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Reconfigurable Assembly Station for Precision Manufacture of Nuclear Fusion Ignition Targets

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RECONFIGURABLE ASSEMBLY STATION FOR PRECISION MANUFACTURE OF NUCLEAR FUSION IGNITION TARGETS

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INTRODUCTION

This paper explores the design and testing of a reconfigurable assembly station developed for assembling the inertial confinement nuclear fusion ignition targets that will be fielded in the National Ignition Facility (NIF) laser [1]. The assembly station, referred to as the Flexible Final Assembly Machine (FlexFAM) and shown in Figure 1, is a companion system to the earlier Final Assembly Machine (FAM) [2]. Both machines consist of a manipulator system integrated with an optical coordinate measuring machine (OCMM). The manipulator system has six groups of stacked axis used to manipulate the millimeter-sized target components with sub-micron precision, and utilizes the same force and torque feedback sensing as the FAM. Real-time dimensional metrology is provided by the OCMM's vision system and through-the-lens (TTL) laser-based height measuring probe. The manually actuated manipulator system of the FlexFAM provides a total of thirty degrees-of-freedom to the target components being assembled predominantly in a cubic centimeter work zone.

MOTIVATION FOR DEVELOPING THE FLEXIBLE FINAL ASSEMBLY MACHINE

The National Ignition Campaign [3] goal of achieving thermonuclear fusion burn and gain with the NIF laser requires building at least one inertial confinement fusion (ICF) target per day. Referring to figures 2 and 3, the target is designed so that the physics package (hohlraum, capsule and the gas between them) can be tailored independently of the thermal-mechanical package that holds it (TMP-halves, diagnostic band, and silicon cooling arms). The required position accuracy of the assembled target components is in the range of ± 2-20 μm. The FlexFAM has already significantly increased the production rate of NIC targets, and its manipulator system is easily reconfigured to accommodate the different target configurations envisioned for NIC experiments.

FIGURE 1. Flexible Final Assembly Machine.

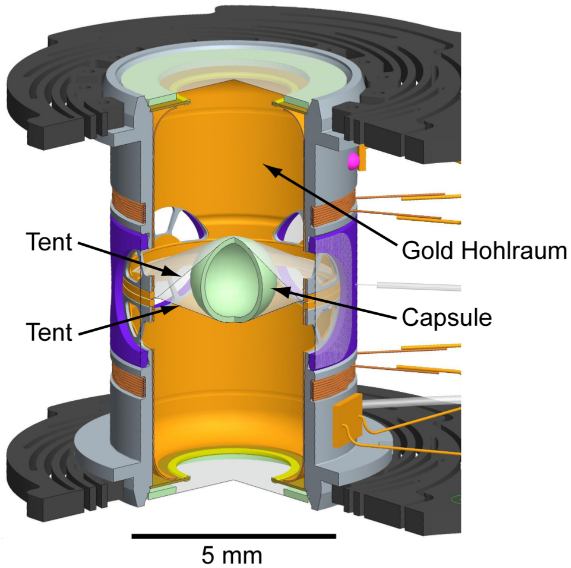

FIGURE 2. Model of a NIC target.

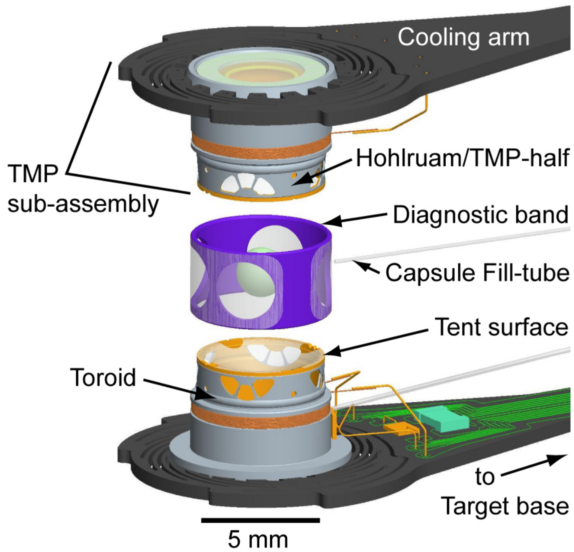

FIGURE 3. Model showing final assembly step for a target.

THE NEED FOR FLEXIBILITY

Referring to Figure 4, the manipulator system of the FlexFAM resides on a platform that can be readily removed and replaced from the OCMM. This allows configuring different manipulator systems to suit various NIC target configurations, many of which would be incompatible with one particular arrangement of manipulator stages. This flexibility reduces the down-time of the target production facility when a different target configuration is introduced. Instead of tearing down and reconfiguring a manipulator system that was arranged and precisely aligned for an earlier target configuration, it can be set aside and replaced with a different manipulator system that could be preconfigured off-line ahead of time. Targets that share similar configurations would then benefit from the rapid start-up time provided by a previously configured, aligned, and warehoused manipulator system. Moreover, the manipulator system could be removed so that the OCMM could be made available more broadly to the target fabrication facility to support dimensional metrology of target components, target sub-assemblies, and completed target assemblies.

