M78
(July 2018)
(Rev.1 Feb 2021)
(Rev.2 Jan 2024)

~~Safety of Internal Combustion Engines Supplied with Low Pressure Gas~~ Reciprocating Internal Combustion Engines Fuelled by Natural Gas

1 General

1.1 Scope

1.1.1 Type of engines

This UR addresses the requirements for ~~trunk piston~~ marine reciprocating internal combustion engines supplied with ~~low pressure~~ natural gas as fuel.

The scope of the UR is intended for natural gas fuelled engines. It may also be referred for engines using similar fuels with main component methane such as bio-methane or synthetic methane.

It shall be ensured by the gas supply system that the gas supplied to the engine is always in gaseous state. This UR does not cover requirements for liquid or cryogenic gas.

The engines can be dual fuel engines (hereinafter referred to as DF engines), gas fuel only engines (hereinafter referred to as GF engines), or any variations thereof including fuel sharing capability.

DF engines and GF engines may not be permitted for emergency applications.

This UR is to be applied in association with other relevant IACS internal combustion engine UR's, as far as found applicable to the specific ~~natural gas burning~~ engine design.

The mandatory international codes for gas carriers (IGC Code) and for other ships burning low flashpoint fuels (IGF Code) must also be considered, as applicable.

Specific requirements of the IGF Code as referenced in this UR shall be applied to engine types covered by this UR installed on any ship, regardless of type, size and trading area, as long as the IGC Code is not referenced or explicitly specified otherwise.

~~Engines can be either dual fuel engines (hereinafter referred to as DF engines) or gas fuel only engines (hereinafter referred to as GF engines).~~

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Notes:

1. The requirements of UR M78 are to be uniformly implemented by IACS Societies for engines for which the date of an application for type approval certification is dated on or after 1 July 2019.

2. The “date of an application for type approval” is the date of documents accepted by the Classification Society as request for type approval certification of a new engine type or of an engine type that has undergone substantive modifications, as defined in UR M44, in respect of the one previously type approved, or for renewal of an expired type approval certificate.

3. Engines with an existing type approval on 1 July 2019 are not required to be re-type approved in accordance with this UR until the current Type Approval becomes invalid. For the purpose of certification of these engines, the current type approval and related submitted documentation will be accepted in place of that required by this UR until the current type approval expires or the engine type has undergone substantive modifications, as defined in UR M44.

4. Rev.1 of this UR is to be uniformly implemented by IACS Societies for engines for which the date of an application for type approval certification is dated on or after 1 July 2022.

5. Rev.2 of this UR is to be uniformly implemented by IACS Societies for engines for which the date of an application for type approval certification is dated on or after 1 January 2025.

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~~Gas can be introduced as follows:~~

- ~~into the air inlet manifold, scavenge space, or cylinder air inlet channel port; or~~
- ~~mixed with air before the turbo-charger ("pre-mixed engines").~~

~~The gas / air mixture in the cylinder can be ignited by the combustion of a certain amount of fuel (pilot injection) or by extraneous ignition (sparking plug).~~

~~The scope of the UR is limited to natural gas fuelled engines~~

~~1.1.2 Applications~~

~~This UR covers the following applications, but is not limited to:~~

- ~~Mechanical propulsion~~
- ~~Generating sets intended for main propulsion and auxiliary applications.~~
- ~~Single engine or multi-engine installations~~

1.2 Definitions

1.2.1 Certified safe equipment is equipment certified by an independent national test institution or competent body to be in accordance with a recognised standard for electrical apparatus in hazardous areas. ~~*Certified safe type* means electrical equipment that is certified in accordance with the recommendation published by the International Electrotechnical Commission (IEC), in particular publication IEC 60092-502:1999, or with recognized standards at least equivalent. The certification of electrical equipment is to correspond to the category and group for methane gas.~~

Note: Refer to IEC 60079 series, Explosive atmospheres and IEC 60092-502:1999 Electrical Installations in Ships – Tankers – Special Features

1.2.2 *Double block and bleed valves* means the set of valves referred to in:

- IGC Code, 16.4.5
- IGF Code, 2.2.9 and 9.4.4 to 9.4.6

1.2.3 Dual fuel engine ("DF engine") means an engine that can burn natural gas as fuel simultaneously with liquid fuel, either as pilot oil or bigger amount of liquid fuel (gas mode), and also has the capability of running on liquid diesel fuel oil only (Diesel mode).

~~1.2.4 Engine room is a machinery space or enclosure containing gas fuelled engine(s).~~

1.2.4 Explosion relief device means a device to protect personnel and component against a determined overpressure in the event of a gas explosion. The device may be a valve, a rupture disc or other, as applicable.

1.2.5 Gas means natural gas used as fuel consisting primarily of methane. ~~a fluid having a vapour pressure exceeding 2.8 bar absolute at a temperature of 37.8ºC.~~

Note: Gas may also be bio-methane or synthetic methane etc. with methane as main component.

