May 2023 - N°28

Message from Jean-Baptiste Boutillier, Vice-President Innovation

Continuous innovation is at the heart of our strategy. It is also one of our core values. Of course, we are talking about innovation in our technologies, but not only. We are also committed to driving innovation in processes, materials, construction methods, etc.

In this issue, you will discover some exciting developments such as Otowose™ our new cleaning laser for welding, and Otoseam™ our new welding robot for Invar. Both developments are aimed to further improving the quality and reliability of the welds in our systems.

These are more examples of how GTT contributes to the improvements in the quality and efficiency of tank construction.

This is amply illustrated in more details in the last article of this edition.

As always, we remain committed to providing you with the best possible service and solutions in the industry. We thank you for your continued support and look forward to collaborating with you on future projects. We hope you enjoy your reading.

OTOSEAM™: THE HIGH SPEED SEAM WELDING MACHINE

In the GTT NO96 technology, the primary and secondary barriers are made of Invar®, a 36% nickel-steel alloy, 0.7mm thick.

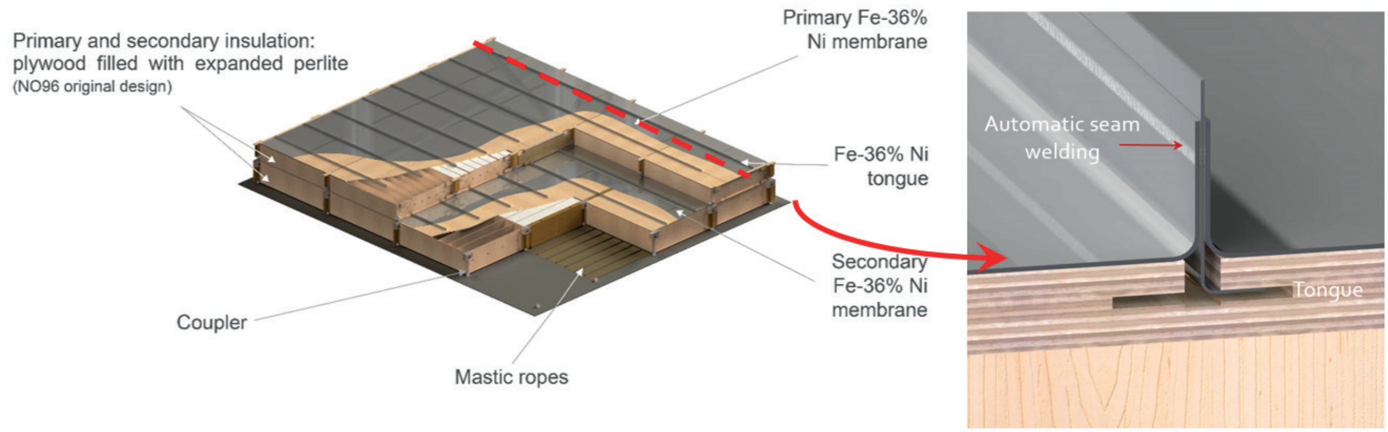


Figure 1: Raised edges on NO96 technologies

The raised-edges (0.7mm membrane / 0.5mm tongue / 0.7mm membrane) are welded continuously over a length of 40 meters thanks to the Resistance Seam Welding machine. On a 174 000m3 NO96 ship, this corresponds to 120km of welding at a speed of 1.6m/min, i.e. 1250 welding hours per LNGC.

In the 1960's, the first generation of seam welding machine was developed in close collaboration between GTT and ERI, a French engineering company, in order to design and produce all the machines for installing and welding NO96 membrane. Since then, many improvements have been made and the latest development in operation today dates from 2003.

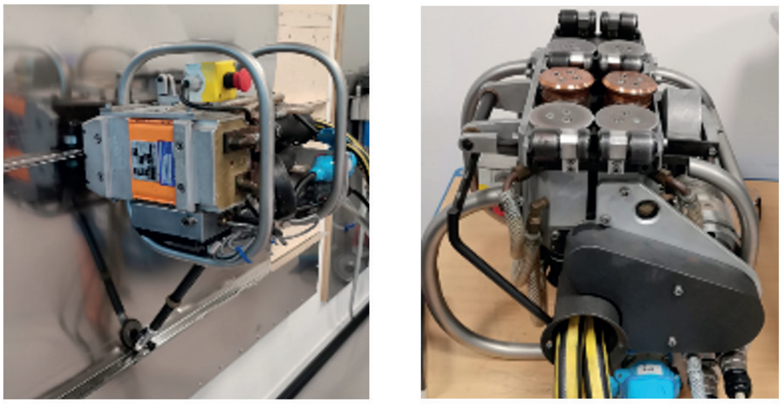


Figure 2: Actual welding machine in operation

To achieve perfect tightness of the primary and secondary membranes, a correct welding is essential.

In 2020, GTT has decided to extend the development of welding machine for the installation of our technologies (NO96 and GTT Next1) with the aim of improving efficiency with a faster seam-welding machine and a constant quality control to ensure zero defects.

Resistance seam welding – How does it work?

The seam-welding machine uses a resistance welding process (often used in automotive assembly lines with electrodes) with wheels instead of electrodes in order to perform multiple spot welding along the parts of the assembly.

These parts must be in close contact, so the electrodes (or wheels) compress the upper sheet onto the lower one. A current of several kilo-Amperes flows through the sheets from one electrode to the other.

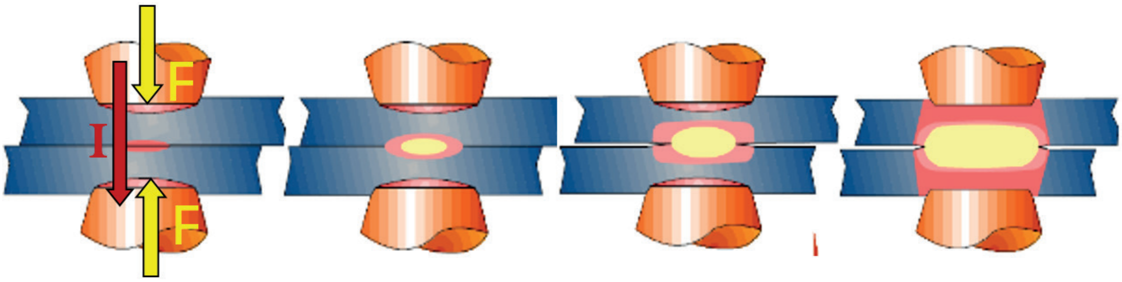


Figure 3: Resistance spot welding

The heating is due to the Joule effect ($E=\int RI^2$) because of the contact resistances Rc2 and Rc3 (see Fig. 5). The spot weld appears migrates from the two interfaces until a full weld is obtained (see Fig 4). The weld seam consists of a very large number of overlapping spot welds (see Fig.5). In order to improve the productivity of the welding process, the electrode was replaced by a wheel that exerts a continuous pressure on the sheets to be joined. The current flow is electronically controlled.

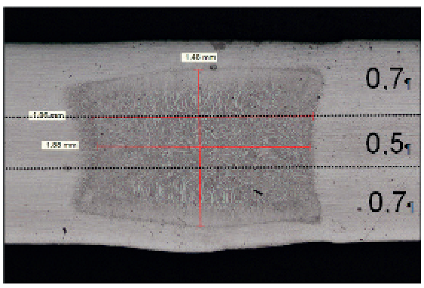


Figure 4: Transversal macro examination of seam welding

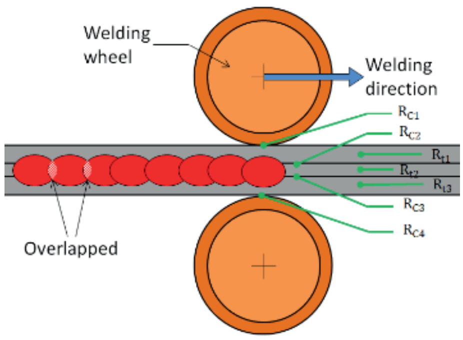


Figure 5: Resistance seam welding schema

Development of the High Speed Seam Welding machine

For the success of this project, GTT decided to collaborate with our historical partner ERI.

