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Abstract

General Atomics, working with the University of Rochester Laboratory for Laser Energetics, has designed and is fabricating a system for the handling and processing of cryogenic targets for inertial confinement fusion (ICF) experiments on the University of Rochester's OMEGA laser system. This equipment will provide the capability to routinely fill 1 mm diameter, hollow spherical plastic targets with up to 1500 atm of a 50/50 mix of deuterium and tritium (DT) gas. The targets are then cooled to <20 K to freeze the DT gas to a solid, and are transferred to a Moving Cryostat which places them into the Target Chamber at the focal point of OMEGA's 60 laser beams. The handling of these delicate targets at temperatures down to 16 K and a vacuum of 10^{-6} Torr presents some unique challenges for remotely operated mechanisms. The remotely controlled target filling process takes place in a specially designed Fill/Transfer Station housed within a glove box. This paper discusses the process of filling and transferring these targets within the Fill/Transfer Station. Three of the remote mechanisms used in this process are discussed. These mechanisms include a target manipulator, a shroud cooler lift, and a stalk aligner. The technical requirements for such devices are reviewed along with the approach selected for this application. Considerations in the approach to actuation, bearings, compliance, cooling, and control under operating conditions are discussed. The Fill/Transfer Station was partially assembled at General Atomics in San Diego and has been shipped to Rochester for final assembly, installation, and system integration.

1. Introduction

As part of the National Inertial Confinement Fusion Engineering Program, General Atomics, working closely with University of Rochester (UR) staff, has designed and constructed the OMEGA cryogenic target system (OCTS).[1] This system will be capable of filling, transporting, layering, characterizing, inserting, and positioning deuterium/tritium (DT) filled cryogenic targets. It will be part of the OMEGA laser at UR's Laboratory for Laser Energetics in Rochester, New York.

Figure 1 shows an overview of the OCTS system as it will be configured at the UR/LLE. The target filling equipment is located within the tritium laboratory. Empty targets aremanually loaded into the Fill/Transfer Station (FTS).[2] This process is accomplished when four mounted targets, assembled into a rack, are placed into an insertion device which installs them into a high pressure permeation cell. The DT mixture is routed to a high pressure Permeation Cell within the FTS where the diffusion filling process takes place. Once filled, the targets are cooled to cryogenic temperatures to condense the DT. The four targets in one rack are filled in one operation and then separated within the FTS for transfer to the Moving Cryostat (MC). Using a precision manipulator, one target is removed at a time from the target rack and installed into the stalk of the MC. The MC (contained in a cart) maintains the cryogenic target environment as the target is moved to the area beneath the target chamber (La Cave), and to target chamber center. The targets are then positioned at the laser convergence point. Immediately before the shot, a protective shroud surrounding the targets is quickly removed to expose the cryogenic target for the laser shot.

