LNG Transfer in Harsh Environments - Introduction of a New Tandem Mooring Concept

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Abstract

For loading LNG shuttle carriers at an offshore terminal, the technical issues of the vessel mooring configuration (side-by-side or tandem configuration) as well as the approach and handling system for the transfer lines (either composite hoses or flexible cryogenic pipes) are influenced and limited by weather conditions, especially by sea state.

This paper introduces the new innovative offshore LNG loading system "Maritime Pipe Loading System 20 (MPLS20)", proposed by the project partners Nexans and Brugg, leading manufacturers of vacuum insulated, flexible cryogenic transfer pipes, IMPaC, an innovative engineering company that has been involved in many projects for the international oil and gas industry for 25 years and the Technical University Berlin, Department of Land- and Sea Transportation Systems, with great expertise in numerical analyses and model tests.

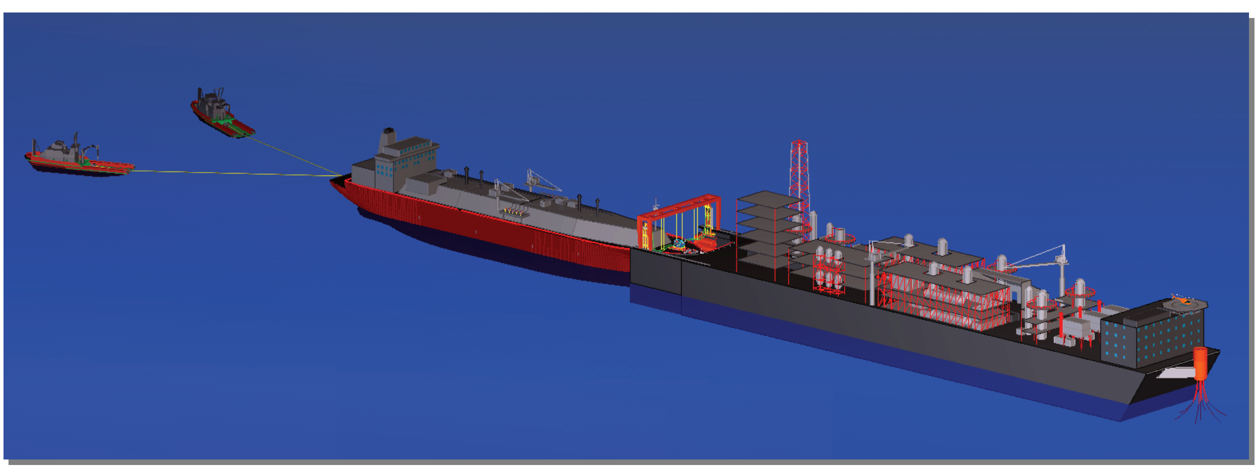


Figure 1: Illustration of the new proposed offshore LNG transfer system with the LNGC berthed in tandem configuration to the 'mooring bay' at the LNG terminal

The new concept is based on a unique tandem mooring configuration (Figure 1). In comparison to standard operations applied in the oil business for about 40 years, the concept introduces a mooring bay for shuttle tankers. Extensive numerical simulations are conducted to determine the working envelope of motions and mooring forces.

As the Nexans/Brugg corrugated metal pipes provide a flexible double containment system all relevant safety issues are well addressed, as required by EN1474-2/-3. Thus, LNG transfer can take place even under severe environmental conditions which makes this new concept superior to other approaches such as side-by-side configurations using composite hoses.

Introduction

For several decades, natural gas was merely a byproduct of oil production. Today, its importance as energy source is still growing. Most natural gas is produced from offshore fields, with associated problems of transportation to further onshore processing. The deployment of LNG tank ships (Liquefied Natural Gas) is an alternative to pipelines with increasing significance (Ref. 6). In order to achieve economically reasonable transportation, the natural gas (mostly methane) is cooled down to -162 degrees C, whereby it is liquefied and reduced to 1/600th of its original volume. For safe storage of LNG, specially insulated loading pipes and tanks are required.

State-of the art technology allows loading/offloading procedures in still water and moderate sea states with 10.5” pipes. The increasing loading capacity of LNG carriers (up to 260.000 m^3) creates a new market for fast and safe loading/offloading concepts — i.e. larger pipe diameters and operations in rough seas.