Technical feasibility (2020)

A comparative study was carried out first. Currently the welding parameters for 0.7/0.5/0.7 Fe-36%Ni raised-edges are:

- 1.6m/min
- 4.2 kA
- 2 hot periods of 20ms and 1 cold (no welding) period of 20ms
- approximately 120daN of force.

The size of the spot welding depends on the value and the application time of current. The current welding machine is supplied by a 50Hz transformer so the minimal period is 20ms. An increase of welding power leads to a bigger welding transformer. An increase of the speed, without reducing the period, leads to a risk of losing the overlapping between welding spots and consequently a loss of tightness (Figure 5).

For this reason, a 1000Hz transformer was chosen, permitting a welding period of 1ms.

Tests at different power levels were carried out with different pressures and periods up to a welding speed of 5m/min. At this speed, the resulting welds met GTT specifications.

For a 5m/min speed, the pressure is still the same and the other parameters are:

- Current between 5 and 7 kA
- 2 hot periods of 6ms and 1 cold period of 6ms.

A longitudinal analysis of the seam confirmed the good continuity of the weld seam.

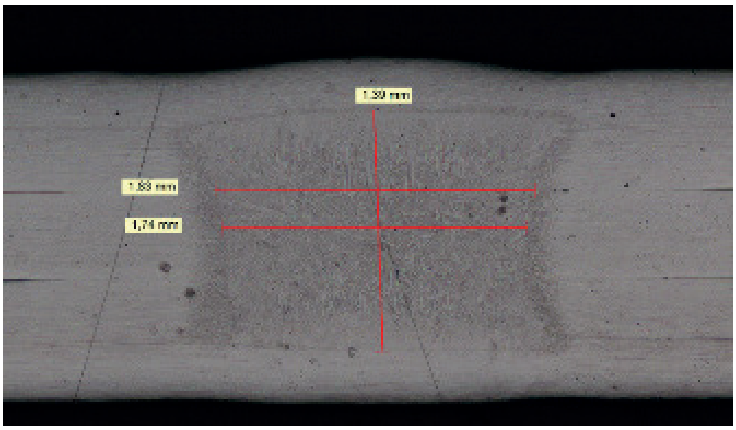


Figure 6: Transversal macro-examination
with the new transformer

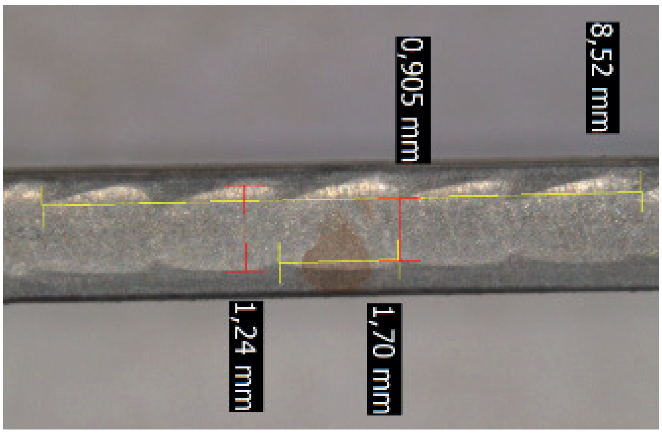


Figure 7: Longitudinal macro-examination

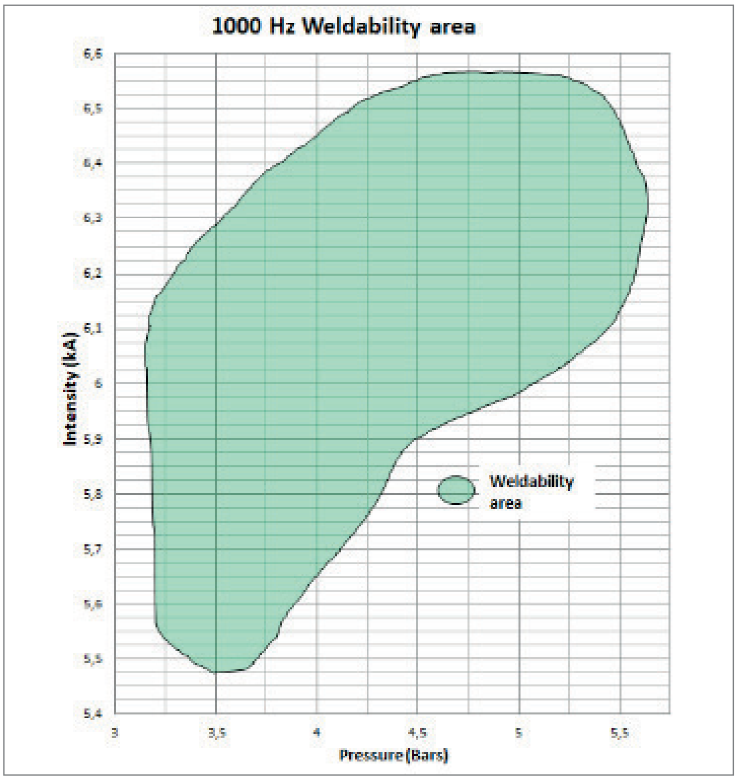


Figure 8: Result of robustness study

Robustness study in 2021

The second step consisted of studying the process repeatability in terms of tolerance to ensure the on-board welding. With ERI, a campaign on more than one hundred samples was made at different pressures, powers, speeds, and hot/cold periods.

Due to the volume of analyses to be carried out, these experiments took place over several months. A wide range of results were found that met the GTT specifications (the result is shown in Figure 8), indicating that the High Speed Seam Welding process is robust and can be applied in the shipyard.

Prototype in 2022

Thanks to the results of the feasibility and the robustness of this technology, GTT decided to make an investment in the development of the prototype. Patents were filed, regarding two main innovations:

- The weld wheels
- The inverter

The weld wheels

On the previous generation of welding machine, the weld wheels diameter was 62mm and after 400 meters of welding, the wheels had to be rectified due to the deterioration of the copper. The temperature during the welding wheels is around 100°C.

Four driving rollers (Ø62mm – Figure 12) and two welding wheels drive the welding head, rotating at the same speed. To avoid the risk of skidding, the welding wheels have to be changed after every 800 metres of welding because they are too small.

Firstly, GTT and ERI have modified the driving system of the welding head to allow free rotation of the welding wheels, which allows variations in diameters between the rollers and the wheels.

The cooling system was also improved with a temperature regulation, better cooling flux, and larger welding wheels to obtain a maximum temperature of 60°C during the welding at 5m/min (5-7kA compared to 4.2kA before).

The inverter

The transformer operates at a frequency of 1000Hz, but the electrical network delivers only 50Hz, so the main purpose of the inverter is to convert 50Hz to 1000Hz and also to control the transformer.

In order to reduce the mass of the inverter, GTT and ERI have developed a customised solution with a positive result: a mass of 4.9kg versus over than 10kg for the current market standard.