OVERVIEW OF THE DESIGN

The FlexFAM was designed to operate in a class 1000 clean room, and consists of an LLNL-developed manipulator system integrated with a commercial OCMM having micron-level

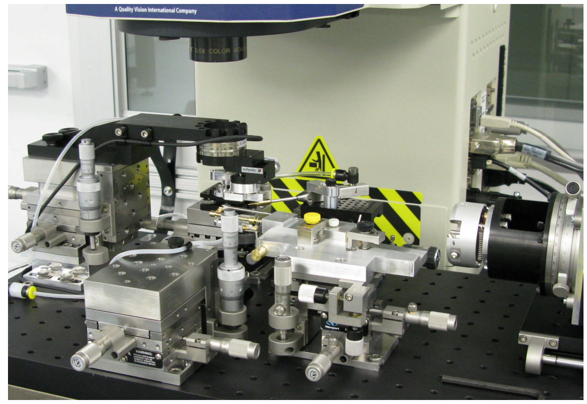

FIGURE 4. FlexFAM manipulator system.

accuracy over a working volume of 30 cm x 15 cm x 20 cm. The manipulator system consists entirely of manually-actuated stages, which enabled a quick path to developing a thirty degrees-of-freedom motion system that is more compact and simpler to operate than the earlier FAM [2]. This choice not only allowed meeting the aggressive timeline for the project, but the smaller envelope of the FlexFAM manipulator system allowed integrating it with a smaller bench-top styled OCMM than the FAM uses, providing easier operator access to the target assembly work zone. As shown in Figure 5, all of the stages are within comfortable reach of the operator so the need for motorized stages was greatly reduced. Functional improvements to the FlexFAM were identified during the design phase by selecting certain axes that would benefit from a future upgrade to motorized stages to enhance the ergonomics and performance for the manipulator system.

FIGURE 5. Target Assembly Technician operating the FlexFAM.

As the target components are aligned and fitted together, sensors embedded in the manipulator system provide 100-milligram resolution force and gram-millimeter resolution torque feedback of the contact loads. The OCMM has a machine-vision system and a laser-based height-measuring probe that provide micrometer-accuracy dimensional measurements of the target while assembling it. The vision system and laser probe 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 delicate target components that fit together with micrometer-level or no clearance. Figures 6 and 7 provide examples of the vision system and force and torque feedback presented to the operator.

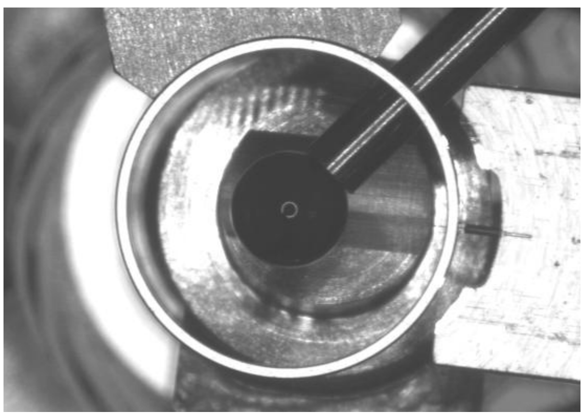

FIGURE 6. Image from the OCMM vision system showing the capsule held by a vacuum wand and the diagnostic band held by a vacuum chuck.

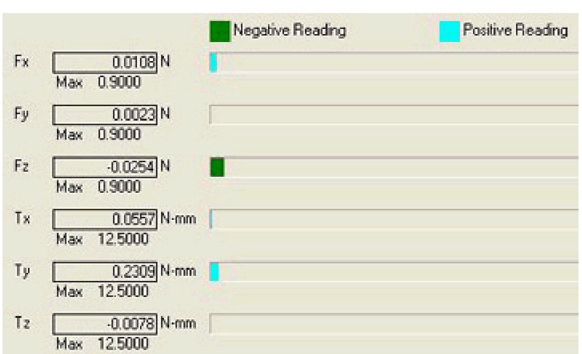

FIGURE 7. Image from the user interface for the force and torque sensor for the lower target half.

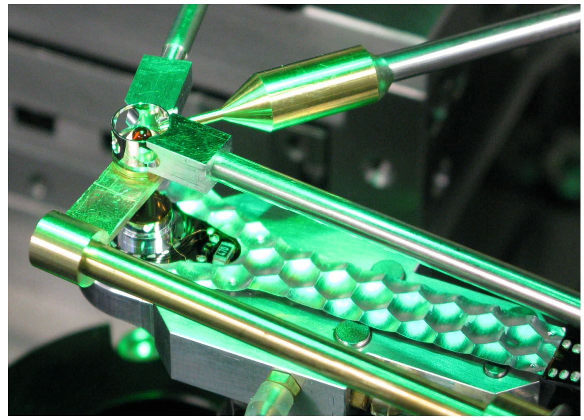

FIGURE 8. A view of the operating arena of the FlexFAM. The lower target half subassembly lies below the tooling used to manipulate the capsule fill-tube assembly and diagnostic band.

