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Abstract

The Precision Robotic Assembly Machine was developed to manufacture the small and intricate laser-driven fusion ignition targets that are being used in the world's largest and most energetic laser, the National Ignition Facility (NIF) [1]. The National Ignition Campaign (NIC) [2] goal of using the NIF to produce a self-sustaining nuclear fusion burn with energy gain — for the first time ever in a laboratory setting — requires targets that are demanding in materials fabrication, machining, and assembly. We provide an overview of the design and function of the machine, with emphasis on the aspects that revolutionized how NIC targets are manufactured.

1 Background

Historically, building laser fusion targets depended on a significant amount of hand-crafting skill and technique involving microscopes and manually driven fixtures. Many of the target components are designed to slip-fit together with micrometer-clearances, and the dimensional accuracy of a fully assembled target is in the range of 2–20 micrometers. Repeatable and consistent production of high-quality, precision ignition targets plays an important role in using NIF's 192 laser beams to explore the high-energy-density regimes associated with nuclear fusion. Shown in Figure 1, the Precision Robotic Assembly Machine [3, 4] provided the needed transformation in how fusion targets are assembled, with a demonstrated ten-fold reduction in manpower needed to assemble a target and improved and repeatable target quality. The reader is referred to another paper presented at this conference containing figures showing models of a NIC fusion target: "Precision Engineering within the National Ignition Campaign" , J.S. Taylor, et. al.

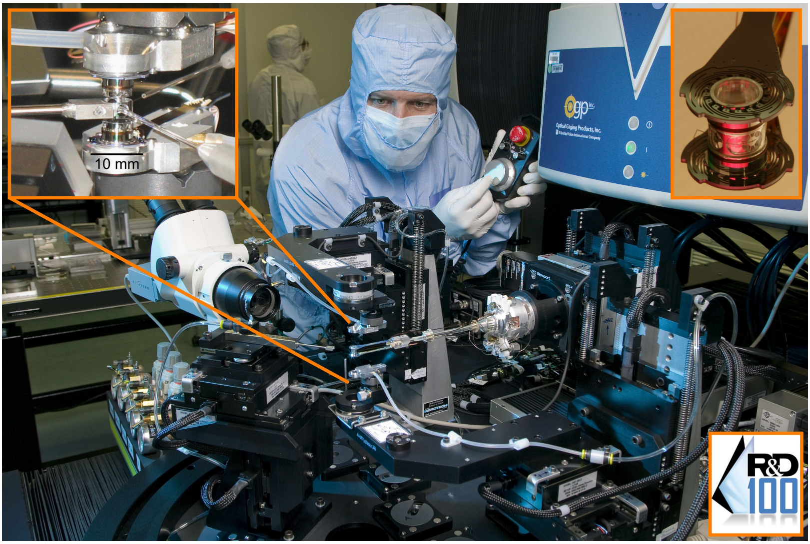

Figure 1: The Precision Robotic Assembly Machine releasing a laser fusion target that was just assembled. Target components being assembled (left inset). A completed target (right inset).

2 Overview of the Machine

The Precision Robotic Assembly Machine operates in a class 100 clean room, and consists of an LLNL-developed manipulator system integrated with an optical coordinate-measuring machine. Figure 2 shows a close-up view of the manipulator system, which can be reconfigured to accommodate different target designs or assembly procedures. Nineteen motorized and ten manual degrees of freedom provide simultaneous manipulation of five objects in a 1 cubic-centimeter operating arena with 100-nanometer repeatability (precision) and micrometer accuracy. Sensors in the manipulator system provide 100-milligram resolution force and gram-millimeter resolution torque feedback of the contact loads between components being assembled with micrometer-level or no clearance. The optical coordinate-measuring machine (OCMM) has a machine-vision system, laser-based distance-measuring probe, and touch-probe that provide micrometer-level accuracy measurements.

Target components are held by a vacuum chuck at the distal end of tooling that attaches that component to its manipulator. Incorporated in the proximal ends of the tooling are kinematic or semi-kinematic mounts that provide accurate remove-and-replace orientation of the tooling. A relatively open operating arena is maintained by using kinematic mounts on the capsule manipulators and on auxiliary mirrors that provide the OCMM with multiple viewing directions into the arena. This allows those systems, and the target base, to occupy the same regions at different times during the assembly process. Additional remove-and-replace systems include a long working-distance binocular microscope with an integral video camera, and a steady-rest that assists the hand-application of adhesives used to hold the target components together.

The vision and measurement systems of the OCMM are used to guide the initial approach and alignment of the target components, and to measure the relative position and orientation of the components. The force and torque feedback is used to guide the final approach, alignment, and mating of the delicate target components. The OCMM's working volume of 61 cm x 66 cm x 30 cm allows the Precision Robotic Assembly Machine to stitch together multiple millimeter-scale operating arenas, over distances spanning tens of centimeters, with micron-level accuracy.

An operator provides top-level control of the machine; initiating and controlling the actions of the motorized instruments with hand movements that are precise in the millimeter-scale world being scaled to precision in the 100-nanometer world. Adding a machine-based top-level control system would allow automating the assembly process.

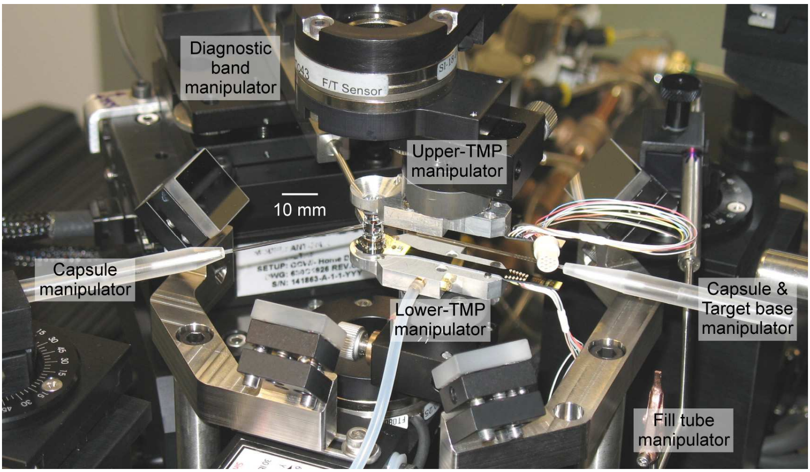

Figure 2: Close-up view of the manipulator system, with a target being assembled.

3 Enabling Technologies

The combination of precision motion control with force and torque feedback provides the operator – whether a person or machine-based control system – active compliance when assembling delicate components. The use of real-time dimensional metrology allows deterministically aligning and joining components, and immediately verifying the accuracy of the completed assembly. These technologies were migrated to other machines used to manufacture NIC fusion targets. The Flex-FAM [5] is a follow-on target assembly machine that utilizes the same real-time dimensional metrology and force and torque sensing as the Precision Robotic Assembly Machine. The Hohlraum Insertion Station [6], which is used to preassemble certain target components, uses the same force and torque sensing. Completing the circle of technology proof-of-principle and propagation, next-generation tooling for assembling targets that was developed with the Flex-FAM has been adapted for use on the Precision Robotic Assembly Machine.

References:

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