Based on existing techniques used for offshore crude oil transfer, a number of studies on LNG transfer have been carried out, resulting in potential vessel mooring configurations and designs for suitable transfer techniques. It is important to point out that no ‘show stoppers’ have been identified within these studies, neither in terms of safety issues nor in terms of LNG production or re-gasification in marine environments.

Two mooring configurations have been identified to work satisfactorily for the connection of shuttle tankers (either LNGC or crude oil tanker) and terminals (for LNG or oil production) for offshore cargo transfer:

The first is the side-by-side configuration, which is based on the emergency unloading technology and proved to work in smooth and moderate weather conditions (Ref. 8).

The second is the tandem configuration which is today’s standard for crude oil transfer between FPSOs and shuttle tankers, especially in harsh environmental conditions like the North Sea (Figure 2). With dozens of installations and hundreds of operations every year, this configuration has shown a very good tracking record in terms of safety and reliability for decades.

The turnaround time of the shuttle tankers depends on the production rate and storage capacity of the terminal vessel. According to current rules and regulations for mooring of crude oil shuttle tankers to terminals in tandem configuration, a distance between the terminal stern and the shuttle tanker bow in the range of 50 to 90 m should be achieved (e.g. Ref. 9).

Figure 2: Tandem mooring configuration for standard offshore crude oil transfer, using floating and submerged hoses; fishtailing movements of the shuttle tankers moored to FPSOs (both left); bow loading systems (right) (Sources: Kongsberg, APL)

Depending on environmental constraints at the specific operational location, the terminal can be spread moored or turret moored to the seabed, the latter allowing the coupled floating vessels to weathervane in 360 degrees around the mooring center. Once the shuttle tanker is moored to the terminal (constituting coupled multi-body system), a phenomenon called fishtailing may occur, where the carrier periodically swings behind the stern of the terminal (Figure 2). To prevent fishtailing, modern shuttle tankers are often equipped with dynamic positioning systems (DP2 or higher) and/or offshore tugs are employed to support station keeping and alignment to the terminal vessel.

Due to the specific thermodynamical properties of the liquid crude oil and the required transfer rate, the transfer line can be designed as a single floating or submerged hose with a length of up to 100 m or more. Here, the coupling of the hose flange to the shuttle tanker receiving flange is realized by means of a specialized and well approved pull-in device located amidships or at the bow of the tanker (Figure 2). Operations with the transfer line in aerial mode (no water contact of the hose or flexible pipe) are rare.

In conclusion, none of the ‘conventional’ vessel mooring configurations and transfer techniques can easily be adapted to meet the requirements of LNG transfer operations, especially when designed for harsh environmental conditions with significant wave heights up to e.g. 5.5 m, zero-up-crossing periods between 8 and 12 seconds as well as significant wind and current loads for transfer durations of 18-24 hours.

It is evident that the choice of the mooring configuration is one major key to the successful development of a suitable offshore LNG transfer system.

Such a new concept should ideally combine the main advantages of the proven configurations – i.e. side-by-side and tandem: A short free span distance of the transfer lines (as featured for SbS configurations) as well as minimum relative motions between carrier and terminal and tolerable mooring forces (as featured for tandem configurations) allowing save and reliable handling, approach and coupling of the transfer lines.

The new offshore transfer system introduced in this paper meets those requirements: The system, which is developed by the project consortium MPLS20, is based on Nexans’ and Brugg’s newly developed CRYOFLEX flexible LNG transfer pipe with ID 16-inch. The unique design of the corrugated and super-insulated pipes with their seamless manufacturing principle provides a flexible and monitorable double containment system for most types of cryogenic fluids.

The overall design of the transfer system is further based on IMPaC’s newly developed and patented offshore ‘mooring bay’ concept. By means of a ‘loading bridge’, it allows simultaneous handling and approach of up to four flexible LNG transfer pipes in aerial mode, providing safe, robust and efficient operations.

In the following sections, the new proposed tandem mooring concept will be presented in detail. An outlook and a brief view on development perspectives conclude the paper.