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1.2.6 Gas admission valve is a valve or injector on the engine, which controls gas supply to the cylinder(s) according to the engine's ~~cylinder(s) actual~~ gas demand.

1.2.7 Gas engine means ~~either~~ a DF engine, ~~or~~ a GF engine, or any variations thereof.

1.2.8 Gas fuel only engine ("GF engine") means an engine capable of operating on gas fuel only and not able to switch over to oil fuel operation.

1.2.9 Gas piping means piping containing gas or air / gas mixtures~~, including venting pipes~~.

~~1.2.10 Gas Valve Unit (GVU) is a set of manual shutoff valves, actuated shut-off and venting valves, gas pressure sensors and transmitters, gas temperature sensors and transmitters, gas pressure control valve and gas filter used to control the gas supply to each gas consumer. It also includes a connection for inert gas purging.~~

1.2.10 High pressure gas means gas with a maximum working pressure greater than 10 bar gauge.

1.2.11 IGC Code means the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, ~~(~~as amended. ~~by IMO Resolutions MSC.370(93), MSC.411(97) and MSC.441(99)).~~

1.2.12 IMO means the International Maritime Organisation.

1.2.13 IGF Code means the International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IMO Resolution MSC.391(95), as amended ~~by Resolution MSC.422(98)~~).

1.2.14 Low pressure gas means gas with a maximum working pressure lower or equal ~~up~~ to 10 bar gauge.

1.2.15 Lower Heating Value ("LHV") means the amount of heat produced from the complete combustion of a specific amount of fuel, excluding latent heat of vaporization of water.

1.2.16 Methane Number is a measure of resistance of a gas fuel to knock, which is assigned to a test fuel based upon operation in knock testing unit at the same standard knock intensity.

Note: Pure methane is used as the knock resistant reference fuel, that is, methane number of pure methane is 100, and pure hydrogen is used as the knock sensitive reference fuel, methane number of pure hydrogen is 0.

1.2.17 Pilot fuel means the fuel oil that is injected into the cylinder to ignite the main gas-air mixture on DF engines.

1.2.18 Pre-mixed engine means an engine where gas is supplied in a mixture with air through a common manifold for all cylinders, e.g. mixed before or after the turbocharger.

1.2.19 Recognized standards means applicable international or national standards acceptable to the Classification Society or standards laid down and maintained by an organisation which complies with the standards adopted by IMO and which are recognized by the Classification Society.

1.2.20 Safety Concept is a document describing the safety philosophy with regard to gas as fuel. It describes how risks associated with this type of fuel are controlled under reasonably

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foreseeable abnormal conditions as well as possible failure scenarios and their control measures. The results of the risk analysis, see 1.4, shall be reflected in the safety concept.

Note: A detailed evaluation regarding the hazard potential of injury from a possible explosion is to be carried out and reflected in the safety concept of the engine.

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1.3 Documents and drawings to be submitted

1.3.1 Documents and drawings to be submitted for the approval of DF and GF engines

The following documents are to be submitted for the approval of DF and GF engines, in addition to those required in UR M44.

No.	Item
1	Schematic layout or other equivalent documents of gas system on the engine
2	Gas piping system (including double-walled arrangement where applicable)[3)]
3	Parts for gas admission system[3)]
4	Arrangement of explosion relief valves (crankcase[1)], charge air manifold, exhaust gas Manifold and exhaust gas system on the engine) as applicable
5	List of certified safe equipment and ~~evidence~~ of relevant certification
6	Safety concept (for information)
7	Report of the risk analysis[2)] (for information)
8	Gas used as fuel specification (for information)

1.3.2 Documents and drawings to be submitted for the approval of DF engine

No.	Item
9	Schematic layout or other equivalent documents of ~~fuel oil system (main and~~ pilot fuel system~~s) on the engine~~
10	Shielding of high pressure fuel pipes for pilot fuel system, assembly
11	High pressure parts for pilot fuel oil injection system[3)]

1.3.3 Documents and drawings to be submitted for the approval of GF engine

No.	Item
12	Schematic layout or other equivalent documents of the i~~I~~gnition system

1.3.4 Where considered necessary, the Society may request further documents to be submitted.

Footnotes:
1) If required by UR M44, see also 2.2.5.1.
2) See 1.4.

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3) The documentation to contain specification of design pressures, working pressure, pipe dimensions and materials.

1.4 Risk analysis

1.4.1 Scope of the risk analysis

The risk analysis is to address:

- a failure or malfunction of any system or component involved in the gas operation of the engine
- a gas leakage downstream of the double block and bleed valves ~~gas valve unit~~
- the safety of the engine in case of emergency shutdown or blackout, when running on gas
- the inter-actions between the gas fuel system and the engine.

