysis is performed by Nova operations personnel utilizing interactive software. Within the image, the operator chooses regions around at least four fiducial points per beam, allowing the software to compute the centroid of each. Then a least squares fit is performed, which along with target metrology data, determines the aim point for each beam on the image. The operator then chooses a region enclosing the image of each beam. The software calculates the centroid of each spot and compares with the aim point, yielding the pointing error for each beam.

From performing a large number of calibration shots, we find that there are two identifiable characteristics of the pointing error for each beam: a random amount of scatter around an average location which differs from the aim point by an amount we call the offset. Some sources of scatter in the data have been identified and significantly reduced. The source of the remaining scatter in the data is likely a combination of many factors, including measurement error, variations in the spatial distribution of energy within the beam on target, and slight differences in the technique each operator uses to set the beam pointing. The source of most of the offset is unknown. We correct for this effect by adjusting the beam pointing after aligning each beam with the 3ω alignment laser to the target, using a weighted average of the measured offsets from the last several calibration shots. Measurements have shown that with several calibration shots taken in the same week, we can achieve a pointing accuracy among the ten beamlines of 30 μm (10 μrad) rms. During the period from October 1994 to March 1995, we performed one calibration shot approximately every two weeks. The rms pointing error among the ten beamlines from these ten shots is 35 μm (Fig. 2). Although increasing the frequency of calibration shots would increase the pointing accuracy, the improvement from 35 μm to 30 μm rms error is generally not considered sufficient benefit to warrant the use of additional Nova shots.

Most Nova targets are shot without using the precision pointing procedure, resulting in a pointing error of approximately 70 μm rms. Several additional tasks are performed in preparing a precision shot. For the first shot in a series of precision shots, the laser operators allow the laser amplifier disks to cool for 45 minutes after the previous shot before starting alignment of the beams through the amplifier chains with the 1ω alignment laser. Once the laser chain alignment is complete, the operators lock the output sensor optics in place to maintain a pointing reference for the rest of the shot series. Then, they point and center the 3ω alignment laser to the 1ω alignment laser very carefully. After pointing each beam to the appropriate spot on the reticle which takes the place of the target during alignment, the operators adjust the pointing using the measured offsets. If more than 45 minutes elapses after the laser chain alignment and before the target shot, the operators instruct the computer to recheck the alignment of the beams to the output sensors. If the next shot requires a change in the pointing of the beams, the operators repeat the entire process. Otherwise, only the amplifier chain alignment is required.

3. PRECISION POWER BALANCE

There are two primary contributors to imbalance in the power among the ten beams of Nova: differences in the 3ω transmission of target chamber optics and differences in the gain and transmission of components in the amplifier chains. Differences in the transmission of target chamber optics are measured as differences in effective frequency conversion efficiency from the output sensors to the inline 3ω target chamber calorimeters. Variations in frequency conversion efficiency require that we produce a different 1ω energy on each arm to produce the same amount of 3ω energy. The output 1ω energy of each beamline is controlled by adjusting its input energy, which is a fraction of the pulse generated in the preamplifier section. Since we are constrained to injecting the same pulse shape into the input of each amplifier chain, we balance the pulse shapes by matching the output 1ω fluences, adjusting the area of each beamline. This allows us to operate all frequency conversion arrays at the same 1ω irradiance as a function of time. However, since the final amplifier sections are operated highly saturated, differences in the gain and transmission of optical components in the final amplifier sections cause pulse shape variations at high energy. To compensate on high energy shots, we decrease the effective gain of the final amplifier section of some beamlines by adjusting the timing of the firing of the flashlamps relative to the energy extraction time. Finally, we make further adjustments to the input energies to achieve the necessary output energy with the reduced gain.

To achieve our goal of power balance to within 10% rms in the "foot" and 5% rms in the peak of shaped pulses, the total energy and temporal shape of each beam must be accurately measured and controlled. The calibration of the energy diodes in the improved 3ω Incident Beam Diagnostics is updated weekly with a shot into the inline calorimeters to account for changes in the transmission of optics. To determine the 1ω energies and beam areas required for a precision shot, the shot director runs a computer code which uses 1ω and 3ω energy data from recent shots. The beam areas are adjusted by manually changing the input apertures on all arms except the arm with the lowest effective frequency conversion efficiency. We use input apertures that span a range of 20% in area with 1.6% increments. Although the 3ω temporal profile of each beamline is measured with a streak camera on each shot, it is used only to report the power vs. time profiles achieved. Only energy data is used in the calculation of the 1ω output energies and areas required for subsequent shots.

Immediately after each shot, a plot is printed of the measured power profile for each beam overlaid with the normalized standard deviation of the power profiles of the ten arms. An estimated systematic diagnostic error of 3% is added in an rms fashion to the normalized standard deviation. This includes systematic errors in the calibration of the inline calorimeters to a reference calorimeter, the calibration of the Incident Beam Diagnostics diodes to the inline calorimeters, and the coupling of light into the streak cameras. Fig. 3 is a typical example of power profiles from a precision shot. We routinely achieve a power balance error less than 10% rms in the "foot" and 5% rms in the peak.

