



Marine Diesel Engines

How Efficient can a Two-Stroke Engine be?

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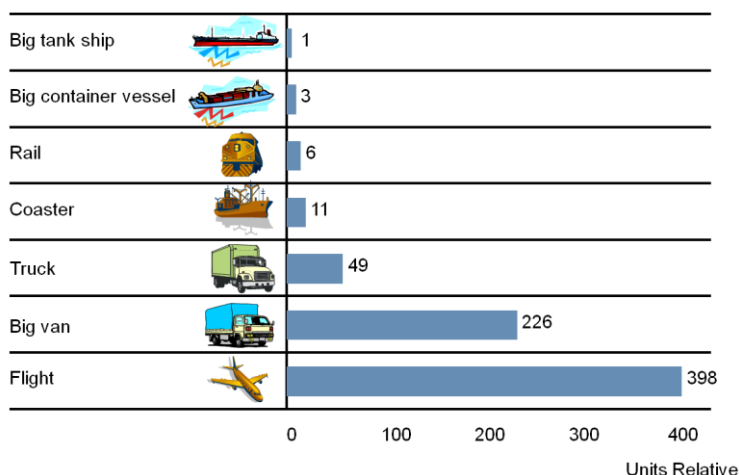
Summary. The coming political demands for reduction of the CO₂ emissions for merchant ships may cause many attractive, but also more expensive, countermeasures on ships, as for example waste heat recovery systems. However, one of the major parameters – not to forget – is the aft body design of the ship itself and its propeller in combination with a reduced design ship speed. For example, the combination of a reduced ship speed and an increased propeller diameter and/or a changed number of propeller blades may reveal many new possible main engine selections not normally used for container ships. Thus, the reliable and high-efficiency super long-stroke MAN B&W two-stroke main engine types such as the S80 and S90 normally used for tankers may also be attractive solutions for some container ship designs of tomorrow, with around 30% reduced CO₂ emissions per voyage compared with the ships of today. Additionally, the use of liquid natural gas (LNG) instead of heavy fuel oil may reduce the CO₂ emission by approximately 23% owing to the different chemical makeup of LNG. MAN B&W dual fuel two-stroke ME-GI engines are available to cater for this demand.

Introduction

One of the future goals in the marine industry is to reduce the impact of CO₂ emissions from ships in order to meet the coming stricter International Maritime Organisation (IMO) greenhouse gas emission requirements. Two CO₂ emission indexes are being discussed at IMO, an ‘Energy efficiency Design Index’ (EEDI) and an ‘Energy Efficiency Operational Indicator’ (EEOI).

The EEDI is used to evaluate the engine and vessel design and the EEOI is used to guide the operator in developing the best practices on board. The goal is to design future ships with a design index to be stepwise reduced in the period from 2012 to 2018 to a maximum level of possibly 70% compared with the 100% design index valid for average designed ships of today. However, it should be emphasised that neither goal nor indexes are definite yet, June 2009.

As a reduction in CO₂ emission is roughly equivalent to a reduction in fuel consumption, the goal for the manufacturers will roughly correspond to a 30% reduction in fuel consumption per voyage of future ships in normal, average service. CO₂ caused by shipping amounts to only 4% of the global scale load. In addition, shipping, in terms of transporting one ton of cargo one mile, has the lowest CO₂ emission compared to all conventional forms of transportation. These values also apply to the fuel consumption and the levels of other pollutants. Nevertheless, shipping can further contribute to improving efficiency, and reducing emissions.



The pollutants in the exhaust gas of two stroke marine engines consist predominantly of:

1. Carbon Dioxide (CO₂), which is reduced by improving the overall efficiency of the engine, and thus fuel consumption. This also includes improvements in:
 - a. Mechanical efficiency
 - b. Thermal efficiency
2. Nitrogen Oxides (NO_x), which are formed during combustion, and can be reduced by the following methods:
 - a. Regulation of the fuel injection (rate shaping)
 - b. Water in Fuel emulsion (WIF)
 - c. Humidification of the scavenge air (Scavenge Air Moistening - SAM)
 - d. Exhaust Gas Recirculation (EGR)
 - e. Selective Catalytic Reduction (SCR)
3. Sulphur Dioxide (SO₂), which can be reduced by low-sulphur fuel, or scrubbing processes.
4. Particulate Matter (PM), caused by nucleation and subsequent agglomeration of Carbon during combustion of Heavy Fuel Oil or Marine Diesel. Removal of PM can be achieved by particle filters or scrubbing processes.