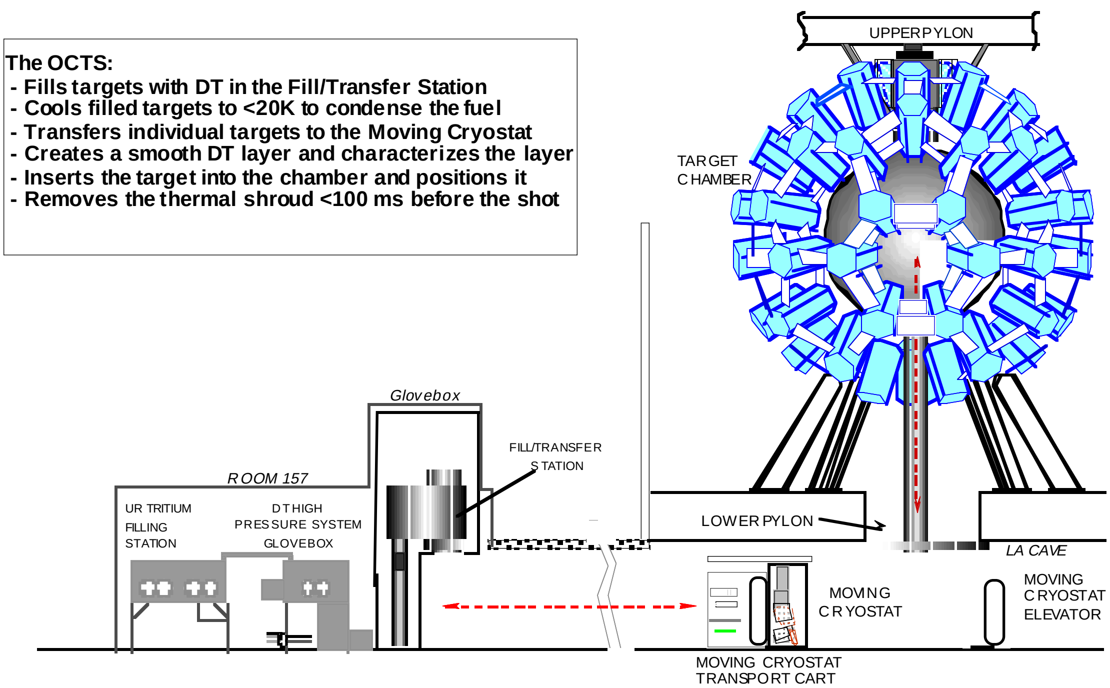

Fig. 1. Overview of OMEGA Cryogenic Target System (OCTS).

2. Cryostat Design

Figure 2 illustrates the layout of the basic components of the fill/transfer station. This station consists of a large cryostat which houses the components and provides a controlled environment for the process. Included as part of the cryostat is the ***inserter*** which loads the targets into the cryostat permeation cell. The ***permeation cell*** is a high pressure containment cell capable of withstanding pressures of 1500 atm and being uniformly cooled to 16 K. A precision ***target manipulator*** is used to move the individual targets from the permeation cell

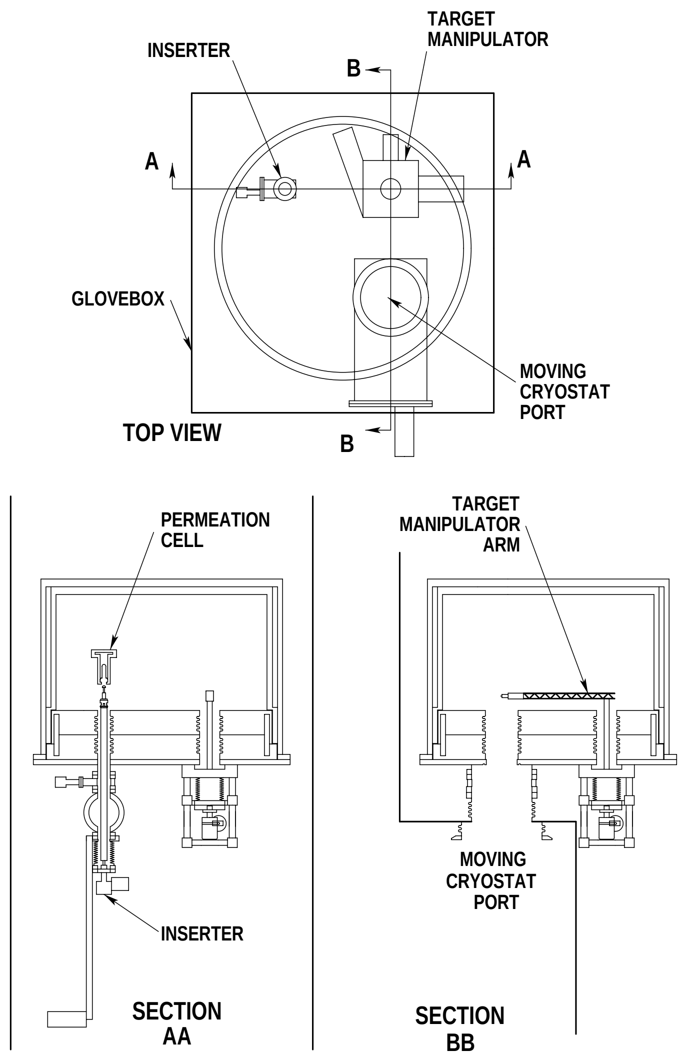

Fig. 2. Sketch of Fill/Transfer Station showing cryostat, glovebox, and major components.