Note: With regard to the scope of the risk analysis it shall be noted that failures in systems external to the engine, such as fuel storage or fuel gas supply systems, may require action from the engine control and monitoring system in the event of an alarm or fault condition. Conversely failures in these external systems may, from the vessel perspective, require additional safety actions from those required by the engine limited risk analysis required by this UR.

1.4.2 Form of the risk analysis

The risk analysis is to be carried out in accordance with international standard ~~ISO~~IEC 31010:20~~0~~19: Risk management - Risk assessment techniques, or other recognized standards.

The required analysis is to be based on the single failure concept, which means that only one failure needs to be considered at the same time. Both detectable and non-detectable failures are to be considered. Consequences failures, i.e. failures of any component directly caused by a single failure of another component, are also to be considered.

1.4.3 Procedure for the risk analysis

The risk analysis is to:

a) Identify all the possible failures in the concerned equipment and systems which could lead:

   1) to the presence of gas in components or locations not designed for such purpose, and/or

   2) to ignition, fire or explosion.

b) Evaluate the consequences (see also 2.1.2)

c) Where necessary, identify the failure detection method

d) Where the risk cannot be eliminated, identify the corrective measures:

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1) in the system design, such as:

- redundancies
- safety devices, monitoring or alarm provisions which permit restricted operation of the system

2) in the system operation, such as:

- initiation of the redundancy
- activation of an alternative mode of operation.

The results of the risk analysis are to be documented.

1.4.4 Equipment and systems to be analysed

The risk analysis required for engines is to cover at least the following aspects:

a) failure of the gas-related systems or components, in particular:

- gas piping and its enclosure, where provided
- gas admission valves ~~cylinder gas supply valves~~

Note: Failures of the gas supply components not located directly on the engine, such as block-and-bleed valves and other components of the gas supply system ~~Gas Valve Unit (GVU)~~, are not to be considered in the analysis.

b) failure of the ignition system (oil fuel pilot injection, ~~or~~ sparking plugs, glow plugs)

c) failure of the air to fuel ratio control system (charge air by-pass, gas pressure control valve, etc.)

d) for engines where gas is supplied~~injected~~ upstream of the turbocharger compressor, failure of a component likely to result in a source of ignition (hot spots)

e) failure of the gas combustion or abnormal combustion (misfiring, knocking)

f) failure of the engine monitoring, control and safety systems

Note: Where engines incorporate electronic control systems, a failure mode and effects analysis (FMEA) is to be carried out in accordance with UR M44, Table 1, Footnote 5.

g) ~~abnormal~~ presence of gas in engine components (e.g. air inlet manifold or scavenge space and exhaust manifold ~~of DF or GF engines~~) and in the external systems connected to the engines (e.g. exhaust duct, cooling water system, hydraulic oil system, etc.).

h) changes of operating modes for DF engines

i) hazard potential for crankcase fuel gas accumulation, for ~~engines where the space below the piston is in direct communication with the crankcase~~ trunk-piston engines, refer to IGF Code 10.3.1.2 and UR M10.

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j) risk of crankcase explosion in connection with active crankcase ventilation which produces a flow of external air into the crankcase, (see UR M10).

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2. Design Requirements

2.1 General Principles

2.1.1 The manufacturer is to declare the allowable gas composition limits for the engine and the minimum and (if applicable) maximum methane number.

2.1.2 Components containing or likely to contain gas are to be designed to:

a) minimise the risk of fire and explosion so as to demonstrate an appropriate level of safety commensurate with that of an oil-fuelled engine;

b) mitigate the consequences of a possible explosion to a level providing a tolerable degree of residual risk, due to the strength of the component(s) or the fitting of suitable explosion ~~pressure~~ relief devices of an approved type.

The strength of the component(s) of arrangement of explosion relief devices shall be documented (e.g., as part of risk analysis) or otherwise demonstrated to be sufficient for a worst-case explosion.

Also refer to the IGF Code 10.2 and 10.3.

~~Note:~~

~~1.~~ 2.1.3 Discharge from explosion ~~pressure~~ relief devices shall prevent the passage of flame to the machinery space and be arranged such that the discharge does not endanger personnel or damage other engine components or systems”.

~~2.~~ 2.1.4 Explosion r~~R~~elief devices shall be fitted with a flame arrester.

2.2 Design Requirements

2.2.1 Gas piping

2.2.1.1 General

The requirements of this section apply to engine-mounted gas piping. The piping shall be designed in accordance with the criteria for gas piping (design pressure, wall thickness, materials, piping fabrication and joining details etc.) as given in the IGF Code chapter 7, or ~~For gas carriers,~~ IGC Code chapter 5.1 to 5.9 and 16 ~~applies~~ as applicable.

Other connections as mentioned in IGF Code 7.3.6.4.4 may be accepted subject to type approval in accordance with the requirements of UR P2.7 and P2.11.