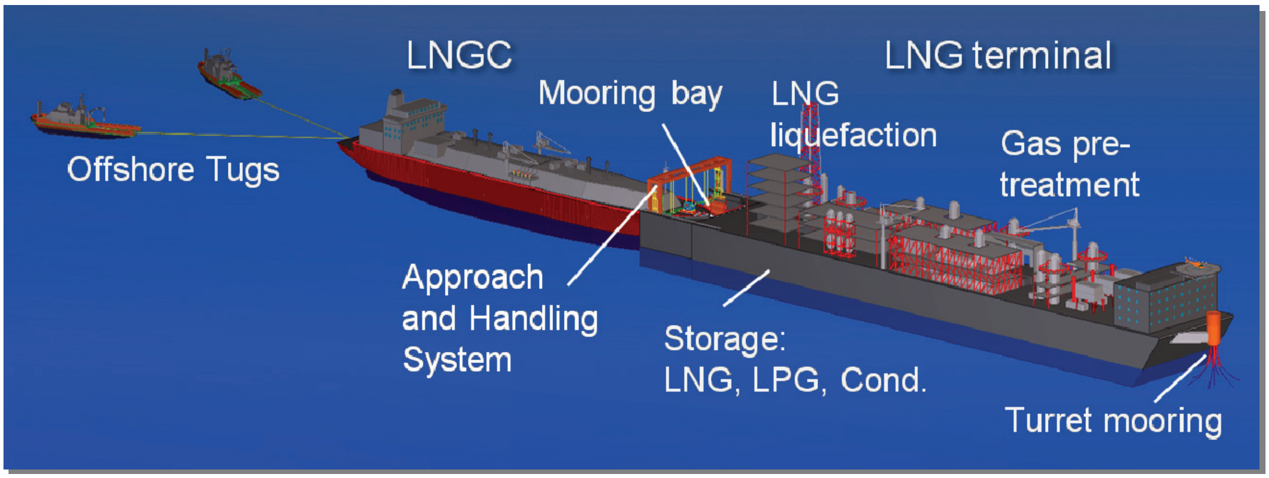


Figure 3: Main components of the new Offshore LNG transfer system: Offshore tugs, LNGC, LNG terminal with turret mooring, mooring bay and approach and handling system

A New Offshore LNG Transfer System

The proposed transfer system features a generic LNG terminal design with the new mooring bay concept, a modified standard LNGC and the approach and handling system for the newly developed transfer pipes. The main components of the system are shown in Figure 3.

As the system design is based on a generic approach, no specific operational location is considered. Nevertheless, the LNG terminal is exemplarily moored at a water depth of 100 m, which is representative e.g. for the North Sea with the associated JONSWAP spectrum. The main dimensions of the terminal and the carrier are listed in Table 1.

Parameter	LNG Terminal	LNG Carrier
Length over all	360 m (+40 m mooring bay)	285 m
Breadth	65 m	42 m
Draught	12 m	12 m
Height	33 m	26 m
Displacement	275.087 m³	103.921 m³
LNG storage cap.	280.000 m³	138.000 m³

Table 1: Main dimensions of LNG terminal and LNG carrier

The LNG terminal hull used in this concept is of barge type with a wave flattening bow, providing an optimum cargo loading capacity of up to 280.000 m³ LNG in five independent SPB tanks (Self-supporting, Prismatic, IMO Type B) which are sloshing-proof and allow a flat deck (Figure 3). With this LNG buffer storage, even today's largest LNGC with transport capacities up to 265.000 m³ can be handled. Additional storage capacity for the gas byproducts LPG (Liquefied Petrol Gases) and hydrocarbon condensate of 25.000 m³ each is also provided. The storage capacity as well as the required deck area of the LNGC is mainly driven by numerous equipment for gas pre-treatment and liquefaction as follows (Ref. 4):

- Columns
- Exchangers
- Compressors / blowers
- Pumps
- Filters
- Tanks
- Vessels / drums
- Boilers / furnaces / flares
- Misc.

Other relevant contributions to the weight and volume magnitude of the terminal are resulting from standard marine equipment like cranes, power generators, ballast control system etc. as well as from accommodations and life saving equipment for the personnel.

Due to active ballasting, the barge is outlined to work with a nearly constant draught of abt. 12 m, which equals the LNGC draught.

The barge is permanently moored to one location by means of a passive 12-point external turret mooring system, allowing the terminal and the coupled multi-body system to weathervane in 360 degrees. It should be noted that it is not intended to design an optimum turret mooring system within the framework of the MPLS20 project.

The aft end deck area is dedicated to accommodate the loading bridge and the transfer pipes with the handling header when in standby or during maintenance works. Due to the LNG and methane gas specifications, it must be checked whether the related deck area has to be classified as explosion-protection-zone (if ex-zone 1 or 2 is not yet defined) so that all equipment mounted to that area complies with related rules and regulations.

