

Recent Development in IC Engine

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Abstract: The objective of this paper is to signify various modern development in IC engines which will not just reduce the fuel consumption but will also assist in reducing emission thus more reliability. The technologies which will be discussed in the paper will be Dual fuel engine, Common rail technology & intelligent engine. Dual fuel engine can significantly reduce NO_x, SO_x, and particulate matter and CO₂. This has led to recognition of the potential for marine engines fuelled by the natural gas to reduce marine environmental problem. When it is run by gas mode it will comply by IMO Tier 3 regulations. Also common rail and Intelligent engine technology has considerably improve the working efficiency of a marine engine.

Keywords: Dual Fuel Engine, Common Rail Technology, Intelligent Engines

1. Introduction

Internal Combustion Engines have an abundant use in every industries, but if you go a few years back the designs that are used previously are not worthy to be used presently as because modern world is not only now focusing on performance but also the industries are focusing on various other factors and one of the most important factors are weather the engines are ecofriendly as the previous designs though they are good in performance but they produce greenhouse gases to a very high extent and moreover over use of fossil fuel is also there .But nowadays global warming has become a major issue . All nations are looking for their technological advancement to make these engines ecofriendly at least to some extent. Hereby in this paper we have focused on various engine modifications that are scientifically tested and nowadays used, and the major advantages that we infer from this modifications are well discussed and how they are working as an ecofriendly, efficient engines has been highlighted and discussed properly. Hope the readers will get a good understanding of the technologies related to engine modification.

2. Dual Fuel Engine:

2.1 History of Dual-Fuel Engines:

Gas engines have a very long history dating back to the invention, just 20 years after James Watt invented the modern steam engine in 1785, of a vacuum type piston engine that utilized coal gas combustion instead of steam. This is now recognized as the first-ever internal combustion engine. Use of internal combustion engines spread rapidly after the Second World War when large amounts of cheap petroleum oil began to be produced in regions such as the Middle East. To make effective use of the natural gas produced by oil rigs as a by-product of oil extraction, this led to the burning of the gas in diesel engines by mixing it with the intake air. This was the first example of a dual-fuel engine. Many different types of dual-fuel engines have been developed since then, many of which have been either diesel-ignited gas engines that use liquid fuel to ignite the gas fuel, or mixed combustion engines in which LNG tanker boil-off gas or the by-product natural gas from oil extraction is used together with another fuel. While these types of dual fuel engines satisfied market demand when the objective was to utilize excess natural gas as a supplemental fuel, engines that use natural gas with the intention of reducing environmental impact must operate by using natural gas as much as possible.

Safety and redundancy requirements specified in ship classifications technical guidelines must be satisfied if natural gas engines are to be used on ships. That is, there is a need secure provision of backup for the case of gas-fuelled operation being lost due to a problem in the fuel supply

system or engine. Dual-fuel engines that are able to switch between gas and liquid fuel are recognized as satisfying this requirement. Such switchable dual-fuel engines were first developed in the late 1990s as four-stroke engines. Practical two-stroke dual-fuel engines did not appear until 2010.

2.2 Basic Features of Gas Engines:

2.2.1 Diesel Engine Combustion:

Four-stroke diesel engines compress their intake air (or fuel mixture) by a ratio of between 1/14 and 1/16 and this increases the air temperature to between 300 and 350°C. Atomized diesel fuel is then injected into the compressed air causing it to react immediately with the surrounding oxygen, initiating combustion. The fuel burns locally, in almost the stoichiometric condition, and the high flame temperature promotes the oxidation of the nitrogen contained in the air. This is why the NO_x levels for diesel combustion are so high.

2.2.2 Gas Engine Combustion:

In the case of a gas engine, the high auto ignition temperature of natural gas means that combustion does not occur simply by injecting it into the compressed air. Accordingly, natural gas engines require an ignition source to initiate combustion. Generally, a spark plug or diesel fuel atomization is used to achieve this. In the case of a four-stroke engine, a pre-mixed homogeneous mixture of the fuel and air is introduced into the cylinder. Here, the formation of NO_x can be reduced by using a pre-mixed fuel-air mixture with a leaner fuel-to-air ratio (excess air ratio > 1, meaning more air than is required by the stoichiometric ratio), because it results in a lower combustion temperature in the cylinder (see Fig. 1).

