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REVIEW ON THE ATYPICAL SYSTEMS OF SLOW-SPEED TWO-STROKE MARINE ENGINES

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ABSTRACT

This Article provides a review of the varying systems of slow-speed, two-stroke marine engines. The paper begins with the operating principles of the typical two-stroke engine cycle employed in these engines, highlighting the intake, compression, combustion, and exhaust strokes. It then continues with defining and describing other unconventional systems rarely found on engines of different sizes and applications. The focus of the study case is on the systems that prevent pollution, as well as various other systems observed in larger marine engines.

Keywords: two-stroke, naval engines, slow-speed, pollution, engines

1. INTRODUCTION

For over a century, marine engines have been the primary source of propulsion for merchant ships. In today's context, these engines are predominantly low-speed, two-stroke, crosshead-type, reversible, flow-scavenged, turbocharged, and electronically controlled. The two-stroke cycle is employed to maximize power-to-weight ratio, minimize engine size, and enable reversibility.[1]

The specific requirements of marine engines, such as the need for low speeds and high piston travel, have led to the development of specific design features not seen in other engine variants. The marine engines have a high stroke-to-bore ratio, which necessitates the use of a crosshead. Turbocharging is an essential aspect of these engines due to the two-stroke cycle and the long stroke. Furthermore, electronic engine control is necessary to achieve flexible tuning optimized across different load ranges. This, combined with the relatively low production volumes in the merchant shipbuilding market, makes low-speed engines highly customized for each application.

The primary market requirements that significantly influence the design of marine Diesel engines are as follows:

- **Engine Power**: The essential requirement for propelling a vessel at a specific speed is the engine power.
- **Engine Speed**: In order to maximize propulsion efficiency with propellers of considerable size as allowed by the vessel design, the required engine speeds are very low compared to other industry segments. To achieve these low speeds, typi-

cally ranging from 1 to 2 Hz, the engine designer selects high stroke-to-bore ratios.

• **Expected Lifetime**: The expected lifetime of a marine two-stroke engine is at least ten times longer than that of an automotive engine.

Requirements that are of equal importance and are commonly shared among various engine industries include adhering to national and international emission regulations, minimizing fuel and lube oil consumption, ensuring reliability, enhancing service friendliness, and reducing manufacturing costs.

2. CHARACTERISTICS OF LARGE TWO-STROKE MARINE ENGINES

Presently, most large marine engines are primarily defined by their prevailing features, namely low-speed operation, two-stroke functionality, crosshead design, reversibility, flow scavenging, turbocharging, and electronic control. These notable attributes define the modern landscape of large marine engine.

Large diesel marine engines typically operate at speeds ranging from 50 to 200 RPM [9]. However, the exact operating speed can vary depending on the specific engine design, application, and vessel requirements.

2.1 OPERATIONAL SPEEDS

Low-speed diesel engines (also known as slow-speed engines) are used in large marine vessels such as container ships, oil tankers, and bulk carriers. These engines have a maximum operating speed of around **50-200 RPM**.[2]

On the other hand, **medium-speed** diesel engines are commonly found in smaller vessels like ferries, fishing boats, and offshore support vessels. They typically operate at speeds ranging from **500-1,000 RPM**. Medium-speed engines strike a balance between fuel efficiency, power output, and compactness.

High-speed diesel engines are primarily used in smaller vessels like pleasure boats, yachts, and speedboats. These engines can operate at speeds exceeding **1,000** RPM, sometimes reaching up to **3,000** RPM or more. High-speed engines offer higher power density and are suitable for applications where space and weight considerations are extremely important.[2]

2.2 TWO-STROKE CYCLE

Most marine engines, not just diesel marine engines, work on the Miller cycle or Atkinson cycle, which accomplish both strokes in one complete revolution of the crankshaft. The first differences between marine two-stroke engines and the more typical counterparts can be seen here, in the admission ports. The exhaust may be via ports adjacent to the airports and controlled by the same piston (loop scavenge) or via piston-controlled exhaust ports or poppet exhaust valves at the other end of the cylinder (uniflow scavenge) as seen in Fig.1. The principles of the cycle apply in all these cases.