Regarding the LNGC, the storage concept is independent from tank types, so that spherical Moss or SPB can be used within the LNGC. In the following investigations, the tanker is equipped with four membrane tanks whose main dimensions and cargo capacities are given in Table 1. Due to active ballasting, the LNGC also operates at a constant draught of abt. 12 m, the same as for the LNG terminal barge.

The carrier must be slightly modified compared to today's standards, as one additional and specially designed receiving manifold is placed at the deck bow area. This bow manifold completely enters the mooring bay at the aft end of the terminal when the LNGC is moored for cargo transfer, significantly reducing the free span lengths of the transfer pipes compared to crude oil transfer techniques.

The bow deck area accommodates standard anchor winches and – if necessary – chain stoppers as well as Quick Release Hooks (QRH) for mooring to the mooring wings.

Due to the LNG and methane gas specification, the LNGC bow deck area around the manifold also has to be classified as ex-zone (if zone 1 or 2 is not yet defined) so that all equipment mounted to that area complies with related rules and regulations.

Bridging the Gap: Tandem mooring with the new 'Mooring Bay' Concept

The new mooring system features a mooring bay, framed by two steel structures, the so called 'mooring wings' (Figure 4), which are fixed to the terminal's aft end at starboard and port side, respectively.

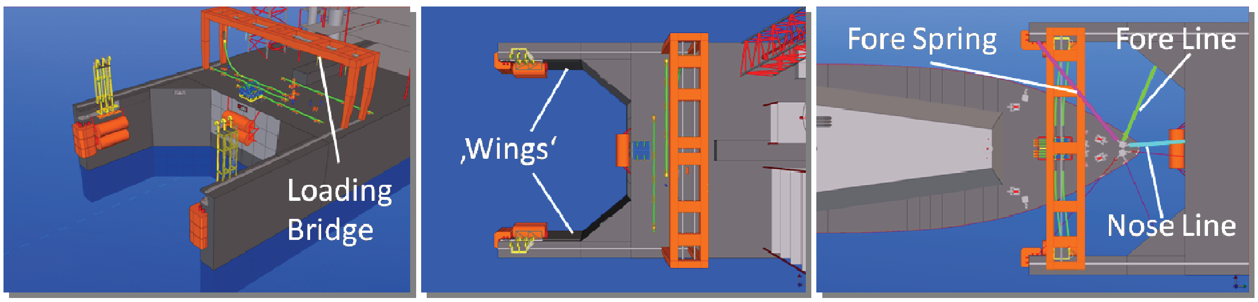


Figure 4: The mooring bay concept features two side ‚wings' with six moorings in a symmetrical arrangement (right)

Each wing provides mooring hawsers for the LNGC resulting in a symmetrical arrangement of four moorings (two 'fore springs' and two 'fore lines').
Together with two additional 'nose lines' reaching from the aft end of the terminal to the bow center of the LNGC, all moorings are fixed to QRHs at the LNGC deck (Figure 4, right).

The mooring lines are operated by load adequate winches and heave compensation systems, reducing line peak loads.

As the LNGC is actively pulled into the mooring bay, the wings with the mooring arrangement provide a unique solution to stop the incoming vessel in a controlled manner at the required position right below the loading bridge.

A number of foam fenders are installed at each inner wall of the mooring bay to prevent hard impacts if the LNGC exceeds the tolerable working envelope inside the mooring bay (Figure 4).

The cargo is transferred via rigid pipes from the terminal LNG tanks through the wings into three separate export flanges at each wing. These rigid pipe flanges are located high above the barge's weather deck so that the handling as well as draining and purging of the flexible transfer pipes can be proceeded in a safe, efficient and reliable way (see paragraph 'Operating Phases').

Flexible LNG Transfer Pipes

Vacuum insulated pipe systems are common in all kind of cryogenic applications. Due to the double containment system, the 'Pipe in Pipe' technology has advantages in terms of leak detection and risk assessment of the installation with best thermal insulation properties.

The LNG industries' demand for vacuum insulated pipe concepts based on the experiences from cryogenic applications is increasing.

Nexans in cooperation with Brugg is developing an adaption of the well known flexible vacuum insulated pipe system CRYOFLEX for offshore LNG loading applications (Figure 5).

