Propulsion of LNG Carriers by MAN B&W Two-Stroke Diesel Engines

-ME and ME-GI Diesel Engines for LNG Carriers

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Propulsion systems of LNG carriers have, until now, been dominated by steam turbine plants. However, MAN B&W Diesel has recently succeeded in getting orders for two-stroke diesel engines in LNG carriers, and a general change from steam turbine propulsion to other types of propulsion seems under way as shipyards update LNG carrier designs. MAN B&W Diesel offers two different two-stroke diesel engine solutions for propulsion of LNG carrier, viz. an ordinary fuel oil diesel engine with a reliquefaction plant, and a dual fuel ME-GI diesel engine. This paper provides a general description of these solutions, focusing on items that make them different from ordinary ME two-stroke diesel engines, and of the installation thereof.

1. Introduction

Until the end of 2004, there was still one market for ocean-going cargo ships to which the two-stroke engine had not yet been introduced, viz. the LNG market. This market has, so far, been dominated by steam turbines, but the first orders for two-stroke diesel engines were given at the end of 2004. Today, 16 x 6S70ME-C engines have been ordered for eight LNG carriers. For these plants, the boil-off gas is returned to the LNG tanks in liquefied form via a reliquefaction plant installed on board.

Furthermore, MAN B&W Diesel has introduced an alternative two-stroke solution, viz. the dual fuel ME-GI (Gas Injection) engine. This engine operates on a 250 bar gas pressure supplied via a compressor station.

The optimal solution for a given project depends primarily on the price of HFO and the price of the natural gas when sold. Calculations carried out by the author's company show that about USD 3 mill. is saved in operational costs per year when using two-stroke diesel engines for LNG carriers.

The HFO diesel engine solution combined with a reliquefaction plant has the same cost level as the steam turbine solution, whereas the dual fuel ME-GI engine with compressor(s) is a cheaper solution.

2. Two-Stroke Diesel Engines for LNG Carriers

The two-stroke diesel engine programme of MAN B&W Diesel fully covers the diesel engines which are appropriate for LNG carriers both in regard to power and rotational speed. The 60, 65 or 70 bore engines as either ME or ME-GI engines are appropriate for a twin engine installation, while the 90 and 98 bore engines are relevant for a single engine installation.

Fig. 1: Engine power for LNG carriers

The two-stroke diesel engines will, on a routine basis, require more maintenance than normally seen on steam turbine plants. However, both a single two-stroke diesel

engine with redundant propulsion in form of an electric shaft motor or twin two-stroke diesel engines in a twin-skeg solution allow maintenance to be performed without immobilising the LNG carrier.

Furthermore, a propulsion solution with two diesel engines in separate engine rooms and with two propellers fulfils the absolutely strictest regulation concerning propulsion redundancy from the classification societies, for instance DNV-RPS. The relevant ME(-GI) diesel engines for LNG carriers from 150,000 m³ and upwards are shown in Table 1.

Size	One propeller	Two propellers
150,000 m ³	8K90ME (32 MW)	2 x 7S60ME-C (2 x 16 MW)
175,000 m ³	8K90ME (34 MW)	2 x 6S70ME-C (2 x 17 MW)
200,000 m ³	7K98ME (37 MW)	2 x 7S70ME-C (2 x 18 MW)

Table 1: ME(-GI) engines for LNG carriers (speed: 20 knots)

3. Reliquefaction and ME Engines

3.1 Two-stroke Diesel Engines

The reliquefaction of the boil-off gas in a reliquefaction plant placed on deck and the absence of gas in the engine room cause that ordinary HFO two-stroke diesel engines become the obvious choice for propulsion of LNG carriers. The performance, reliability and the economic advantages of the two-stroke diesel engines are already well-established and documented by a market share in excess of 90% for other types of cargo ships.

3.2 Reliquefaction Technology

Reliquefaction is widely used in gas handling on land and onboard LPG Carriers, where heavier hydrocarbons, as butane, are reliquefied.

