Preprint
UCRL-JC-141053

National Ignition Facility Target Chamber

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This article was submitted to
21st Space Simulation Conference, Annapolis, MD,
October 23 – 26, 2000

October 5, 2000

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

NATIONAL IGNITION FACILITY TARGET CHAMBER

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ABSTRACT

On June 11, 1999 the Department of Energy dedicated the single largest piece of the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) in Livermore, California. The ten (10) meter diameter aluminum target high vacuum chamber will serve as the working end of the largest laser in the world. The output of 192 laser beams will converge at the precise center of the chamber. The laser beams will enter the chamber in two by two arrays to illuminate 10 millimeter long gold cylinders called hohlraums enclosing 2 millimeter capsule containing deuterium, tritium and isotopes of hydrogen. The two isotopes will fuse, thereby creating temperatures and pressures resembling those found only inside stars and in detonated nuclear weapons, but on a minute scale. The NIF Project will serve as an essential facility to insure safety and reliability of our nation's nuclear arsenal as well as demonstrating inertial fusion's contribution to creating electrical power.

The paper will discuss the requirements that had to be addressed during the design, fabrication and testing of the target chamber.

A team from Sandia National Laboratories (SNL) and LLNL with input from industry performed the configuration and basic design of the target chamber. The method of fabrication and construction of the aluminum target chamber was devised by Pitt-Des Moines, Inc. (PDM). PDM also participated in the design of the chamber in areas such as the Target Chamber Realignment and Adjustment System, which would allow realignment of the sphere laser beams in the event of earth settlement or movement from a seismic event.

During the fabrication of the target chamber the sphericity tolerances had to be addressed for the individual plates. Procedures were developed for forming, edge preparation and welding of individual plates.

Construction plans were developed to allow the field construction of the target chamber to occur parallel to other NIF construction activities. This was necessary to achieve the overall schedule. Plans had to be developed for the precise location and alignment of laser beam ports.

Upon completion of the fabrication of the aluminum target chamber in a temporary structure the 130 ton sphere was moved from the temporary construction enclosure to its final location in the target building.

Prior to the installation of a concrete shield and after completion of the welding of the chamber penetrations vacuum leak checking was performed to insure the vacuum integrity of target chamber.

The entire spherical chamber external surface supports a 40 cm thick reinforced concrete shield after installation in the target building.

The final task is a total survey of the laser ports and the contour machining of spacer plates so that laser devices attached to these ports meet the alignment criteria.

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

INTRODUCTION

On December 19, 1996, the U. S. Department of Energy issued the Record of Decision for the *Programmatic Environmental Impact Statement for the Stockpile Stewardship and Management Program*, approving the construction of the National Ignition Facility (NIF). The NIF is currently under construction at Lawrence Livermore National Laboratory (LLNL) where it will be the latest in a series of high-power laser facilities used for research in inertial confinement fusion. The world-class NIF design team includes experts from LLNL, SNL, Los Alamos National Laboratory (LANL), and the University of Rochester's Laboratory for Laser Energetics (URL). When completed the NIF will house 192 laser beamlines that run the length of the facility and direct their energy inside the target chamber upon a fusion fuel capsule the size of a BB.[1]

The task facing a team of engineers from LLNL and SNL was to design and deliver a vacuum vessel that would operate at least 30 years, withstand earthquakes as well as debris and gamma radiation from experiments, maintain deep vacuum and ultrafreezing environments required for experiments, and accommodate nearly a hundred diagnostic instruments, 192 beamlines, and associated optics and equipment. All of the chamber work also had to be completed on a schedule consistent with the building schedule so that installation of the chamber could be accomplished without impacting building progress. The engineering team first consulted with laser scientists, optical experts, target physicists, laser physicists, and facility designers at LLNL, SNL, LANL, URL, and the Defense Threat Reduction Agency about their requirements for the target chamber. These requirements included the absolute synchronization of laser beams arriving at the target simultaneously, fixed focal plane distances from the final optics to the targets, minimizing x-ray influence on the chamber walls, proximity of myriad instruments, and ease of ingress and egress of systems to transport, hold, and freeze the tiny targets. The result was a 10 centimeter thick spherical vessel measuring 10 meters in internal diameter, with over 200 holes of varying diameters located over its surface to accommodate the beamlines, diagnostic instruments, vacuum pumping system and other equipment.[2] Sphericity was very important in this design and the stated requirement was for the inside diameter of the chamber to be within ½% of the theoretical diameter or 5 cm rather than the ASME Code requirement of 1% or 10 cm. The material chosen for the chamber was ASME A5083-0 aluminum. This is a strain hardening alloy that is very formable and weldable. It also possesses a chemistry that will have low activation from neutrons and gamma rays formed in the destruction of the targets.

ANALYSIS

The analytical modeling of the target chamber was carried out by both SNL and LLNL using Patran and Nastran. Both static and dynamic seismic analyses were done. The seismic models also considered the interaction with the building and support pedestal. The exterior 40 cm concrete neutron/gamma ray shield was modeled as a dead weight non-supporting member (this was considered as a worst case). An initial concern was the determination of the required chamber shell plate thickness, considering the number and placement of the port holes, to produce a chamber that would not buckle and maintain a factor of safety of three (based on yield stress) under normal operating conditions. A 10 cm wall thickness met these criteria (an additional forming thickness was added for fabrication).