Figure 5: The LNG transfer pipe system CRYOFLEX offers a newly developed design with 16-inch inner diameter

A corrugated inner pipe (5) of 316L, surrounded by another corrugated stainless steel pipe (2) of 316L is insulated by the vacuum space and super insulation (3) between these two pipes. A stainless steel braiding (4) on the inner pipe bears the end cap load of the pipe. For mechanical protection an outer sheath of PE or PA can be applied.

The vacuum does not need any active pumping during operation for more than 15 years. The pipe structure offers leak detection in the vacuum space, which gives a signal to the system, if the vacuum degrades due to a leak in either the inner or the outer pipe. Nevertheless, in case of a leak, the gas cannot escape to the environment because of the double containment system.

This pipe is widely used in cryogenic applications. Amongst others the ARIANE space rocket test fields use an installation with this technology for more than ten years without any maintenance.

The pipe design in Figure 5 is a special development for LNG offshore loading for lengths up to 30 m. With this technology, the MPLS20 requirement for reasonable short length and high flexibility can be achieved with good fatigue properties.

Other LNG offshore systems require longer pipes with a more robust and stiff pipe design. Tandem loading configuration with connection to the standard amidships manifold can be achieved by either floating or submerged pipe configuration. For these scenarios, a similar pipe system with heavier steel armor in a riser-like design will be tested according to EN1474-2.

Loading Crane and Header for safe handling of Transfer Pipes

When moored to the mooring bay, a rail mounted moveable gantry crane (the so called loading bridge) bridges the bay from one wing to the other (see Figure 4).

The loading bridge is designed to handle all four transfer pipes simultaneously by means of a header structure. For coupling of the flexible transfer pipes to the receiving flanges of the LNGC, standard components for Quick Connect/Disconnect Couplers (QCDC) and Emergency Release Couplers (ERC) can be used.

At the terminal side, the transfer pipes are connected to the rigid conductor pipes by manual couplers. Here, two out of three available rigid pipes can be used to for LNG transfer; one flange per wing is spare. Three pipes are dedicated for LNG transfer, one pipe for vapor return.

Motion analyses show tolerable torsion in the pipes during operations, so that swivels are not required in the transfer line assembly (refer paragraph ‘Motion and Mooring Analysis’).

The two part header structure combines the following active functionality (Figure 6):

- simultaneous support and operation of all four flexible pipes with related QCDC and ERC
- winch driven fine approach, alignment and landing at the LNGC receiving manifold aided by guide posts
- damping of the touch down at the manifold by means of hydraulic dampeners
- operation (closing and disconnection) of all four QCDCs
- operation (disconnection) of all four ERCs in an ESD situation
- remote controlled departing of both header parts (and subsequent lifting of the upper part to a safe position by means of pre-tensioned wires suspended from the loading bridge) in an ESD situation

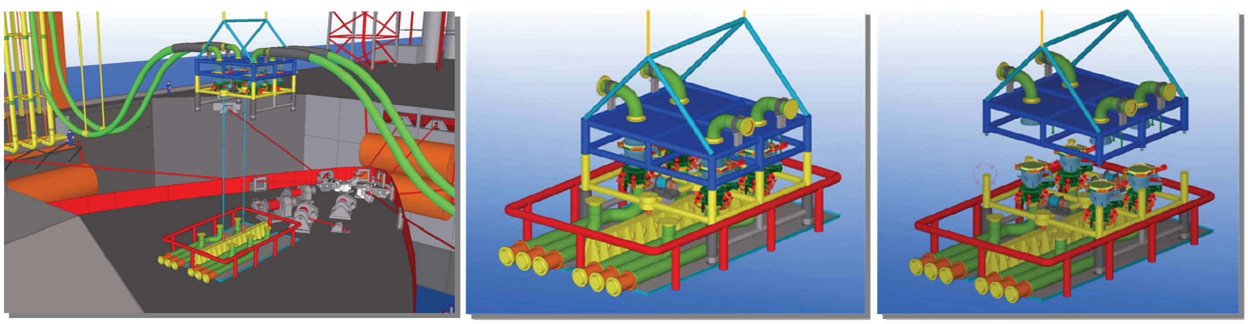


Figure 6: Pull-in of the header to the manifold (left); header and flanges connected for cargo transfer (middle); ESD situation (right): ERCs disconnected, header departed and upper part lifted off the lower part to a safe position

The flexible transfer pipes are mounted to rigid pipe elbows fixed to the upper part of the header. A bending stiffener is mounted to the endings of each pipe to prevent excessive bending moments. In addition, pre-tensioned wires reaching from air-winches mounted on traveling trolleys at the loading bridge support the header as well as the free spanning section of the pipes (Figure 6, left).