Figure 9: Longitudinal macro-examination of seam welding with the new inverter

OTOSEAM™

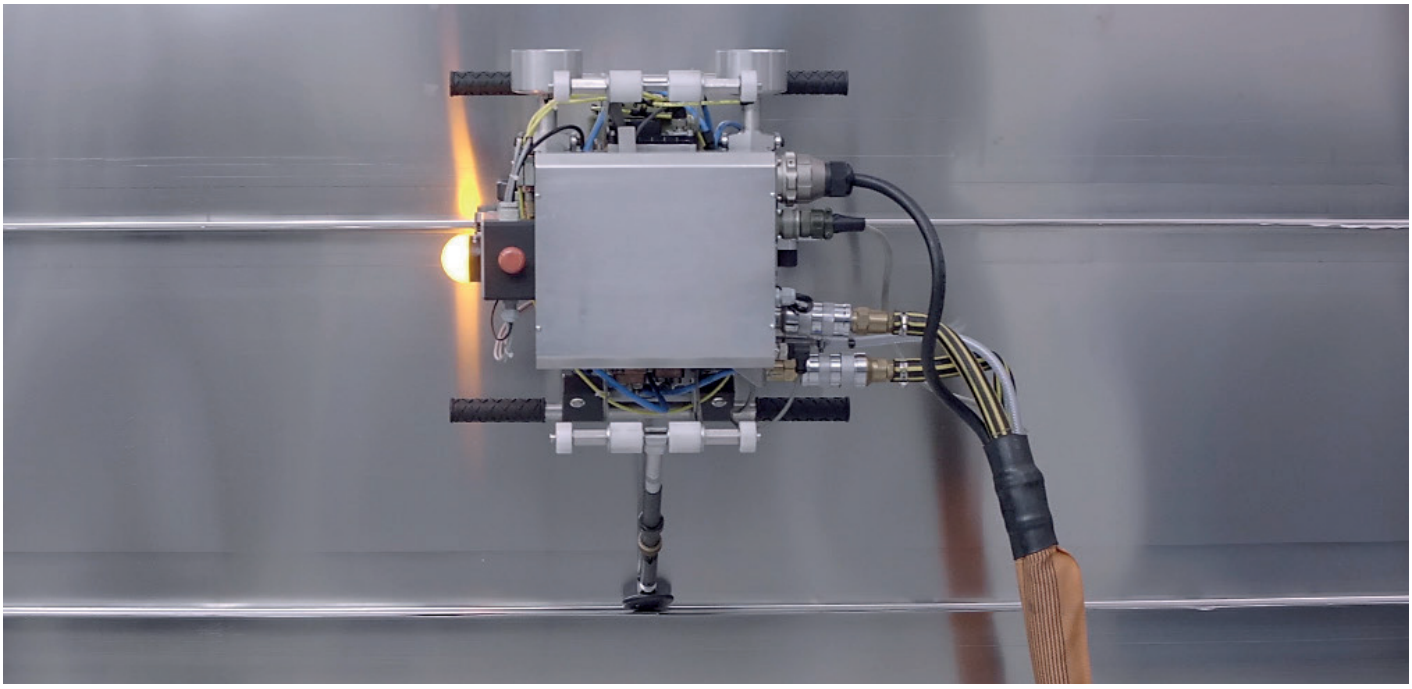


Figure 10: Horizontal position view

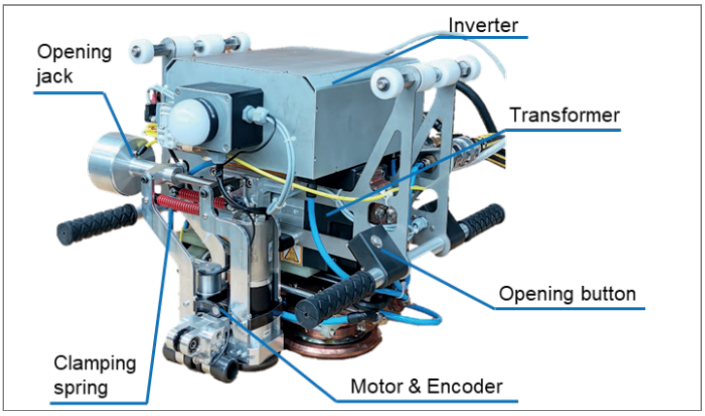


Figure 11: Front view

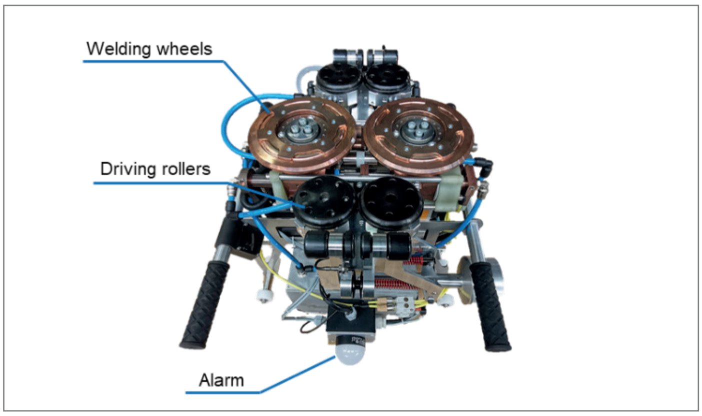


Figure 12: Bottom view

Figure 13: Control Panel

Comparison with previous generation machine

Descriptions	Standard	Otoseam™
Speed (m/min)	1,8	5
Transformer	50Hz	100% 62,5kVa – 1000Hz
Inverter	Without	Integrated
Weight (Kg)	From 52	49
Drive/Welding roller (mm)	Ø62/Ø62	Ø62/Ø150 (free in rotation)
Driving system	Gear + belt + electrical motor 4 driving rollers + 2 welding wheels	2 geared motors 2 driving rollers
Cooling system	Radiator cooling system	Reefer units - Temperature tank: ~25°C
Weld wheel during welding (°C)	Over 200	~65
Changing of welding wheels	Each 800m	No skidding risk – Some kilometers

Conclusion

This project proves that it is always possible to improve the efficiency of an existing solution by upgrading with new technologies.

This new generation of seam welding machine called Otoseam™ is now available.

This technology demonstrates a significant productivity gain for the operator thanks to a higher production speed (1.8 to 5 meters/min). Less wheel change means less downtime for predictive maintenance and a continuous quality control through a control of the welding parameters.

OTOWOSE™, THE LASER PICKLING SOLUTION: A FAST, PRECISE AND INNOVATIVE SOLUTION

The primary barrier of the GTT Mark III Technology is made of 304L, an austenitic stainless steel alloy, 1.2mm thick (Figure 1).

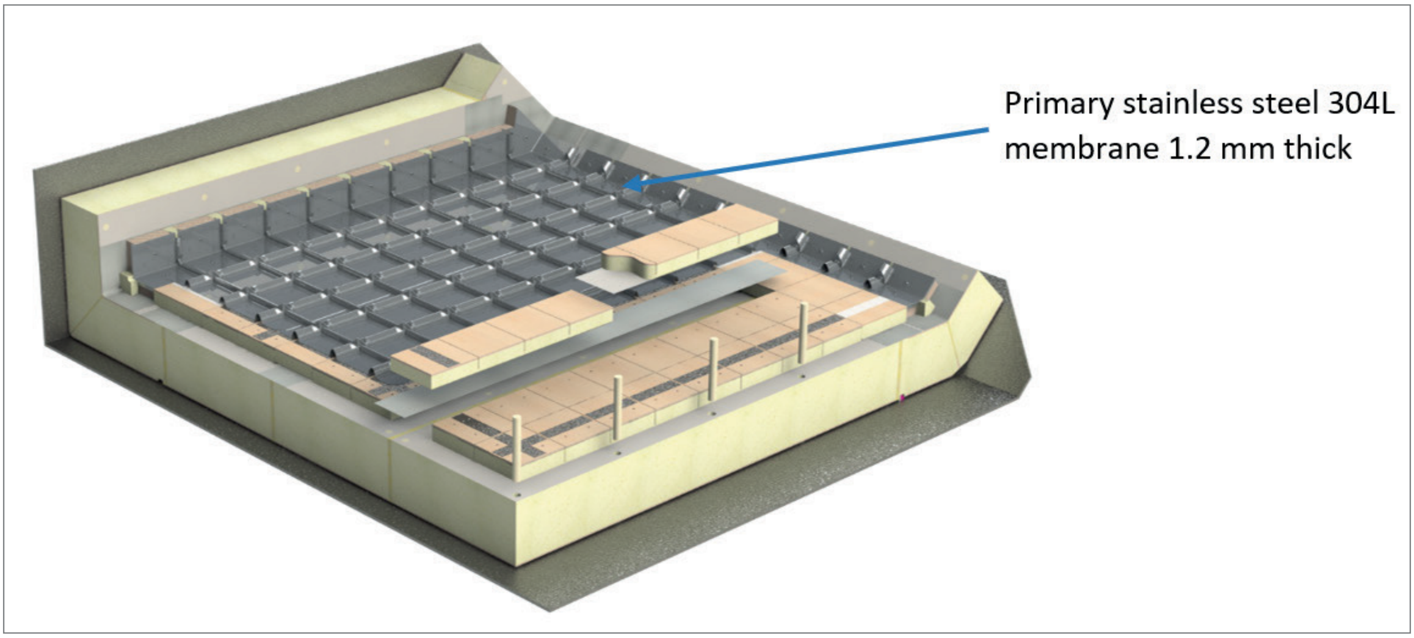


Figure 1: Primary barrier in 304L

The tightness between each membrane is obtained by welding. This operation creates oxides, which must be removed to avoid corrosion (Figure 2).