All single walled or high-pressure gas pipes should be considered as Class I.
Low pressure double walled gas pipes should be considered as Class II.
All secondary enclosures for gas pipes should be considered as Class II.

Single walled gas vent pipes, if permitted, should be considered as Class I, except it is justified that the maximum built up pressure is less than 5 bar gauge, in which case it should be considered as Class II.

Gas vent pipes protected by a secondary enclosure should be considered as Class II.

Secondary enclosure for vent pipes should be considered as Class III.

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Table 1: Design pressure for gas pipes

	Design pressure	
Gas pipe, low pressure	see IGF 7.3.3.1	see IGC Code 5.4.1
Gas pipe, high pressure	see IGF 7.3.3.1	see IGC Code 5.4.1
outer pipe, low pressure	see IGF Code 9.8.1	see IGC Code 5.4.4
outer pipe, high pressure	see IGF Code 9.8.2	see IGC Code 5.4.4
Open ended pipes	see IGF Code 7.3.3.2	see IGC Code 5.4.1

Flexible bellows used in the fuel gas system on the engine shall be approved based on the requirements of IGF Code 16.7.2, and IGC Code 5.13.1.2, as applicable.

The number of cycles, pressure, temperature, axial movement, rotational movement and transverse movement which the bellow will encounter in actual service on the engine should be specified by the engine designer.

Endurance against high cycle fatigue due to vibration loads shall be verified by testing or alternatively be documented by the Expansion Joint Manufacturers Association, Inc. (EJMA) calculation or equivalent (i.e., more than 10^7 cycles).

Note: The fatigue test due to ship deformations in IGF 16.7.2.4 is considered not relevant for bellows which are an integral part of the engine.

2.2.2 Arrangement of the gas piping system on the engine

Pipes and equipment containing fuel gas are defined as hazardous area Zone 0 (refer to IGF Code 12.5.1).

The space between the gas fuel piping and the wall of the outer pipe or duct is defined as hazardous area Zone 1 (refer to IGF Code 12.5.2.6)

2.2.2.1 Normal “double wall” arrangement

The gas piping system on the engine shall be arranged according to the principles and requirements of the IGF Code 9.6. For gas carriers, IGC Code 16.4.3 applies.

The design criteria for the double pipe or duct are given in the IGF Code 9.8 and 7.4.1.4.

In case of a ventilated double wall, the ventilation inlet is to be located in accordance with the provisions of IGF Code, regulation 13.8.3. For gas carriers, IGC Code 16.4.3.2 applies.

The pipe or duct is to be pressure tested at 1.5 x design pressure ~~in accordance with UR P2.8.1~~ to ensure gas tight integrity and to show that it can withstand the expected maximum pressure at gas pipe rupture.

2.2.2.2 Alternative arrangement

Single walled gas piping is only acceptable:

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a) for engines supplied with low pressure gas and installed in ESD protected machinery spaces, as defined in IGF Code 5.4.1.2 and in compliance with other relevant parts of the IGF Code (e.g. 5.6);

b) in the case as per footnote 18 to paragraph 9.6.2 of IGF Code.

For gas carriers, the IGC Code applies.

In case of gas leakage in an ESD-protected machinery space, which would result in the shut-down of the engine(s) in that space, a sufficient propulsion and manoeuvring capability including essential and safety systems is to be maintained.

Therefore the safety concept of the engine is to clearly indicate application of the “double wall” or “alternative” arrangement.

Note: The minimum power to be maintained is to be assessed on a case-by-case basis from the operational characteristics of the ship.

2.2.3 Charge air system and exhaust gas system on the engine

The charge air system and the exhaust gas system on the engine are ~~is~~ to be designed in accordance with 2.1.2 above.

In case of a single engine installation, the engine is to be capable of operating at sufficient load to maintain power to essential consumers after opening of the explosion ~~pressure~~ relief devices caused by an explosion event. Sufficient power for propulsion capability is to be maintained.

Note: Load reduction is to be considered on a case-by-case basis, depending on engine configuration (single or multiple) and relief mechanism (self-closing valve or rupture ~~bursting~~ disk).

2.2.4 ~~Exhaust system on the engine~~

~~The exhaust gas system on the engine is to be designed in accordance with 2.1.2 above.~~

~~In case of a single engine installation, the engine is to be capable of operating at sufficient load to maintain power to essential consumers after opening of the pressure relief devices caused by an explosion event. Sufficient power for propulsion capability is to be maintained.~~

Continuous relief of exhaust gas (through open rupture disc) into the engine room or other enclosed spaces is not acceptable.

Suitable explosion relief system for air inlet manifolds, scavenge spaces and exhaust system should be provided unless designed to accommodate the worst-case overpressure due to ignited gas leaks or justified by the safety concept of the engine. A detailed evaluation regarding the hazard potential of overpressure in air inlet manifolds, scavenge spaces and exhaust system should be carried out and reflected in the safety concept of the engine.

