

Automatic TIG Welding for Raised Edges of Tank Corners on Membrane LNG Tanks

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Membrane LNG tanks are constructed of a laminate of thin plate invar (Fe-Ni) and a heat-resistant (perlite) box. Invar is 0.5 to 3.0 mm thick—extremely thin compared to the ship structure, and requires highly skilled tungsten inert gas (TIG) welding. Although machine welding centered on relatively simple components has been developed in Europe, complex components continue to require highly skilled welders. We have developed TIG automatic welding for use on the raised edges of tank corners, a type of component requiring high-level welding skills. These welds are highly confined, and the joint shape changes in a complex manner. Key technologies include seam tracking for the weld line, automatic setting of welding conditions, and miniaturization to within 7 kg per unit. The apparatus that we developed is effective for automated, efficient high-level TIG welding, and the first Japanese example of such application in the fabrication of membrane LNG ships is currently being studied.

1. Introduction

LNG (Liquefied Natural Gas) is an important source of energy for the industrial world that is expected to be widely used in the 21st century, particularly with a purpose of reducing carbon dioxide emissions. In order to make effective use of such an important energy source, it is absolutely necessary to secure a steady supply. In view of the fact that the supply of LNG in Japan depends mostly on transportation from abroad, the reliability, safety, and high performance of LNG carriers as a means of transportation are extremely important. Shipbuilding firms are accordingly required to constantly their shipbuilding technology⁽¹⁾ to higher levels in order to produce advanced LNG ships.

Mitsubishi Heavy Industries, Ltd. (MHI) already has a solid track record and enjoys an excellent reputation in terms of reliability in the building of aluminum spherical tank type Moss LNG carriers. Membrane tank type LNG carriers are constructed of a laminate of thin plate invar (36% nickel steel) and a heat-resistant box. Ranging from 0.5 to 3.0 mm, invar is extremely thin in comparison with ship structural members, and requires highly skilled tungsten inert gas (TIG) welding. Although machine welding centered on relatively simple components has been developed in Europe, complex components still depend on highly skilled welders.

MHI has therefore developed TIG automatic welding for use on the raised edges of tank corners, a type of component requiring advanced welding skills. This weld is highly confined, and the joint shape changes in a complex manner, calling for various positional welding techniques such as flat, horizontal, and overhead.

This paper describes the basic technologies, i.e., seam tracking for the weld line, automatic setting of welding conditions, and miniaturization of apparatus, and re-

ports on the effectiveness (validity) of the newly developed automatic TIG welding approach on the basis of the results of verification tests.

2. Components for Use

Fig. 1 shows the raised edges of tank corners. The edges of the components for use are spread all over the tank corners at an interval of about 500 mm, with the number amounting to several thousand pieces per ship. As is clear from the figure, the welds located about 50 mm from the side wall surface are highly confined. Welding has to be performed at the top of the raised edge, i.e., the thin invar plate has to be rolled over and the ends have to be joined before being sealed. A detailed view of the rolled joint for raised edges is given in Fig. 2, indicating clearly that the joint shape of the rolled section is not simple. A weld with a welding length of about

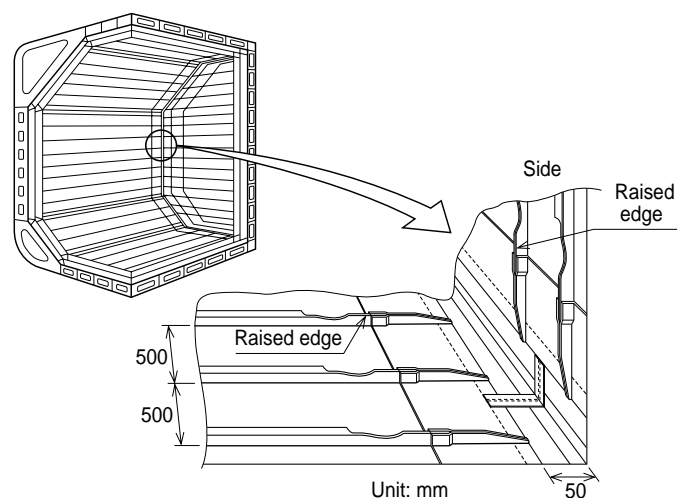


Fig. 1 Raised edges of tank corners on membrane LNG ships

The edges are spread throughout the ship, with the number amounting to several thousands of pieces per ship. The welds are highly confined, calling for all-position welding.

