Liquefied natural gas (LNG) tank – Optimizing quality and cost with automation technology for the world's largest class LNG tank


Kawagoe Thermal Power Station LNG tank Nos. 5 & 6 for Chubu Electric Power

LNG tanks require high standards of safety and quality as they store natural gas liquefied at a cryogenic temperature of –164 °C.

Kawasaki has been developing automated welding technology as part of an effort to ensure consistent quality. For aboveground LNG tanks, an automated welding robot was developed for the processing of knuckle plates to ensure consistent quality and high efficiency. For in-ground LNG tanks, a new automated welding technology was developed for membrane panels. By applying this technology to block welding in shop fabrication, Kawasaki has achieved both excellent quality and an automation rate of 95%.

Preface

Liquefied natural gas (LNG) emits less carbon dioxide than any other fossil fuels when burned, and as such, it has been attracting considerable attention as a clean energy source. Particularly in Japan, the 2011 Great East Japan Earthquake triggered a surge in demand for LNG as fuel for thermal power generation, and usage has been increasing steadily since.

Against this background, LNG storage tanks are being constructed around the country to ensure a steady supply of LNG, and Kawasaki is keeping pace by offering various types of storage tanks that incorporate the latest technology.

1 Overview of aboveground and in-ground LNG storage tanks and Kawasaki's development efforts

(1) Overview of aboveground LNG storage tank

Figure 1 gives an overview of our aboveground LNG storage tank. This storage tank consists of an inner tank that ensures liquid- and gas-tightness and earthquake resistance, an insulation layer that provides thermal insulation, an outer tank that prevents leakage of the nitrogen gas filling the insulation layer, and a protective dike that ensures liquid-tightness in the event of LNG leakage from the inner tank.

The inner tank is made of 9% Ni steel for cryogenic strength and toughness as well as weldability.

(2) Overview of in-ground LNG storage tank

Figure 2 gives an overview of our in-ground LNG storage tank. This storage tank consists of a membrane that ensures liquid- and gas-tightness, an insulation layer that provides thermal insulation and transfers the pressure from the membrane, a tank body that provides resistance to liquid and earth pressure and protection against the ingress of groundwater, and a steel roof that ensures gas-tightness and load resistance. The membrane is made of corrugated stainless steel sheets that absorb thermal shrinkage.

(3) Kawasaki's development efforts

To date, Kawasaki has received an order for a total of 32 aboveground LNG storage tanks (of which 7 are under construction) and 12 in-ground LNG storage tanks (of which 1 is under construction) around the world. We are currently developing automated welding technology to respond to increased demand for larger LNG storage tanks, shorter construction periods, and reduction of construction costs seen in recent years.