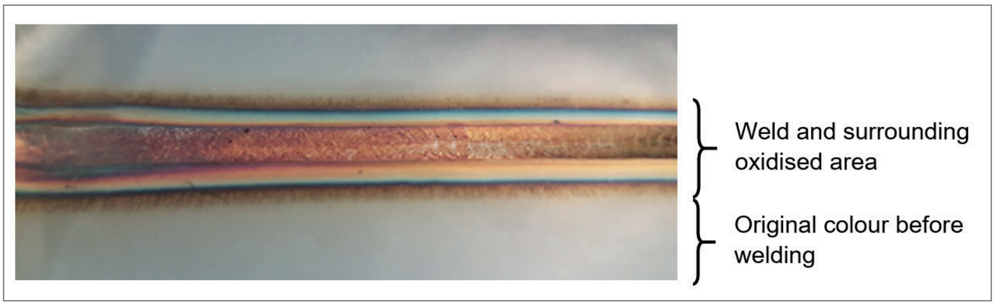


Figure 2: Oxides

Currently, cleaning the weld and surrounding area is a manual operation using a metallic brush.

This operation is difficult and time-consuming (approximately 50km of welds per ship), the ergonomic conditions are poor (vibration, dust and posture), and the repeatability of the operation is uncertain.

With this new prototype, GTT is proposing an alternative to the shipyard in order to:

1. Improve the working conditions,
2. Reduce the cost by cleaning the weld faster with a single pass,
3. Improve repeatability to 100%.

GTT's Industrialisation Department has defined the process to meet these requirements: the laser pickling robot called Otowose™, *OTO* for automatic and *WOSE* for Weld Oxyde Sublimation Equipment.

How does it work?

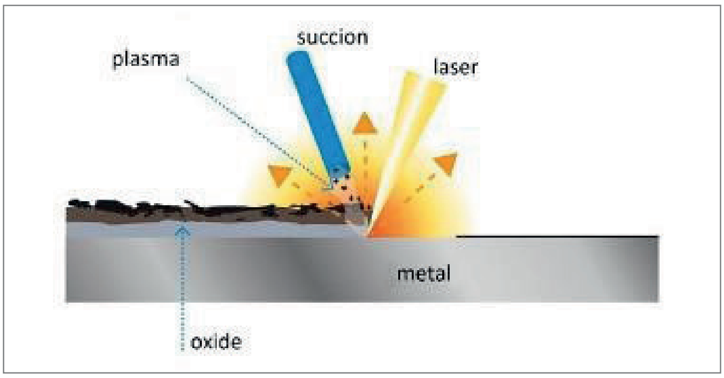


Figure 3: Overview

Figure 3 shows that the laser hits the contamination, in this case the oxides, by using powerful and very short laser pulses, which create a micro-plasma and a shockwave which ejects the contamination.

The fumes and the dust are removed by suction through the suction hose located next to the laser impact.

A closer look reveals a succession of impacts. The aim is to optimise the overlap between each impact to ensure that the oxides are effectively removed. (Figure 4)

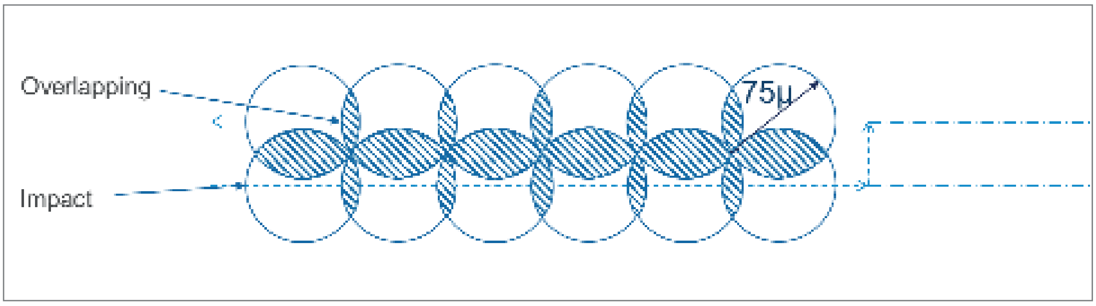


Figure 4: Zoom on impacts

The diameter of the spot depends on the laser parameters and the contamination that it will hit. The darker the oxide, the larger the laser absorption and the larger the impact.

Development of the Laser Pickling

To support GTT in this project, two suppliers well known for laser technology have been selected:

- Méliad, a French company specialised in residual stress measurement, non-destructive tests (by using Barkhaussen noise) and surface preparation by laser process.

- CleanLASER, a German company, which develops and produces high-precision laser systems for industrial surface treatment.

To complete this project successfully, it was necessary to identify all the constraints within a containment system, the working environment, space requirements, handling and fixing of the machine. All these inputs were necessary to evaluate the possibility of implementing this type of machine. A second phase of feasibility and robustness studies, which was divided into two sub-phases, was also completed.

- First sub-phase feasibility study.

The aim of this study was to verify the ability of the laser to remove all the oxides in the weld and surrounding area. Using a laser mounted on a 5-axis Robot (Figure 5), welded stainless steel plates were used to find the appropriate laser parameters.

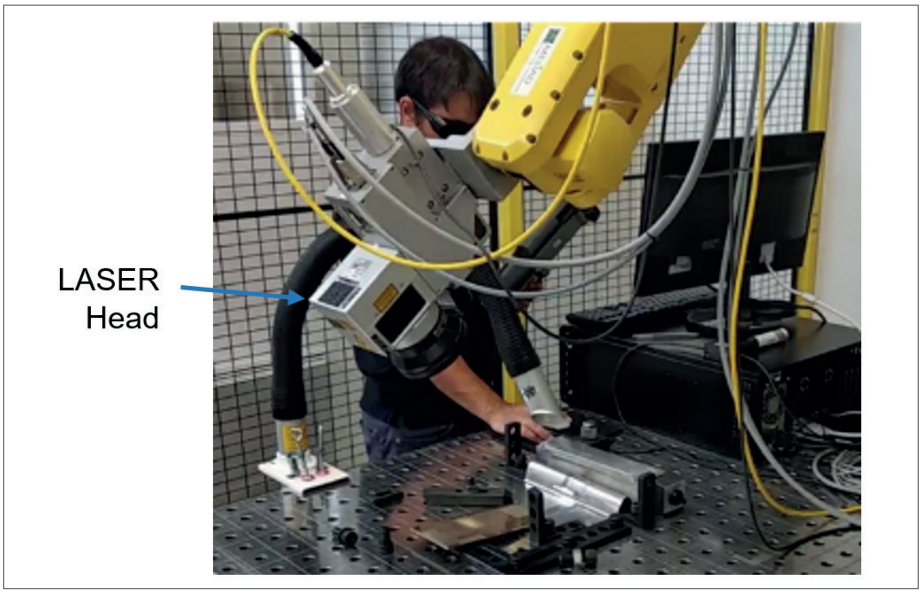


Figure 5: 5-axis robot equipped with the laser head

The samples were then subjected to visual inspection (Figure 6), Scanning Electron Microscopy (SEM) (Figure 7) and salt spray test (Figure 8) to check any start of corrosion. Each test was passed successfully.

