Cutting Performance of Remote Fiber Laser Cutting System for Dismantling HLW Glass Melter – 14093

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ABSTRACT

The Remote Fiber Laser Cutting System, one of the most important equipment for dismantling the used HLW glass melter in Rokkasho Vitrification Facility, has been developed since 2008. A 10 kW high-power fiber laser has been applied to the system. It makes possible a smooth and speedy cutting work for stainless steel which is a major metal material composed of the glass melter. A small laser torch is also suitable for a remote operation in the limited area of the hot cell. In the first half of 2013, the final stages of cold cutting tests of the system were performed toward installation to the facility in early 2014. Practical laser cutting parameters were obtained through over a hundred times of laser cuttings for stainless steel plates. Safety interlock parameters, which are used to protect the surface of the wall and the equipment in the cell, were also taken by getting their tendencies of temperature increase for a laser irradiation. In addition, the laser cutting tests for some special metal components made of painted steels, aluminum alloy, and Inconel used for the glass melter and its accessories were carried out in order to confirm the applicability of the laser cutting. Through these cutting tests, it was verified that this system is an appropriate cutting method for dismantling highly-contaminated equipment like a HLW glass melter.

INTRODUCTION

In the Rokkasho Vitrification Facility, there are two complete vitrification process lines to produce vitrified wastes that contain HLW generated from spent nuclear fuel reprocessing. Major components of the vitrification process including glass melters, off-gas treatment systems and canister handling systems are deployed in a large hot cell called “Vitrification Cell” (see Figure 1).

The glass melter, of approximate outer dimensions 3.1 m long, 2.9 m wide and 2.8 m tall, consists of dual metal casings as the strength members, refractories as the inner wall, electrodes for joule heating of the glass, and its accessories such as lid heaters and induction-heated nozzle. The overview of the glass melter is shown in Figure 2.