Recently, the technology for reliquefying LNG on board ships has been matured and commercialised. The description below is based on the Moss Reliquefaction, sold worldwide

by Hamworthy KSE, Ref. [1].

The patented system (Moss RS) for reliquefying boil-off gas, establishes a solution for pumping LNG back to the tanks and delivering more LNG to the buyers of gas.

Fig. 2: Standard Moss RS reliquefaction system

The boil-off gas reliquefaction concept is based on a closed nitrogen cycle extracting heat from the boil-off gas. Several novel features such as separation and removal of incondensable components have resulted in a compact system with low power consumption.

The concept has the following technical merits:

- The nitrogen in the LNG boil-off gas (BOG) is not reliquefied; this results in reduced nitrogen in the tanks during the voyage, better control of tank pressure and lower power requirement for the RS system.
- The system uses only proved components with extensive references from air-separation and peak-shaving plants worldwide.
- The system is prefabricated on skids for easy installation and hook-up.
- The system has automatic capacity control.
- The system can be stopped when the cargo pumps are in operation. This eliminates the need for extra generator capacity.
- During ballast voyage, the cargo tank temperature can be maintained by spraying reliquefied LNG back into the cargo tanks. Thus, the charter/owner can enjoy a big advantage by increasing unloaded cargo.

The process can be described as follows: The LNG boil-off is compressed by the low-duty (LD) compressor (BOG

compressor), and sent directly to the so-called cold box. The cold box in which the boil-off is reliquefied is cooled by a closed refrigeration loop (Brayton cycle) with nitrogen as the working medium.

Redundancy for handling of the boil-off gas is required by the International Class Society Associations (IACS). This requirement can be fulfilled by one of the following options:

- 1 x 100% Reliquefaction plant + Thermal oxidiser or flare system capable of burning the maximum boil-off rate
- 2 x 100% Reliquefaction plants
- 3 x 50% Reliquefaction plants

In addition to the eight references mentioned earlier, this technology has been used on a land-based liquefaction plant in Norway since March 2003. The land-based plant deviates somewhat from a reliquefaction plant onboard an LNG carrier in the cargo cycle. However, the nitrogen cycle and cold box are equivalent to those in a reliquefaction plant on an LNG carrier.

4. ME-GI Diesel Engines

4.1 General Design of the ME-GI Diesel Engines

The GI (Gas Injection) technology is an add-on package to the ME engine. This means that the ME-GI engine in terms of engine performance (output, speed, thermal efficiency, auxiliary systems, etc.) is identical to the well-established ME engine series both in pure fuel oil and dual fuel mode.

The ME-GI dual fuel diesel engine is based on the diesel process meaning that the compressed boil-off gas is injected into the cylinder at the desired time for combustion and after, and only after, a pre-injection of pilot oil has taken place. The ME-GI diesel engine is, thereby, indifferent to the LCV or methane number of the boil-off gas.

The mechanical parts for the GI engines, the additional auxiliary system and the safety system are based on the experience gained from the dual fuel 12K80MC-GI diesel engine built by Mitsui Engineering & Shipbuilding Co. and installed in the Chiba power plant in the Tokyo area (Fig. 3).

Fig. 3: 12K80MC-GI in operation, since 1994

The control system of ME-GI will allow any ratio between fuel oil and gas, however, with a minimum fuel amount to be used for pilot injection. The electronically system controls the gas injection and ensures that the amount of gas is not overdosed, compared to the desired engine output, or that more gas than available from the boil-off is consumed by the engine.

The control system for the ME engine will then simply add up with the necessary fuel oil to maintain the desired engine speed and adjust the fuel oil amount within revolutions to any deviation in the supply of fuel gas.

The fuel modes of the dual fuel ME-GI diesel engine are shown in Fig. 4.