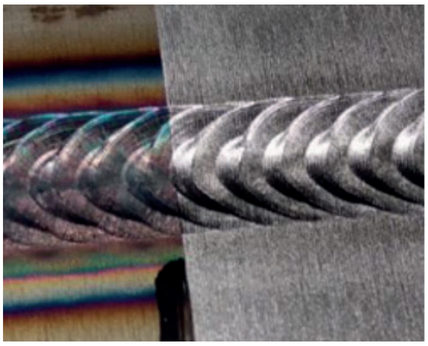


Figure 6: Visual examination

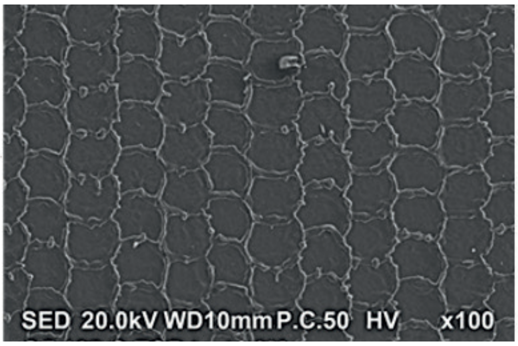


Figure 7: SEM examination

Figure 8: Salt spray test

- A second sub-phase “robustness” analysis was carried out in order to assess the positioning tolerance of the laser and to verify that the parameters chosen in sub-Phase 1 provide a satisfactory result for both small and large corrugations of the membrane of the Mark III technology. The samples were subjected to the same test and all were satisfactory.

It took about a year to design the robot, to create its specific software and to manufacture the robot prototype. This prototype was tested on a corrugated membrane and all tests met the GTT specifications.

Description of the prototype Otowose™

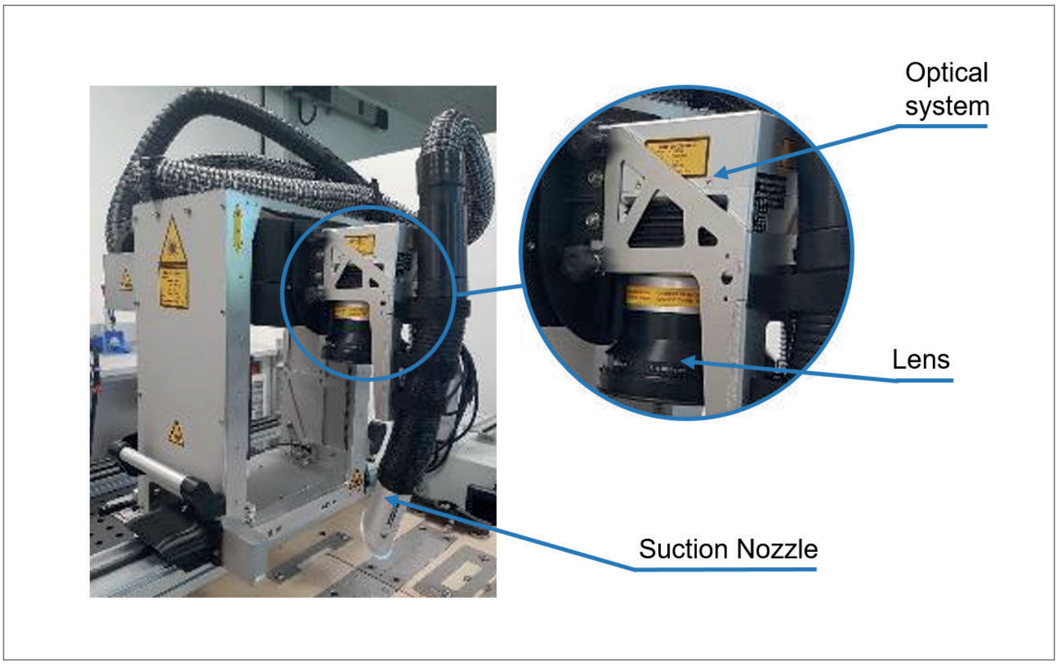


Figure 9: Front view

The optical system which moves the laser is equipped with a 330mm focal length.

To keep this focal length constant throughout the pickling operation, a specific development was required. Using a sensor, the robot is able to know its exact position without any human assistance.

The laser head is equipped with a suction nozzle to remove the fumes and the dust.

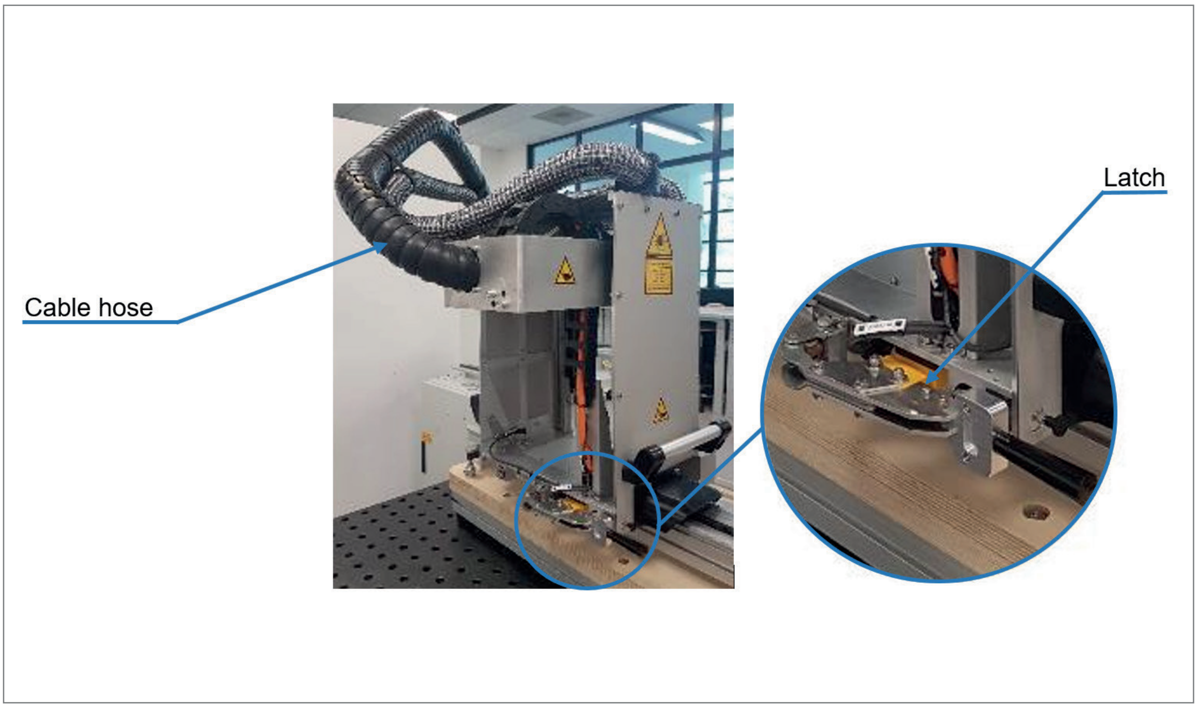


Figure 10: Rear view

The control box is connected to the robot through a specific cable hose that contains the power supply wires and the fibres, which transmits the laser from the generator to the laser head. This cable hose also prevents from an excessive bending that could deteriorate the fibre.

The latch has two functions: to secure the robot on the guide rail and to secure the ignition of the laser.

If the robot does not detect the presence of the rail and the locking handle is not closed, the laser will not emit.

Results and performance

The prototype fully validates the initial objectives:

- The prototype has demonstrated that the cleaning operation is perfectly repeatable with a global speed of 80cm/min (twice the welding speed)
- The operator is not exposed to dust and fumes; his working position is improved as the robot realises the cleaning automatically without any human assistance
- The laser pickling solution is clearly a fast, precise and innovative solution.

Our project fits perfectly into the future technology, which facilitates the working processes of the shipyards.

Schedule and opportunities

Otowose™ has been presented to the shipyards, and attracted significant interest.