Explosion relief devices for air inlet and exhaust manifold shall be type approved according to UR M82.

The necessary total relief area and the arrangement of the explosion relief devices shall be determined taking into account:
- The worst-case explosion pressure depending on initial pressure and gas concentration,

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- the volume and geometry of the component, and
- the strength of the component.

The arrangement shall be determined in the risk analysis (see 1.4.4.g) and reflected in the safety concept.

2.2.5 Engine crankcase

2.2.5.1 Crankcase explosion relief valves

Crankcase explosion relief valves are to be installed in accordance with UR M9. Refer also to IGF Code 10.3.1.2.

For engines not covered by M9, the detailed evaluation as required in 1.4.4.i is to determine if crankcase explosion relief valves are necessary.

2.2.5.2 Inerting

For maintenance purposes, a connection, or other means, are to be provided for crankcase inerting and ventilating and gas concentration measuring.

2.2.5.3 Crankcase ventilation

Ventilation of crankcase (either supply or extraction), if arranged, is to comply with UR M10. Relevant evidence is to be documented in Safety Concept.

The ventilation systems for crankcase, sump and other similar engine spaces are to be independent from the systems on the other engines.

2.2.6 Gas ignition in the cylinder

2.2.6.1 Requirements of IGF Code 10.3 apply. For gas carriers, IGC Code 16.7 applies.

2.2.7 Control, monitoring, alarm and safety systems

The engine control system is to be independent and separate from the safety system.

The gas admission ~~supply~~ valves are to be controlled by the engine control system or by the engine gas demand.

Combustion is to be monitored on an individual cylinder basis.

In the event that poor combustion is detected on an individual cylinder, gas operation may be allowed in the conditions specified in IGF Code 10.3.1.6.

If monitoring of combustion for each individual cylinder is not practicable due to engine size and design, common combustion monitoring may be accepted.

Unless the risk analysis required by 1.4 of this UR proves otherwise, the monitoring and safety system functions for DF or GF engines are to be provided in accordance with Table ~~1~~ 2 of this UR in addition to the general monitoring and safety system functions given by the Classification Societies.

Note: For DF engines, Table 2 ~~1~~ applies only to the gas mode.

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2.2.8 Gas admission valves

Electrically operated g~~G~~as admission valves shall be certified safe as follows:

1) The inside of the valve contains gas and shall therefore be certified for Zone 0.

2) When the valve is located within a pipe or duct in accordance with 2.2.2.1, the outside of the valve shall be certified for Zone 1.

3) When the valve is arranged without enclosure in accordance with the "ESD-protected machinery space" (see 2.2.2.2) concept, no certification is required for the outside of the valve, provided that the valve is de-energized upon gas detection in the space.

However, if they are not rated for the zone they are intended for, it shall be documented that they are suitable for that zone. Documentation and analysis ~~is~~ are to be based on IEC 60079-10-1:2015 or IEC 60092-502:1999.

Gas admission valves operated by hydraulic oil system are to be provided with sealing arrangement to prevent gas from entering the hydraulic oil system.

Table 2 ~~1~~: Monitoring and Safety System Functions for DF and GF Engines

Parameter	Alarm	Automatic activation of the double block-and-bleed valves	Automatic switching over to oil fuel mode[1]	Engine shutdown
Abnormal pressures in the gas fuel supply line	X	X	X	X [5]
Gas fuel supply systems - malfunction	X	X	X	X [5]
Pilot fuel injection or spark ignition systems - malfunction	X	X [2]	X	X [2)5)]
Exhaust gas temperature after each cylinder - high	X	X [2]	X	X [2)5)]
Exhaust gas temperature after each cylinder, deviation from average – low [3]	X	X [2]	X	X [2)5)]
Cylinder pressure or ignition - failure, including misfiring, knocking and unstable combustion	X	X [2)4)]	X [4]	X [2)4)5)]
Oil mist concentration in crankcase or bearing temperature [6] - high	X	X		X [9]
Pressure in the crankcase – high [4) 8)]	X	X	X	
Engine stops - any cause	X	X		

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Failure of the control-actuating medium of the block and bleed valves	X	X	X	
Failure of crankcase ventilation system, if applicable	X	X [7)]	X [7)]	

Footnotes:

1) DF engine only, when running in gas mode
2) For GF engines, the double block-and-bleed valves and the engine shutdown may not be activated in case of specific failures affecting only one cylinder, provided that the concerned cylinder can be individually shutoff and the safe operation of the engine in such conditions is demonstrated by the risk analysis.
3) Required only if necessary for the detection of misfiring
4) In the case where the failure can be corrected by an automatic mitigation action, only the alarm may be activated. If the failure persists after a given time, the safety actions are to be activated.
5) GF engine only
6) Where required by UR M10
7) Automatic safety actions to be activated as specified by the engine manufacturer, see UR M10
8) Only for trunk piston engines. This pressure sensor cannot replace or substitute a gas detector.
9) Only for trunk piston engines. For crosshead engines slow down shall apply (see UR M35 Tab.1)

3. Specific Design Requirements

3.1 DF Engines

3.1.1 General

The maximum continuous power that a DF engine can develop in gas mode may be lower than the approved MCR of the engine (i.e. in oil fuel mode), depending in particular on the gas composition and its quality or the engine design.