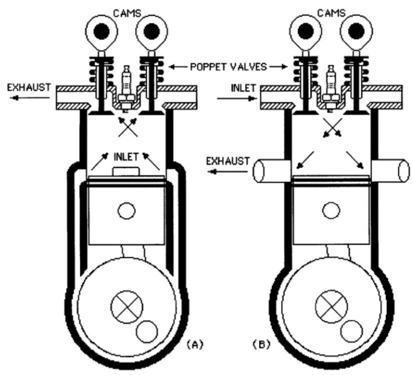

Fig. 1. working principle of uniflow intake and exhaust system

The schematic below demonstrates the different stages of a diesel uniflow scavenged, two-stroke engine cycle:

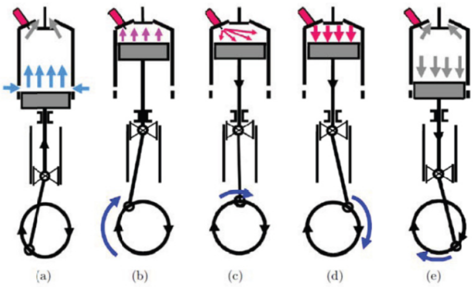

Fig. 2. working principle of uniflow intake and exhaust system

(a) The piston starts at BDC. Both the scavenge inlet ports, and exhaust valves are open. Fresh air is entering the cylinder and exhaust gasses are being scavenged through the exhaust valves.

(b) The piston moves towards TDC, blocking the scavenge ports and compressing the air.

(c) The fuel is injected in the sealed compression chamber, before TDC is reached. There, the fuel is mixed with the air and the mixture self-ignites once TDC is reached. The arrangement and number of Injection nozzles varies from by design.

(d) When the necessary temperature and pressure is reached, combustion occurs causing the piston to move towards BDC, executing the power stroke.

2.3 TURBOCHARGING

Compared to four-stroke engines, using a turbocharger in two-stroke engines is a more complicated task. This complexity arises due to start-up limitations of the turbocharger. At low engine loads, the exhaust gases do not possess enough kinetic energy to drive the turbocharger at the necessary speed to achieve the required airflow.

Two-stroke engine turbocharging is accomplished through two distinct methods known as the "constant pressure" and "pulse" systems.[3]

In **constant pressure** turbocharging, the exhaust gases from each cylinder are collected and directed into a **common exhaust manifold**. From the manifold, the gases flow into a turbine of a turbocharger. The turbine is driven by the energy of the exhaust gases, causing it to spin and power a compressor on the other end of the turbocharger.

In **pulse system** turbocharging, each cylinder of the engine is equipped with its own **individual exhaust manifold** and turbocharger (Fig. 3.). The exhaust gases from each cylinder are directed to their respective turbochargers rather than being combined into a common receiver.

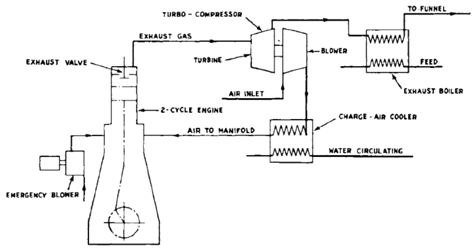

Fig. 3. Working principle of a two-stroke constant pressure turbocharged engine [3]

2.4 USE OF A CROSSHEAD

In two-stroke marine engines, the crosshead design plays a crucial role in ensuring smooth and efficient operation. Typically seen on larger models, the crosshead serves a mechanical linkage between the piston rod and the connecting rod, facilitating the **conversion of linear motion** into rotational motion. By doing so, it helps **reduce the wear** and tear on the engine's main bearings. Another advantage of the crosshead design in two-stroke marine diesel engines is its contribution to effective lubrication. The crosshead and guide interface can be supplied with lubricating oil, helping reduce friction and wear at this critical contact point.

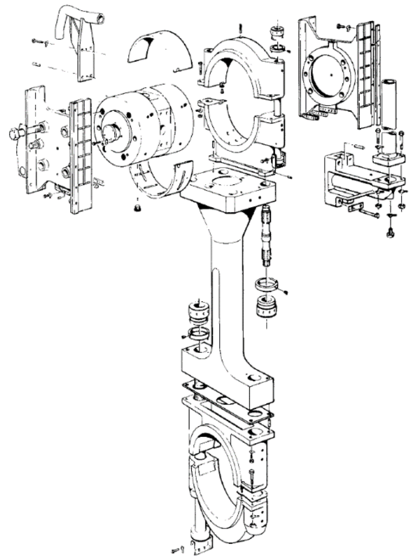

Fig. 4. Exploded view of a crosshead from a Burmeister and Wain Engine [3]

2.5 TYPES OF SCAVENGING SYSTEMS

There are mainly three types of scavenging systems used in two-stroke marine diesel engines: Cross-Scavenging, Loop-Scavenging and Uniflow Scavenging.
In the **cross-scavenging** system, the scavenge/air intake is on the opposite side of the cylinder exhaust port, as seen in Fig. 5. Both the intake and exhaust ports are opened and closed by piston during its motion. The exhaust port opens before the intake port, and some portion of exhaust gases, being at higher than atmospheric pressure, leave the cylinder. Then, piston uncovers the intake port. The piston gets a special shape which directs the airflow up towards the cylinder head, and then down to the exhaust port, removing the exhaust gases.[2]
The **uniflow scavenging** system is by far the most efficient and widespread system.

