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INFORMATION CONCERNING THE APPLICATION OF GAS ENGINES IN THE MARINE INDUSTRY

The International Council
on Combustion Engines

Conseil International
des Machines a Combustion

Contents

Information concerning the application of Gas Engines in the Marine industry

1 Motivation

Over the last few years gas-fuelled engines have become more popular also in the marine industry both for on-board power generation and propulsion duties. Whereas the use of gas-fuelled marine engines was originally limited to the gas-shipping trade (LNG tankers) they are now being applied in other ship types as well, mainly because of easier compliance with the stricter emission limits of NOx and SOx now being introduced all over the world. However gas fuels (LNG) holds further emission advantages (smoke, particulates), it is now becoming more available and at reduced prices. Therefore, the CIMAC Working Group "Gas engines" has prepared this information document about various aspects with gas fuelling of marine engines as this stands to-day, and at the same time pointing out that this technology is still in steady development.

2 Types of marine gas engines

2.1 Development background

Three main types of gas-burning engines are meanwhile available to the marine industry, further described in 2.2 below, and which come out of different development directions and hence with some different characteristics.

The spark-ignited "gas only" engines were first developed for the land-based power industry with simplicity and good overall performance at lowest total emissions as their prime requirements. These engines are dependent on permanent gas supply and initially came into the marine industry as engines for short-distance ferries.

The diesel-ignited gas engine with dual fuel capability was also originally developed for powerplant use where its ability to operate both on liquid and gaseous fuels at high specific power was a particular advantage. Development focus was originally on low NOx emissions at high loads, recently also on part load performance and variable speed capability. The diesel-ignited gas engine was the first type to establish itself in the marine industry and is currently the dominating engine type in this market.

The diesel gas engine with direct gas injection first came to use in the offshore industry where it's high fuel flexibility and very high power density was of prime attraction. This concept is unique in posing no particular requirements to the self-ignition stability of the fuel gas and its Diesel operating principle ensures that the combustion of the gas fuel is very complete, but at the cost of higher NOx emissions than other gas engine types. However, at the time of writing its use in the industry is still limited.

2.2 Marine gas engine particularities:

Gas burning engines operate according to two different principles, the "pre-mixed" Otto- and direct-injected Diesel cycles:

Otto Gas engines:

- o Spark-ignited gas engines ("gas only") with either carburettors or port injection of gas. These are "single-fuel" engines and must therefore for marine applications meet special redundancy requirements, - see under Sec. 4.1.
- o Diesel-ignited gas engines with conventional low pressure gas feed (as above) but with ignition by the injection of a certain quantity of Diesel fuel, also known as the "Otto DF" or "low pressure DF" principle. These will always need a certain quantity of diesel fuel for running even in Gas mode, but on the other hand they may also run on 100% liquid fuel (diesel- or HFO), i.e. dual fuel capability.

Otto Gas engines with their homogeneous combustion generally have low NOx emissions and high efficiency and will typically comply with the IMO Tier III limits without exhaust after-treatment. However, they require a certain stability of the fuel gas against self-ignition ("knocking", as expressed by the methane number MN) and they must be carefully developed in order to keep un-burnt gas ("methane slip") to a minimum. Spark-ignited and diesel-ignited gas engines show some differences in this respect, especially at part load.

Diesel Gas engines:

- o Here the fuel gas is directly injected at high pressure into the cylinder after the diesel pilot fuel has ignited. This is also known as "Diesel DF principle" or the "GD-principle", such engines have dual fuel capability and may also run on 100% liquid fuel (diesel-or HFO).

The Diesel Gas engines have diffusion burning which ensure good capability of burning gases with low knocking stability ("low MN") and at the same time producing low UHC emissions ("methane slip"). However they require a high-pressure gas system (typically 300 bar) and additionally exhaust after-treatment (EGR, SCR) is needed to comply with IMO Tier III NOx emission limits.

2.3 Some marine requirements to gas engines

Firstly, the ***base engine*** must meet all relevant Class/ IACS rules regarding its design, and which is not always given for a gas engine originally intended for stationary use.