This maximum continuous power available in gas mode and the corresponding conditions shall be stated by the engine manufacturer ~~and demonstrated during the type test~~.

~~For the application of 4.1.4, 4.2.1 and 4.3 referring to UR M71.5, UR M51.3.3 and UR M51.4.4, the 110% load tests are not required in the gas mode for DF engines.~~

3.1.2 Starting, changeover and stopping

DF engines are to be arranged to be started using ~~use~~ either oil fuel or gas fuel ~~for the main fuel charge and~~ with pilot oil fuel for ignition. The engines are to be arranged for rapid changeover from gas use to fuel oil use. In the case of changeover to either fuel supply, the engines are to be capable of continuous operation using the alternative fuel supply without interruption to the power supply.

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Changeover to gas fuel operation is to be only possible at a power level and under conditions where it can be done with acceptable reliability and safety as demonstrated through testing.

Changeover from gas fuel operation mode to oil fuel operation mode is to be possible at all situations and power levels.

The changeover process itself from and to gas operation is to be automatic but manual interruption is to be possible in all cases.

If the power level or other conditions do not allow safe and reliable gas operation, changeover to oil fuel mode shall be automatically performed.

In case of shut-off of the gas supply, the engines are to be capable of continuous operation by oil fuel only.

3.1.3 Pilot injection

Gas supply to the combustion chamber is not to be possible without operation of the pilot oil injection.

Note: Pilot injection is to be monitored for example by fuel oil pressure and combustion parameters.

3.2 GF Engines

3.2.1 Spark ignition system

In case of failure of the spark ignition, the engine is to be shut down except if this failure is limited to one cylinder, subject to immediate shut off of the cylinder gas supply and provided that the safe operation of the engine is substantiated by the risk analysis and by tests.

3.3 Pre-Mixed Engines

3.3.1 Charge air system

Inlet manifold, turbo-charger, charge air cooler, etc. are to be regarded as parts of the fuel gas supply system. Failures of those components likely to result in a gas leakage are to be considered in the risk analysis (see 1.4).

Flame arresters are to be installed before each cylinder head, unless otherwise justified in the risk analysis, considering design parameters of the engine such as the gas concentration in the charge air system, the path length of the gas-air mixture in the charge air system, etc.

3.4 Two-stroke engines

3.4.1 Scavenge air system

The risk analysis required in 1.4 is to cover the possible gas accumulation in a scavenge space.

3.4.2 Crankcase

The risk analysis required in 1.4 is to cover the possible failure of a piston rod stuffing box.

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4. Type Testing, Factory Acceptance Tests and Shipboard Trials

4.1 Type Testing

4.1.1 General

Type approval of DF and GF engines is to be carried out in accordance with UR M71, taking into account the additional requirements below.

4.1.2 Type of engine

In addition to the criteria given in UR M71.3.3 the type of engine is defined by the following:

- gas admission method (~~direct~~ cylinder injection after compression stroke, cylinder-individual injection before compression stroke ~~charge air space~~ or pre-mixed)
- gas admission ~~supply~~ valve operation (mechanical or electronically controlled)
- ignition system (pilot injection, spark ignition, glow plug or gas self-ignition)
- ignition system (mechanical or electronically controlled)

Note: Cylinder-individual injection before compression stroke may be port injection into the air inlet channel before the cylinder inlet valve, injection into the cylinder before or during compression stroke, or similar arrangements.

4.1.3 Safety precautions

In addition to the safety precautions mentioned in UR M71.4, measures to verify that gas fuel piping on engine is gas tight are to be carried out prior to start-up of the engine.

4.1.4 Test programme

The type testing of the engine is to be carried out in accordance with UR M71.5, taking into account the additional requirements of this UR.

~~For DF engines, the load tests referred to in UR M71.5 are to be carried out in gas mode at the different percentages of the maximum power available in gas mode (see 3.1.1).~~

The influence of the methane number and LHV of the fuel gas is not required to be verified during the Stage B type tests. It shall however be justified by the engine designer through internal tests or calculations and documented in the type approval test report.

4.1.5 Measurements and records

In addition to the measurements and records required in UR M71.6, the following engine data are to be measured and recorded:

- Each fuel index for gas and diesel as applicable (or equivalent reading)
- Gas pressure and temperature at the inlet of the gas manifold
- Pilot fuel temperature and pressure (supply or common rail as appropriate)

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- Gas concentration in the crankcase

Note: The gas concentration in the crankcase should normally be measured inside the crankcase or at the crankcase outlet (crankcase vent pipe).
Gas concentration measurements may be carried out as part of Stage A if the method and the results are properly documented.

