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Ships and marine technology — Design and testing of marine transfer arms for liquefied hydrogen

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Foreword

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This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology,* Subcommittee SC 2, *Marine environment protection.*

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Introduction

The twenty-first session of the Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) was held in Paris, France in December 2015 and finally adopted an agreement for the prevention of global warming, the Paris Agreement. The Agreement requires Parties' efforts to achieve zero net anthropogenic greenhouse gas (GHG) emissions during the second half of the 21st century. The International Maritime Organization (IMO) adopted a strategic plan to reduce GHG emissions from the maritime sector by 50 % in 2050 and finally to zero level within this century. Since the required reduction of GHG emissions is not attainable by a simple improvement in efficiency, the substitution of alternative fuels, including hydrogen, ammonia, and biofuels, for present fossil energies must be considered. Among them, hydrogen is one of the most present energy carriers, not only as fuel, but also as storage and transportation media.

A massive and long-distance transport of hydrogen by ships from production areas to consumption areas would be necessary because production plants are often constructed far from consumption areas, which are typically cities and industrial areas where hydrogen would be used in gas/steam turbine power plants and transportation systems such as railways, automobiles and ships.

In the marine transportation system of liquefied hydrogen, transfer from shore to ship would take place using transfer arms. A number of transfer arms are currently used for the loading and unloading of liquefied natural gas (LNG) at marine terminals. However, the temperature difference between LNG (–162 °C) and liquefied hydrogen (–253 °C) is critical and requires a significant change in the design of the transfer arms. Transfer systems minimize heat loss by applying high performance heat insulation technology. Liquid oxygen (–183 °C) formation on the outer surface of the system should be strictly prevented because some materials can detonate unpredictably from sources of ignition such as flames, sparks or impact from light blows if soaked in liquefied oxygen (LO2). Leakage should also be prevented because the hydrogen molecule is small in size and hydrogen gas is flammable over a wide range of concentrations.

To ensure the safe and smooth transportation of liquefied hydrogen, well-qualified transfer arms that are compatible with the on-board equipment of hydrogen carriers should be installed at each terminal. This document is, therefore, developed to provide technical guidance and safety requirements for liquefied hydrogen marine transfer arms.

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Ships and marine technology — Design and testing of marine transfer arms for liquefied hydrogen

1 Scope

This document specifies the design, minimum safety requirements, and inspection and testing procedures for liquefied hydrogen (LH2) marine transfer arms intended for use at onshore LH2 terminals handling LH2 carriers. It also covers the minimum requirements for safe LH2 transfer between ship and shore.

Although the requirements for power/control systems are covered, this document does not include all of the details for the design and fabrication of standard parts and fittings associated with transfer arms. This document is mainly focused on hard pipe type transfer systems; hose type transfer systems are not described in detail in the general description of this document. However, hose type transfer systems can also be considered as reasonable vacuum insulated technology for the design of transfer arms for liquefied hydrogen.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3452-1, *Non-destructive testing — Penetrant testing — Part 1: General principles*

ISO 4406, *Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles*

ISO 9934-1, *Non-destructive testing — Magnetic particle testing — Part 1: General principles*

ISO 10474, *Steel and steel products — Inspection documents*

ISO 10497, *Testing of valves — Fire type-testing requirements*

ISO 16904, *Petroleum and natural gas industries — Design and testing of LNG marine transfer arms for conventional onshore terminals*

ISO 17636-1, *Non-destructive testing of welds — Radiographic testing — Part 1: X- and gamma-ray techniques with film*

ISO 17636-2, *Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors*

IEC 60079-10-1, *Explosive atmospheres — Part 10-1: Classification of areas - Explosive gas atmospheres*

IEC 60079-0, *Explosive atmospheres — Part 0: Equipment - General requirements*

IEC 60079-1, *Explosive atmospheres — Part 1: Equipment protection by flameproof enclosures “d”*

IEC 60079-2, *Explosive atmospheres — Part 2: Equipment protection by pressurized enclosure “p”*

IEC 60079-5, *Explosive atmospheres — Part 5: Equipment protection by powder filling “q”*