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600 mm contains 3 different types of joint: 2-ply joint (1.5/1.5 mm), 5-ply joint (1.5/0.7/0.5/0.7/1.5 mm), and 3-ply joint (0.7/0.5/0.7 mm). In addition, the top of the raised edge that forms the welding line has a complex shape with inclined, parallel, and arc sections. Further, since the joints are spread all over the tank, different positions such as flat, sloop angle, horizontal, and overhead are required during welding, calling for the setting of welding conditions to match the welding position.

Thus, with the complex joint shape and highly confined situation calling for various welding positions, welding currently depends entirely on the advanced techniques of skilled welders. Further, even a skilled welder has to change the welding conditions for each joint shape, so that continuous welding is impossible in spite of the short welding length of about 600 mm. Obviously, it is quite a difficult job for a welder to carry out overhead position welding while fixing his/her eyes on the arc and molten pool. In order to automate edge welding, then, the technologies (1) – (4) given below are

required.

- (1) Seam tracking for the weld line
- (2) Automatic welding condition setting function for each joint shape
- (3) Miniaturization of the equipment (in weight and size)
- (4) Stabilization of welding quality

Next, the new automatic TIG welding equipment (robot) developed on the basis of the aforesaid technologies is described.

3. Automatic TIG Welding Equipment (Robot)

3.1 Equipment components

Fig. 3 shows the components of the automatic TIG welding equipment, composed mainly of the 4 units given below.

First is the guide rail equipped with a clamping mechanism capable of strongly clamping the start point. The clamp unit holds the invar through soft copper plate so to avoid damage, and is capable of withholding 100 kgf even during overhead position welding. The entire guide rail is of honeycomb structure of aluminum alloy, with the total weight reduced to below 7 kgf.

Next is the carriage that travels along the weld line over the guide rail. The carriage has three axes: one that allows the semi-automatic arc welding torch to move freely in the horizontal direction, another in the vertical direction, and the third for carriage traveling. These axes are driven, as will be explained later, according to the signals from the conditions set for weld line seam tracking and automatic welding. A small size pulse motor is adopted as the driver, contributing to the reduction of carriage weight to about 3 kgf. The equipment is small enough to hold in one hand to allow easy handling even at overhead position welding.

Then, there is a controller located on the welding power source that controls the various functions of this equipment such as welding sequence, sensing condition, welding condition, and automatic setting parameter, in addition to the pulse motor driver. The last unit is the

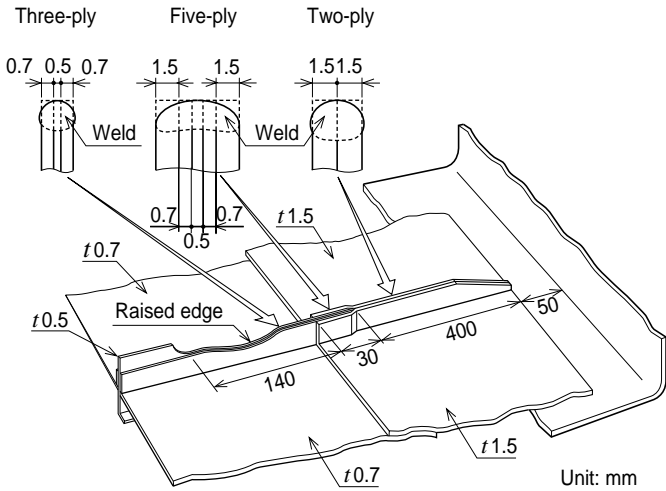


Fig. 2 Welding joint shape of raised edges
 Along a welding length of about 600 mm the welding joint takes three different shapes in addition to the presence of inclined and arc sections, calling for advanced skills.

