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High-speed fiber laser cutting of thick stainless steel for dismantling tasks

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ABSTRACT

A high-speed fiber laser cutting technology of thick steels for dismantling tasks was achieved using a 6-kW fiber laser system. At first, a new cutting head for efficient cutting of thick steels was developed, which was composed by a collimator with a focal length of 160 mm and mirror-type focusing objects with a long focal length of 600 mm. The long focal length of the focusing object made it possible for the beam size to be small through the thick cutting material and the cutting efficiency was expected to increase compared with the short focal length. In addition, folding the beam facilitated the compact cutting head with a size of 160 mm (width) × 80 mm (height) × 640 mm (length) and a weight of 6.9 kg. In the cutting experiment, the laser beam was delivered to the cutting head by a 25-m long process fiber with a core diameter of 100 μm. The cutting performances were studied against the thicknesses of stainless steel plates. A maximum cutting speed of 72 mm/min was obtained for the 60-mm thick stainless steel plate cutting and the cut specimen showed an excellent kerf shape and a narrow kerf width. To the best of our knowledge, this cutting speed was higher than other previously reported results when cutting with a 6-kW laser power.

1. Introduction

Laser cutting technology is a powerful tool for dismantling tasks such as the decommissioning of nuclear power plants. The laser cutting is efficient and shows a narrow kerf width giving a low waste of materials compared with other cutting technologies such as mechanical cutting, plasma arc cutting, and abrasive water jet (AWJ) cutting [1,4,6]. In addition, remote control is possible because only the fiber delivered cutting head is located at the work place without the need for any complicated electrical and mechanical equipment. Furthermore, the laser cutting shows no repulsive force by non-contact cutting and thus it is profitable for cutting with such a robot-arm. Such advantages make laser cutting technology the most suitable tool, especially for the remote dismantling of radioactive nuclear power plants.

For this reason, the laser cutting technology for dismantling tasks has been developed by many research groups around the world [1–11]. The Wakasa Wan Energy Research Center (WERC) and Japan Atomic Energy Agency (JAEA) in Japan have researched laser cutting with high power fiber lasers for over a decade, and in 2012 obtained successful cutting results of 100 mm-thick stainless steel and carbon steel plates with 10 (6 + 4) kW laser power [1–3]. Furthermore, they also developed underwater cutting technology in 2013 [4]. Moreover, they recently researched the cutting of a very thick structure of more than 100 mm such as 300 mm-thick stainless steel and carbon steel plates by applying a 30-kW fiber laser system [5–7]. Commissariat à l'Energie Atomique (CEA) in France is another research group studying the cutting performance using a continuous wave Nd:YAG laser, and they developed a cutting head for the dismantling of former nuclear workshops [8]. The 100-mm thick stainless steel plates were cut at a laser power of 8 kW. TWI Ltd. in the United Kingdom has also developed laser cutting technology with a 5-kW fiber laser for nuclear decommissioning as "LaserSnake" project funded by the UK government. They developed their own laser cutting heads for cutting in air and underwater, and showed the cutting results of 32-mm thick stainless steel underwater at a speed of 100 mm/min [9,10].

Although leading groups have shown good results for thick steel cutting, the cutting speed has remained low. JAEA and WERC incompletely cut 100-mm thick stainless steel with a 15-mm/

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min cutting speed and obtained a maximum cutting speed of ~62 mm/min for 60-mm thick stainless steel using 10 (6 + 4) kW laser power [2]. At CEA, the maximum cutting speeds obtained were 7.5 mm/min for 100-mm thick stainless steel with 8-kW laser power and 20 mm/min for 60-mm thick stainless steel with 6-kW laser power [8]. For a higher speed cutting of thick steel, a new cutting head and our own laser cutting techniques were developed in our group. The developed cutting head was composed of mirror-type focusing objects with a long focal length. A long focal length showed a larger sized beam spot than that of a short focal length, but was profitable for the cutting of thick steels because the depth of focus was longer than the cutting head with a short focal length, and thus a small beam size with a large power density was sustained inside the thick cutting material. This paper contains the design of the developed laser cutting head and the recent experimental results of the high-speed cutting of the thick stainless steel plates with this head and a high power fiber laser.

2. Laser cutting head

Fig. 1(a) and (b) shows the designed scheme and a view of the developed laser cutting head. A commercial water-cooled collimator with a focal length of 160 mm (D50-F160, IPG Photonics Corp.) was applied to collimate the diverging laser beam from the fiber exit to the parallel beam. The collimated beam met the focusing mirror with a focal length of 600 mm and was focused with a reflection angle of 30°. The plane mirror located after the focusing mirror folded and reflected the focused beam to the nozzle exit. Folding the beam facilitated the compact cutting head in spite of the optical arrangement with a long focal length. The compact size of the cutting head gave an advantage of the remote control with a robot arm in the work place. The focusing mirror had a parabolic surface to eliminate the optical aberration effect. In addition, both the focusing and plane mirrors were water-cooled copper mirrors with a high-reflection coating of more than 99.5%. They were designed to endure 20-kW laser power without surface damage. After the plane mirror, a protection window was placed to avoid decontamination of the optical components from the cutting debris. The protection window was antireflection coated, and the thickness of this window was designed to endure the 20-bar pressure of the compressed gas. In addition, a part of the head body was water-cooled to conductively cool down the protection window. The transmitted beam from the window propagated inside the cylindrical tube and passes through the nozzle exit. The nozzle was a cone-shaped copper nozzle with an exit diameter of 2 mm. And an assisting gas was applied to the nozzle assembly and coaxially ejected out of the nozzle exit. The developed cutting head had a compact size of 160 mm (width) × 80 mm (height) × 640 mm (length) with a weight of 6.9 kg, even though it contained a 600-mm focal length component.