Additional measurements may be required in connection with the design assessment.

4.1.6 Stage A – internal tests

In addition to tests required in UR M71.7, the following conditions are to be tested:

- DF engines are to run the load points defined in UR M71.7 in both gas and diesel modes (with and without pilot injection in service) as found applicable for the engine type.
- For DF engines with variable liquid / gas ratio, the load tests are to be carried out at different ratios between the minimum and the maximum allowable values.
- For DF engines, switch over between gas and diesel modes are to be tested at different loads.
- The influence of the methane number and LHV of the fuel gas on the engine's maximum continuous power available in gas mode is to be verified.

4.1.7 Stage B – witnessed tests

4.1.7.1 General

Gas engines are to undergo the different tests required in UR M71.8.

In case of DF engine,

- all load points must be run in both gas and diesel modes that apply for the engine type as defined by the engine designer ~~(see 4.1.4)~~. The independent ~~This also applies to the~~ overspeed protection device has to be tested both in gas and diesel mode (UR M71.8.2).
- ~~In case of DF~~ For engines with variable liquid / gas ratio, selected ~~the~~ load tests are to be carried out at different ratios between the minimum and the maximum allowable value~~s~~. (most relevant and critical loads and ratios should be selected for the test)
- The maximum continuous power available in gas mode (see 3.1.1) is to be demonstrated.
- Overload testing is not required in gas mode for DF engines, provided that changeover to oil fuel mode is automatically performed in case of overload.
- The load tests are to be carried out in diesel mode and in gas mode at the different percentages of the engine's MCR.

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4.1.7.2 Functional tests

In addition to the functional tests required in UR M71.8.3, the following tests are to be carried out:

- For DF engines, the lowest specified speed is to be verified in diesel mode and gas mode.
- For DF engines, switch over between gas and diesel modes are to be tested at different loads.
- For DF engines, verification of automatic changeover to diesel mode when the load demand exceeds the maximum continuous power available in gas mode (see 3.1.1 and 3.1.2)
- The efficiency of the ventilation arrangement or other approved principal of the double walled gas piping system is to be verified.
- ~~Simulation of a gas leakage in way of a cylinder gas supply valve~~.

Engines intended to produce electrical power are to be tested as follows:

- Capability to take sudden load and loss of load in accordance with the provisions of UR M3.2.~~3~~
- For GF and premixed engines, the influences of LHV, methane number and ambient conditions on the dynamic load response test results are to be theoretically determined and specified in the test report. Referring to the limitations as specified in 2.1.1~~2~~, the margin for satisfying dynamic load response is to be determined.

Notes:

1. For DF engines, switchover to oil fuel during the test is acceptable.
2. Application of electrical load in more than 2 load steps can be permitted in the conditions stated in UR M3.2.3.

4.1.7.3 Integration Tests

GF and DF engines are to undergo integration tests to verify that the response of the complete mechanical, hydraulic and electronic engine system is as predicted for all intended operational modes. The scope of these tests is to be agreed with the Society for selected cases based on the risk analysis required in 1.4 of this UR, and shall at least include the following incidents:

- Failure of ignition (spark ignition or pilot injection systems), both for one cylinder unit and common system failure
- Failure of a ~~cylinder~~ gas admission ~~supply~~ valve
- Failure of the combustion (to be detected by e.g. misfiring, knocking, exhaust temperature deviation, etc.)
- Abnormal gas pressure

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- Abnormal gas temperature[1)]

4.1.8 Stage C – Component inspection

Component inspection is to be carried out in accordance with the provisions of UR M71.9. The components to be inspected after the test run are to include also:

- gas admission ~~supply~~ valve including pre-chamber as found applicable
- spark igniter (for GF engines)
- pilot fuel injection valve (for DF engines)

4.1.9 Engine type approval certificate

For DF engines, the maximum continuous power available in gas mode should be specified on the type approval certificate in addition to the maximum continuous rating in diesel mode if differing.

Footnote:

1) This test may be carried out using a simulation signal of the temperature.

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4.2 Factory Acceptance Test

4.2.1 General

Factory acceptance tests of DF and GF engines are to be carried out in accordance with UR M51, taking into account the additional requirements below.

For DF engines, the load tests referred to in UR M51.3.3 are to be carried out in diesel mode and in gas mode at the different percentages of the engine's MCR.
Maximum continuous power available in gas mode is to be demonstrated (see 3.1.1).

4.2.2 Safety precautions

In addition to the safety precautions mentioned in UR M51.1, measures to verify that gas fuel piping on engine is gas tight are to be carried out prior to start-up of the engine.

