LASER-BEAM WELDING FOR A TPS BEAM-POSITION MONITOR

I. T. Huang#, C. C. Chang, S. N. Hsu, G. Y. Hsiung, NSRRC, Hsinchu, Taiwan
J. R. Chen, NSRRC and NTHU, Hsinchu, Taiwan

Abstract
The TPS beam-position monitor has two feedthroughs in one flange structure [1]. The hermetic seal was formed with laser-beam welding (LBW). Nd-YAG LBW was adopted to weld a button electrode with a feedthrough; CO_2 LBW served for a feedthrough and a flange, Fig. 1. A robotic arm was used for Nd-YAG LBW so that it could accomplish the complicated geometry of the welded joint. Although the CO_2 laser was not coordinated with a robotic arm, fixtures were made to implement a circular welded joint the same as welding the feedthrough into a flange. For not only Nd-YAG but also CO_2 LBW, the cover gas is the major key that avoids oxidation from atmospheric oxygen and maintains shiny weld beads. Taguchi methods were exploited to find the appropriate parameters for the Nd-YAG pulsed laser, for instance, the laser power, pulse-filling time, frequency etc. [2]. This paper presents the process and details of laser-beam welding of two types for a beam-position monitor.

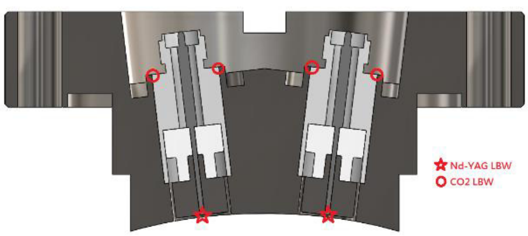

Figure 1: Schematic diagram for laser-beam welding of two kinds and the corresponding weld region for each.

INTRODUCTION

Laser-beam welding (LBW) is widely employed in industry as it does delicate work well without a redundant environment and equipment limitations and is applicable for mass production with an affordable cost. As the zone affected by the heat of LBW is small, it is applicable to make a weld in a narrow region and is reliable for repetitive work. Nd-YAG and CO_2 LBW are applied for two distinct specifications of welding quality here; one is to weld a button electrode to an electric feedthrough, demanding a non-removable and coaxial structure; the other is to join a button-feedthrough within a flange, seeking ultra-high vacuum and freedom from leakage.

Figure 2 shows the experimental setups of these two types. The Nd-YAG pulsed laser combined with a robotic arm can realize various welding routes. Unlike a YAG pulsed laser, a continuous CO_2 laser is equipped as a fixed station but it possesses a greater power density than a YAG laser. The weld depth, 1 mm, for a feedthrough and a flange is thus performed with CO_2 LBW. A YAG laser could perform the same work as the CO_2 laser, but it involves more time and requires cumbersome set-up conditions; we hence applied it to weld a button electrode to a 50-Ω feedthrough. For pulsed-laser welding (YAG), the power, pulse-filling time and frequency must be set before displaying the welding. We use $L_9(3^4)$ of Taguchi methods to deduce the appropriate parameters, Table 1. In contrast, we tune only the average power of the continuous laser (CO_2) to match the standards. As long as the related parameters are set properly, one could sit back and relax until the work is completed. In the next section we describe two welding processes involving the YAG and CO_2 lasers.


Figure 2: (left) YAG-laser work station; (right) CO_2 LBW equipment.

Table 1: $L_9(3^4)$ of Taguchi method for YAG LBW

No.	Power (%)	Pulse width (ms)	Frequency (Hz)	Velocity (cm/s)
S1	30	4	2	3
S2	30	6	4	3
S3	30	8	6	3
M1	40	4	4	3
M2	40	6	6	3
M3	40	8	2	3
L1	50	4	6	3
L2	50	6	2	3
L3	50	8	4	3

COURSE OF LASER BEAM WELDING

To perform laser-beam welding, one must prepare appropriate fixtures designed on considering the actual situation to be encountered. One focuses on how to control the concentricity between the button and the feedthrough and devotes attention to the stand of the interface when attaching the button electrode to the feedthrough, whereas the other is sought to be airtight and free of leakage after welding the button feedthrough and the flange together.