Due to the distribution of the optics and diagnostic ports the vertical weight of the chamber would have to be supported on a relatively small pedestal area. This would not provide adequate lateral support to the chamber during a seismic event. Thus a total of 17 lateral seismic restraints were added above and below the equator. This effectively tied the chamber to the building. The seismic analysis had to consider the interaction of these supports both on the chamber and the building.

FABRICATION

The contract for the target chamber and its neutron/gamma ray shielding was awarded to Pitt-Des Moines, Inc. (PDM) in July 1997. The method of fabrication and construction of the target chamber was PDM's responsibility. Due to the extreme thickness of the chamber shell, 111 mm after allowance for thinning during the forming process, and the fact that final welding of the shell segments would be done in Livermore, it was determined that every effort should be made to maximize the size of the shell plate segments thereby decreasing the amount of welding. PDM used its normal spherical vessel plate layout pattern of an expanded cube (6 sides) with 3 plates per side (18 plates total). The design, looking like a giant volleyball, features 6 symmetric middle plates and 12 asymmetric outer plates. As manufactured, the 18 aluminum plates measure 2.4 by 6.9 meters and weigh about 7.5 tons each.

Accurate fabrication of the shell plate segments was essential in delivering the target chamber within the stringent tolerances prescribed by LLNL. The aluminum plates were manufactured domestically and sent to France to be warm formed in a closed die press to a calculated radius of curvature that would allow for weld shrinkage. These segments were then shipped back to the United States and after removal of the excess edge material, the edges were precisely machined to the proper dimensions with the required weld preparation applied. The first 'set' of three plates were trial fit together and inspected for dimensional accuracy. They were found to be acceptable and the remaining plate segments were machined, re-inspected for dimensional accuracy and sent to Livermore for assembly.

CONSTRUCTION

Due to the fast track nature of the project and the need to control the environment where the chamber was assembled, a protective temporary enclosure was designed and constructed. This allowed for temperature control and shielding from the wind and sun, elements that could seriously affect the quality of the welding process and precision of the installed port locations. A 2-ton polar crane was also incorporated with the enclosure to assist with the placement of the ports for welding into the chamber.

Once on site the first three plates that formed the bottom portion of the sphere were welded together as a subassembly and placed on the pre-assembled chamber support structure. All chamber welding was done using the gas metal arc welding (GMAW) process. The shell complete penetration butt welds took approximately 155 passes to complete and the welding was sequenced to control weld shrinkage/distortion in order to maintain the necessary geometrical tolerances. Once the bottom three-plate subassembly was placed on the chamber support structure the remaining plates that formed the sphere were fit together without welding and the chamber geometry was checked by precision survey with a laser tracker to verify proper sphericity prior to welding. Again, the sequencing of the welds was necessary to assure control of critical dimensions. During the welding process the chamber sphericity was re-checked to assure the requisite shape was being maintained.

PENETRATION INSTALLATION

After welding was complete, the laser tracker was again used to perform a precision survey of the interior surface. This survey verified that the chamber was well within tolerance (slightly over ¼% or 2.54 cm) and established the best-fit center of the sphere. The tracker was then used to accurately mark all port locations referenced from the best-fit center as well as over 400 beam dump brackets. PDM then developed special fixtures to bore pilot holes for the ports. These pilot holes became the reference feature used by PDM's specialty machining subcontractor to precisely bore the holes for the ports. Each hole was set specifically to a diameter not more than 3.2 mm larger than the outside diameter of the specific port designated for that location. This was done to minimize the potential for subsequent welding of the port to the chamber to cause the port to fall outside its prescribed location tolerances. PDM then used other custom designed fixtures to accurately position the ports in the holes for welding.

PLACEMENT OF CHAMBER IN TARGET BAY

Once this work was complete PDM joined forces with LLNL personnel to move the target chamber from the temporary enclosure to its final location in the target bay of the NIF building. At this point the target chamber weighed approximately 130 tons and the move was accomplished in two steps. First the chamber was lifted from the temporary enclosure by a 14-story-tall Manitowoc 4600 ringer crane and moved approximately halfway to the target bay. There it was displayed and dedicated at a ceremony attended by Energy Secretary Bill Richardson and representatives of the science communities in Great Britain and France who are pursuing similar experiments. The following week it was lifted again by the repositioned Manitowoc 4600 and set in the target bay on its massive concrete support pedestal.

At this time the target bay walls were roughly half their final height thus the remaining tasks were coordinated with other subcontractors responsible for completion of the conventional building facilities. With the chamber set roughly in final position it was time to test the vacuum integrity of the chamber.

VACUUM LEAK CHECKING

The target chamber is designed to operate at 5×10^{-5} torr for non-cryogenic target shots and 5×10^{-6} torr for cryogenic target shots. The requirement for surface finish was mill finish or equal. After all of the fitting and welding that took place the chamber's interior surfaces were hand smoothed with fine grit flapper wheels to approximate the mill finish. The chamber was thoroughly rinsed with a high-pressure water spray. Subsequent construction dust was swept out prior to initial vacuum pumping of the chamber. Temporary o-rings were installed in all 217 flanged joints on the chamber and attached plenum.