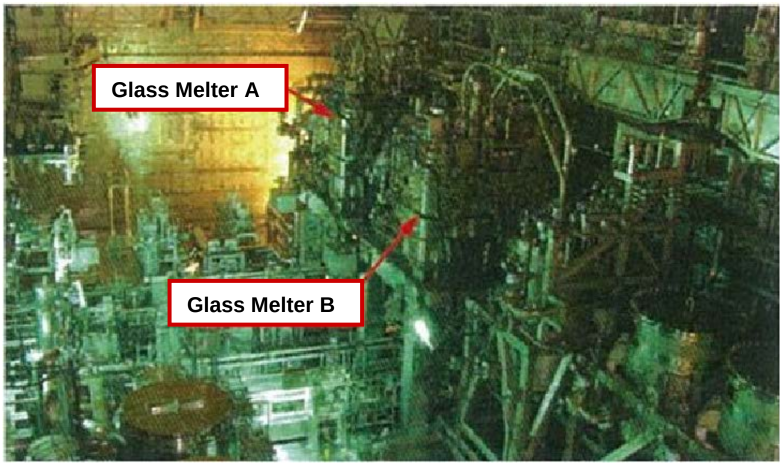

Figure 1: The Vitrification Cell

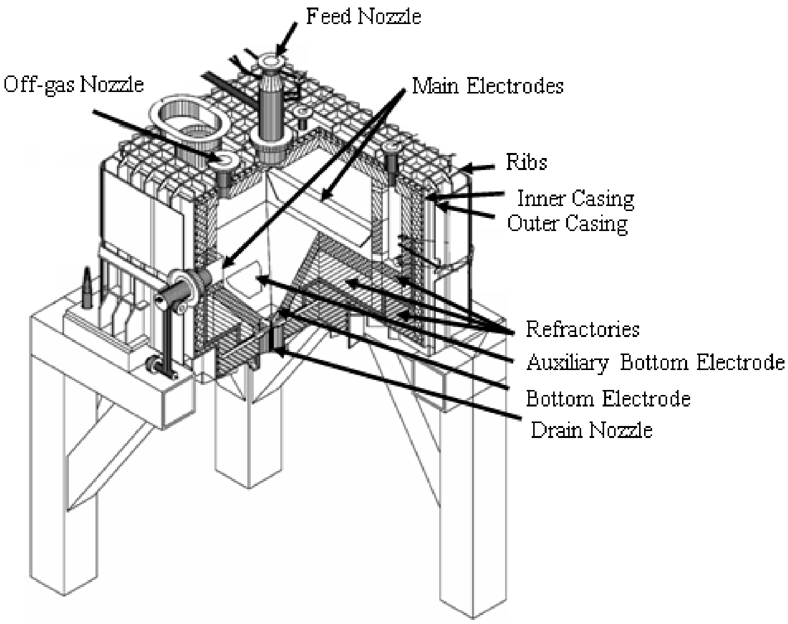

Figure 2: The Glass Melter (Liquid-Fed Ceramic Melter)

The glass melter needs to be periodically replaced before reaching its lifetime and thus, the used one also needs to be periodically dismantled and removed from the Vitrification Cell. Due to a quite high-dose radiation of the glass melter, the dismantling work for the glass melter has to be done by a fully-remote operation. In addition, the wastes have to be taken apart to small pieces in order to be packed into designated waste baskets to carry out of the cell. Though it generally needs a lot of time to accomplish such a remote dismantling work, the period of the requirement is not so long. Therefore, high cutting performance, high remote controllability and robustness are required for the equipment for dismantling the glass melter.

The Vitrification Cell has an enclosed area, called "Dismantling Area", used for dismantling highly-contaminated solid wastes including the glass melter. The basic equipment needed for dismantling work such as an overhead crane, cameras, master-slave manipulators and ventilation systems have initially been deployed in the area. However, the major equipment for dismantling the glass melter has not been installed yet.

In order to realize an effective dismantling work for the glass melter, two types of electrically powered manipulators will be deployed as the major remote-controlled devices in the dismantling area. They will perform a variety of remote operations such as cutting, shearing, crushing and collecting the debris using dedicated tools.

DEVELOPMENT OF REMOTE FIBER LASER CUTTING SYSTEM

To select an effective cutting method for metal components is a very important key to success of the melter dismantling because the major part of the glass melter is composed of stainless steel. Through several evaluations and demonstrations, the remote fiber laser cutting system was selected as the most suitable metal cutting method for dismantling the melter.

There are two main reasons why the system was selected. The first is that a 10 kW fiber laser applied to the system has a high cutting efficiency. Basically, a laser cutting performs a smooth and speedy cutting work compared to other cutting methods like a mechanical cutting. In addition, a fiber laser provides a more stable and higher output power than other type of lasers. The second is a good remote controllability of the system. An easier remote operation has a high priority for dismantling the melter because the dismantling work has to be done in a limited space in the cell. The compact laser torch of this system makes possible an efficient and flexible remote cutting operation using power manipulators.

Development of the remote fiber laser cutting system was started in 2008. A large amount of cutting test has verified that the system has an enough cutting performance and safety to meet the requirement. Moreover, all of assumed remote operations of the system by the power manipulators such as installation, cutting operation, laser power measurement and maintenance works have been checked and reviewed by using 3D simulation model. As a result, the laser torch, the umbilical hoses and cables, and the support equipment deployed in the cell have been optimized for the remote operation. The fabrication of major parts of the system started in 2012 and finished in early 2013.

CUTTING TESTS

Overview

Through the development processes as stated above, the final cold cutting tests before installation to the facility were accomplished in the first half of 2013. These included an optimization of the laser cutting parameters used for the actual operation, a confirmation of the safety-interlock parameters to protect the surface of the wall and the equipment in the cell, and a validation of the applicability to special metal components. These tests were held at the laser testing facility in the R&D facilities of IHI Corporation in Yokohama, Japan.

As the configuration of the test equipment, the laser torch, the optical fiber and the laser oscillator were all actual ones. An industrial robot arm for the operation of the laser torch was applied to simulate the actual operation by the power manipulator (See Figure 3).