- Further, gas-fuelled ***marine gensets*** need to comply with Class requirements regarding transient load response. This is normally expressed as a number of load-steps, -each given as a certain % of the rated load, and the limit is defined in *the accepted frequency drop and required recovery time back to stable conditions*. Another option is *the "AMC" approach*, i.e. an agreement between manufacturer and customer, in which the actual step loading and recovery time is specified. This is also accepted by the Classification Societies.
- Although of importance for marine drives, so far *no specific transient response- or variable speed requirements* have been put down yet in the Class rules for marine gas engines *in mechanical propulsion applications.*

Therefore, CIMAC would like to remind about the importance of the transient load capability when a Gas Engine is selected for marine propulsion. This is because most marine duties will include transient load changes as well as part- and low load operation, even over extended periods.

- The CIMAC WG "Gas engines" has issued a Position Paper which explains some of the issues concerning the transient response capabilities of Gas engines, and reference is made to that document.

Regarding differences between gas engine types in their characteristics, CIMAC would on a general basis like to point at some typical capabilities of each with particular relevance to Marine applications:

- o Port- or direct injected Gas engines (any type) generally have better transient and governing characteristics than mixture-charged ("carburetted") engines. They may also have practical advantages in fulfilling the requirements of double-walled gas piping systems for the installation in conventional engine rooms ("Gas safe").

- o Diesel-ignited gas engines ("Low-pressure DF") are best used in steady medium- to high load applications and with more than one engine connected to a suitable load management system to ensure this and limit the transients.

- o Diesel gas engines have part load and transient response characteristics similar to Diesel engines provided the fuel gas system is capable of handling such variable demand.

3 Transmission types

3.1 General

- So far, most vessels have been fitted out with electric transmissions, independent of Gas engine type.

  Benefits:
  - o This gives great operating flexibility while ensuring constant speed and limited load fluctuations for the engines.
  - o It also offers certain advantages with respect to redundancy requirements, as prescribed in the Classification rules, see Sec 4.1.

- Mechanical transmissions

  Benefits:
  - o These offer cost and simplicity advantages in the installation compared to gas-electric transmission.
  - o They give part-load efficiency advantages, so this is currently being considered for many Marine Gas Engine applications.

As already stated, mechanical transmissions require certain variable speed and load response capabilities from the Gas engine in question, and which must be taken into account if this system is selected (see 2.3).

4 Safety and Classification Issues

4.1 General

This is a comprehensive topic and only some general statements can be listed here. For details, reference is made to a special overview prepared by the CIMAC WG 2, the IMO rules as well as specific Class rules.

- Currently there are still no general and mandatory safety regulations available for Marine Gas Engines (MGEs), but IMO is developing an International Gas Fuel Code (IGF) which is based on the Interim Guideline MSC.285(86) of 2009. The work has been somewhat delayed and the current plan targets implementation in 2017.
- Until general and mandatory regulations are implemented, acceptance must be obtained from the actual Flag administrations in each case.

- Many of the internationally recognized Classification Societies have issued their specific sets of rules for MGE installations, which are either already applicable or out as preliminary drafts.
- The dominating philosophies in the current safety rules for MGEs are that of *avoiding danger of explosion* (see 4.2 below) *as well as maintaining the ship operational*; i.e. redundancy of propulsion power in case of a shut-down in the gas supply system (because of leakage or other reasons).
- This has so far lead to a *favoring of a "Dual Fuel" principle* or alternatively in the form of a *mixed propulsion system with a combination of Gas- and Liquid-fuelled engines* in order to be unaffected in case of such a shut-down.
- Ways of achieving similar redundancy for "Gas only" (SI) engines can be by placing the engines in two separate engine rooms each with separate gas supply, or to provide a means of back-up propulsion (PTI from a Diesel engine). Another solution which is currently in discussion in case of one single SI engine is to require *two fully separate gas feed systems from one LNG tank* (who in itself must fulfill strict requirements).
- Some type of mis-firing and/or knock detection is required by all Institutions and which brings the engine into a safe operating condition (load reduction, shut-down or others) in such a situation.