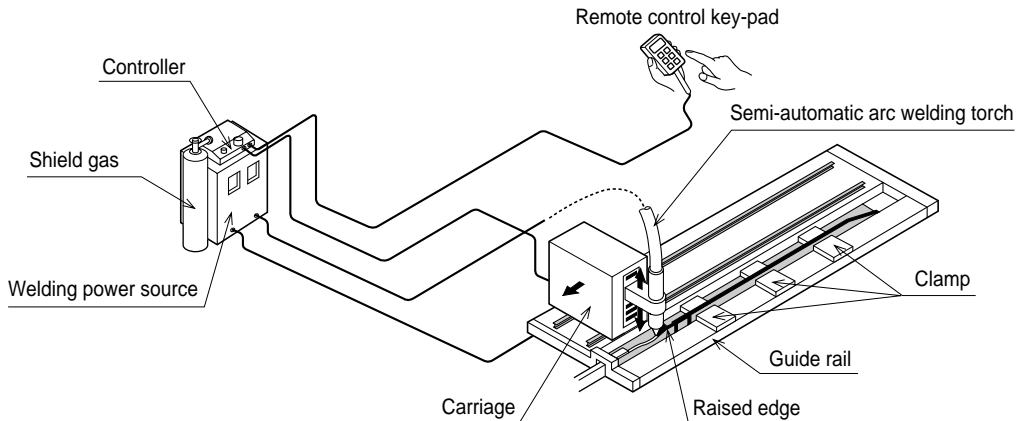


Fig. 3 Automatic TIG welding robot with lightweight unit
 The robot composed of 4 units is light and compact, with a guide rail of no more than 7 kgf and a carriage of less than 5 kgf.

remote control key-pad, which allows the input of parameters before welding. The remote control key-pad can also be used to operate the welding position manually and to change the welding condition parameters, while monitoring the welding state during welding.

As for the welding sequence, the required parameters of welding and sensing conditions are input in advance before fixing the guide rail to the edge and the carriage to the guide rail. Next, EXECUTE is selected from the remote control key-pad to move the equipment automatically to the welding start point before coming to a stop. Similarly, on receiving the WELDING START command from the remote control key-pad, the equipment starts

automatic welding. **Fig. 4** shows the welding state using the newly developed equipment (robot).

3.2 Automation technology

The movement of the semi-automatic arc welding torch using the newly developed automated equipment is shown in **Fig. 5**. Initially, the movement of the torch is in the vertical direction H , where the arc length constant control is carried out to align the torch position against the edge top section. In other words, the torch height is subjected to adaptive control according to the carriage driving axis, so that the arc length L_a shown in the figure always remains constant. In actual practice, however, an arc voltage almost equivalent to arc length

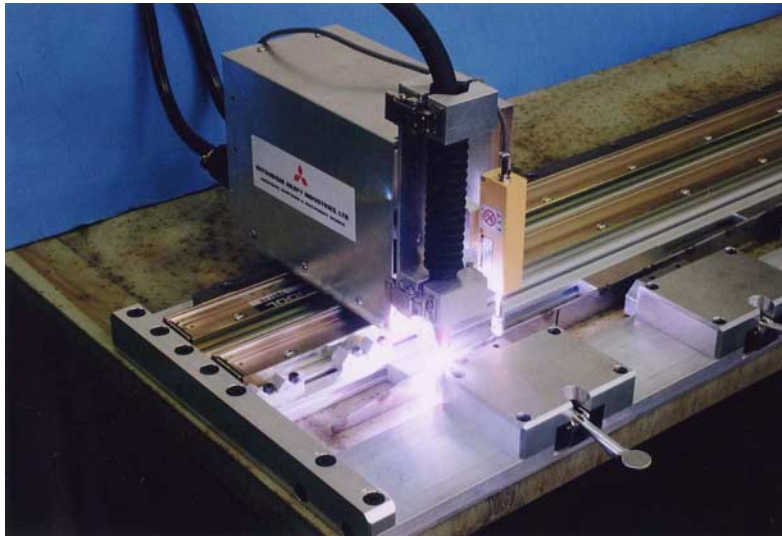


Fig. 4 Appearance of automatic TIG welding using the newly developed robot

The functions of seam tracking for the weld line and automatic setting of welding conditions enable continuous automatic welding.