Recent diagnostic improvements have increased the accuracy with which we are able to report power balance data and reproduce pulse shapes. The original design of the output sensors and Incident Beam Diagnostics included coupling each optical signal from the sensor to the streak camera through a single fiber optic. Initial attempts at power balance revealed a problem with speckle noise at the input to the fibers, distorting the pulse shapes by up to 10%.[3] We have installed fiber optic bundles in both sets of sensors to reduce speckle noise. The 1ω fiber bundles each has 22 fibers, which reduce the speckle noise to a maximum of approximately 0.5% of the signal level. The 3ω fiber bundles each has 7 fibers, due to a limited supply of UV fiber optics, which reduce the speckle noise to about 2.5% of the signal level. Comparisons of temporal profiles from fiber bundle coupled streak cameras with those from fast photodiode/transient digitizer systems show very good agreement, except for the effects of the faster response of streak cameras.

As experimenters on Nova have become more concerned with the accuracy with which temporal pulse shapes are reproduced from shot to shot, we have developed new tools. When an experimenter requests a particular pulse shape, a variable impedance strip line is cut during a maintenance day to generate the pulse shape in the master oscillator room (MOR) required to produce the requested 3ω pulse shape[4]. A computer model now accurately predicts the 3ω pulse shape from an MOR temporal profile, allowing the experimenter to review the accuracy of the shape before attempting a target shot. Additionally, a plot of the average of the measured 3ω power profiles overlaid with the requested pulse shape is printed immediately after each precision shot.

4. BEAM SYNCHRONIZATION

In the power balance plot displayed in Fig. 3, the temporal power profile of each beamline is aligned to an arbitrary zero time at the 50% point of the leading edge, which is reasonable only if all ten pulses arrive at the target at nearly the same time. A timing shift between beams irradiating the target would cause an imbalance in the power among the beamlines as described by

$$\Delta P/P=(\Delta t/P)(dP/dt).$$

To reduce this effect, we verify that all beams arrive at target chamber center to within 10 ps rms. The power imbalance induced by a 10 ps rms timing error in the most quickly varying regions of Nova temporal pulse shapes is approximately 2.5%. Timing errors do not cause significant power imbalance in regions of constant power.

Changes in beam timing have two primary causes; inaccurately compensating for the difference between the thickness or placement of an occasional damaged optic and that of its replacement and inaccurately resetting the timing of a beamline which had been intentionally adjusted to backlight a target. The timing of the beams on target is measured about twice a year with an x-ray streak camera that images the x-ray emissions from a gold ribbon target irradiated with a 100 ps pulse[5]. Also, the timing of each beam through the amplification chain relative to an optical fiducial is measured on an output sensor streak camera. Corrections are made by adjusting beam path lengths at a point immediately prior to each amplification chain.

5. "FAIL SAFE CHIRP"

To be certain that SBS in the large 3ω target chamber optical components does not remove significant amounts of energy from the beams, we now use a system that ensures that all high energy, long pulses have sufficient bandwidth to suppress SBS. Previous experiments[6] show that a significant amount of energy is sidescattered in a Nova target chamber focus lens when the product of the 3ω energy and pulsewidth exceeds 13 kJ-ns. Results of a recent test of this system verify that the addition of bandwidth adequately suppresses SBS. In this test, fast optical diodes read with transient digitizers were placed at the edge of a target chamber focus lens pointed in the direction of maximum SBS light. Fig. 4 compares the levels of sidescattered light on shots with high energy, long pulsewidth and 19 GHz of bandwidth with that of a lower energy, narrow bandwidth shot. All shots with added bandwidth have at least a factor of ten less sidescattered light than the narrow bandwidth shot. Previous measurements show that a bandwidth of 8 GHz is sufficient to suppress SBS losses up to about twice the SBS threshold.

The "fail safe" system is composed of an RF subsystem that generates and measures the microwave drive to the phase modulator[7] and a bandwidth subsystem that measures the optical bandwidth of the laser pulse. Both subsystems operate at the 10 Hz rate of the long pulse oscillator. Diagnostic signals from four points in the RF subsystem are measured for correct amplitude and timing using fast electronics. If all measured signals are within acceptable ranges, a Pockels cell is activated which is necessary for the current laser pulse to propagate through the Nova amplifier chains.

The bandwidth subsystem uses a Fizeau interferometer and a diode array detector to measure the bandwidth on each pulse in the pulse train produced by the long pulse oscillator. If the bandwidth of the measured pulse does not exceed the preset minimum, Pockels cells within the pulse shaper and slicer components are not enabled, blocking the next pulse in the train. For a pulse to propagate out of the MOR while the "fail safe" system is active, the RF subsystem must be functioning correctly during that pulse and the optical bandwidth of the previous pulse must have been sufficient. Also, facility controls software prevents the laser from firing if the installed strip line (each of which is uniquely encoded) is designed to produce a high energy, long pulse and the "fail safe chirp" system is inactive.