4.2 Explosion prevention / engine room ventilation

- This is a major topic in all safety rules, and which put down specific requirements to the venting arrangement as such, to the number of "air exchanges pr hrs", number and locations of gas detectors in the engine room, in the tank room, etc.
- For installation of Gas engine(s) in a normal engine room to be accepted, it will be required that engines have *double-walled Gas feed piping*, and this piping must be provided with venting of the space between the inner and outer pipe walls to a gas detection system. Alternatively, this space may be pressurized with nitrogen and monitored by pressure sensors. This allows for other equipment in such an engine room to be of conventional design (no EX requirements).
  This concept is often referred to as *"Inherently safe"* or *"Gas safe"* machinery space.
- An alternative solution is to place the engines in separate gas-tight and ventilated engine rooms which each has its own gas supply, required number of air exchanges pr hrs, is protected with gas sensors and has the required pressure-relief and escape ducting etc. This of course require an installation with two or more gas engines -preferably with electric transmission, and which otherwise may be of conventional design without double-walled gas piping system. Other equipment in the engine room may also be of conventional design. This concept has become particularly popular for small high-speed gas engines where *the entire gas engine set is enclosed in a Gas-tight container* and which is then placed in an otherwise conventional engine room.
- In case of a Gas leakage inside such a gas-tight engine compartment, the complete room (or module), -except for EX-certified equipment, is then shut off and vented to a safe area. Each such compartment is seen as an "Emergency Shutdown (ESD)-protected" or "Safeguarded" machinery space.

4.3 Use of Ex-proof electrical equipment

- This is another of the topics normally dealt with in the current Class rules, and which is largely influenced by the engine room ventilation and Gas sensing requirements as described in Sec. 4.2.
- ATEX requirements (like surface temperature limits, crankcase ventilation requirements etc) are already implemented in the general engine Class rules and which are requirements up front and there are so far no additional requirements for MGEs.

5 LNG tanks and gas systems in the ship

5.1 General

- Normally, vacuum insulated, pressurized, cylindrical "type C" tanks are used as fuel tanks on board Gas-fuelled vessels. Their advantage is ready availability, flexibility and ease of operation.
  For DF installations only one LNG tank is required and this is currently under discussion for "Gas only" SI engines also. These have so far required two separate tanks and gas feed systems, see 4.1.
- Evaporators are normally heated by a glycol circuit which again is heated either by engine cooling water, electrical, or in combination. Evaporators have up to now been placed in a box welded to the outer skin of the C-tank, named the "cold box". This cold box contains all inlets, outlets valves and evaporators needed to supply the engine/-s with a Gas at the specified conditions.
- There are special requirements in the Class rules for the tank itself as well as for the evaporator room with respect to location in the vessel, ventilation, Gas detection, pressure release, bunkering procedures, etc.

- Ahead of the engine, a Gas pressure control unit ("gas module") with necessary shut-off valves is normally installed. This unit must be specially enclosed, ventilated and protected with Gas sensors, as prescribed in the rules.
- Developments are ongoing in order to arrive at more space-efficient designs for the LNG tanks by integrating them into the ship structure, - referred to as types "A" and "B" tanks. One disadvantage is that these have only limited capability of maintaining pressure inside from evaporation of the LNG over time (0.7 barG).
- About tank space requirements: the LNG will require approx. *double the space of Diesel fuel* for the same fuel energy. Depending on the chosen tank solution*, the total size of the LNG tank may be 3 - 4 times bigger than an equivalent Diesel fuel tank.*
- Diesel Gas DF engines require a special gas feed system ahead of the engine and which is capable of providing the high pressure required by this principle (typically 300 bar). This will either be HP gas compressor(s) if the fuel is in gas phase; -or HP LNG pump(s) as well as HP LNG evaporator(s) if the fuel is compressed in the liquid phase. Double walling and special safety valves are required for the equipment involved.

6 About the composition of LNG

6.1 General

Experience shows that LNG "quality" (= composition) vary considerably of several reasons:

- By the *origin*
- Depending on if it is "*natural boil-off gas*" from top of a tank or: - if it is "*forced boil-off gas"* from the tank bottom, supplied through an evaporator.
- Because of *change in composition of the LNG in the tanks over time*, caused by gradual evaporation of the lightest fractions, referred to as *"LNG ageing*".

These are important factors, particularly for Otto Gas engines (DF and SI), and have to be considered when defining their nominal performance settings during projecting stages as well as during operation (preferably by monitoring the Gas composition). The engines need to be capable of coping with such variations by their control- and safety systems, see 4.1, which normally adjust critical operating parameters and/or the power if this is causing any operating issues (and ramps it back again) - although this may then lead to a temporary reduction in available power.