Next step is to begin implementation in each yard.

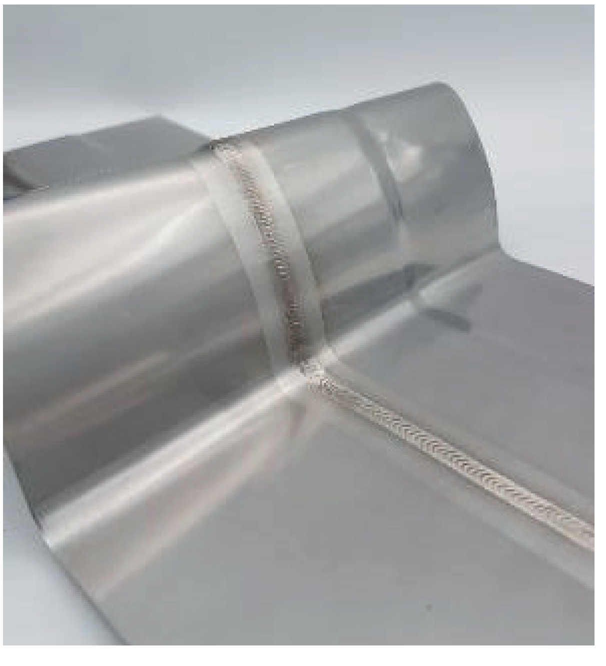


Figure 11: Cleaned Membrane corrugation

ENSURING SAFETY, PERFORMANCE AND OPERATIONAL FLEXIBILITY OF LNGCS

GTT continuously invests in research and development to improve its systems and offer innovative solutions to clients. Nevertheless, ensuring seamless project execution is equally important as the success lies in the details.

At the earliest stage, during the bidding process, GTT provides support to its clients to ensure that the ship's specifications regarding the containment system can be met. GTT assists its clients in order to define the most accurate proposal, and provides all necessary preliminary information needed in this respect, from the tank basic design, or the bill of materials to the preliminary boil-off calculations.

Once the project is confirmed, GTT initiates the engineering phase, during which its teams of expert engineers based in Paris work for approximately 9 months to deliver approximately 470 engineering reports and thousands of drawings. Throughout the life of the vessel, GTT continues to ensure the proper implementation of its technologies, addressing any queries raised by shipyards, ship owners, or classification societies on a day-to-day basis and provide all the engineering support on the Cargo Containment System (CCS)[1] that may be necessary.

After delivery of the vessel, GTT offers its detailed knowledge of the containment system's design and construction, and eventually its specificities, to support maintaining the CCS and monitoring its operational performance.

While membrane containment technologies are by nature complex, the LNG transportation industry is one of the very rare hazardous industries that had fortunately never suffered from a major accident over time.

The vigilance and professionalism of all the industry players obviously accounts for this tremendous result.

GTT is proud to have contributed, through its expert engineering, to the safe growth of an industry that should accelerate its development over the next decade. This article provides a more detailed overview of the engineering capabilities of GTT.

A team of experts dedicated to the CCS design

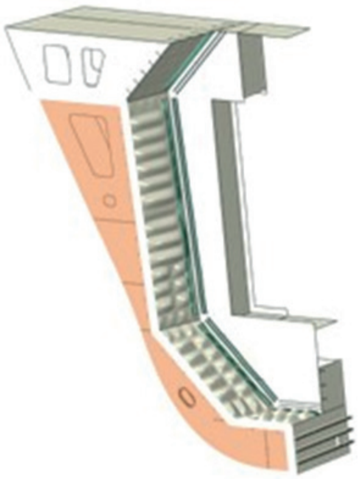
GTT's cryogenic containment systems are proven to be reliable. This is explained by the resources dedicated by GTT when designing each and every LNGC cargo containment system. GTT's technical division, comprising over 300 engineers, is entirely mobilized to design each CCS in order to meet the ship owner's specifications, the shipyard's design, the class and flag requirements, and ensure **c**ompliance not only with the latest codes and standards but also with the latest state-of-the-art on the GTT's technologies.

GTT's engineering capabilities on CCS have been specifically organized to address three concerns:
• safety
• performance
• operational flexibility

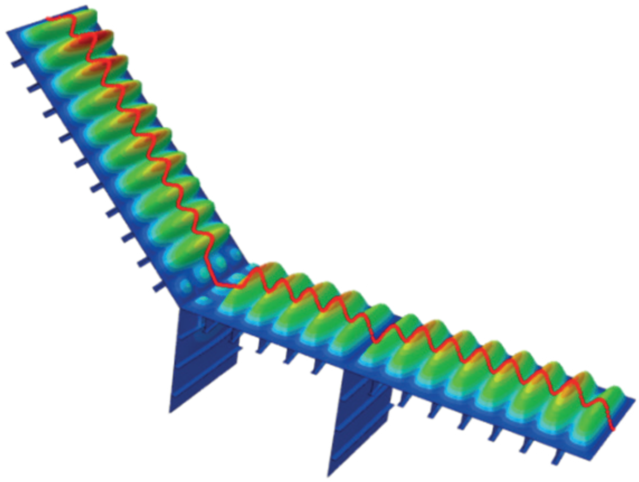
Safety of the CCS always remains a major concern

Membrane CCS is one complex technology, which reserves many surprises and sometimes unexpected difficulties. Indeed the CCS is subject to a wide range of stresses caused by hull-induced bending moments, cargo and ballast pressure. For every project, GTT evaluates the stress levels and deformations stemming from the hull and provides guidance on structural enhancements needed to ensure that the CCS operates within a valid acceptable range of stresses.

[1] defined as all the structural elements connected to the hull: the membrane system, the pump tower base support, the liquid dome, the gas dome, the cargo piping etc.



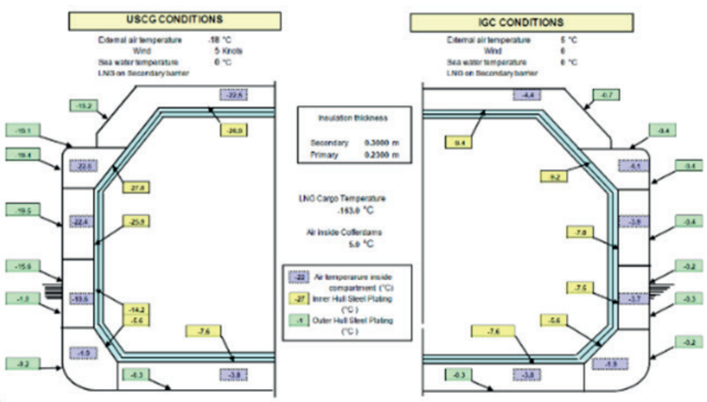
Effect of ballast pressure on CCS behaviour



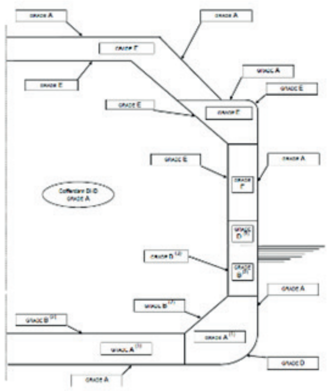
Simulation of local inner hull deformation

This assessment is at the heart of GTT's engineering expertise. It comprises a large scope of technical areas, among which, without limitation:

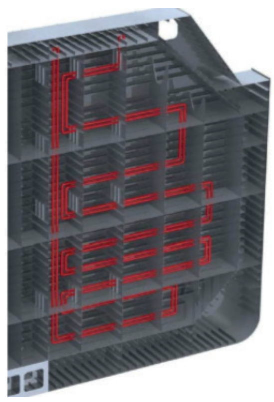
- Review of the steel grades
- Examination of the heating power required for cofferdam heating systems