Figure 3: Equipment for the laser cutting tests

Optimization of Cutting Parameters

A laser cutting basically needs to set several cutting parameters suitable to a cut object, such as laser power, cutting speed, standoff, waiting time and a kind of assist gas. In order to input the appropriate cutting parameters to the computer of the system in advance, the data of cutting parameters for typical cut objects were obtained and optimized through over a hundred of laser cuttings. Thickness from 10 mm to 100 mm of stainless steel plates were chosen as the typical cut objects of the melter dismantling work.

The optimum laser cutting parameters obtained by the laser cutting tests are shown in TABLE I and examples of the cut test pieces are shown in Figure 4 and 5. In case of the 10mm thickness plate, a condition of 3 to 4 kW laser power and 500 to 750 mm/min cutting speed gave an optimum laser cutting with less generation of fume and spatter. In case of the 100 mm thickness, the optimum condition was 9 kW laser power and 30 mm/min cutting speed.

The optimum Standoff value (= 10 mm) was selected by taking both cutting performance and remote operation into consideration. The thicker plate generally requires the more waiting time to increase heat input to the plate, so 3 sec waiting time was given to the 60 mm to 100 mm thickness plates. In regards to the assist gas, air was appropriate for the 10 mm to 30 mm thickness plates and oxygen was appropriate for the 60 mm to 100 mm thickness plates.

TABLE I: Optimum laser cutting parameters for 10 mm to 100 mm thickness stainless steel plates

No.	Thickness of Stainless Steel [mm]	Laser Power [kW]	Cutting Speed [mm/min]	Standoff [mm]	Waiting Time [sec]	Assist Gas
1	10	3	500	10	0	Air
2		4	750	10	0	
3	20	5	250	10	0	
4	30	6	150	10	1	
5	60	7	90	10	3	O2
6	80	8	50	10	3	
7	100	9	30	10	3	

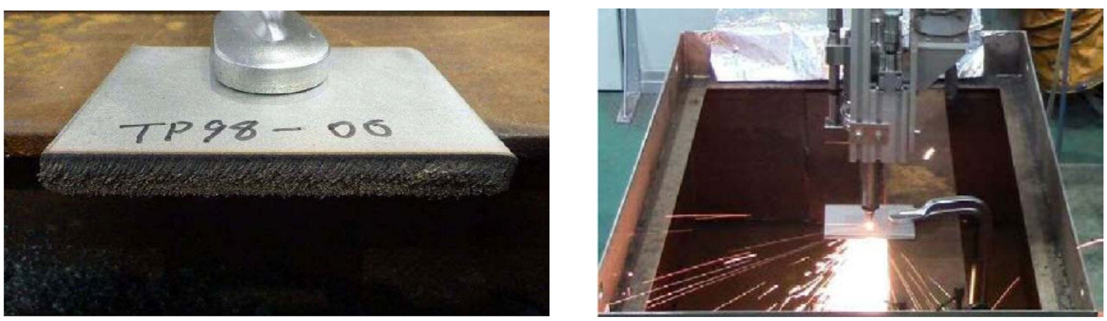

Figure 4: Example of the cut test pieces for 10 mm thickness stainless steel plate (Laser Power: 3kW, Cutting Speed: 500 mm/min)

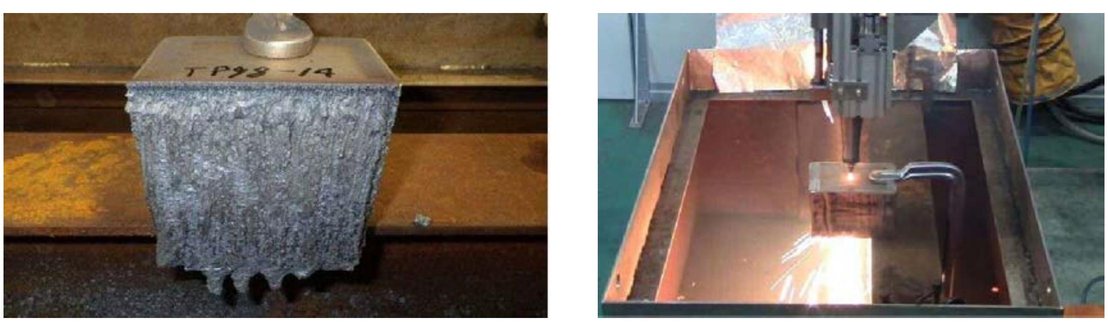

Figure 5: Example of the cut test pieces for 100 mm thickness stainless steel plate (Laser Power: 9kW, Cutting Speed: 30 mm/min)