to the moving cryostat port. A ***shroud cooler*** and ***stalk aligner*** (not shown in Fig. 2) are located at this port to assist in making a successful transfer of the targets to the moving cryostat. The targets are placed on the end of the MC's stalk (a long rod) and then surrounded by a cooled shroud. The MC, including the stalk and shroud, retracts through the port into its own vacuum chamber.

The cryostat is of "bell jar" design and consists of a fixed base and a removable dome. The joint between the base and the dome is a bayonet design with a nominal 0.10 in. (2.5 mm) gap. This joint is sealed by a room temperature elastomeric o-ring at the joint between the base and dome. The cryostat is 49 in (1.25 m) in diameter and 43 in. (1.10 m) high and is fabricated from 316 stainless steel. Both the base and dome are vacuum insulated. These vacuum spaces are isolated to prevent tritium from contaminating the multilayer insulation (MLI). The cryostat wall has cooling tubes attached to it through which cold helium gas is circulated. This wall maintains a 16 K nominal temperature. Inside the insulating space, a liquid nitrogen cooled thermal shield is used to intercept both radiation heat transfer and conduction heat transfer coming up the mouth of the dome. For maintenance of equipment on the inside of the cryostat, the dome is simply unbolted and lifted vertically off the base using a lift mechanism built into the glovebox that houses the cryostat. This design also allows warm alignment and operations of all equipment, both outside and inside the cryostat.

3. Inserter and Permeation Cell

The mounted target, shown in Fig. 3, includes a 0.040 in. (1 mm) diameter polymer spherical shell. This shell is suspended from a beryllium wire "C" frame by three spider webs. This assembly is attached to the top of a boron post. The entire mount is about 2.14 in. (54.4 mm) tall. Four of these target assemblies are placed in a cylindrical rack for handling during the filling process. A complete rack of targets is manually placed into an insertion mechanism that utilizes gate valves and an isolation chamber to transfer the targets into the permeation cell inside the cryostat. The target rack sits on the lower part of a breech lock which interfaces and seals against the permeation cell. A sixty degree rotary motion of the inserter mechanism is used to lock and unlock the breech-lock mechanism on the permeation cell. The inserter motion is accomplished using a precision motion drive located outside the cryostat. Vacuum feedthroughs transmit motion to the thin walled tubular rod used to insert the targets into the permeation cell. Each axis of motion is driven by a stepper motor and controlled by a motion controller. Both axial and rotary motion are provided by the inserter mechanism. Access to the cryostat utilizes a vacuum lock and a gate valve through which the targets pass. After target filling, the inserter mechanism also provides rotary motion to present each of the individual targets to the target manipulator for transport to the MC.

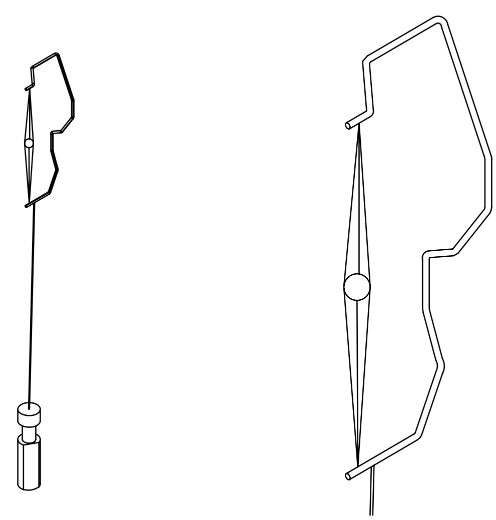

Fig. 3. Sketch of mounted cryogenic target. Sketch on right is enlargement of beryllium ''C'', target sphere, and spider webs.