Here, the intake ports are situated near the BDC of the piston. An exhaust valve is used to control the exhaust ports, while intake ports are controlled by the moving cylinder head.

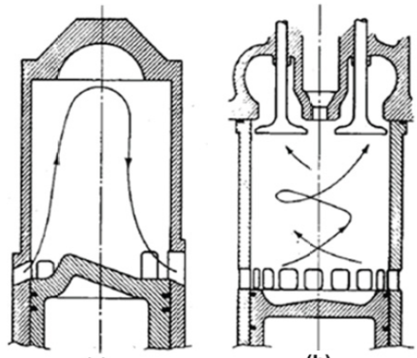

Fig. 5. Schematic pictures of types of scavenging: (a) – Cross Scavenging, (b) –Uniflow scavenging [2]

As discussed before, the air flows from the intake ports, through the cylinder chamber, and pushes exhaust gasses out, creating a single flow direction. Most uniflow scavenge marine engines have a single large exhaust port.

2.6 FUEL INJECTION

On modern two-stroke marine engines, these systems need to meet several key requirements, including:
- **High accuracy** in maintaining consistent performance across cylinders and injectors.
- Achieving very **low** and **stable injection** quantities
- Capability to use **multiple fuels** and perform multiple injections.
- **Valve actuation** that is fully variable and independent of the load
- Ensuring ease of serviceability, reasonable initial cost, and maintenance cost.

Given the current market dynamics defined by **increasing fuel oil prices** and considerable uncertainty surrounding **reducing emissions**, the flexibility and ability to accommodate multiple fuels in these systems have emerged as crucial requirements.[4]

There are various fuel injection system architectures available, ranging from pump-line-nozzle systems to advanced Common Rail (CR) systems that offer complete flexibility and variability in timing and injection pressure. Among these options, CR systems have become the obvious choice for modern two-stroke marine engines.

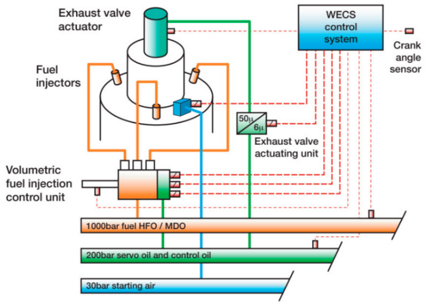

Fig. 6. Schematic of CR injection systems in WinGD engines.

2.7 EXHAUST SYSTEM

The exhaust valve, usually positioned centrally, is housed within a cage that features an intensively water or oil cooled seat above individual pistons. Its actuation is carried out by a **dedicated hydraulic system**, varying from manufacturer to manufacturer.

Constructed from high heat-resistant material, the valve incorporates a reliable rotative drive mechanism, to even out the wear on the seat and valve head.

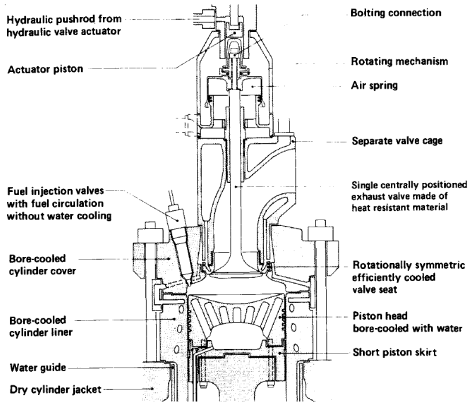

Fig. 7. Combustion chamber components of a Sulzer Marine Diesel Engine [3]

2.8 COOLING SYSTEM

The cooling process for large marine engines involves the circulation of a cooling liquid through internal passages within the engine. This liquid is typically **freshwater generated onboard** the ship via a freshwater generator.

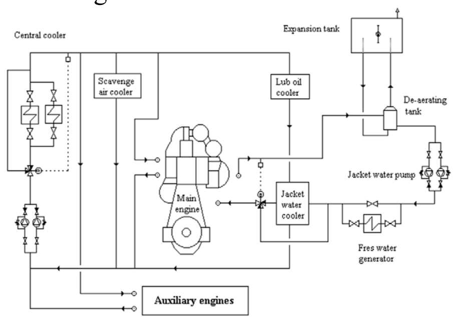

Fig. 8. Typical freshwater cooling system in slow-speed marine engines

Another method of achieving the cooling of important components is the use of **two water loops**. where freshwater can be directly used for cooling machinery, while seawater is employed to cool the freshwater as it passes through a heat exchanger.