Confirmation of Safety Interlock Parameters

During the laser cutting operation, the wall and the equipment in the dismantling area, mainly made of stainless steel, have to be protected from a laser irradiation. The remote fiber laser cutting system has the safety interlock system that watches an interference between the laser irradiation model and the protected object model in the 3D-CAD system in real time. If the interefence occurs, the system prohibits a laser oscillation and limits the power of laser.

The laser irradiation model is a cone shape which is determined by “L”, “La” and “r" as shown in Figure 6. “L” is defined as Laser Reference Point which means standoff, “La” is defined as Reference Area (Length) which means a distance between a cut object and a protected object, and “r” is defined as Reference Area (radius) which means a beam radius calculated by a beam spread angle and “La”. A limiting value of temperature increase for a protected object is 300 degree C as the temperature that it is possible to influence the surface of stainless steel (change the color of the surface).

In order to construct the laser irradiation model corresponding to each laser power, the termperature increase tendencies of the surface of stainless steel by a laser irradiation were confirmed as shown in Figure 7. TABLE II shows the safety interlock parameters calculated from the obtained data.

For example, if there is a protected object at 700 mm distance from the top of the laser torch (L+La), the laser oscillation under 4 kW power will be permitted but prohibited the laser oscillation higher than 5 kW power.

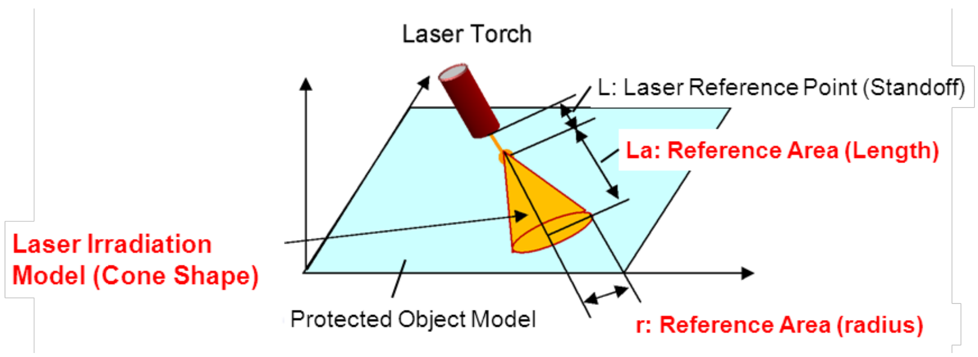

Figure 6: Concept of the safety interlock system for a laser irradiation

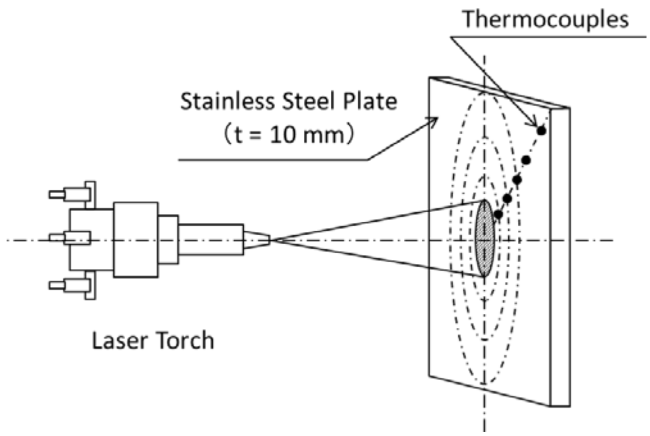

Figure 7: Confirmation of the tendencies of temperature increase of a stainless steel plate for a laser irradiation