During standby or maintenance, the loading bridge can be moved on rails and secured onto the service deck area at the very aft end of the terminal (see Figure 4, left and middle). At the current design status, a deck area of 10-15 m × 65 m will be necessary for this purpose. This region will also be part of the transfer system ex-zone declaration.

In analogy to the terminal flanges, the LNGC receiving manifold provides two rows of three flanges, offering flexibility in case of connectivity problems. The flange openings are horizontally oriented, but in case of minor spillages of LNG after decoupling of the QCDCs or ERCs, collecting trays and a sheathing permanently flooded with water are mounted on the deck below and besides the manifold area (Ref. 7).

Operating Phases

Based on the new 16-inch ID transfer pipes as well as the new concepts for the mooring bay and the approach and handling system for the transfer lines, the following specific operating phases can be identified (Table 2), an illustration is shown in Figure 7:

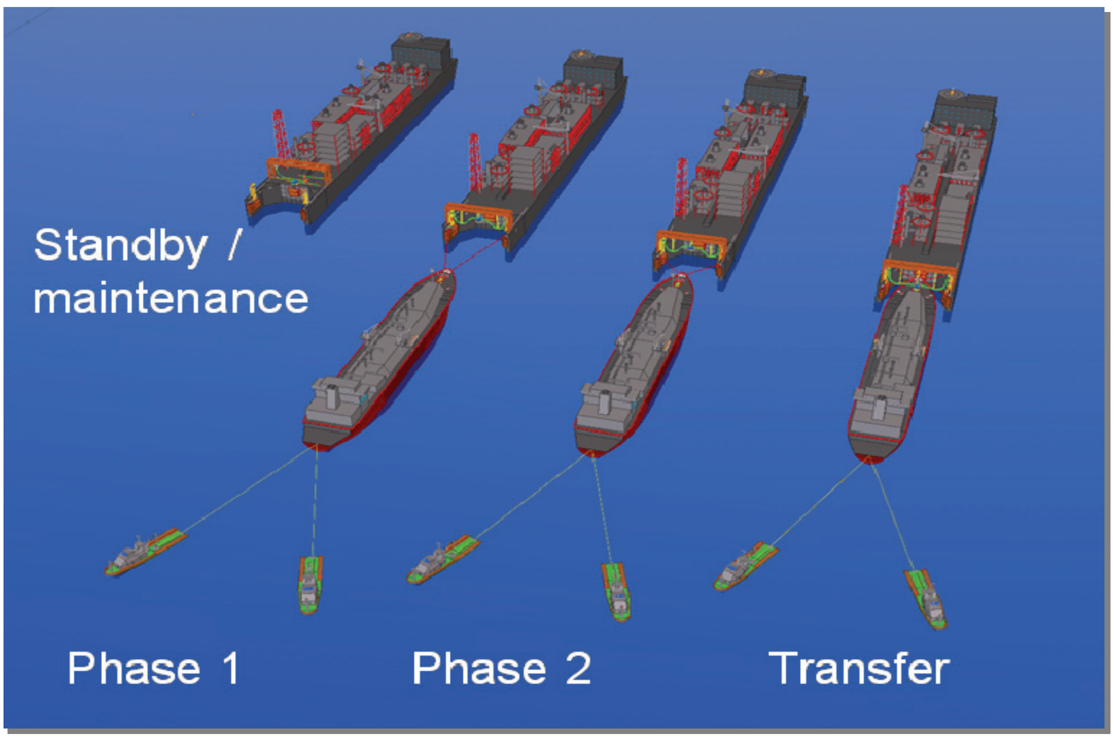


Figure 7: Operation of the LNGC close to the LNG terminal: Terminal stand-alone (standby/maintenance), LNGC connected to mooring bay (phase 1), near approach to the mooring bay (phase 2), final position during cargo transfer