Calculation of hull temperature

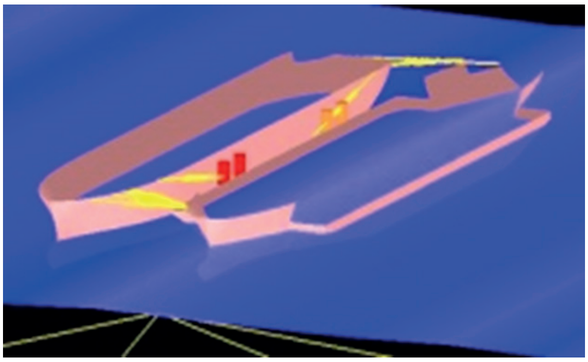


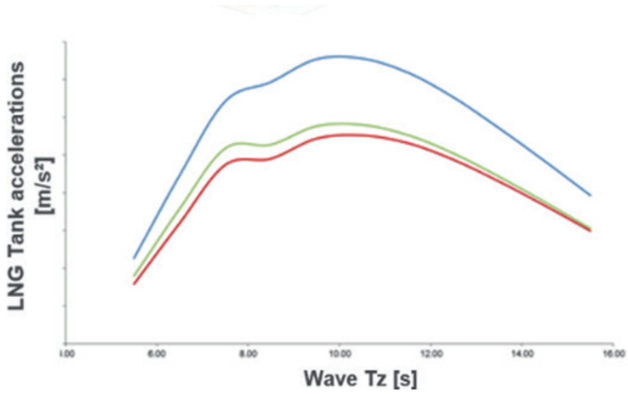
Stell grade selection



Sizing of cofferdam heating

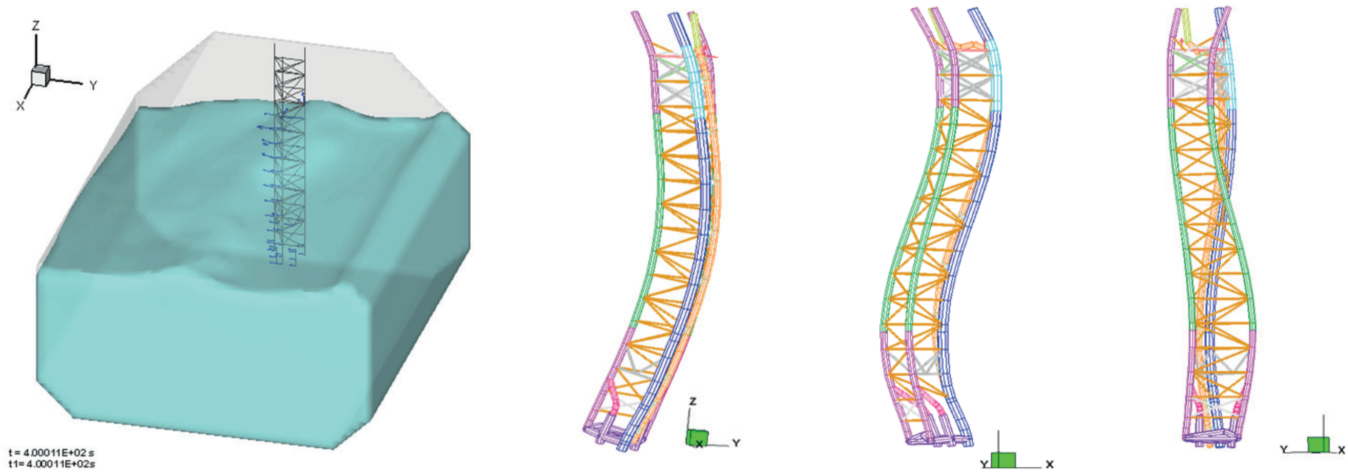
• Sea-keeping analysis for vessel behaviour in various sea conditions, allowing for the determination of the loads that the CCS (including for the avoidance of doubt the pump tower) are likely to experience,
• Ship bending moment and mechanical assessment of the CCS,





Calculation of ship movement and acceleration during STS operations depending on Wave period

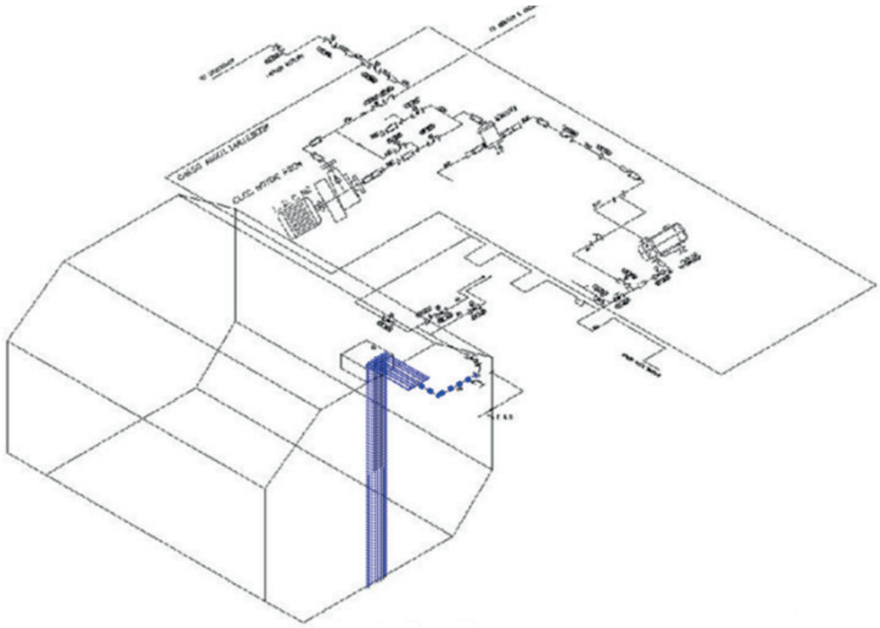
• Sloshing load assessment and tank insulation strength and performance optimisation,
• Detailed panel and component arrangement with required tolerance to ensure correct assembly and correct arrangement to ensure the design safety,
• Detailed design of pump tower tubular structure via the determination of the hydrodynamic and inertial loads by finite elements analysis to assess the acceptability of design with regards to strength and fatigue,



Evaluation of liquid velocities & accelerations — First bending mode — Second bending mode — First torsion mode

• Vibration analysis to avoid resonance on structural elements,
• Validation of the piping on deck and in the cargo auxiliaries room through stress analysis,
• Design of the nitrogen system, equipment, and instrumentation of the CCS to ensure that the insulation spaces can be safely maintained through inert gas, at the appropriate pressure, under all possible scenarios,

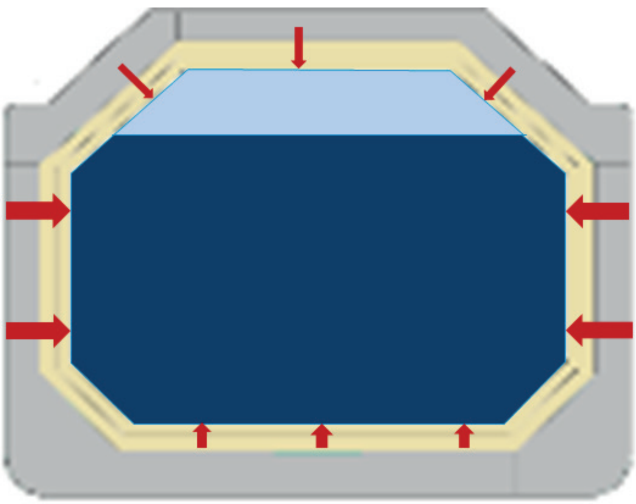
• Proper sizing of safety equipment, such as cargo tank safety valves, insulation safety valves, and Gas Combustion Units,
• Proper procedures to safely manage all critical scenarii described in the Cargo Operating Manual.   These scenarios may include Nitrogen sweeping operations, IBS drainage, and IS water drainage, among others.



IS and IBS Drainage through nitrogen piping

Performance is at the heart of GTT's designs

GTT conducts an assessment of the Boil-Off Rate (BOR) for the CCS, taking into account the tank geometry, the ship design, and the thermal performance requirements specified by the IGC Code. On this basis, GTT provides a BOR value. Additionally, GTT utilizes the BOR value to determine the appropriate sizing of cargo handling equipment (such as compressors, heaters, vaporizers,etc) that are involved in managing the boil-off.