TABLE II: Safety interlock parameters for each of laser power

No.	Laser Power	Standoff	Reference Area (Length)	L + La	Reference Area (radius)	Reference Area (Cross Section)
	[kW]	L [mm]	La [mm]	[mm]	r [mm]	A [mm^2]
1	1	10	463	473	21.8	1488
2	2	10	488	498	22.9	1649
3	3	10	508	518	23.8	1784
4	4	10	537	547	25.2	1990
5	5	10	1088	1098	42.1	5574
6	6	10	2086	2096	60.3	11406
7	7	10	2557	2567	73.8	17108
8	8	10	3401	3411	98.1	30207
9	9	10	4332	4342	124.8	48947

Cutting Tests for Special Metal Components

The most of metal components used for the glass melter and its accessories are stainless steel as stated above. However, some of them are made of other special metal materials such as painted steel, aluminum alloy and Inconel. Then, the laser cutting tests for those materials were performed in order to verify the applicability of the laser cutting system.

The laser cutting for painted steels was very smooth without any ignition and a large amount of fume (See Figure 8). For cutting of aluminum alloy, the laser torch was a little tilted to protect the system from a reflected beam during laser cutting. As a result, the cutting was successful without any damages to the system (See Figure 9). The laser cutting for double Inconel pipe was also successful (See Figure 10). For reference, the system provides a good cutting performance for pipe-shaped components as well as plates. The example of the laser cutting for stainless steel pipe is shown in Figure 11.

Figure 8: The laser cutting for painted steel of 30 mm in thickness
(Laser Power: 6 kW, Cutting Speed: 190 mm/min)

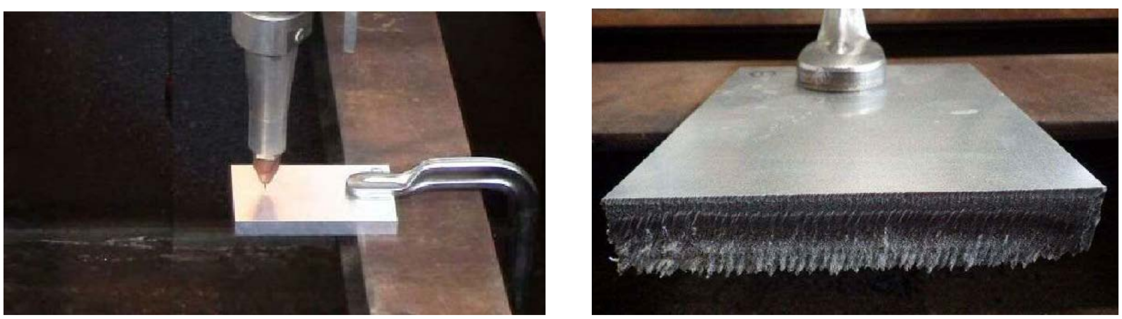

Figure 9: The laser cutting for aluminum alloy of 10 mm in thickness
(Laser Power: 5 kW, Cutting Speed: 250 mm/min)

Figure 10: The laser cutting for double Inconel pipe (Outer pipe: φ84 mm and t = 5mm, Inner pipe: φ60 mm and t = 4 mm, Laser Power: 8 kW, Cutting Speed: 150 mm/min)

Figure 11: The laser cutting for stainless steel pipe
(φ165.2 mm and t = 5 mm, Laser power: 9 kW, Cutting Speed: 100 mm/min)

CONCLUSIONS

The final cold cutting test for the remote fiber laser cutting system before installation to the facility was performed in the first half of 2013. The results successfully gave the practical laser cutting parameters for stainless steel plates and the safety interlock parameters to protect the wall and the equipment in the cell during the laser cutting operation. It was also verified that the system was applicable to some special metal components of the glass melter and its accessories as well as stainless steel.

These results showed that this remote fiber laser cutting system has an enough capability for dismantling the HLW glass melter in the Rokkasho Vitrification Facility. Moreover, it is expected for the system to be applied to various remote dismantling works under high-level radiation environment.

REFERENCES

1. Japan Nuclear Fuel Limited: High-level Liquid Waste Vitrification Facility (Japanese) Information found on the internet at http://www.jnfl.co.jp