3. EMISSION REGULATIONS

Marine engines are a significant source of air pollution in ports and coastal areas, contributing to harmful emissions that affect the environment. To address this issue, the International Maritime Organization (IMO) has established Emission Control Areas (ECAs) to reduce emissions from ships and improve air quality in such regions as the Baltic Sea and North Sea.

To further address this issue, The IMO has implemented the **Regulations for the Prevention of Air Pollution from Ships of 1977(MARPOL),** with the latest revision in 2017. There, the limits for NO_x emissions are presented graphically in Fig.9. The NO_x emission limits apply to both used and new marine vessels. The Tier I and Tier II limits are global, but the Tier III standards only apply to NO_x ECAs.

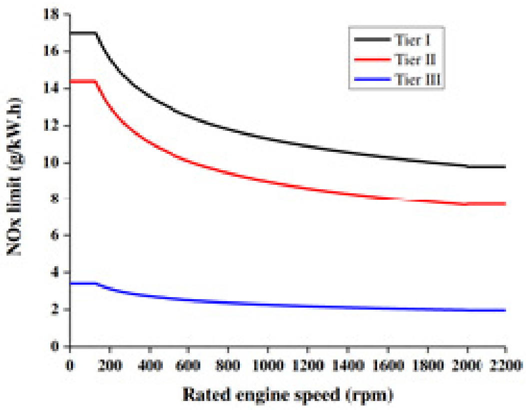

Fig. 9. Annex VI of MARPOL; NO_x emission limits after 2000 (Tier I), after 2011 (Tier II) and after 2020

3.1 EMISSION CONTROL SYSTEMS

To comply with increasingly stringent emission regulations, marine diesel engines have three available strategies for reducing emissions:

- fuel technologies
- in-cylinder purification
- exhaust gas aftertreatment

In **fuel technologies**, different combinations of clean fuels are introduced to the intake ports or cylinders for combustion. If necessary, certain additives may be included in the fuels.

For **in-cylinder purification**, techniques such as combustion optimization, water injection, and exhaust gas recirculation (EGR) are implemented to reduce emissions.[7]

Exhaust gas aftertreatment methods are highly effective in reducing emissions without significantly impacting engine power and fuel economy. Selective Catalytic Reduction (SCR) is utilized to decrease NO_x emissions, while Diesel Particulate Filters (DPF) are employed to remove PM emissions. Furthermore, large ships are required to utilize scrubbers as an aftertreatment device, which effectively eliminates SO_x emissions.[8]

DE-SOX

The simplest De-SOx method employed, implies the use of non-sulfur or low-sulfur content fuel in marine engines. However, it is not practical to use these fuels all the times due to the price gap between the low sulfur content fuel and high sulfur content fuels (HFO or residual oil). Therefore, other than using alternative clean fuels, exhaust after treatment methods seem to be more plausible to reduce SOx emissions of ships, than complete use of lower sulfur content fuel.

The most used De-SOx after treatment [6] method is gas scrubbing, namely the **exhaust gas cleaning system** (EGCS), which is divided into the wet type and the dry type. The dry type of scrubbing was restrained in ships due to heavy or bulky equipment, instability, large space occupation of scrubbers and piping. Wet scrubbing is generally used in marine diesel engines. Wet scrubbing includes open loop systems, closed loop systems and hybrid systems.

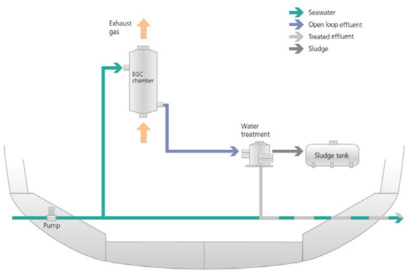

Fig. 10. Open loop EGCS

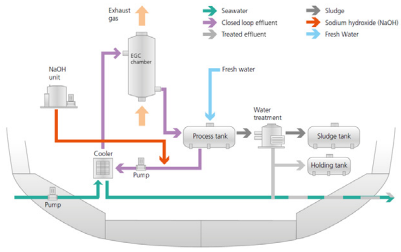

Fig. 11. Closed loop EGCS

Figures 10 and 11 show the **open loop** and **closed loop EGCS** arrangement. In the open loop system, the natural alkalinity of the seawater neutralizes Sox quite efficiently. In the closed loop system, the alkali liquid formulated from water and sodium hydroxide is used to desulfurize exhaust gases and wash water is continuously circulated. The open loop system has several unique advantages, such as low operational costs and a simpler system, but it has poor efficiency due to low seawater alkalinity as well as causing sea water pollution.