IEC 60079-6, *Explosive atmospheres — Part 6: Equipment protection by liquid immersion “o”*

IEC 60079-7, *Explosive atmospheres — Part 7: Equipment protection by increased safety “e”*

IEC 60079-11, *Explosive atmospheres — Part 11: Equipment protection by intrinsic safety “i”*

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IEC 60079-14, *Explosive atmospheres — Part 14: Electrical installations design, selection and erection*

IEC 60079-18, *Explosive atmospheres — Part 18: Equipment protection by encapsulation "m"*

IEC 60079-25, *Explosive atmospheres — Part 25: Intrinsically safe electrical systems*

IEC 60034-5, *Rotating electrical machines — Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP code) — Classification*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 62305-3, *Protection against lightning — Part 3: Physical damage to structures and life hazard*

ASME, *Boiler and Pressure Vessel Code Section IX*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
apex swivel
articulated, fluid-carrying joint located between the *inboard arm* (3.19) and *outboard arm* (3.32)

Note 1 to entry: See Figure B.2.

Note 2 to entry: It provides *luffing* (3.25) of the outboard arm relative to the inboard arm.

3.2
attitude
various modes of use and/or location of the *transfer arm* (3.58) (i.e. manoeuvring, stowed, connected, hydrostatic test, and maintenance)

Note 1 to entry: The transfer arm can take several positions for each attitude.

3.3
base riser
riser
vertical assembly which bolts to the loading platform and supports the articulated assembly of the *transfer arm* (3.58)

Note 1 to entry: See Figure B.2.

Note 2 to entry: Sometimes referred to as "standpost".

3.4
bottom swivel
swivel joint accommodates the *pitching* (3.34) motion of the *LH2 carrier* (3.24) and is located adjacent to *presentation flange* (3.36) in horizontal part of the *TSA* (3.59)

Note 1 to entry: See Figure B.2.

3.5
brinelling
permanent indentation in the *swivel* (3.54) or *structural bearing* (3.49) raceways caused by excessive loading of balls or rollers

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3.6
cargo manifold
pipe assembly mounted on board a *LH2 carrier* (3.24) to which the *presentation flange* (3.36) or *QCDC* (3.38) of the *transfer arm* (3.58) is connected

Note 1 to entry: See Figure B.2.

3.7
cavitation
formation and collapse of bubbles in a liquid at or below the liquid saturated vapour pressure

Note 1 to entry: The collapse releases energy and may cause erosion at the cavitation sites, sometimes with an audible sound and vibration.

Note 2 to entry: Such low pressures occur in high velocity zones such as the inner radius of elbows, or at places with variations of diameters.

3.8
clash
contact during design operational conditions, or as a result of an emergency separation

Note 1 to entry: This contact can occur between any part of a *transfer arm* (3.58) and:

— adjacent transfer arm while both arms are operating, or one arm is operating, and the other arm is stowed (e.g. the counterweights (3.10));

— adjacent section of the same transfer arm (e.g. triple swivel assembly (3.59) and the outboard arm (3.32));

— loading platform equipment (e.g. counterweight (3.10) and piping or valves).

3.9
contact angle
α
angle between the plane of the *swivel joint* (3.54) or *structural bearing* (3.49) balls or rollers and the centre of contact at the ball or roller raceway interface

3.10
counterweight
system of weights used to balance the *inboard arm* (3.19) and *outboard arm* (3.32) assemblies

Note 1 to entry: Some *transfer arms* (3.58) have a single counterweight for this function and others have multiple counterweights.

3.11
design pressure
pressure for which the *transfer arm* (3.58) is designed

3.12
design temperature
range of temperatures for which the *transfer arm* (3.58) is designed

3.13
drift
longitudinal and/or lateral displacement of the *LH2 carrier* (3.24) due to the influence of environmental forces

Note 1 to entry: See also *surge fore* (3.51) or *surge aft* (3.50) and *sway* (3.53).