The pumping system used for helium spray probe leak testing of the target vacuum chamber consisted of an atmospheric rotary vane pump (120 cfm) and a mechanical pump (140 cfm) that would pump the chamber from 760 torr to 20 torr. Then a Roots blower (1250 cfm) was turned on and backed by the mechanical pump. Below 10×10^{-3} torr, a 6-inch turbomolecular pump (500 l/sec) was gradually valved in and the Roots/mechanical unit was valved out. Then a 10-inch turbomolecular pump (2000 l/sec) was brought on line. Once the chamber pressure was below 1 x 10^{-4} torr a 20 inch cryopump was turned on. Note that during the early stages of leak testing the chamber pressure would not allow for more than just barely opening the 6-inch turbopump valve.

Testing was performed while the building was still being constructed around the chamber and conditions were not ideal when the o-rings were installed and pumping system components mounted. Despite this, testing proceeded much as planned with repeated cycles of pumping down – leak testing – venting to repair leaks. Each successive pump down cycle resulted in an improved base pressure and smaller leaks not visible at higher pressure were identified and corrected. The source of these leaks was about equally split between weld leaks in the ports and o-ring leaks. Once all leaks were eliminated the chamber was segmentally bagged to verify the integrity of all shell butt welds and port welds. The combination of pumps used above was able to take the target chamber repeatedly to a pressure of less than 8 x 10^{-7} torr! A final rate of rise test was performed to establish a baseline. This was subsequently successfully compared to a repeated rate of rise test performed after application of the neutron/gamma ray shield to verify that the vessel was still sound.

CHAMBER SHIELDING

The neutron/gamma ray shield consists of 16 inches of borated concrete applied as layers of gunite sprayed onto the outside shell of the target chamber. Two layers of steel reinforcing bars were mounted in a grid pattern to studs welded to the chamber. A bonding agent was used to improve the tie between the concrete and the chamber shell. The tubular portions of the ports and all structural supports below the surface of the concrete were isolated from the concrete to guard against an overstressed condition in the event of a seismic occurrence. After all of the gunite layers were applied and the concrete cured for about six weeks the surface was hand worked to a smooth finish and painted with two coats of epoxy paint.

CHAMBER SURVEY

The next significant activity was a re-evaluation of the spherical geometry of the chamber after placing over 200 tons of concrete on the exterior. Again, a precision survey with laser tracker was done to determine the current best-fit center based on evaluating the most critical chamber components: the location of the 72 Final Optics Assembly (FOA) or laser ports. Now knowing the location of the best-fit center and its relationship to the FOA ports, the chamber was ready to be accurately positioned on the pedestal support.

CHAMBER ALIGNMENT

Since most of the surface of the chamber is covered with ports, it was obvious that the equipment necessary to position the chamber could not be permanently installed. PDM developed a system of hydraulic jacks and multi-ton rollers that could elevate, translate and rotate the chamber in small incremental moves. This system was installed on a substantial steel jacking ring that is supported through embedments in the chamber pedestal support. A second jacking ring is attached to the chamber support structure and lines up directly above the jacks and rollers. PDM, with the help of the precision surveyors using two laser trackers on opposite sides of the chamber, was able to place this massive structure within less than 1 mm of the desired location.

Once in position the actual gaps between the base of the chamber support and the top of the pedestal were measured and custom shims were machined and installed to lock the chamber in position. Next a number of horizontal seismic stabilizing struts were connected to the chamber. The chamber was then given a rough cleaning with warm water and a low concentration of detergent. All port covers were then removed and the flange faces and o-ring grooves wiped clean. The covers were reinstalled along with the vacuum pumping system components, except for the cryopump. The chamber was then pumped down to below 10×10^{-5} torr and all flanged connections were leak tested to verify vacuum integrity.

FOA SPACERS

At the current time the target bay is not environmentally controlled and the variation in temperature does not allow measurements with the necessary degree of accuracy to be made to verify the final position of the chamber. Another related task that is incomplete is the measurement of the position of each FOA port flange. Once the plane and location of the flange surface can be established, custom-machined spacers will be made for each of these ports. The purpose of the spacers is to correct the plane to within 0.23 degrees and the position to within 0.12 mm for the equipment that mounts to this port.

PROGRAM STATUS

The NIF construction project is scheduled for completion by the end of fiscal year 2008. Some of the beam lines will be in use well before that date, however. The current plan calls for making a few beam lines available in fiscal year 2005 so that the experimental community can begin using NIF's advanced capabilities. The goal for fusion ignition and energy gain on NIF is scheduled toward the latter half of this decade.

1. National Ignition Facility Poster; 40-00-0295-0563C 3/97

2. Arnie Heller, "Target Chamber's Dedication Marks Giant Milestone", Lawrence Livermore National Laboratory, Science & Technology Review – September 1999, UCRL-52000-99-9