Improving the overall efficiency of the two stroke marine engine

In general, the larger the propeller diameter, the higher the propeller efficiency and the lower the optimum propeller speed. Referring to an optimum ratio of the propeller pitch and propeller diameter, the corresponding propeller speed will be reduced and the efficiency will also be slightly reduced, when increasing the propeller pitch, depending on the degree of the changed pitch. The same is valid for a reduced pitch, but here the propeller speed will increase. Thus as low as possible a propeller speed (within design restrictions of the ship) is desirable, but some tuning can be done without significantly affecting the propulsion efficiency. This is important to always consider as a starting point, and MAN Diesel has numerous variants of their two-stroke MAN B&W engine designs available to match the requirements for propeller speed of the particular vessel in direct drive configurations.

The efficiency of a two-stroke main engine particularly depends on the ratio of the maximum (firing) pressure and the mean effective pressure. The higher the ratio, the higher the engine efficiency, i.e. the lower the Specific Fuel Oil Consumption (SFOC). Furthermore, the larger the stroke/bore ratio of a two-stroke engine, the higher the engine efficiency. This means, for example, that a super long-stroke engine type, e.g. an S80ME-C9, will have an even higher efficiency compared with a short-stroke engine type, e.g. a K80ME-C9.

Compared with a camshaft (mechanically) controlled engine, an electronically controlled engine has more parameters which can be adjusted during the engine operation in service. This means that the ME/ME-C engine types, compared with the MC/MC-C engine types, have relatively higher engine efficiency under low NO_x IMO Tier II operation. When the design ship speed is reduced, the corresponding propulsion power and propeller speed will also be reduced, which again may have an influence on the above-described propeller and main engine parameters. The following is a summary of the major parameters described:

Propeller

- Larger propeller diameter involving:
 - Higher propeller efficiency
 - Lower optimum propeller speed (rpm)
- Lower number of propeller blades involving:
 - Slightly higher propeller efficiency
 - Increased optimum propeller speed(rpm) (from 6 to 5 blades means approximately 10% higher rpm)

Main engine

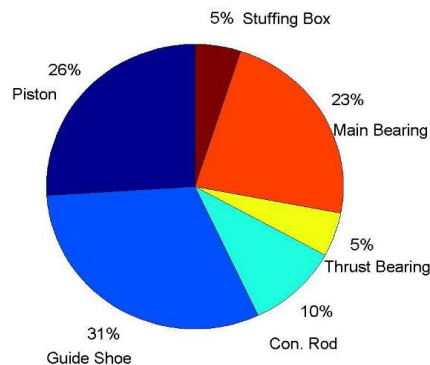
- Increased p_{\max}/p_{mep} pressure ratio involving:
 - Higher engine efficiency (e.g. by derating)
- Larger stroke/bore ratio involving:
 - Higher engine efficiency (e.g. S-type engines have higher efficiency compared with K-type engines)
- Use of electronically controlled engine instead of camshaft controlled:
 - Higher engine efficiency (improved control of NO_x emissions)

Ship with reduced design ship speed

- Lower propulsion power demand and lower propeller speed.

Improving the mechanical efficiency of the two stroke marine engine

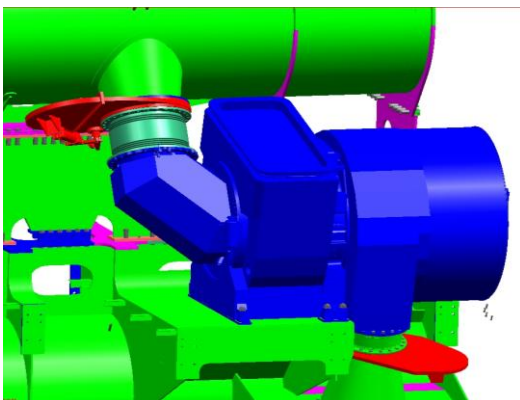
The key issue in improving the mechanical efficiency of the engine is reducing friction on all moving parts. As shown in figure 2, the dominating causes for frictional losses are the piston ring package and the guide shoe bearing. Therefore MAN Diesel has successfully implemented low friction guide shoe bearings, reducing friction in this area by 20%