3.14
emergency release system
ERS
system that provides a positive means of quick release of *transfer arms* (3.58) and safe isolation between the *LH2 carrier* (3.24) and shore, following a predefined procedure including an *emergency shutdown (ESD)* (3.15)

Note 1 to entry: This is also known as an *emergency release coupling* (ERC).

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Note 2 to entry: See Figure B.2.

3.15
emergency shutdown
ESD
method that safely and effectively stops the transfer of LH2 and vapour between the *LH2 carrier* (3.24) and shore

3.16
freeboard
vertical distance between the ship's deck and the water level at the manifold location

3.17
free wheel
ability of a hydraulically operated *transfer arm* (3.58) when connected to a *LH2 carrier* (3.24) to follow freely, without hydraulic restraint, the vertical and horizontal motions of the LH2 carrier's manifold (draft changes and *sway* (3.53) and surge motions)

3.18
heave
vertical motion of the *LH2 carrier* (3.24) due to wave action

3.19
inboard arm
product-carrying pipe and any structural members contained between the *apex swivel* (3.1) and the *trunnion swivel* (3.60)

Note 1 to entry: See Figure B.2.

3.20
included angle
angle formed between *inboard arm* (3.19) and *outboard arm* (3.32)

Note 1 to entry: See Figure B.2.

Note 2 to entry: The maximum and minimum included angles are left to the transfer arm manufacturer.

Note 3 to entry: The included angle in the stowed position of the *transfer arms* (3.58) is such, that the arms are parked with the *triple swivel assembly* (3.59) behind the berthing line.

3.21
insulating flange
electrical insulating system, usually dedicated, that is installed in the lower end of the *outboard arm* (3.32) or in the vertical part of the *triple swivel assembly* (3.59)

Note 1 to entry: Its purpose is to prevent stray currents from causing an arc at the *LH2 carrier's* (3.24) flange as the *transfer arm* (3.58) is connected or disconnected.

3.22
jack
permanent, adjustable load-carrying mechanism potentially installed in the *triple swivel assembly* (3.59) to transfer a portion of the *transfer arm* (3.58) fluid weight to the deck instead of the *LH2 carrier's* (3.24) manifold

Note 1 to entry: See Figure B.2.

3.23
jetty control centre
control centre situated on or adjacent to the jetty primarily to control and/or monitor the *transfer arms* (3.58)

Note 1 to entry: Sometimes referred to as “jetty control room” or “local control room”.

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3.24
LH2 carrier
LH2C
tank ship designed for the carriage of LH2

3.25
luffing
rotary motions of the *inboard arm* (3.19) and *outboard arm* (3.32) in the vertical plane

Note 1 to entry: See Figure B.2.

3.26
main hydraulic unit
MHU
hydraulic unit that generates hydraulic power to ensure the normal operation and emergency release sequence of the arms

3.27
manifold setback
horizontal distance between the board side of the *LH2 carrier* (3.24) and the face of the *cargo manifold* (3.6)

3.28
manifold spacing
horizontal distance between two adjacent *cargo manifold* (3.6) flange axes

3.29
middle swivel
swivel joint accommodates *yawing* (3.62) and surge of the *LH2 carrier* (3.24) and is located between the *top swivel* (3.56) and b*ottom swivel* (3.4) in the vertical part of the *TSA* (3.59)

Note 1 to entry: See Figure B.2.

3.30
onshore LH2 terminal
LH2 exporting or receiving terminal that is located on shore and that has marine *transfer arms* (3.58) for the loading or unloading of *LH2 carriers* (3.24) in a harbour or other sheltered coastal location

3.31
operating envelope
volume in which *presentation flange(s)* (3.36) of a (group of) *transfer arm(s)* (3.58) is (are) required to operate

3.32
outboard arm
product-carrying pipe and any structural members contained between the *apex swivel* (3.1) and the *triple swivel assembly* (3.59)

Note 1 to entry: See Figure B.2.