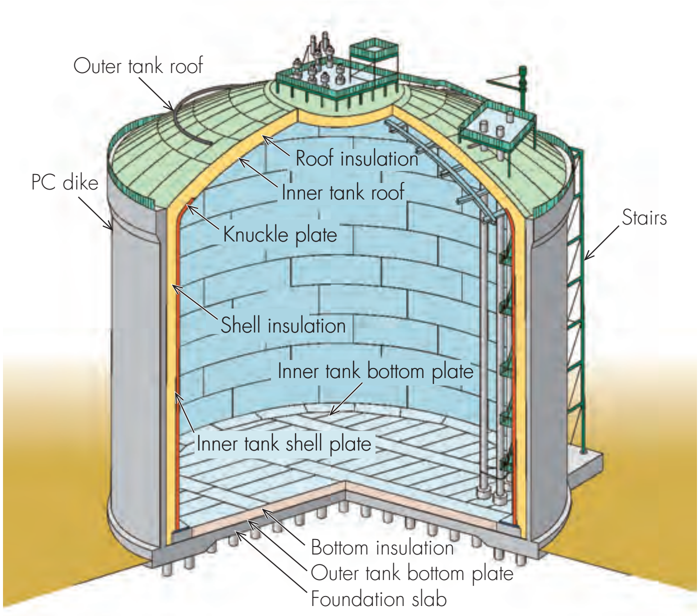

Fig. 1 Aboveground LNG tank structure

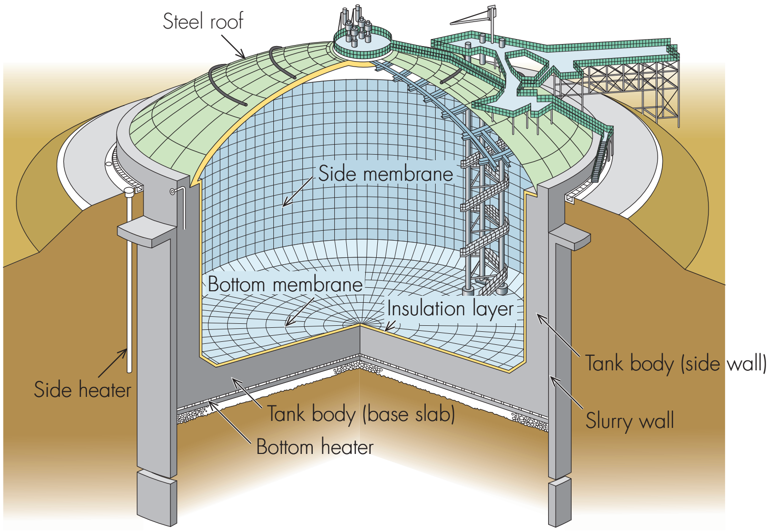

Fig. 2 In-ground LNG tank structure

2 Automated welding in shop fabrication

Kawasaki's LNG storage tanks feature a modular design in which critical structures such as the roof, side walls, and bottom slabs are shop-fabricated in large blocks (modules) by assembling and welding a number of components. In the modular construction method, further automation can be introduced to improve quality, thereby minimizing factors that contribute to variations in quality and processes compared to the on-site construction method, which relies more heavily on the skill level of the operator and is therefore more easily influenced by the work environment. In addition, by moving work off site, construction can be carried out more safely and in a shorter period of time, achieving greater stability in quality as a result. We will now take a look at our automated welding technology in shop fabrication.

(1) Automated welding of aboveground LNG tank knuckle plates

As shown in Fig. 3, knuckle plates (thickness: max. 50 mm) are critical parts that join the roof and side wall of the inner tank of an aboveground LNG storage tank. To shorten the construction period and achieve stable quality, we adopted a modular design in which two to three knuckle plates are welded together in shop using automated welding robots.

The joint welding of knuckle plates is a highly demanding task requiring continuous welding of three-dimensional curved surfaces of 9% Ni steel plates in a vertical or upward-facing position for an extended length of time.

To overcome these challenges, we developed an automated knuckle welding robot described below.

(i) High-functional remote monitoring system

Figure 4 gives an overview of the high-functional remote monitoring system developed to ensure stable quality in continuous knuckle plate joint welding. This system features a laser sensor for the automatic recognition of groove shapes and an arc monitor camera for the remote monitoring of arc conditions, enabling simultaneous operation of multiple welding robots by a single welder.

(ii) Application

Multiple automated knuckle welding robots have been employed to streamline the welding process, shorten the overall construction period, and achieve stable quality. Figure 5 shows an automated knuckle welding robot equipped with this system at work.

(2) Automated welding of in-ground LNG tank membrane panels

Kawasaki is currently constructing a 220,000-kl in-ground LNG storage tank in Japan scheduled for completion in 2016. The in-ground storage tank also uses the modular construction method to optimize quality and the construction process. At our dedicated plant, we construct prefabricated modules combining a number of membrane

