Cool-down performance of the new apparatus for fuel layering demonstrations of FIREX targets

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Abstract. FIREX targets have been developed under two layering strategies: foam shell and cone guide laser heating methods. Basic studies have been conducted by the collaboration research between ILE and NIFS. Then the next stage requires the characterization of a layered solid fuel. The present system is at the disadvantage of optical observations. Therefore, a new apparatus is designed to solve it. Glass windows with a wide aperture are installed for an interferometer and a microscope. To isolate the vibration from a cryocooler, active vibration control units are equipped, and flexible thermal conductive links are utilized. Furthermore, a quick target exchange mechanism is applied to deal with different types of FIREX targets. A target holder is detachable from a main vacuum chamber. A metal gasket with not fixing bolts but a load of ~ thousand newtons on ensures GHe leak tightness for target cooling. Eventually, the design temperature of 10.00 K at a target container has been achieved. The cool-down performance indicates that the new apparatus provides a cryogenic environment for fuel layering demonstrations.

1. Introduction

Fast Ignition Realization EXperiment (FIREX) targets have been developed under the collaboration between the Institute of Laser Engineering (ILE), Osaka University and the National Institute for Fusion Science (NIFS). A typical target consists of a 500 µm plastic shell, a gold cone guide and a glass fill tube as shown in figure 1. To complete a FIREX target, ILE and NIFS have two fuel layering strategies: a foam shell method [1-4] and a cone guide heating technique for polystyrene (PS) shell [5]. The final goal is to form a uniform solid DT or D₂ fuel layer with ~20 µm in thickness on the inner surface of the plastic shell. To date, preliminary studies have been conducted: the reduction of residual void spaces in a solid fuel layer within an aerogel material [4] and the layering demonstration in a 2 mm PS shell prototype target [5]. The formation of a 20 µm uniform solid fuel layer in the FIREX targets is a remaining issue.

The present apparatus provides a large multipurpose space for cryogenic experiments [6]. The lowest temperature is available at ~12 K, and vibrations from a refrigerator are successfully reduced to less than 10 µm at the target position. The mechanical insulation utilizing flexible thermal conductive links is valid to be compatible with cooling performance. Other ideas to control the vibrations are also employed. Eventually, it is possible to observe a target with several 10 µm resolution. Its limit mainly depends on dimensions of the apparatus. For the next step, higher resolution is demanded to characterize a layered solid fuel with 20 µm in thickness. Based on the cryogenic and the mechanical
components developed for the vibration control, we built a new apparatus especially designed for the characterization of the solid fuel layer. Furthermore, it has another feature of a quick target exchange mechanism to deal with different types of FIREX targets. In this paper, its design and cool down performance are described.

2. Design of the new apparatus

The configuration of the new apparatus is shown in figure 2. The Gifford-McMahon (GM) cryocooler RDK-415D (Sumitomo Heavy Industries, Ltd.) is used to cool down the whole system. The refrigeration capacity is 1.5 W at 4.2 K. Its disadvantage is generating low frequency vibrations. Therefore, the cryocooler and the vacuum chamber with a target can are supported by individual structures with vibration control units. Flexible copper braids are also applied as thermal conductive links to mechanically insulate from each other. These should provide a low vibration environment. Four viewing windows are equipped for optical observations. To deal with different types of FIREX targets, the detachable target holder makes an easy and quick target exchange possible.

![Figure 1. Typical FIREX target with a PS or a foam shell. All parts are glued by an epoxy adhesive with gas leak tightness.](image)

![Figure 2. Schematic of the new apparatus.](image)

Figures 3 and 4 show the detail of the target can and the cross section of the apparatus, respectively. A target is contained in a gold plated copper container with regulated temperature, which is connected to the second stage of the cryocooler via flexible thermal conductive links, and cooled by ambient
gaseous helium (GHe). The target can is thermally insulated from room temperature with a thermal shield, which is connected to the first stage. For the characterization of a layered solid fuel, a target rotation mechanism on the z-axis is equipped, and the shortest distance between the target centre and room temperature is designed to be 80 mm to apply the digital microscope VHX-100 (Keyence Corporation) with the long-distance zoom lens VH-Z50L (Keyence Corporation). To realize an easy and quick target exchange, the metal gasket U-TIGHTSEAL® with an indium plated copper sheath (Usui Kokusai Sangyo Kaisha, Ltd.) is applied without fixing bolts. The target holder can apply a load of some thousand newtons (N) on the metal gasket to ensure GHe leak tightness in a cryogenic environment. A top handle can regulate the loading force. A gasket is valid for several time uses without its replacement.

Figure 3. Detailed view in the target can. A heater and a temperature sensor are embedded in the copper container.

Figure 4. Cross section of the new apparatus. Temperature sensors are attached on the first stage (1), the second stage (2), the thermal shield (3), the outer tube for GH2 supply (4), the GFRP support (5) and the copper target container (6). A load cell measures the pressure loaded to a metal gasket. The rectangular area corresponds to the detailed view of the target can shown in figure 3.

3. Cool-down performance
Cool-down performance was tested without a target. Temperature sensors are attached at the positions represented in figure 4. Cernox™ sensors (Lake shore Cryotronics, Inc.) are used except for a silicon diode on the second stage, which are calibrated within several 10 mK. After the evacuation of the vacuum chamber and the target can, the system was cooled down. Figure 5 represents the cool-down performance. The target container is designed to be able to cool a target at less than 10.00 K. 10 hours were required to reach 10.00 K. Eventually, the lowest temperature was (1) 31.32 K, (2) 4.86 K, (3) 36.95 K, (4) 101.44 K or less, (5) 19.84 K and (6) 9.72 K at each point. The heat leak to the target can...
must be more than 1.5 W according to the specification of the cryocooler. Major heat leaks have been estimated to be via cryogenic supporting structures. The cool-down performance indicates that the new apparatus provides a cryogenic environment for fuel layering demonstrations.

4. Summary

The new apparatus, which has two features: the design for the optical observation by the digital microscope and the quick target exchange mechanism, was built for the characterization of a solid fuel formed in a FIREX target. Its cooling performance was tested without a target. 10 hours were required to cool it down to 10.00 K, where is the design temperature at the target container. The lowest temperature reaches 9.72 K. The cool-down performance indicates that the new apparatus provides a cryogenic environment for fuel layering demonstrations.

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References

[1] Sacks R A and Darling 1987 Direct drive cryogenic ICF capsules employing D-T wetted foam Nucl. Fusion 27 447-52
[2] Norimatsu T, Kato Y, Nakai S and Kubo U 1989 Target fabrication for laser fusion research in Japan J. Vac. Sci. Technol. A7 3 1165-68
[3] Iwamoto A, et al. 2008 Study on a fuel layering sequence of the foam target for the FIREX project J. Phys.: Conf. Ser. 112 032067
[4] Iwamoto A, Fujimura T, Nakai M, Norimatsu T, Sakagami H, Shiraga H and Azechi H 2013 Nucl. Fusion 53 083009
[5] Iwamoto A, Fujimura T, Nakai M, Nagai K, Norimatsu T, Azechi H, Maekawa R and Sakagami H 2010 Study on possible fuel layering sequence for FIREX target J. Phys.: Conf. Ser. 244 032039
[6] Iwamoto A, Maekawa R, Mito T, Okamoto M, Motojima O, Sugito S, Okada K, Nakai M, Norimatsu T and Nagai K 2006 Cool-down performance of the apparatus for the cryogenic target of the FIREX project Fusion Eng. Des. 81 1647-52