3.33
owner
designated agent
company or group of companies for whose use the *transfer arms* (3.58) are installed, responsible for the safe design and construction of the installation

3.34
pitch
rotation of the *LH2 carrier* (3.24) around the transversal horizontal axis

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3.35
powered emergency release coupling
PERC
powered device to provide a means of quick release of the *transfer arms* (3.58) when such action is required only as an emergency measure

3.36
presentation flange
transfer arm (3.58) flange for connection to either the *cargo manifold* (3.6) or *spool piece* (3.46)

Note 1 to entry: See Figure B.2.

3.37
product
fluid transferred using *transfer arms* (3.58)

Note 1 to entry: Fluids are LH2 or GH2.

3.38
quick connect disconnect coupler
QCDC
coupler
manual or hydraulic mechanical device used to connect the *transfer arm* (3.58) to the *cargo manifold* (3.6) or *spool piece* (3.46) without employing bolts

Note 1 to entry: See Figure B.2.

3.39
remote pendant control
remote control
device to facilitate the fine manoeuvring operation of the *transfer arms* (3.58) from a remote location (e.g. *LH2 carrier's* (3.24) *cargo manifold* (3.6) area)

Note 1 to entry: The system can use a trailing wire or radio-controlled system.

3.40
riser and trunnion swivel assembly
fluid carrying system consisting of a *riser swivel* (3.42), *trunnion swivel* (3.60) and elbows, and mounted on top of the *base riser* (3.3)

Note 1 to entry: See Figure B.2.

3.41
riser flange
transfer arm (3.58) flange for connection to LH2 piping

Note 1 to entry: See Figure B.2.

3.42
riser swivel
swing joint in the *riser and trunnion swivel assembly* (3.40) which permits *slewing* (3.45) of the *transfer arm* (3.58)

Note 1 to entry: See Figure B.2.

3.43
roll
rotation of *LH2 carrier* (3.24) around longitudinal horizontal axis

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3.44
safety integrity level
SIL
statistical representations of the integrity of the safety instrumented system when a process demand occurs

Note 1 to entry: See Clause 6.

3.45
slew
horizontal, rotary motion of the *transfer arm* (3.58) around the *base riser* (3.3)

Note 1 to entry: See Figure B.2.

3.46
spool piece
short length of pipe for the purpose of matching the *cargo manifold* (3.6) to the *presentation flange* (3.36) or the *QCDC* (3.38)

Note 1 to entry: Sometimes referred to as "adaptor" or "short distance piece".

3.47
spotting line
pre-determined location on the jetty used by the *LH2 carrier* (3.24) when berthing to align with the LH2 carrier vapour manifold

Note 1 to entry: See Figure A.1.

3.48
stress analysis
detailed calculation of the structural loading in the *transfer arm* (3.58) and *cargo manifold* (3.6) for various positions and attitudes to check the integrity of the transfer arm for the service intended

3.49
structural bearing
bearing in the load carrying components supporting the product line that, in combination, allow the *transfer arm* (3.58) to follow freely the motion of the *LH2 carrier* (3.24)

3.50
surge aft
longitudinal *LH2 carrier* (3.24) afterward motion

3.51
surge fore
longitudinal *LH2 carrier* (3.24) forward motion

3.52
surge pressure
rapid change in pressure as a consequence of a change in flow rate in a pipeline and/or piping systems (including *transfer arms* (3.58))

3.53
sway
transverse *LH2 carrier* (3.24) motion

3.54
swivel joint
swivel
swing joint contained in the *transfer arm* (3.58) to permit the arm to follow freely the motion of the *LH2 carrier* (3.24)

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3.55
terminal
LH2 producing/receiving plant with loading/unloading facilities

3.56
top swivel
swivel joint accommodates *rolling* (3.43), *heave* (3.18) and *sway* (3.53) motion of the *LH2 carrier* (3.24) and is located between the *outboard arm* (3.32) and *middle swivel* (3.29) in the horizontal part of the *triple swivel assembly* (3.59)

Note 1 to entry: See Figure B.2.

3.57
transfer
loading or unloading operation

3.58
transfer arm
arm
articulated metal transfer system used for transferring *product* (3.37) to or from the *LH2 carrier* (3.24) with the capability of accommodating differences in tides, *freeboard* (3.16) and the LH2 carrier's motions

Note 1 to entry: See Figure B.2.