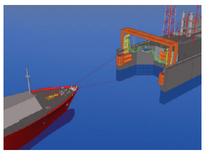
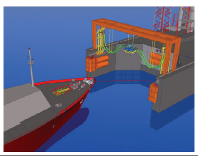
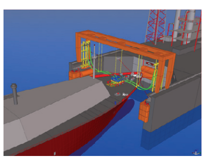
Distance between LNGC and mooring bay entrance	Operations	Operating Phase
> 100 m	The LNG terminal stand-alone: Transfer system standby, waiting for next LNGC or ready for carrying out maintenance works	Standby / maintenance
100 to 80 m 	Shoot over of mooring pilot lines from the terminal to the LNGC; start of the terminal winches for slow controlled pull-in of the LNGC to the terminal aft end; LNGC thrusters slowly backwards; tug(s) assisting at heading alignment	Phase 1
50 to 30 m 	slow motion of winches; employment of next moorings; final alignment of the vessels aided by LNGC thruster and (two) offshore tug(s); further slow pull-in with winches; LNGC thrusters slowly backwards	Phase 2
0 to -20 m	very slow pull-in of the LNGC via bow mooring lines; loading bridge is in standby	
-20 to -30 m	Full stop of pull-in; stopping aided by backward pulling moorings reaching from mooring bay entrance; tightening of all six mooring lines in a symmetrical arrangement; tension control of mooring lines	
~ -30 m 	Loading header coupled to the LNGC bow manifold; transfer pipes cooled down and start of cargo transfer; mooring winches and heave compensation systems act for reduction of peak loads in the hawsers	Cargo transfer phase
~ -30 m 	Pumps stopped; transfer lines drained and purged with nitrogen; QCDCs decoupled; header lifted from the manifold; moorings partly decoupled, partly remaining for controlled cast off of the LNGC from the terminal; LNGC backward leaving the mooring bay by own thrusters, assisted by pulling tugs	Normal stop of cargo transfer
~ -30 m	Emergency Situation: Cargo pumps stopped; valves closed in less than 30 s; disconnection of the ERCs; parting and lifting of the upper header part; activation of QRHs and cast off of the LNGC from the mooring bay, assisted by tugs	ESD 1 / ESD 2

Table 2: Main operating phases of the tandem loading system: LNGC and LNG terminal with 'mooring bay'

Motion and Mooring Analyses

For ensuring save loading and offloading procedures, detailed knowledge on the motion characteristics of the carrier and the terminal in tandem configuration is required. Due to the turret mooring of the terminal, the entire system is weathervaning according to the angle of attack β of the superimposed environmental loads from waves, current and wind (Figure 8).

As an idealized case, head waves ($\beta = 180$ degrees) are exclusively considered in the investigations. The focus lies on the transfer configuration with completely filled cargo tanks and the respective distance of 10 to 12 m between terminal stern and carrier bow is applied for all computations.

In the next step of the project, differing angles of attack resulting from incoming waves, wind and currents will also be considered.

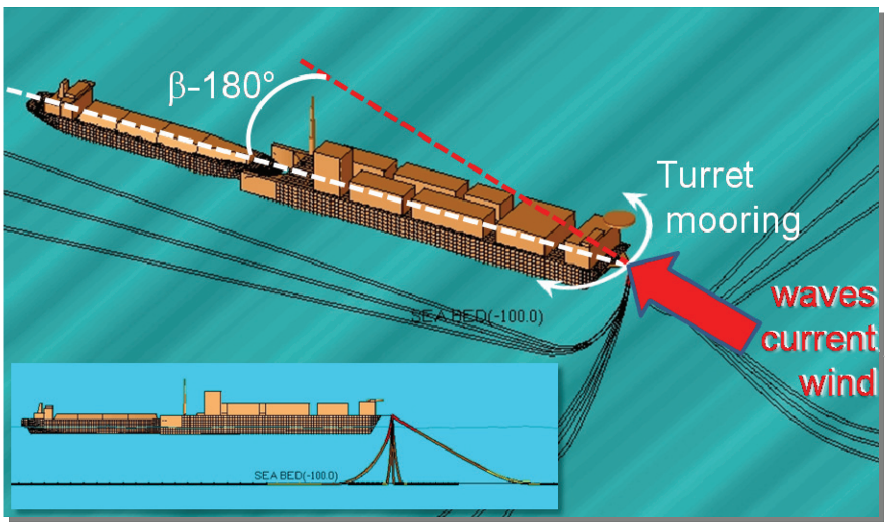


Figure 8: Environmental loads acting on the new proposed offshore LNG transfer system with the LNGC berthed to the 'mooring bay' at the LNG terminal in tandem configuration

The design criteria are resulting from the following environmental conditions, which are assumed to be maximum values for the analyses:

Environmental Design Parameter	Design Values
significant Wave Height, H_s	5.5 m
range of zero up-crossing Periods, T_0	8-12 s
Wave Spectrum, peakedness factor γ	JONSWAP, $\gamma = 3.3$
Wind speed, v_w	30 m/s
Current speed, v_c	1.0 m/s
angle of attack for all loads (current stage of analysis), β	180°
Water depth, d	100 m

Table 3: Generic design criteria for the new offshore LNG transfer system

The two software packages ANSYS AQWA and WAMIT have been applied independently by the MPLS20 partners IMPaC and TUB to determine the motions and reaction forces in the moorings of the multi-body system (Ref. 1, Ref. 5).