Fig. 4: Fuel modes: 1. Fuel oil only, 2. Pilot oil only and 3. Specified gas

4.2 New and Modified Engine Parts

The cross-section of an S70ME-GI with new or modified parts of the ME-GI engine is shown in Fig. 5. The mechanical modifications consist of double-wall gas supply pipes, a large-volume accumulator block on each cylinder, a cylinder cover with two gas injection valves, modified Hydraulic Cylinder Units (HCU) with an ELGI (Electronically Gas Injection) valve for hydraulic actuation of the gas injection valves.

The exhaust gas receiver is strengthened to withstand uncontrolled ignition of gas in the event of a malfunction of an exhaust gas valve. Furthermore, the following modifications of pipes are required: Pipes for sealing oil to the gas injection valves, Hydraulic pipes from the HCU blocks to the gas injection valves, Pipes for ventilation air, Pipes for nitrogen purging and minor modification to the manoeuvring system.

Fig. 5: New or modified parts on the ME-GI engine

The gas for the ME-GI engine is supplied by a common gas pipe and with branches to each of the accumulator blocks on the cylinders. The gas injection valves and the combustion chamber are then supplied by gas from the accumulator block via bores in the cylinder cover.

The accumulator blocks have a gas volume, which contains approximately 20 times the gas amount required by a gas injection at full engine load. The gas pressure in the accumulator block falls to a pre-determined level during a normal gas injection. Abnormalities in the injected gas amount can, thereby, immediately be detected by measuring

the gas pressure in the accumulator block. The accumulator block is also equipped with a gas shut-off valve, a gas blow-off valve and a valve for nitrogen purging of the gas system.

Fig. 6: Gas injection valve

The gas injection valve complies with the traditional design principles of compact design and the use of mainly rotational symmetrical parts. The gas injection valve is actuated for open/closed position by control oil from the 200 Bar hydraulic oil system. The difference between the gas supply pressure and the cylinder pressure will be the driving force in the gas injection. The control oil and gas are separated by pressurised sealing oil in order to ensure that gas does not leak into the control oil system.

The time for gas injection and length of it (= power) is controlled electric-hydraulically by the ELGI valve as can be seen from Fig. 7.

Fig. 7: ME-GI fuel injection system

The normal FIVA-valve of the ME engines controls the fuel oil pressure booster, which supplies pilot and add-up fuel oil in the dual fuel operation mode.

The electrical actuation of the ELGI valve is restricted until pilot oil injection has taken place in order to eliminate the risk of unburnt gas in the exhaust gas receiver.

4.3 Control Unit Hardware

The dual fuel control system for the ME-GI engines is based on software and hardware developed by MAN B&W Diesel. The actual number of controllers depends on the number of cylinders of the engines. The function of the controller types is mentioned below:

(Gas Engine Control Unit): The GECU monitors the conditions of the auxiliary system and the network connections and calculates the fuel gas index.

(Gas Cylinder Control Unit): The GCCU controls the ELGI valves based on the fuel gas index signal from the GECU.

(Gas Auxiliary Control Unit): The GACU contains facilities necessary for the control of sealing oil, ventilation and the inert gas system.

(Gas Cylinder Safety Unit, PMI on-line): The GCSU monitors the cylinder pressure, the fuel oil injection pressure, the accumulator gas pressure during injection, etc. of the individual cylinders. In the event of abnormalities, the GCSU will send a dual fuel stop signal to the GSSU.

(Gas Safety System Unit): The GSSU monitors all auxiliary systems and Hydrocarbon sensors. The GSSU will, in the event of abnormalities, overrule any other signals and a fuel gas shut down signal will be released.

4.4 Auxiliary System for ME-GI Engines

The ME-GI diesel engine requires additional auxiliary systems in addition to the normal cooling, lubrication, starting air and fuel oil system. The systems are:

- Double-wall ventilation air system
- Sealing oil system
- Inert gas system
- Gas supply system

4.4.1 Double-Wall Ventilation Air System

The purpose of the ventilation system is to ensure that the outer pipe of the double-wall gas pipe system and the assemblies on the engine are ventilated by air. Ventilation is achieved by means of an electrically driven mechanical fan, which keeps the pressure in the outer pipe below that of the engine room and ensures approx. 10 air changes per hour. The ventilation system is equipped with Hydrocarbon detectors for detection of gas leakages.