(I) Nd-YAG LBW

The YAG-laser work station that we used is packaged with a robotic arm; the only requirement is hence to specify to the controller all positions that are ready for the laser shots. Before launching the YAG laser, the parameters dominating the welding quality are of concern. We applied the $L_9(3^4)$ table of the Taguchi method to decide the values

ISBN 978-3-95450-147-2

of those parameters; the respective results are presented in Fig 3. One could deduce from the results that a large power, a protracted filling time and a large frequency are prone to hot cracks, degrading the welding quality [3]. Depending on the metallography of each sample, it is inferred that pulses of power rate 35 %, pulse filling period 6 ms and launching in a single mode would conform to the standards for welding the button electrode. To begin this art work, the parameters and position data are all set carefully; then a protective gas, Ar, follows the robotic arm that would fire the pulsed YAG laser. These aspects are shown in Fig. 4.

(II) CO_2 LBW

Unlike a YAG laser, only one parameter, average power, is required for the CO_2 LBW. The cover gas, in this case He, serves to isolate the environment in which CO_2 LBW is performed; several small pieces of steel wool are stuffed into a gas tube so as to disturb the orientation of the blowing gas and build an almost non-directional gas flow. Moreover, to evaluate a leak-free and strong welding interface, it is suggested that there should be a trench near the weld joint so as to confine the heat around the regions to be welded. Instead of a protective gas following the operating YAG laser, a cap served to build an isolated environment filled with He gas as a cover gas that would benefit the high-power laser welding. The upper hole of this cap serves to aim and to weld the target; the other two holes are for feeding the protective gas. A gas holding interval 3 to 5 s before actuating the CO_2 laser is advised; the power shape of the CO_2 laser should not be constant during the work session. A positive slope of the curve initially and a negative slope for termination are also recommended. The period of steady CO_2 laser power is 1 s; a rotary motor is utilized to ensure that, during such a small period, there is at least one revolution but not more than two because of the heat concern. The overlap of the weld bead is enough for about 1/5-1/3; too great an overlap would overheat the device and too little would not be sealed to ultra-high-vacuum. Figure 5 shows the process of applying the CO_2-laser welding to the beam-position monitor flange.

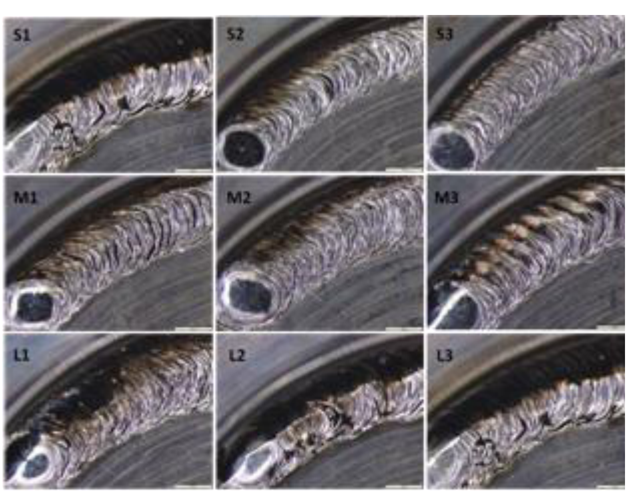

Fig 3: $L_9(3^4)$ experimental results after use of a Nd-YAG pulsed laser with a cover gas, Ar, under 40x manification.

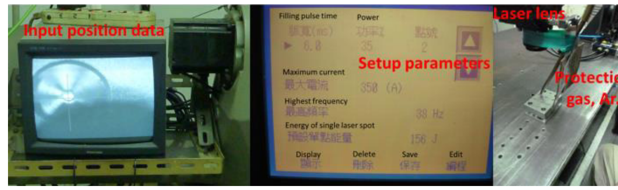

Fig 4: Nd-YAG pulsed laser for welding button electrodes.

Fig 5: Jointing a feedthrough into a flange with CO_2 LBW

RESULTS AND DISCUSSION

A pulsed laser, such as a Nd-YAG laser, is like a machine gun: when describing a pulsed laser, the peak power, average power, pulse energy, pulse width and frequency are used to specify the laser properties. Their relations are indicated in the following equations. The peak power is related to the weld penetration; the pulse-filling time controls the heat transported to the weld materials, which is correlated with the size of the weld bead [4].

$$P_{peak} = \frac{m}{t} \quad (W) \tag{1}$$

$$P_{average} = f * m \quad (W) \tag{2}$$

m: energy per pulse (J)
t: filling time of laser pulse (s)
f: repetition rate (Hz)