Both programs are based on potential theory and good agreement for the results of frequency domain analyses have been achieved (see Ref. 2 for details). Due to different modeling capabilities, comparisons of time domain results have been carried out exemplarily for the same significant wave heights and ranges of wave periods. Additional analyses for the combined set of environmental loads listed in Table 3 as well as time domain analyses for a standard three hour short-time statistical approach are carried out with ANSYS AQWA exclusively.

Note that the given environmental loads are defined to be maximum values in which regular decoupling procedures of the transfer system as well as ESD operations must be possible in a safe and reliable manner. Normal cargo transfer should be possible up to these values. It is assumed that the assisting offshore tugs are not the limiting factor for the operations, since they do not come into direct contact with the LNGC hull.

Due to the early stage of the project analyses results must be treated as preliminary. Nevertheless, it turns out that the relative motions in x- and z-direction as well as the maximum loads in the mooring lines between LNGC and LNG terminal for the multi-body system (LNGC, LNG terminal barge, turret mooring) exposed to extreme head seas resulting from second-order wave (drift) forces, can be accommodated with the mooring bay concept. More detailed analyses will follow and results will be presented in a later stage.

Compared to second-order forces, first-order forces resulting from linear sea state induced body motions are significantly higher and cannot be absorbed by the mooring lines. Thus, the moorings have to be veered and hauled up by individual heave compensation systems and/or active winches in order to reduce excessive peak loads and prevent damages in the mooring lines.

Conclusion and Outlook

An innovative offshore LNG transfer system is introduced, where the shuttle carrier is towed into a mooring bay at the stern of the LNG terminal. By using six hawsers in a symmetrical arrangement with the unique geometry of the mooring bay, the LNGC can be stopped in a distance of abt. 10 to 12 m behind the terminal, right below a standby loading crane. The loading crane is founded on the so called mooring wings and bridges the mooring bay. By means of pre-tensioned wires reaching from the crane, four flexible transfer pipes with an inner diameter of 16-inch (or more) are operated via a dedicated header structure, which provides all required functionality - even in ESD situations.

The transfer pipes introduced are newly developed by Nexans and Brugg and feature 16-inch ID. They provide a double containment system for the cryogenic cargo, allowing monitoring of the vacuum super-insulation for more than 15 years without intervention.

First results from numerical motion and mooring analyses for the newly developed system prove that LNG transfer can take place in open seas even at harsh environmental conditions.

Within the joint project MPLS20, the focus lies on the development of a new offshore LNG transfer system. This system may require new operational procedures for safe loading and unloading of cargo at sea. One issue to be investigated in detail is the influence of partly filled tanks with associated free fluid surfaces on the motion behavior of the carrier vessel during loading and unloading operations.

Since the superposition of waves, wind and currents from different directions can lead to a range of headings from 150 to 210 degrees, further investigations have to be conducted. For these cases, the influence of the roll motion is no longer negligible and requires detailed knowledge of viscous damping coefficients in order to obtain reasonable results.

Extensive tank tests will be carried out in the next project phase aimed at the determination of the damping coefficients as well as on the verification of the numerical analyses. It is planned to model and visualize the main operations in a Ship-Handling-Simulator; results will be discussed with experienced mooring masters.

The project developments are accompanied from the beginning by a 'Failure Mode and Effects Analysis' (FMEA) carried out by Germanischer Lloyd. The objective is to consider critical feedback in the early design phase to receive an 'Approval in Principle' for the offshore LNG transfer system and its related operations.

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Biography of Speaker

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Sven Hoog studied Naval Architecture and Ocean Engineering at the Technical University of Berlin, where he also received his Doctoral degree in ocean engineering.

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Since several years he is also engaged in the development of LNG transfer systems, for onshore as well as for offshore application.

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