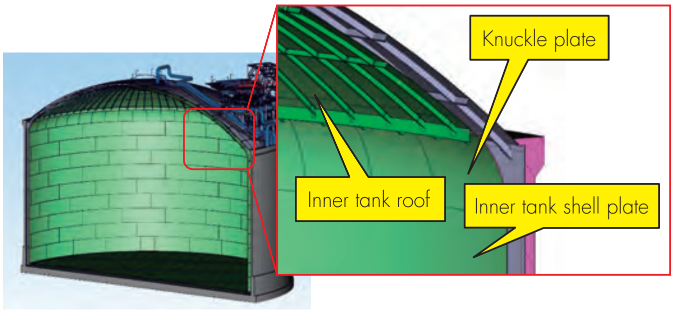

Fig. 3 Knuckle plate

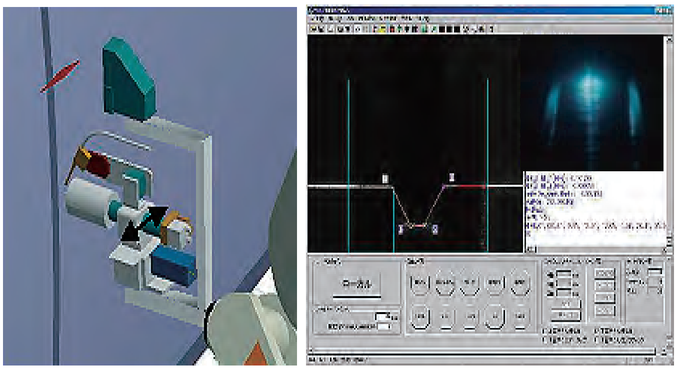

Fig. 4 High-functional remote monitoring system

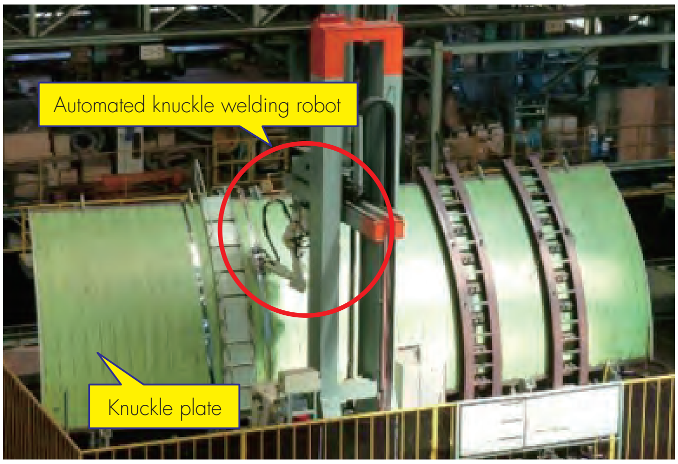

Fig. 5 Automated knuckle welding robot

panels made of stainless steel sheets (SUS304; thickness: 2 mm) machined with a corrugator (Fig. 6).

In the past, the membrane panels of in-ground LNG storage tanks were welded by skilled welders using automated TIG welding equipment. They corrected the position of the welding torch and made fine adjustments to welding conditions in response to the distortion of components due to welding.

To increase the reliability of welding operations, we developed a new automated membrane panel welding system that can perform welding operations without human supervision and does not rely on the skill level of the operator.

(i) Automated welding technology

Mainly the following issues were faced when welding membrane panels with the previous equipment.

① The target position of the welding torch (electrode) would change due to weld distortion. For this reason, the operator had to constantly monitor the condition of the arc and adjust the position of the welding torch.

② Occasionally, the stainless steel sheets warped significantly during welding, bringing the welding equipment to a halt. This would result in welding defects, making repair welding necessary.

To address the above issues, we applied Kawasaki's automation and robot technologies and developed an automated membrane panel welding system that can operate without the supervision of an operator, and also ensures stable quality. Main features of the newly developed system are outlined below.