Note 2 to entry: It can be referred to as a “loading arm” or “unloading arm”.

3.59
triple swivel assembly
TSA
group of three *swivels* (3.54) and elbows located at the end of the *outboard arm* (3.32)

Note 1 to entry: See Figure B.2.

3.60
trunnion swivel
swing joint in *riser and trunnion swivel assembly* (3.40) which permits the *inboard arm* (3.19) to rotate around the horizontal axis

Note 1 to entry: See Figure B.2.

3.61
uninterruptible power supply
UPS
back-up of the electrical supply system providing power to critical control and safety systems so that the plant can be kept in safe conditions

3.62
yaw
rotation of the *LH2 carrier* (3.24) around vertical axis

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4 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

CPMS	constant position monitoring system
DL	dead load
EMC	electro-magnetic compatibility
ERS	emergency release system
ESD	emergency shutdown
FL	fluid load
GH2	gaseous hydrogen
He	helium
H2	hydrogen gas
IP	ingress protection
LHe	liquefied helium
LH2	liquefied hydrogen
LNG	liquefied natural gas
LH2C	liquefied hydrogen carrier
LN2	liquefied nitrogen gas
LO2	liquefied oxygen
MHU	main hydraulic unit
NDE	non-destrucive examination
N2	nitrogen gas
OBE	operating basis earthquake
PERC	powered emergency release coupling
PL	pressure load
QCDC	quick connect disconnect coupler
SSE	safe shutdown earthquake
TL	thermal load
WL	wind load

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5 Design of the arms

5.1 Definition and description of the arms

5.1.1 General

The transfer arm general arrangement is given in Figure B.2.

The length and the configuration of the transfer arms shall allow for the connection of the onshore piping to the ship's cargo manifold. The connection shall allow for free movement within the operating envelope.

The transfer arms are normally composed of the following (see definitions in Clause 3):

— triple swivel assembly (TSA) including emergency release system (ERS), if specified;

— outboard arm;

— apex swivel assembly between the outboard and inboard arm;

— balancing system;

— inboard arm;

— riser and trunnion swivel assembly between the inboard arm and the base riser;

— base riser.

All product carrying components shall be adequately heat insulated against ambient temperature to avoid producing liquefied oxygen and to minimize heat in leak (e.g. vacuum) insulated double wall construction, where the inner piping shall be free to expand or contract with the outer piping.

All piping supports shall be adequately designed so that stresses in the piping and the structure are within allowable limits for all attitudes and positions.

No parts of the transfer arm, e.g. seals, bolts, and nuts, shall come off or unfasten and drop into product piping due to product flow, vibration, negative pressure and cryogenic conditions.

The characteristics of hydrogen are described in ISO/TR 15916.

The main hazards to be considered in the design of transfer arms for liquefied hydrogen are:

— low ignition energy;

— a wide range of flammability limits;

— cryogenic temperature and liquefaction/solidification of inert gas and constituents of air which can result in an oxygen-enriched atmosphere;

— high permeability;

— low viscosity;

— hydrogen embrittlement including weld metals;

— cryogenic temperatures which can cause injury to people (frostbite) and also damage non-cryogenic materials such as carbon steel, which lose their mechanical properties, become brittle and thus have a greater susceptibility for fracture.

NOTE Local and national rules and regulations can apply.

The complete TSA and outboard arm shall be balanced in the empty condition without ice. It shall be balanced at the apex swivel.

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The complete, articulated assembly shall be balanced in the empty condition without ice. It shall be balanced about the trunnion swivel.

The design of the transfer arms shall consider, in addition to the normal operation, the emergency release of the arms in both the empty and full conditions. There shall be no clash of the arms with the ship or the jetty. Risk assessments of such operational scenarios shall also be conducted.

5.1.2 Arms dimensions

Transfer arm dimensions shall be determined by the transfer arm manufacturer to ensure that the transfer arm satisfies all specified requirements.

Clearance study shall be carried out by following the description specified in ISO 16904.