Target components are held by LLNL-developed vacuum tooling and specialized fixtures, like the ones shown in Figures 8, 9, and 10. In figure 8, the capsule is being centered in the diagnostic band. Figure 9 shows the target components aligned and ready for the final assembly step: the upper and lower target halves are brought together inside the diagnostic band so that the tent on the end of each target halve closes on the capsule, suspending it in the mid-plane of the target assembly. Referring to Figure 10, incorporated in the FlexFAM tooling are kinematic and semi-kinematic mounts that ensure accurate and repeatable remove-and-replace orientation of the tooling.

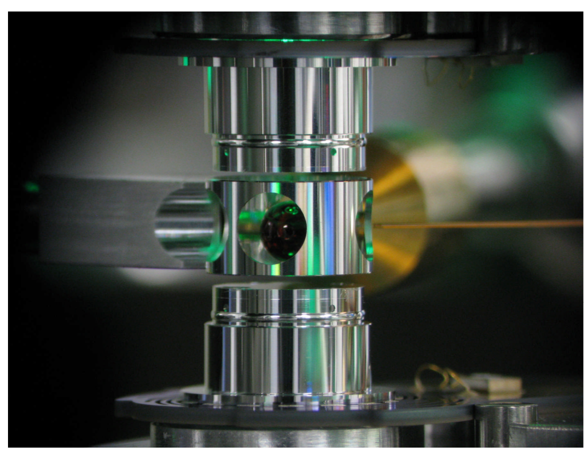

FIGURE 9. A second view of the operating arena of the FlexFAM. The capsule is centered inside the diagnostic band and between the upper and lower target halves. The capsule fill tube is visible on the right side of the figure.

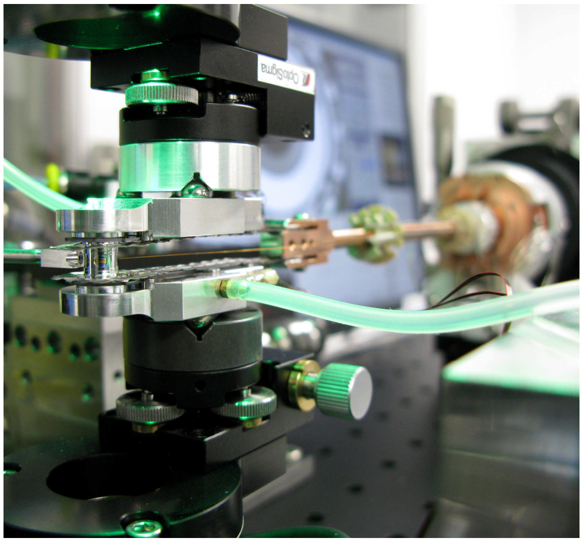

FIGURE 10. The upper and lower target half subassemblies are held in the FlexFAM by magnetically-coupled kinematic tooling mounts. The relatively long target base assembly, which gets connected to the ends of the upper and lower target half subassemblies, fades out of focus on the right side of the figure.

Future Work

The manipulator system is attached to the OCMM with fasteners threaded into the manufacturer-provided holes in the OCMM stage. A concept for a kinematic mounting system is being developed into hardware that will provide accurate and repeatable mounting and removal of the manipulator system. This will better support a major goal that the FlexFAM provide a rapid turnaround in re-tooling the target production facility in response to changes in the configuration of targets required by the National Ignition Campaign.

The novel tooling shown in Figure 8 for manipulating the capsule fill-tube assembly and diagnostic band is being migrated to the earlier Final Assembly Machine, which is also building NIC targets [2]. The specialized fixture that is used to thread the capsule fill-tube assembly into the diagnostic band is being perfected for use with both target assembly machines. As experience using the FlexFAM and its copies is gained by target production personnel, the need to motorize certain axes will be revisited.

Conclusion

The Flexible Final Assembly machine is being used to assemble production ignition targets for the National Ignition Campaign. Figure 10 shows one of these targets being built on the FlexFAM by one person in a single 8-hour shift, five months after starting this project. The FlexFAM successfully demonstrated that it can assemble inertial confinement fusion ignition targets that meet the required micron-level tolerances. Its manipulator system provides the precise and repeatable motion needed for assembling a target, the force and torque feedback allows an operator to deterministically engage the components being assembled, and the OCMM provides the requisite alignment of components during the assembly process and provides an immediate verification of the accuracy of the as-assembled target. The simplicity of use afforded by the manually-actuated manipulator system is allowing a rapid transfer of the FlexFAM from its development team to the target production team. Novel target assembly tooling developed for and tested on the FlexFAM is being migrated to other machines being used to build NIC targets.

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[3] National Ignition Campaign. https://lasers.llnl.gov/programs/nic/icf/.