(ii) Automated weld seam tracking system

To achieve high quality welding of membrane panels, the target position of the welding torch had to be corrected as necessary relative to the weld distortion. Therefore, we developed a sensing system that can measure the position of the weld seam and gap between welded components with a laser sensor in real time, and automatically correct the target position of the weld torch. Figure 7 gives an

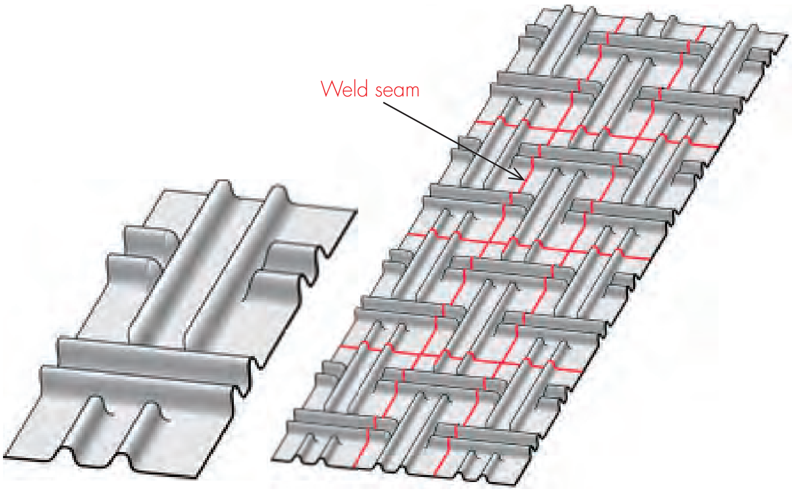

Fig. 6 Membrane panel of in-ground LNG tank

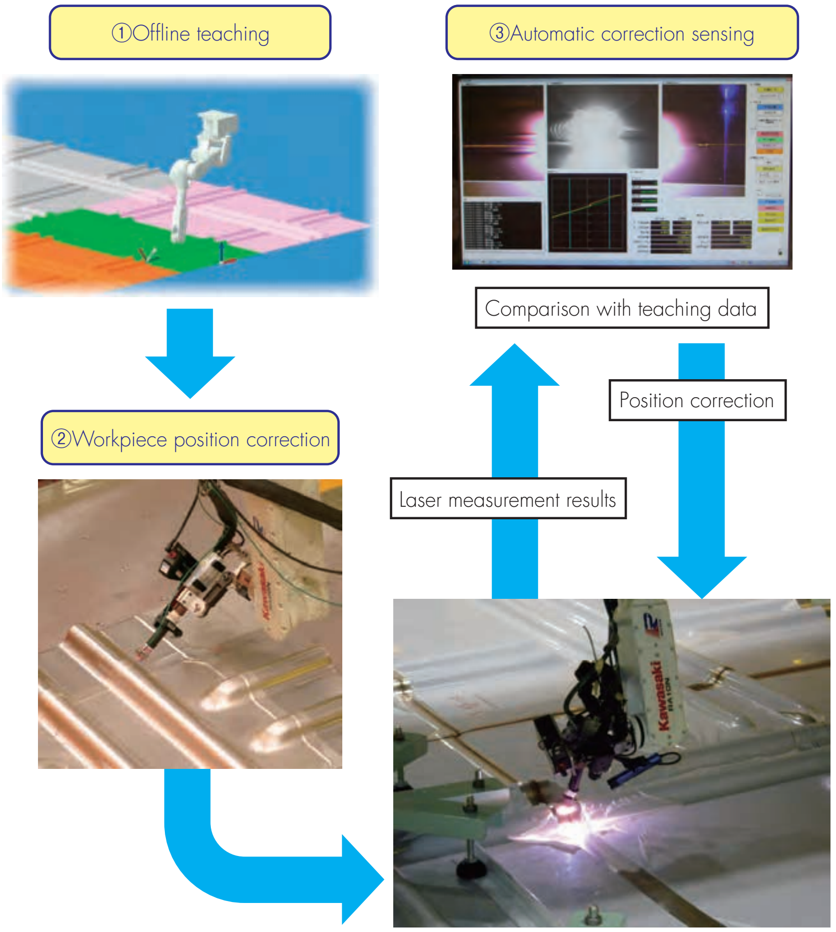

Fig. 7 Automated weld seam tracking system

overview of the automated weld seam tracking system.

① Offline teaching

Teaches welding robots offline (feeds CAD-based weld seam data on a computer, without using the actual robot).