The permeation cell is located inside the cryostat. Although the cryostat interior walls remain cold, the permeation cell temperature varies from 473 K to cryogenic temperatures. After the targets are inserted, the permeation cell is sealed to allow for pressurization. This is accomplished by means of the breech lock and a pneumatic actuator built into the cell. The pressure seal consists of mating sixty degree cones, similar in design to high pressure tube fittings. During target fill, the permeation cell is warm to allow the DT to permeate the plastic target wall. Once the desired pressure is reached, up to 1500 atm (152 MPa), the permeation cell is cooled to trap the solid DT inside the target. The permeation cell is manufactured from A286, a precipitation-hardened high strength stainless steel alloy. To minimize thermal gradients, a copper sleeve is press fit onto the cell wall. Electric heaters attached to this sleeve maintain the cell temperature during target fill. To cool the cell, helium gas is flowed through tubes attached to the outside of the permeation cell. This helium gas is cooled by liquid nitrogen and a cryocooler in the cooling module.

4. Design Considerations

Stainless steel was used though out the construction of the handling mechanisms because of its corrosion resistance and its ductility at cryogenic temperatures. Metal seals were used at locations exposed to cryogenic temperatures since elastomeric materials would become embrittled. Moving mechanisms located in the cryostat pose some special problems. Bearing greases become hard and are not effective at the cryogenic temperatures. Because of the potential exposure to tritium, materials containing fluorocarbons cannot be used as they tend to degrade and produce hydrofluoric acid. Other polymer materials were avoided because of tritium incompatibility. Where metal to metal rolling bearings and sliding surfaces were required, tungsten disulfide (trade name Dicronite™) dry lubricant was selected. This material has been successfully used on metal to metal surfaces at temperatures below 10 K. Allowances for thermal expansion were provided where ball bearing materials of 440C stainless steel interface with a housing made of 300 series stainless in order to prevent seizing or binding at low temperature.

5. Target Manipulator

The target manipulator moves individual targets between the permeation cell and the moving cryostat. These movements are performed in four degrees of freedom by an x-y-z and rotary vacuum manipulator. The target manipulator must handle the targets while they are at cryogenic temperatures. The drive for this mechanism consists of precision motion stages driven by stepper motors located outside the cryostat. Motion is transmitted through a vacuum/bellows feed through to the chamber interior. Each axis of motion is controlled by stepper motors and a motion controller. Motion range of ± 1.0 in. (25 mm) in x and y, ± 0.5 in. (13 mm) vertical, and 92 degrees rotation are provided.

The target manipulator mechanisms located inside the cryostat consists of a thin-walled stainless steel tube extending up from the manipulator. Attached to the tube is a horizontal arm with a compliant target gripper on the far end. This gripper utilizes stainless steel leaf spring compliance in two directions and a spring loaded tapered lead-in to pick up an individual target and place it on the MC stalk, see Fig. 4. Motion of this device is

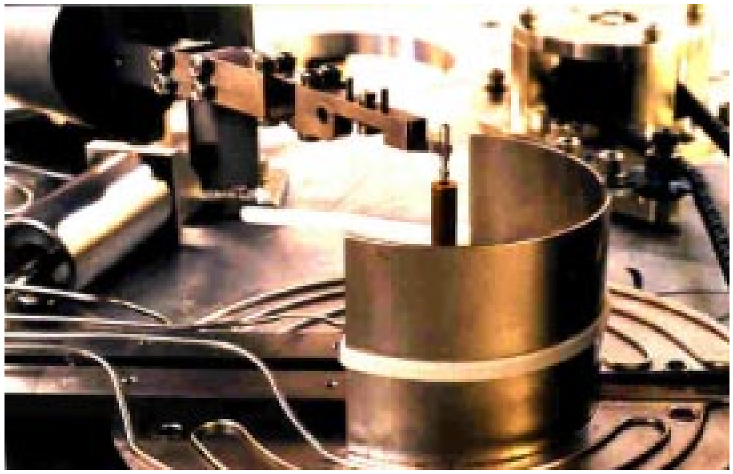

Fig. 4. Target being placed on Moving Cryostat stalk.