6. CONCLUSION

We routinely operate Nova with levels of precision that are very close to the best we have ever demonstrated. Recent improvements to laser diagnostics have increased the speed and accuracy with which we report the level of power balance achieved on each precision shot. As the community of experimenters on Nova widens, we continue to make Nova more user friendly.

7. REFERENCES

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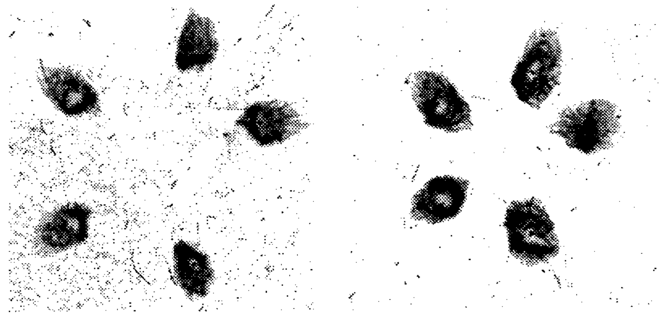

Fig. 1. Digitized x-ray images showing beams and fiducials from two sides of a pointing target.

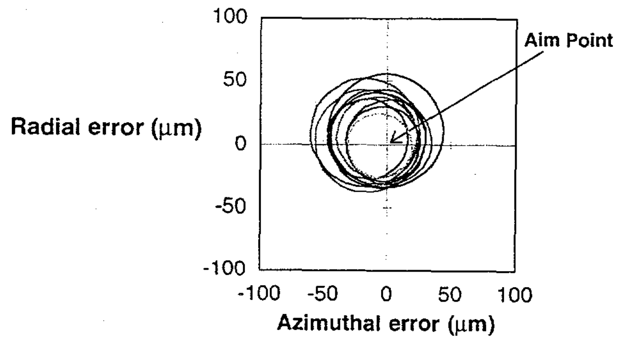

Fig. 2. Measured pointing scatter from ten calibration shots. The radius of each circle represents the rms scatter of one beam. The total rms error in these data is 35 μm.

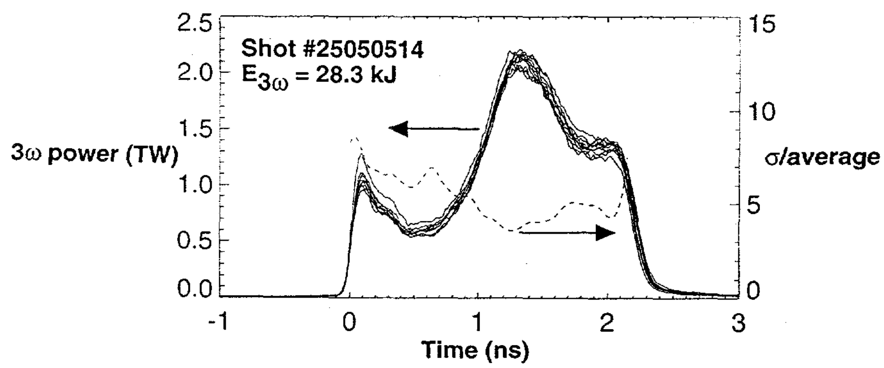

Fig. 3. Power profiles of each beam with normalized standard deviation from a typical Precision Nova shot.

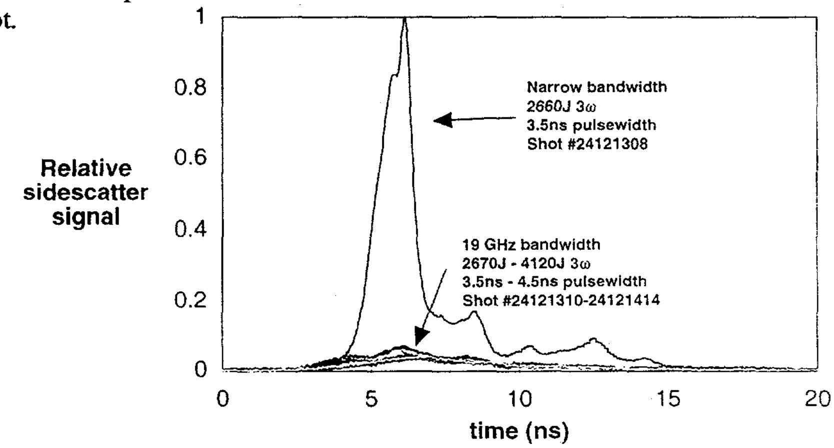

Fig. 4. Measurements of sidescattered light in a focus lens show that bandwidth prevents significant energy loss due to SBS.