② Workpiece position correction

Corrects the welding position of membrane panels using the touch sensing function of the welding robot.

③ Automatic correction sensing

Measures the position and height of lap joints as well as gaps in real time during welding operations using a laser sensor. Calculates the amount of correction based on the difference with teaching data, and automatically corrects the welding target position to an accuracy of 0.1 mm.

(iii) Weld distortion prediction technology

Membrane panel modules are fabricated in shop by combining 18 panels into a block of approximately 5 x 11 m. To maintain the quality of the modules and shorten the time required for installation on site, it is important to minimize the weld distortion of the overall modules. However, when seam welding multiple joints, it used to be difficult for the operator to accurately predict the amount of weld distortion in the finished work. We sought to solve this issue by simulating the weld distortion of sheet metal membrane panels and determining the optimal welding procedure to minimize distortion.

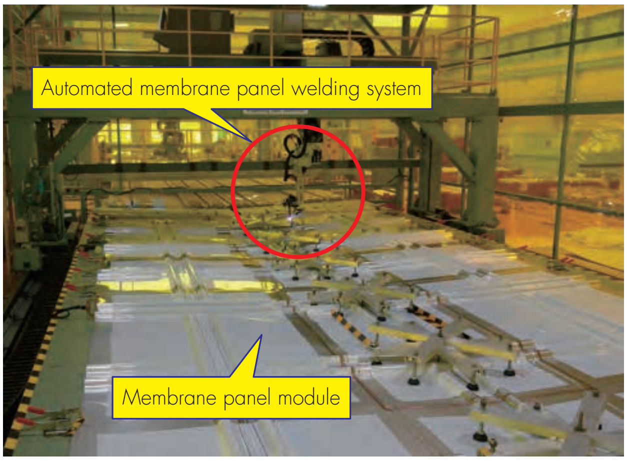

Fig. 8 Automated welding of membrane panels

We verified the simulation results by testing the procedure on a mockup and comparing the weld seams with those welded by a skilled welder using the conventional procedure. This test demonstrated that the new procedure can reduce the amount of weld distortion by half. We applied this procedure to the actual shop fabrication of modules and successfully minimized weld distortion.

(iv) Application

We were able to achieve excellent weld quality by applying an automated membrane panel welding system featuring an automated weld seam tracking system and a welding condition database to in-shop module fabrication. We also achieved an automation rate of approximately 95% for the welding of prefabricated modules by eliminating the need for an operator to monitor the process. Figure 8 shows an automated membrane panel welding system in operation.

3 Development of streamlined welding technology for on-site fabrication

Welding operations at construction sites of aboveground LNG storage tanks overseas can be faced with such issues as difficulty securing skilled welders with the required skill level for nickel steel welding, or inability to use special automated welding equipment due to obstacles related to construction site facilities or environmental factors. To address these issues, the use of flux-cored arc welding (FCAW) has been required in pressure-resistant components of the inner tank. FCAW is a highly efficient welding method that does not rely heavily on the skill level of the operator, and can also help shorten the construction period. Kawasaki has been applying FCAW to non-pressure-resistant components of storage tanks in Japan from about 10 years ago. With a view to applying the process to pressure-resistant components of the inner tank, we evaluated the weldability and joint performance of FCAW materials. As a result, we were able to confirm that the process fully satisfies the performance requirements of LNG storage tanks, and offers excellent fracture toughness as well as joint strength and toughness that are at least equal to the level achieved by the shielded metal arc welding method currently used. We have also established appropriate welding conditions that ensure crack resistance. Therefore, we have started applying the process to the fabrication of pressure-resistant components of the inner tank in LNG storage tanks currently under construction overseas. We are working with an eye to applying the process to the pressure-resistant components of LNG storage tanks in Japan as well, once we have accumulated sufficient technical data and experience.

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Concluding remarks

LNG continues to be in high demand around the world as an environmentally-friendly, clean energy source. As part of its ongoing contribution to society, Kawasaki is working to develop products that help ensure a steady supply of energy through lower cost, higher quality, and more efficient processes.