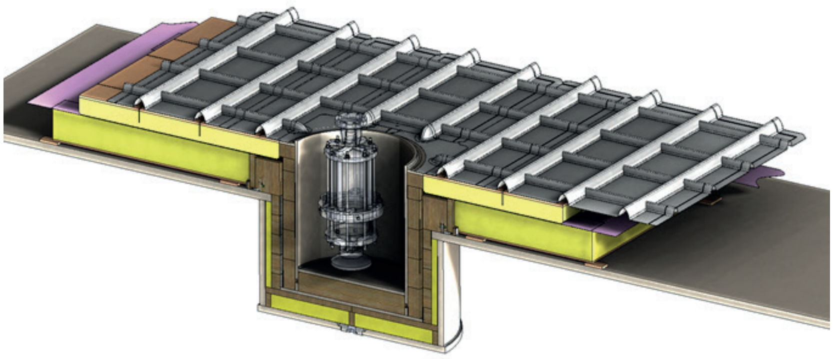


Thermal flows going through the insulation

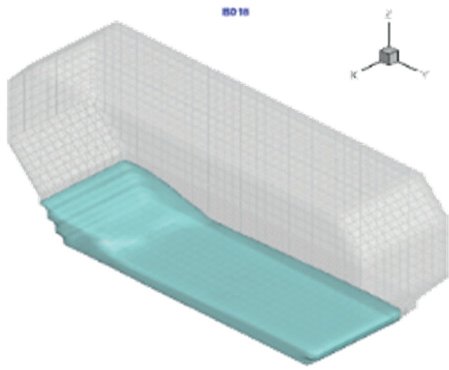
Equipment for LNG management

GTT also conducts hydraulic studies to calculate the maximum fluid velocities and pressure drops within critical lines. These studies ensure that the equipment selected by the shipyard, such as pumps, strainers, valves, and pipes, will enable the vessel to meet the performance requirements specified in the shipbuilding specification.

Using sea-keeping analysis and pump characteristics, GTT determines the minimum allowable heel that can be left in the tank before the pump trips. This assessment involves CFD calculations and enables the evaluation of the likelihood of pump tripping for various sea conditions depicted on the scatter diagram. The results of this analysis are further used to alert the crew of any potential risks associated with the operation of the pump.

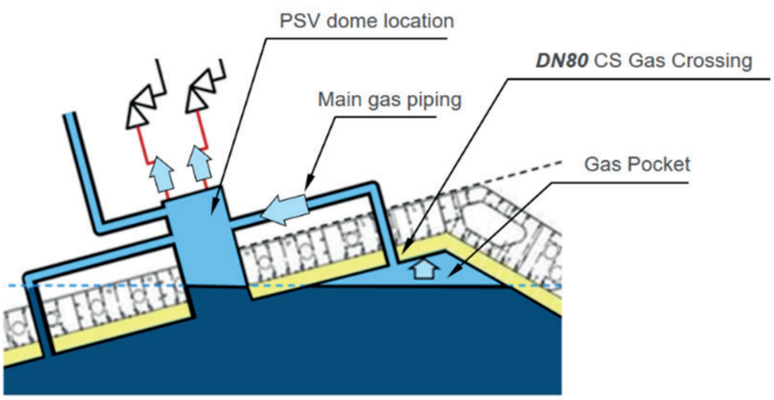


Design of a sump for MarkIII

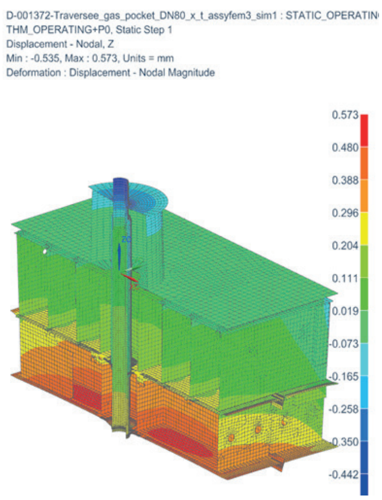


CFD for pump tripping evaluation

To address the performance of the vessel in terms of loading capacity, GTT conducts an assessment to determine the maximum LNG volume that can be loaded. This assessment takes into account various factors, including the cargo tank geometry, the cargo tank's maximum allowable relief valve setting pressure, and the trim and list conditions required by the IGC code. When a Gas Pocket Crossing System is present, GTT evaluates the increased loading capacity that it provides and conducts a structural analysis to ensure that the crossing pieces are capable of withstanding the thermal and mechanical loads.



Principle of gas crossing to prevent gas pockets



Displacement around a gaspocket crossing system

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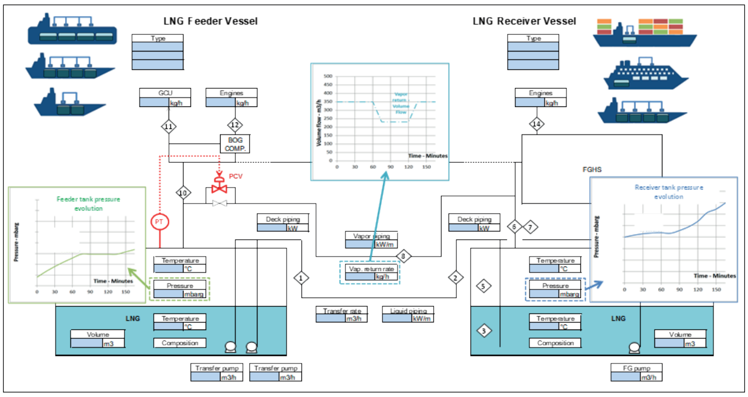
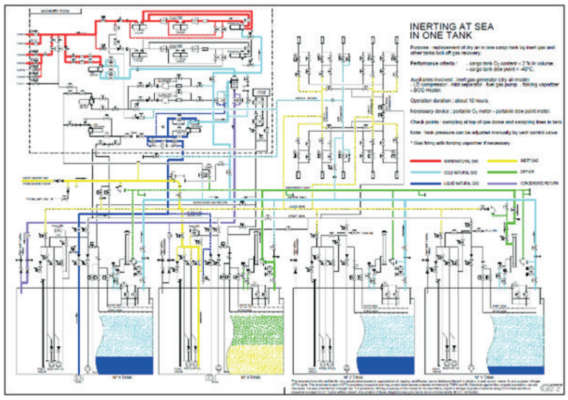
GTT's designs aim at preserving the widest operational flexibility

GTT has gained extensive knowledge of ship operations through thermodynamic assessment and return of experience at sea. This expertise ensures the safe and efficient conduct of cargo operations and empowers crew members to make informed decisions regarding equipment and system use.

To go beyond the safety requirements of the IGC Code, GTT has developed guidelines on equipment sizing and Fuel Gas Handling System (FGHS) architecture, providing the crew with maximum flexibility in managing day-to-day operations. In addition, GTT offers operators essential guidance to ensure that operations such as commissioning, decommissioning, tank cooling down, tank-to-tank transfer, and one-tank operations are carried out safely and efficiently.



Simulation to manage BOG during ship to ship operation



Guidance regarding one tank operation

GTT has developed a unique design expertise to continuously meet the market demands in terms of performance and operational adaptability, all the while maintaining system safety.

Through relentless efforts and open dialogue with industry stakeholders, GTT has successfully halved the Boil-Off Rate (BOR) of its technologies within less than a decade. Simultaneously, it has contributed to safely develop new equipment such as FSRUs, FLNGs, arctic vessels or LNG- fuelled ships.

Currently, GTT is actively working on new designs in order to enhance, through innovation and improved flexibility in operations, the thermal performance of LNGCs and align with the International Maritime Organization's emission targets. It also aims at lowering ship costs through innovative solutions and pave the way towards a Net Zero scenario with future synthetic fuels.