4.4.2 Sealing Oil System

The sealing oil system consists of two small redundant pumps, which supply sealing oil to the gas injection valves and ensure complete separation between the gas and control oil. The pressure of the sealing oil is 25-50 Bar higher than the gas pressure. The leakage of sealing oil into the gas corresponds to an oil consumption of less than 0.1 g/BHPH.

4.4.3 Inert Gas System

The complete gas supply system and ME-GI diesel engine will after a normal engine stop signal, compressor stop signal or in the event of abnormalities be purged by an inert gas (N_2 , CO_2). The natural gas will in that case be released to a safe position on the vessel and the gas system is purged until non-explosive mixture is present.

4.4.4 Gas Supply System

The gas supply system is by far the biggest difference between an ME engine and an ME-GI engine. The gas supply system will not only be able to deliver gas for the ME-GI engine at the correct pressure, but will also ensure that the pressure in the cargo tanks is kept stable at the desired level and that any excess gas is burnt in a Gas Combustion Unit

The gas compressor system consists of:

- Low-pressure gas compressors (LP)
- High-pressure reciprocating compressor (HP)
- Cooling system for reciprocating compressor
- Buffer tank to smoothen fuel gas supply pressure
- Capacity control system and safety system
- Gas Combustion Unit (GCU)

Fig. 8: Gas supply system

The layout of the Flotech™ packaged compressor system is shown in Fig. 8. The redundancy of the compressor system is, in this example, kept simple by only using one high-pressure reciprocating compressor. This is sufficient, since the ME-GI engines can operate on fuel oil and the boil-off gas can be burnt in the Gas Combustion Unit(s). The low pressure compressors will be based on a fully redundant solution, since they are used to control the cargo tank pressure.

The dimensioning of the compressor capacities depends on the requirement by the operator. The capacities can either be dimensioned for the maximum boil-off rate or for the maximum engine load (forced evaporation of LNG).

Stable control of cargo tank pressure is the primary function of the LP compressor control system. The capacity variation is achieved by a combination of compressor speed variation and gas discharge to recycle.

The discharge pressure of the LP compressor will be between 3 and 5 Bar(a) depending on the balance between evaporated gas and gas consumed by the engine. The control system of the HP compressor has a limiting set-point of lower inlet gas pressure of approximately 3 Bar(a) ensuring that the HP compressor and diesel engines do not use more gas than available. The GCU will, in a similar way, be triggered by a high discharge pressure from the LP compressor ensuring that the correct amount of excess boil-off gas is burnt in case of low consumption by the diesel engine(s).

The balancing between delivery of gas from the HP compressor and consumption by the diesel engines will be based on a difference in the set-points for the desired gas pressure of the two parts. This ensures that the control

system of the diesel engine(s) and gas compressor system is completely separated and that they function independently of each other.

The only signals being transferred between the diesel engines and the compressor system are availability signals and the desired level of gas outlet pressure as a function of the engine load.

The compressor system are protected by a series of Pressure High, Pressure Low, Vibration High, Liquid level High/low,... sensors. which will automatically shut down the compressor(s), if a fault is detected by the local control system.

5. Summary

The well-known two-stroke diesel engines of MAN B&W Diesel are viable solutions for propulsion of LNG carriers both as ordinary ME diesel engines with a reliquefaction plant or as dual fuel ME-GI diesel engines.

References

- [1] "Two-stroke Diesel Engines and Reliquefaction Systems for LNG Carriers", P. Skjoldager, MAN B&W Diesel A/S, T. Lunde and E. Melaaen, Hamworthy KSE Gas Systems, The Motorship Conference 2003

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