3. Cutting experiment and analysis

For the performance study of the developed cutting head, a 6-kW multimode ytterbium doped fiber laser (YLS-6000, IPG Photonics Corp.) was applied and the cutting experiment was accomplished. The wavelength of this laser beam was 1070 nm with a linewidth of 3 nm. The laser beam from the feeding fiber with a 50-μm core diameter was coupled with the process fiber with a 100-μm diameter. The fiber coupled beam was delivered to the work place with a 25-m long process fiber, and focused by the laser cutting head. The spot diameter of the laser beam was be geometrically calculated as 375-μm with a combination of the f = 160 mm collimator and f = 600 mm focusing mirror. As the width, the experimentally measured spot diameter was 362 μm

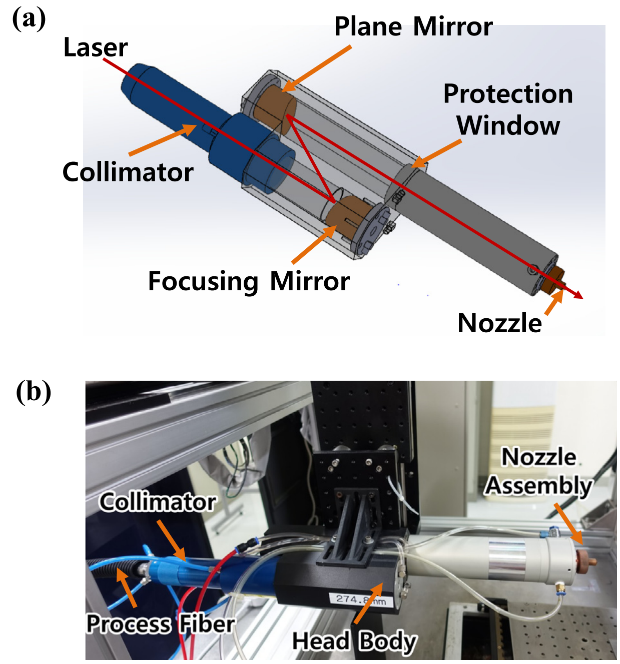

Fig. 1. The developed cutting head: (a) the designed scheme and (b) the view of the cutting head installed on the X-Y-Z stage.

at a peak intensity of $1/e^2$. This spot size was almost same as the geometrically calculated value. The beam parameter product was measured to be 3.568 mm·mrad, and the divergence angle was measured to be 39.372 mrad.

In the cutting experiment, the developed cutting head was installed on the X-Y-Z stage. A computerized numerical control (CNC) tool controlled the position of the X-Y-Z stage and the moving speed of the cutting head. Fig. 2(a) shows a view of the laser cutting experiment. During the experiment, stainless steel (SUS304L) plates with a size of 100 mm × 100 mm × t (thickness) were used as cutting specimens. The thicknesses (t) of the cutting specimens were 36 mm, 50 mm, and 60 mm. In addition, the focal position was set to be just at the surface of the specimen, and the stand-off distance, which means the distance from the nozzle exit and the surface of the specimen, was set to 1 mm. And compressed air was used as an assisting gas to blow the molten material. The gauge pressure of the supply gas was ~1 MPa, and the flow rate was 470 l/min expressed under ANR (Atmosphère Normale de Référence) condition (20 °C, 101.3 kPa, 65% relative humidity). The fume generated during the cutting was gathered by the fume suction unit with the exhaust ducts. In addition, the remaining laser power passing through the cutting material was blocked using a water-cooled beam dumper with a graphite plate.

The cutting was started from the side of the specimen, and the cutting speed was determined by the speed of the head movement. The speed was step-like increased during the cutting because the cutting efficiency was much higher than the cutting with a constant speed. In the experiment, cutting at a constant speed showed poor efficiency and lowered the maximum cutting speed. This was another key technique for achievement of the high-speed cutting. The step-like increase was achieved as follows. First, low-speed cutting was applied for a certain distance of the cutting from the start position. This low-speed cutting offered preheating, which provided thermal energy to the material before the high-speed cutting, which was called preheat cutting herein. Next, high-speed cutting was applied after the preheating procedure. However, discrete cutting was observed, and a part of the cutting material was not perfectly cut when the cutting speed was steeply increased.