Fig. 5. Target manipulator arm with gripper and fiberscope.

programmed with check points at critical interfaces. A remote viewing fiberscope allows the operator to check the alignment at critical transitions points before the operation is completed. Manual adjustments to position can be made using the manual override on the drive control if necessary. A light weight tubular structure provides stiffness and low thermal mass. A view of the target manipulator is shown in Fig. 5 with the fiberscope attached.

6. Stalk Aligner

A long thin target support tube (stalk) penetrates up through the bottom of the cryostat gate valves for loading of the target. This stalk is part of the MC and supports the target during transport. Because of the precision required to locate and mount the target on this unsupported length, a stalk aligner device is required. The stalk aligner will center and steady the stalk during target transfer. It also provides some thermal shielding and active cooling to prevent heating of the target during the transfer process. A helium cooled sheet metal shield covers the port opening during the transfer process. The stalk aligner is shown in Figs. 6 and 7 and is constructed entirely of stainless steel. The two arms are each actuated using a stainless steel bellows actuator that can be pressurized with helium at differential pressures up to 60 psi. The two arms pivot on shoulder screws with meshed gear segments to assure symmetrical motion from each arm. An adjustable centering pin provides the centering stop and alignment to guarantee precise location. All moving points and rubbing surfaces are lubricated with Dicronite™ coating. The stalk aligner is spring balanced to be fail safe (open) under loss of pressure so that targets can be removed under this condition.

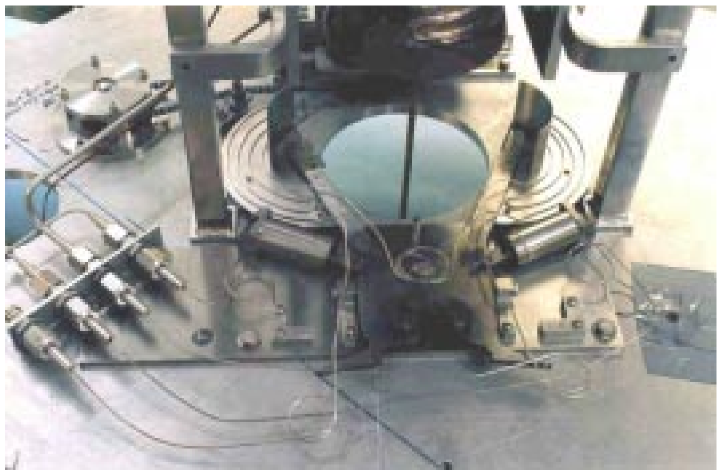

Fig. 6. Stalk aligner open position.

Fig. 7. Stalk aligner closed position.

7. Shroud Cooler

The shroud cooler shown in Fig. 8 is used to remove the MC shroud, to cool it to cryogenic temperature, and, after the target is placed on the MC stalk, to replace the shroud on the MC.

Fig. 8. Shroud cooler with lifting mechanism.

The shroud cooler is a stainless steel cylinder with helium cooling lines brazed to the exterior diameter. It is raised and lowered using a ball screw driven slide with linear ball bearing ways. The base plate of the vertical slide assembly includes integral cooling passages with connections to the helium lines. All rotating ball bearings, linear ball bearings, a ball nut, drive chain, and sprockets used in this assembly are made from stainless steel and lubricated with Dicronite™ dry lubricant. The stainless steel chain drive transfers motion to the lift mechanism from a shaft which passes through a vacuum feed from a stepper motor drive located outside the chamber. Hermetically sealed vacuum limit switches provide end of travel indication. Raising the shroud cooler activates a pair of rods in a tapered guide to grip the shroud and carry it along during the loading process.

9. Status

The components of this system have been procured and were partially assembled at General Atomics in San Diego, California. Preliminary fit and function testing was conducted there. The equipment was then shipped to UR's Laboratory for final assembly, integration, and testing. Commissioning is expected to occur in late spring of 1999.

Acknowledgments

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