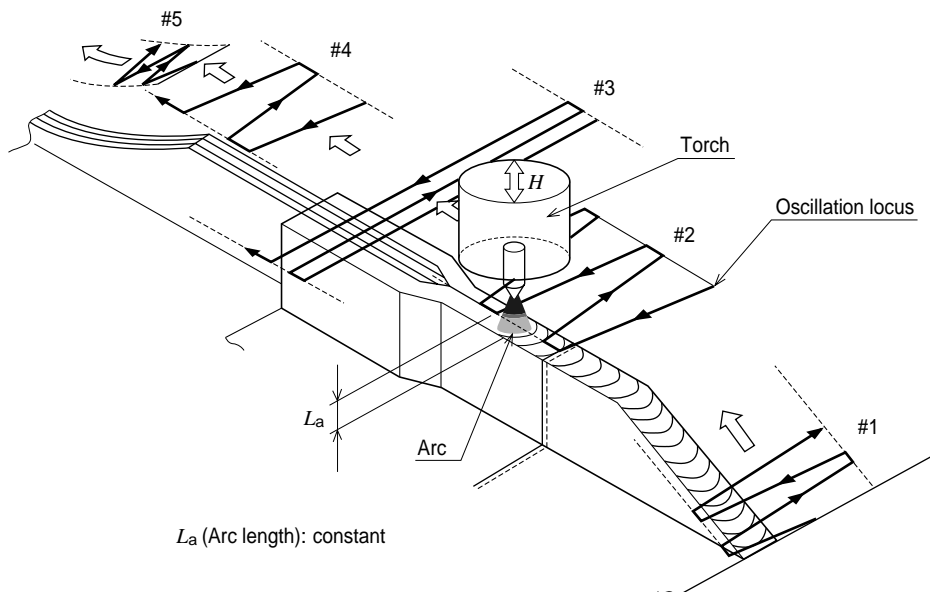


Fig. 5 Seam tracking with arc length control and automatic setting of welding conditions

Equipped with a seam tracking function for the weld line according to the arc length constant control and an automatic setting function for appropriate welding conditions for each joint shape

Table 1 Functions of the newly developed automatic TIG welding robot for raised edges

Features	Function	Effect
Automatic function	Arc length constant control (Arc voltage constant control)	Arc length (Arc voltage) is kept constant against the two-dimensional weld line Heat input constant Stable weld penetration
	Automatic setting of welding conditions	Detects the position of joint change and automatically sets the welding conditions for each joint Continuous welding Excellent workability
Light and small (Miniaturization)	Weight: below 7 kgf/component	Excellent portability, and can be easily fixed even in the overhead position by means of clamping mechanism Light Excellent workability
Stable quality	Arc oscillation	Ensures substantial penetration on both sides of the joint. Ensures stability of penetration radius R (standard).

L_a is detected to calculate the deviation by comparing the actual arc voltage with the preset appropriate arc voltage. On the basis of this deviation, the vertical drive axis of the torch in the carriage is operated to carry out feedback control of the torch height. As shown in Fig. 5, this enables seam tracking of the torch against the vertical change of the edge weld as well, ensuring stable penetration quality.

The next required item is the automatic setting of welding conditions against the change in joint shape. In conventional welding, a welder has to stop welding to reset the welding conditions every time the joint shape is changed. This problem was solved in the following manner with the newly developed equipment (robot). Markers are installed in advance along the guide rail at places where the welding conditions need to be changed. These markers are then detected when the carriage passes over them to inform the user of changes in joint shape or the places for changing the welding conditions. On receiving the marker detecting signal, the appropriate welding conditions corresponding to that particular joint are called up to keep the welding going. As shown in Fig. 5, five welding conditions from #1 to #5 are set for a short welding distance of about 600 mm. This means that edge welding cannot be done successively unless the welding conditions are divided elaborately into small parts. Of the various welding conditions, the oscillation condition of the welding arc is the most important parameter. It is necessary to change the oscillation speed, stop time at both ends, welding speed, etc. simultaneously for each joint shape. These welding conditions are deduced in advance as the appropriate welding conditions for each welding position. The features of the newly developed welding equipment and the effects thereof are summarized in **Table 1**.



