Building Fusion Targets with

AS the National Ignition Facility (NIF) prepares to begin fusion ignition and sustained burn experiments for the first time ever in a laboratory setting, a team of Livermore scientists and engineers is focusing on ways to efficiently and cost-effectively produce the tiny, intricate fusion targets that will be at the center of these experiments. Producing these targets is extraordinarily demanding when it comes to assembling components. Accurate alignment of target components on the micrometer scale is one of the critical requirements for achieving ignition with energy gain.

Historically, building laser fusion targets required a significant amount of handcrafting skill and technique involving microscopes and manually driven fixtures. Now, Livermore scientists are transforming the way fusion targets are manufactured with a new device called the precision robotic assembly machine. The Livermore development team is led by systems engineer Richard Montesanti and funded by the National Ignition Campaign Program. Early investments from Livermore's Laboratory Directed Research and Development Program and Engineering Directorate provided roots for the expertise in precision engineering needed to take on this challenge. The team, along with three private companies, has won an R&D 100 Award for the technology. Collaborators are from General Atomics in San Diego, California; Aerotech, Inc., in Pittsburgh, Pennsylvania; and Indicate Technologies, Inc., in Santa Clara, California.

The precision robotic assembly machine can manipulate tiny fusion target components with unprecedented precision in an operating arena the size of a sugar cube. Unlike in other machines, the innovative use of visual and force feedback allow an operator to drive the machine like a surgical robot and automate the assembly process. Furthermore, the precision robotic assembly machine demonstrates improved target quality and a tenfold reduction in manpower needed to assemble laser fusion targets.

Precision Mechanics

The precision robotic assembly machine was developed to manufacture small and complex laser-driven fusion ignition targets for NIF, although it can be adapted to build other complex miniature devices. The machine can manipulate five target components at once in a 1-cubic-centimeter operating arena. Each target is designed so that the inner physics package can be tailored independently of the surrounding thermal–mechanical package.

At the heart of the precision robotic assembly machine is a Livermore-developed reconfigurable manipulator system that assembles millimeter-scale components with micrometer accuracy and 100-nanometer precision (repeatability). Nineteen motorized axes and ten manual axes are arranged to form six manipulators for positioning the target components. The manipulator system is integrated with an optical-coordinate measuring machine that provides dimensional measurements of the target with micrometer accuracy during assembly. Auxiliary mirrors provide this measuring tool with multiple views of the target while it guides the initial

Development team for the precision robotic assembly machine: (front row, from left) Richard Montesanti, Monika Witte, Robert Kent, Manuel Carrillo, Dawn Lord, Elizabeth Dzenitis, and Jeff Atherton; (back row) Robert Bickel, Jack Reynolds, John S. Taylor, Richard Seugling, Jeffrey Klingmann, Ethan Alger (General Atomics), Evan Mapoles, Abbas Nikroo (General Atomics), and Carlos Castro. (Not shown: Livermore retiree George L. Miller.)

Precision Robotics

alignment of the target components and measures their relative positions and orientations. The force and torque feedback is used to guide the final alignment and mating of delicate target components that fit together with zero to micrometer-level clearance.

A Standout Machine

A unique attribute of the precision robotic assembly machine is its ability to stitch together multiple millimeter-scale operating arenas—within each, many components can be manipulated with 100-nanometer precision and 100-milligram resolution force feedback—over distances spanning tens of centimeters. The machine's manipulator system provides precise and repeatable motions, the force and torque feedback enables deterministic mating of delicate components, and the real-time dimensional metrology enables precise alignment of components and immediate verification of as-built accuracy.

"The multiple technologies integrated into the precision robotic assembly machine bridge the gap between building miniature- and man-size machines," says Montesanti. "Our machine could provide a key enabling platform for significant advances in the development and manufacture of centimeter-scale systems that integrate millimeter- and micrometer-scale optical, electrical, mechanical, and biological subsystems."

Systems engineer Richard Montesanti operates the precision robotic assembly machine. The inset shows an assembled fusion ignition target.

Other systems for manufacturing fusion targets are limited to simultaneously manipulating just two or three components in the assembly arena, and only a few of those systems can do so with 100-micrometer precision and micrometer accuracy. No other system uses force and torque feedback, which according to Montesanti is crucial when assembling a complex miniature machine made up of delicate components that contact each other.

The success of the initial precision robotic assembly machine motivated the building of a second machine to expand target production capability. "We need to build at least one target per day for the campaign, while maintaining flexibility for changes in target parameters," says Montesanti. "The precision robotic assembly machine enables that production rate, and its reconfigurable nature has already accommodated changes to the target design."

Fusion in Our Future

Assembling fusion ignition targets requires a deterministic and efficient manufacturing system that can simultaneously manipulate many delicate components with precision and accuracy. Repeatable and consistent production of high-quality, precision ignition targets will play an important role in using NIF's 192 laser beams to explore high-energy-density regimes relevant to developing commercial fusion energy.

NIF fusion ignition experiments will bring the study of stars and their environments into the laboratory, with the potential to greatly expand our understanding of the nature and origin of the universe. Fusion targets will be at the center of this monumental achievement. "Our precision robotic assembly machine is building the targets that will become the miniature Suns on Earth during the fusion ignition process," says Montesanti.

—Kristen Light

Key Words: force and torque feedback, fusion ignition targets, National Ignition Facility (NIF), precision robotic assembly machine, R&D 100 Award.

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