A continuous laser, such as a CO_2 laser, is like a faucet in that, when it is opened, only the average power is used to characterize its proceeding. Unlike YAG LBW, the welding bead of CO_2 LBW is seamless. One can distinguish between them from Fig. 6. Laser-beam welding is incompatible with materials of large thermal conductivity, such as copper, aluminium etc., because heat deposited from the laser energy cannot be restricted within a local region in which the weld is intended; a laser of greater power and a harsh bead design are necessary in welding materials of large thermal conductivity, and the yield may be not as great as with materials of poor thermal conductivity. Furthermore, materials with carbon, sulfur or phosphorus, in large concentrations, for example SUS303, cannot be welded with LBW. Those chemical elements act as impurities and would diffuse into the base material under conditions of high temperature, resulting in a situation susceptible to hot cracks that would severely degrade the quality of welding. As for cases discussed in this paper, the materials for the button electrode and the feedthrough are SUS316L and Kovar respectively. The pin of the feedthrough is about 0.65 mm and four laser spots are made along the circumference. It is a great help to use a robotic arm to perform LBW; the trace data are first loaded into a control computer and then pressing the start button completes the remaining. The specifications of welding a button electrode are less rigorous than welding a feedthrough with a flange. For the latter, an enclosure of space filled with a protective gas is essential; without such a condition, leak-free and crack-free results are unattainable. Although a pulsed laser could also be applied to weld a feedthrough with a flange, it is time-consuming compared to a continuous laser, but, when it comes to welding an intricate structure, taking advantage of a pulsed laser coordinated with a robotic arm is highly beneficial. Which one is better? It depends on the kind of consequence that somebody seeks. The welding results for these two applications are exhibited in Fig 6. The small zone affected by heat, HAZ, and the tiny welding interface are evidently powerful traits of LBW, apart from the fact that its reliable operating conditions are valuable for mass production.

Fig 6: Welding beads of YAG and CO_2 LBW respectively

CONCLUSIONS

We introduce here lasers of two types, Nd-YAG (pulsed) and CO_2 (continuous) laser, that we used to weld core components to form a beam-position monitor. A cover gas plays an important role, especially in situations that claim a strong and deep welding interface, which is typically done on increasing the laser power, which is liable to bring about solidification cracks due to cooling stress induced during the welding process and which would be a serious issue particularly for materials with impurities such as carbon, sulphur, phosphorus etc. at large concentration. No matter what kind of laser one chooses, it is strongly recommended to test mandatory laser parameters before setting them and to find a comfortable way to take advantage of a cover gas, for instance, He, Ar or N_2, which would not alter the weld quality but enhance the resistance to oxidation and maintain a bright bead surface. Figure 7 is a testimony to the utilization of a cover gas. Another criterion is the weld joint design: an appropriate design not only improves the qualified yield but makes feasible the welding of highly reflective materials or for distinct materials of slightly varied thermal conductivity. Laser-beam welding opens a whole new world to those seeking exquisite welding work and an affordable cost, which is now widely spread to electric devices. Look! Your own smart phone case is most likely welded with LBW; you can henceforth distinguish the kind of laser welding exerted on them by yourself.

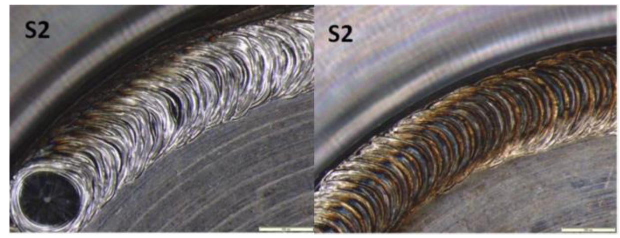

Fig 7: Weld beads with (left side) and without (right side) cover gas.

ACKNOWLEGEMENT

We thank the company, Laser Station, Inc., for energetically supporting materials and generously sharing professional knowledge to accomplish this challenging work [5]: laser beam welding is not just technology, it is a form of art. We hope that it will bring you a colourful life someday.

REFERENCES

[1] I. T. Huang, et al., “Design and manufacture of TPS BPM diamond-edge gasket”, IPAC2012, Louisiana, USA, WEPPD023, p. 2549 (2012).
[2] Tsung-Yuan Kuo, et al., "Taguchi method for 304 Stainless Steel Nd-YAG Laser Beam welding", Advanced Materials Research-Application of Engineering Materials, vol. 287-290, pp. 3112-3115 (2011)
[3] Lippold, J.C., Solidification behavior and cracking susceptibility of pulsed-laser welds in austenitic stainless steels, Welding Journal, 73(6):129s-139s, (1994)
[4] Bransch, H. N., et al., “Effects of pulse shaping on Nd:YAG spot welds in austenitic stainless steel.” Welding Journal 73(3): 141-s to 151-s, (1994)
[5] Private communication with Huang Chihchiang at Laser Station, Inc., Taoyuan County 333, Taiwan

ISBN 978-3-95450-147-2