(a) Overhead position welding



(b) Horizontal position welding

Fig. 6 Welding tests including horizontal and overhead positions with developed robot

Automation of welding in various positions is expected to improve the efficiency

4. Verification Test

Fig. 6 shows the welding tests including horizontal and overhead positions using the newly developed automatic TIG welding equipment.

In order to start welding automatically, all the welder needs to do is to set the equipment (robot) and press the START button. However, some improvements are still needed in areas such as durability and operability, and we are planning to make these improvements before the actual construction of the robot.

Fig. 7 shows the cross-sectional macro-structure of the joint subjected to automatic welding using the newly developed equipment.

The welds of all joint shapes in all welding positions are found to be excellent. Further improvements are being made for higher weldability, and MHI is planning to apply the newly developed equipment to the building of membrane LNG ships for the first time in Japan.

5. Conclusion

Ships used for transporting LNG, an important source of energy, are to be characterized by high reliability, stability, and performance, which must be assured by means of shipbuilding technology. Welding forms the very foundation of shipbuilding technology and therefore requires enhanced efficiency through automation, in addition to

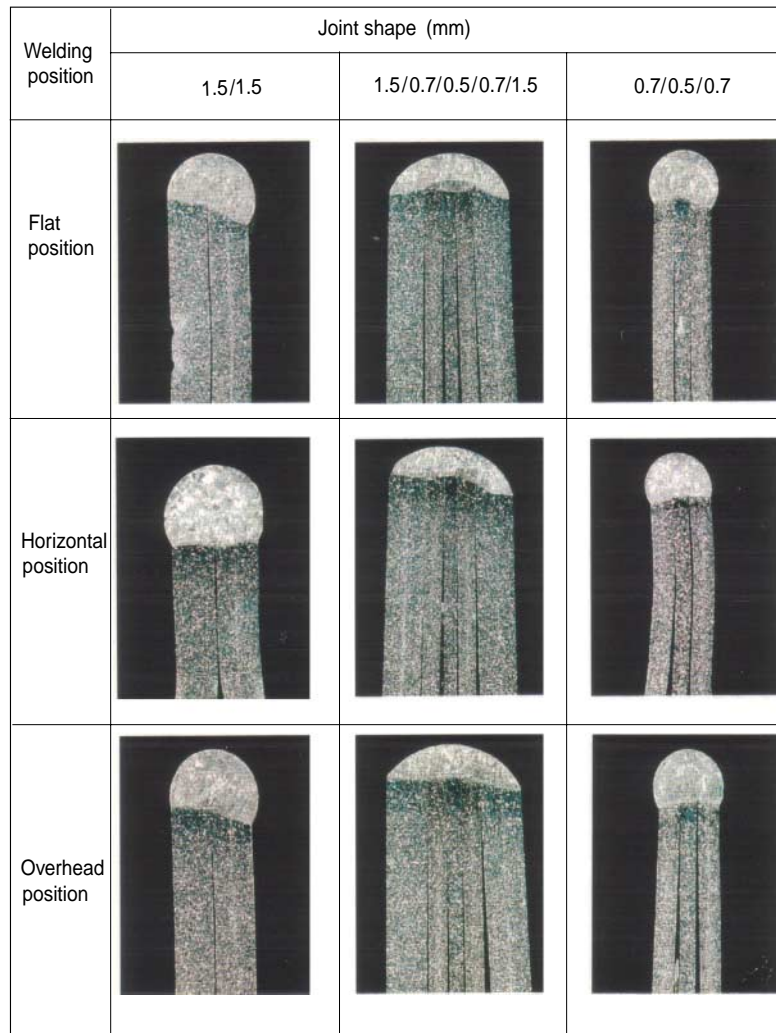


Fig. 7 Cross-sectional macro structures of a bead produced by the newly developed robot

All 3 types of joints subjected to welding in various positions have excellent welding.

higher welding quality. This paper describes a newly developed high-quality and high-efficiency automatic welding technology for the welds that conventionally depended on the advanced skills of human welders. MHI is planning to apply this newly developed technology to the building of membrane LNG ships for the first time in Japan.

Welding is a key technology for manufacturing heavy structures as represented by ships. MHI is determined to make efforts in developing new technologies to make further contributions to society.

Reference

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