Improving the thermal efficiency of the two stroke marine engine

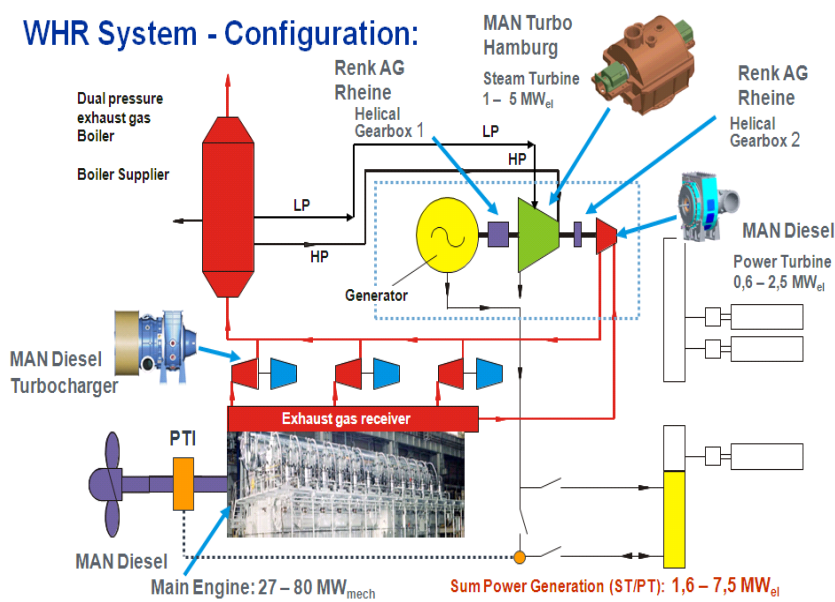
Various techniques & technologies can be applied to the modern day two stroke marine engine in order to improve the thermal efficiency:

- Auto-tuning; is a control technique that can be applied to the engine to maintain optimal operating conditions during operation. This is achieved by increasing the individual maximum cylinder pressures (P_{max}) so that they are closer to the limit specified for the engine. Thereby achieving a potential gain in P_{max} of 5-10 bar on an average maintained engine. A 5-10 bar gain in P_{max} can give up to 1-2 g/kWh reduction in fuel consumption.
- Low load operation (reduction of ship speed); can be set up in electronically controlled engines, whereby an optional 'Low load' running mode, will optimise the engine to run at a lower engine load, thus giving a further reduction in SFOC of 1-2 g/kWh. In addition to the SFOC reduction, a slower sailing speed will also significantly reduce fuel consumption, for example a reduction from 25 knots to 20 knots will result in only a 40-50% propulsion power requirement.
- Turbocharger cut-out; provides the possibility to cut-out a turbocharger when running at lower loads, and thereby reduce SFOC by up to 5g/kWh.



- Variable Turbine Area turbocharger; allows for dynamic load optimisation of the engine, by adapting scavenge air delivery to demand continuously, at all engine loads and speeds. This reduces fuel consumption up by up to 3 g/kWh.
- Waste Heat Recovery (WHR); exploits the heat lost in the exhaust gasses, and converts it into electricity for use on board the vessel, thereby reducing fuel consumption for auxiliary engines by up to 10%.

WHR System - Configuration:



Niels B. Clausen, born in 1965, graduated as a mechanical engineer from the Technical University of Denmark in 1989. For next three years he was employed by the Danish consultancy company Carl Bro A/S and worked as a consulting engineer within the field of design of mechanical systems for various companies in the Danish industry. In 1992 he joined MAN Diesel, Copenhagen, with engine installation and engine application as his working field. Through this work Mr Clausen has been heavily involved in numerous investigations of various propulsion system installations for a wide range of merchant ships. In 2002 Mr Clausen was appointed Manager of the Marine Installation department. In 2006 Mr Clausen completed an MSc degree in Marine Technology (Marine Engineering) with distinction from the University of Newcastle in England after having undertaken post graduate studies along with his usual business activities at MAN Diesel. Later in 2006 Mr Clausen was appointed Personal Assistant to the Senior Vice Presidents of R&D and Engineering. In 2007 Mr Clausen was appointed Senior Manager of Engine and System Application. In 2008 Mr Clausen was given overall responsibility for coordination of MAN Diesel's contribution to the project "Green Ship of the Future". In "Green Ship of the Future" MAN Diesel collaborates with Danish ship owners, shipyards, marine equipment suppliers, consultants, and research institutes on developing environmentally sustainable solutions for the propulsion of ships.