4.2.3 Records

In addition to the records required in UR M51.3.2, the following engine data are to be recorded:

- Fuel index, both gas and diesel as applicable (or equivalent reading)
- Gas pressure and temperature
- Pilot fuel temperature and pressure (supply or common rail as appropriate)

4.2.4 Test loads

Test loads for various engine applications are given in UR M51.3.3. DF engines are to be tested in both diesel and gas mode as found applicable. In addition, the scope of the trials may be expanded depending on the engine application, service experience, or other relevant reasons.

4.2.5 Integration tests

GF and DF engines are to undergo integration tests to verify that the response of the complete mechanical, hydraulic and electronic system is as predicted for all intended operational modes.

The scope of these tests is to be agreed with the Society for selected cases based on the risk analysis required in 1.4 of this UR and shall at least include the following incidents:

- Failure of ignition (spark ignition or pilot injection systems), for one cylinder unit
- Failure of a ~~cylinder~~ gas admission ~~supply~~ valve
- Failure of the combustion (to be detected by e.g. misfiring, knocking, exhaust temperature deviation, etc.)
- Abnormal gas pressure
- Abnormal gas temperature

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The above tests may be carried out using simulation or other alternative methods, subject to special consideration by the Society.

4.3 Shipboard Trials

A leak test is to be carried out for the gas piping system (IGF Code 16.7.3.3) after assembly on board.

Shipboard trials are to be carried out in accordance with the provisions of UR M51.4, considering the additional requirements below.

For DF engines, the test loads required in UR M51.4.4 are to be carried out in all operating modes (gas mode, diesel mode, etc.) as applicable (see 3.1.1).
The maximum continuous power available in gas mode is to be demonstrated.

Note: If a test load is performed in all applicable operation modes without interruption (direct changeover at same power and speed), the duration as required in UR M51.4.4 may be considered as the total duration demonstrated in all fuel modes. However, demonstration at each mode shall not be less than one hour.

The starting maneuvers required in UR M51.4.2 are to be carried out in diesel mode and gas mode, if applicable.

For DF engines, automatic switching over to oil fuel mode is to be tested.
Further, manual change over from diesel to gas mode and vice versa is to be tested.

~~For DF engines, the load tests referred to in UR M51.4.4 are to be carried out in gas mode at the different percentages of the maximum power available in gas mode (see 3.1.1).~~

The efficiency of the ventilation arrangement, or other approved principle, of the double walled gas piping system is to be verified.

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5. Certification of Engine Components

The principals, definitions, and general requirements of UR M72 apply.
In addition to those components specified in UR M72, the engine components listed in Table 3 shall be documented as listed in the table.

Table 3: Required documentation for engine components.

Part	Material properties	Non-destructive examination	Pressure testing	Visual inspection of welds	Component certificate
Gas pipe Low-pressure double walled	W(C+M)	W 2), 6)	W 4)	X	
Single walled Gas pipes	W(C+M)	W 1)	W 4)	X	SC
High-pressure gas pipes	W(C+M)	W 1)	W 4)	X	SC
Secondary enclosure for gas pipes	W(C+M)	W 2)	W 3)	X	
Gas pipe Low-pressure, Flanges*	W(C+M)	W 2), 6)		X	
Gas pipe High-pressure, Flanges*	W(C+M)	W 1)		X	SC
Gas pipe Low-pressure, Fittings and other components	W(C+M)		W 4)	X	
Gas pipe High-pressure, Fittings and other components	W(C+M)		W 4)	X	SC
Gas pipe Low-pressure Bodies of valves, 7)	W(C+M)		W 4)		
Gas pipe High-pressure Bodies of valves	W(C+M)		W 4)		SC
Gas venting pipes and flanges*, build up pressure less than 5.0bar	TR(C+M)	W 2)	W 4)	X	
Gas venting pipes and flanges*, build up pressure at 5.0bar or more with secondary enclosure	TR(C+M)	W 2)	W 4)	X	
Gas venting pipes and flanges*, build up pressure at 5.0bar or more	W(C+M)	W 1)	W 4)	X	SC
Gas venting pipes Secondary enclosure			W 5)	X	

Footnotes:
1) 100 % radiographic or ultrasonic inspection of all butt-welded joints (IGF Code 16.6.3.1)
2) 10 % radiographic or ultrasonic inspection of butt-welded joints (IGF Code 16.6.3.4)
3) Pressure test at 1.5 x design pressure to ensure gas tight integrity, not less than the expected maximum pressure at gas pipe rupture (as per IGF 16.7.3.4, and 9.8.4)
4) Pressure test at 1.5 x design pressure
5) Leak test.
6) If inside diameter > 75 mm or wall thickness > 10 mm: 100 % radiographic or ultrasonic inspection of all butt-welded joints (IGF Code 16.6.3.1)
7) If nominal diameter > 25 mm
(*) "Flanges" limited to the final connection to the engine.

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