DE-NOX

Current denitration technologies for marine diesels include **SCR**, **lean-burn NOx capture** technology, and low temperature **plasma-assisted catalysis** technology. They are derived from land-based applications. Among them, **SCR** is the **most dominant** and mature exhaust gas after-treatment technology for controlling NOx emissions from marine diesel engines.

According to the arrangement and configuration in the exhaust pipeline, SCR systems are divided into **low pressure** selective catalytic reduction (LP-SCR) and **high pressure** selective catalytic reduction (HP-SCR), shown in figure 0.1 and 0.2, The LP-SCR and HP-SCR system are installed after and before the turbine, respectively.[6]

The open loop system has several advantages such as low operational cost and simple system, but it has poor desulfurization efficiency due to low seawater alkalinity and causes sea water pollution.

3.2 EXHAUST GAS RECIRCULATION (EGR)

EGR, also known as Scavenging, implies NO_x emission reduction in combustion chambers by recirculating a portion of the exhaust gas back into the system. By mixing the recirculated exhaust gas with fresh air, the heat capacity of the air-fuel mixture increases, leading to a reduction in combustion temperature and subsequently

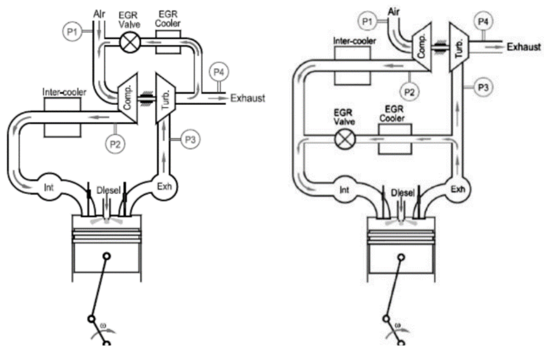

Fig. 10 Diagram of (a) Low pressure and (b) high pressure loop EGR [8]p

lowering the production of NO_x emissions.

There are two modes of EGR: **internal EGR** and **external EGR**. In turbocharged marine engines, external EGR is employed and can be further divided into low-pressure and high-pressure loop EGR, as illustrated in Fig. 10 [8]

4. CONCLUSION

This article has provided an overview of the main features and advantages of that differentiate slow-speed two-stroke marine engines from their more usual counterparts, such as the Miller cycle, the uniflow scavenging, crosshead use, and De-NO_x systems. These systems can improve the fuel efficiency, reduce the emissions, and enhance the performance of marine engines, which are essential for the sustainability and competitiveness of the maritime industry. The article has also discussed some of the challenges and limitations of these systems, such as the complexity and variety of design.

5. REFERENCES

1. The Development of the Modern Low-Speed Two-Stroke Marine Diesel Engines. Kyrtatos, Andreas. Helsinki: s.n, 2016.
2. Experimental and Numerical Study of Swirling Flow in Scavenging Process for 2-Stroke Marine Diesel Engines. Haider, Sajjad. Copenhagen: Danish Technical University, 2011.
3. **Wight, D. A.** *Pounder's Marine Diesel Engines Sixth edition.* s.l. : Butterworth and Co. Ltd., 1986. 0-408-01136-X.
4. Design and Optimisation of Marine Two-Stroke Diesel Engines. Ifunanya Stella Ezeoye, Mohammad Orangian.: International Journal of Marine Engineering Innovation and Research, 2019, Vol. 3. 2548-1479.
5. MARINE SLOW SPEED TWO-STROKE DIESEL ENGINE - NUMERICAL ANALYSIS. PhD. Mrzljak Vedran, Student Žarković Božica, Prof. PhD. Prpić-Oršić Jasna. Rijeka, Croatia: s.n. 1314-507X.
6. A review on regulations, current status, effects, and reduction strategies of emissions for marine diesel engines. Peiyong Nia, Xiangli Wang, Hu Li: White Rose Research Online, 2020. 0016-2361.
7. International Maritime Organization. MARPOL - International Convention for Marine Pollution of 1977,
8. Lloyd's Register Group Limited. Exhaust gas cleaning systems: Guidelines for the management of consumables and waste products: Lloyd's Register Group Limited, 2019.
9. MAN Two stroke engines portfolio 2023

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