5.2 Design basis

5.2.1 Product line diameter and product data

The LH2 product line shall be sized in consideration of allowable pressure loss and acceptable cavitation and vibration unless otherwise specified by the owner.

Pressure loss curve for LH2 and vapour return within the transfer arms shall be provided by the transfer arm manufacturer and agreed with the owner.

5.2.2 Material and grades

Material and grades shall have chemical, physical and mechanical properties conformable to the specified design conditions, such as pressure, temperature, wind and earthquake loads, and environment application.

Material and grades used for critical parts such as pressure containing parts including bolts and nuts and main structural parts are subject to the owner's approval.

In the product carrying components, austenitic stainless steel (304, 304L, 316 or 316L) shall be used for fracture toughness at cryogenic temperature and hydrogen embrittlement. The corrosion resistant property of stainless steel in a chloride environment shall be considered.

Other material and grades may be considered for use if it can be demonstrated that it meets all safety and operational performance criteria.

If the transfer arms are installed at a low ambient temperature, the grade used for the structure shall be adequate. The same applies to parts between the product line and the structure which can be subject to low temperature.

5.2.3 Stress analysis

5.2.3.1 General

A complete analysis of stresses and deflections in the transfer arm and the force on the LH2 carrier's manifolds incurred by the loading arm shall be performed for all appropriate arm conditions.

The calculated stresses shall be lower than or equal to the allowable design stress.

The loading combination, allowable design stress and design loads shall be in accordance with 5.2.3.2 to 5.2.3.9. Local or national standards and regulations can be applicable, with agreement of the owner.

5.2.3.2 Loading combination

The transfer arm manufacturer shall prepare a stress report for the loading combinations in Table A.6 at all appropriate transfer arm attitudes within the envelope. The LH2 carrier manifold shall be included, if required.

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Where combinations other than those in Table A.6 (e.g. exclusion of a load) can be shown to lead a greater feasible loading effect, then the design shall also allow for that condition.

Where applicable, the stress report shall also include loading effects of using any installation/maintenance lifting lugs.

5.2.3.3 Allowable design stress

The basic allowable design stress (Sd) for pressure containing and non-pressure containing structural components shall be the lower of either:

— yield strength / 1,5, or

— ultimate tensile strength / 3 for austenitic steels, and ultimate tensile strength / 2,4 for ferritic steels.

The yield strength and ultimate tensile strength shall be the values specified in the applicable material standards.

The allowable design stress is obtained by multiplying the basic allowable design stress with the K factor as exemplified in Table A.6.

5.2.3.4 Pressure load

The pressure loads (PL) shall be based on internal design pressure. Vacuum condition (negative pressure) shall also be considered as pressure load, if required.

5.2.3.5 Fluid load

The fluid loads (FL) shall be based on the density of LH2 at its specific conditions.

5.2.3.6 Ice build-up

Unless otherwise specified on the OCIMF website, Table A3,[12] the dead load and wind load (DL and WL) shall include appropriate ice build-up (specific gravity = 0,80) for cold parts.

5.2.3.7 Thermal load

The thermal loads (TL) are the loads caused by material temperature differences. The temperature differences used in the design shall be based on the design temperatures specified and the ambient and solar radiation temperatures. These temperatures shall be applied in the most extreme combination.

Cool-down and warm-up procedures shall be included in the operating procedures. These procedures should provide temperature gradients across fluid and structural members and/or recommended maximum cool-down/warm-up rates and minimum cool-down/warm-up durations to prevent excessive stresses and strains.

An item such as a bellows or compensators should be equipped, if necessary, to avoid significant thermal stress caused by the temperature difference, which is greater with LH2 than LNG.

The arm and its components shall be designed for the expected amount of thermal cycles over the lifetime of the arm and consequential fatigue induced stresses, if necessary. When adopting the fatigue design, the number of cycles shall be agreed upon with the owner.

5.2.3.8 Wind load

The wind loads (WL) shall be calculated for the worst direction(s) by following the method presented in appropriate local rules or specifications, or ISO 16904.

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