As already stated, Diesel Gas engines ("high pressure DF") are little influenced by such gas quality variations.

The CIMAC WG "Gas engines" has issued a Position Paper which points at some of the issues connected to the use of LNG as fuel and reference is made to that document.

- Studies of using other gas types as ship fuel has started as well, initially that of LPG, but any ship operation with this is not yet known to CIMAC. Safety issues connected to the use of "high flammability gases" as well as "gases heavier than air" are also being considered and may be included into the IMO IGF code at a later stage.

7 Emission issues

7.1 General

- LNG fuelling of ships is currently seen as one of the most promising ways of complying with future IMO Tier III NOx emission limits and which is already now being implemented within the ECAs (Emission Control Areas, currently including the North Sea, the Baltic Sea and the east- and west coasts of US and Canada). The introduction of more ECAs around the world is being discussed, and with that the interest in LNG fuelling is expected to spread even wider.
- Although not part of the IMO emission limits yet, there is increasing local focus on Smoke and PM emissions from shipping along coast lines and in harbor areas around the world. LNG fuelling is also here seen as a very good remedy to comply with such local regulations, if and when introduced.
- So far, not all Marine Gas Engines are covered by the general IMO emission limits which make no reference to "Gas only" engines, although an update of this is expected soon. The exception is in Norway, where a more complete set of emission limits have been put down for certain ship types (ferries) and which besides NOx include limits for un-burnt methane as well.
- It is considered that methane-fuelled high-efficiency Gas Engines are currently the best prime mover concept in terms of low CO2 emissions, and this is outlined in another Position Paper by this CIMAC Working Group, (in making).

8 LNG availability and logistics

8.1 General

- Over the last decade LNG trading and supply has increased very strongly. Locations and number of LNG terminals has spread around many parts of the world. However, it is not automatically given that a LNG terminal (for LNG trading) also is suitable as a bunkering station for LNG-fuelled general cargo ships. Hence, before changing to LNG fuelling of a new service route, one should check out suitable bunkering locations and travel distances when projecting and planning the design and capacities of the ships to be ordered.
- CIMAC is aware that there are talks about the possibility of making LNG bunkering facilities available at - or close to LNG trading terminals around the world. With such initiatives now being taken the LNG fuelling situation world-wide is expected further to improve.
- ISO is currently working on the standardization of bunkering equipment (hoses, couplings etc) with an aim to have this ready by the time the IMO IGF code is released.

9 Education and training of the crew

- This is becoming an increasingly important issue as LNG-fuelling of ships is gaining popularity around the world. Therefore, this issue is also part of the scope of work concerning the coming IMO IGF code.

10 Attractive ship types for LNG fuelling

10.1 General

This is steadily developing, but already some trends can be seen about attractive ship types for LNG fuelling:

- Ships in the LNG trade; i.e. big and small LNG tankers of various designs
- Various ship types for the Oil and Gas industry
- Coastal and "short sea" ships like:
  ferries and passenger vessels
  harbor and coastal tugs and workboats
  coastal cargo and "container-feeder" vessels

10.2 Future trends

It is likely that both the number of ECAs around the world will increase and the availability of LNG as a marine fuel will improve. On that background one can expect most types of ships to be considered for LNG fuelling and among the promising candidates are:

- Bigger RoPax ferries on fixed routes
- Cruise vessels
- Vessels for Inland waterways
- Larger vessel types (container, tankers etc) for "long sea" operation are also being considered.

In the case of LNG-fuelled RoPax ferries discussions are currently on-going about the bunkering procedures for these in case of simultaneous off- and on-loading of passengers and cars during their limited harbor resting times.

11 References:

There are already many important documents and papers available which deal with Gas engines in marine applications and related topics. Particular attention is drawn to the following:

[1] CIMAC WG 17 "Gas engines" Position Papers:

"Information about the use of LNG as engine fuel"
"Transient response behaviour of Gas engines"
"Methane and formaldehyde emissions from Gas engines" (in progress)

[2] IMO Guideline and Codes:

Interim Guideline MSC.285(86) of 2009
International Code for Gas Carriers (IGC)
International Gas Fuel Code (IGF), to be released in 2014.

[3] IACS Unified Requirements:

M59 "Control and Safety Systems for Dual Fuel Diesel Engines"

[4] Classification Rules:

See the specifics from the various Class societies