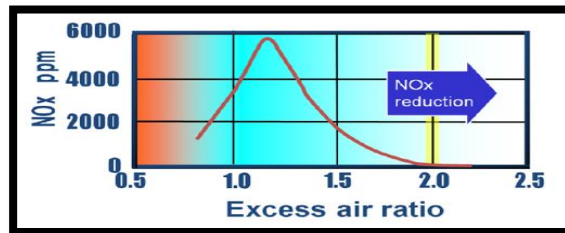


Fig. 1 Gas Engine Excess Air Ratio and NO_x Emission Characteristics

The way combustion should work in a gas engine is for the ignited flame to propagate through the unburned fuel mixture until combustion is complete. However, if the thermal load and combustion pressure in the cylinder increase for some reason, such as an increase in load, the unburned fuel mixture may ignite spontaneously prior to being reached by the propagating flame. If spontaneous ignition sets off a chain reaction, this can result in serious damage to the engine due to severe pressure or temperature increases. This type of combustion is known as knocking, and it is something absolutely to be avoided in gas engines (see Fig. 2).

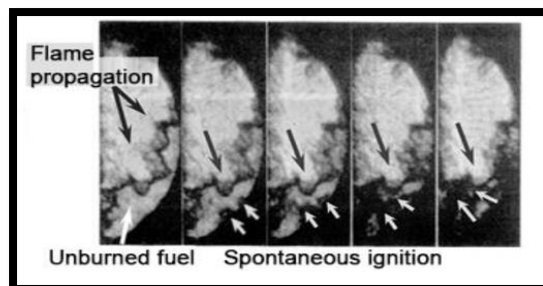


Fig. 2 Gas Combustion (Knocking)

Ways of avoiding knocking include reducing the compression ratio to reduce the compressed air temperature, and increasing the excess air ratio as high as possible (using a leaner mixture) to reduce the combustion temperature. However, reducing the temperature by too much may cause

misfiring due to failure of the mixture to ignite. And because misfiring may result in fires due to unburned fuel mixture escaping into the exhaust pipe, it is something to be avoided.

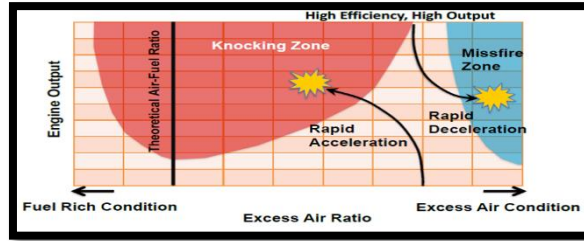


Fig. 3 Combustion Characteristics of Gas Engine

Fig. 3 shows gas engine combustion characteristics, where the horizontal axis represents the excess air ratio and the vertical axis represents engine output. Knocking occurs when output is high in the region where the excess air ratio is around one, whereas the region in which misfiring occurs is at higher excess air ratios. When developing a gas engine, the combustion conditions are selected so as to avoid the excess air ratio being in the regions where knocking or misfiring occur when operating under the expected load. However, when the load varies continuously, as is the case when used for ship propulsion, there is an increased risk of knocking or misfiring due to operation deviating from the target excess air ratio. In particular, because the inlet air flow depends on the speed of the turbocharger, the engine may fail to operate under load due to the turbocharger speed being unable to follow quickly to changes in load.

To achieve high output while aiming to keep the excess air ratio in the intermediate zone between the regions where knocking or misfiring occur, many recent gas engines incorporate mechanisms for adjusting the excess air ratio in accordance with operating conditions. Fig. 4 shows one such mechanism for adjusting the intake air flow. In addition to the main intake passage, it equips a bypass that returns some of the intake air to the turbocharger inlet. A bypass valve in the bypass closes under full load so that all the air discharged by the turbocharger is supplied to the engine, but it partially opens under partial load by adjusting valve opening angle to maintain the correct intake air flow to the engine.

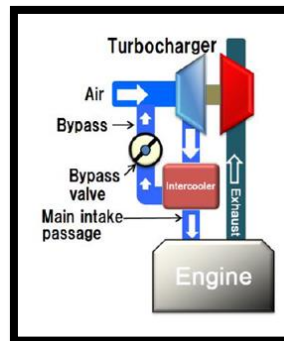


Fig.4 Intake Air System with Bypass

2.3 Dual-Fuel Engines

2.3.1 Four-Stroke Dual-Fuel Engine

Gas fuel is supplied during the intake stroke of a diesel engine, and the exhaust emissions vary according to the proportions of diesel fuel and gas fuel in the total fuel (see Fig. 5). Because the concentration of CO₂ in the exhaust gas depends on the composition of the fuel, it can be reduced by up to about 25% according to the proportions of diesel fuel and gas fuel. On the other hand, because the concentration of NO_x depends on the combustion temperature, reductions in NO_x can only be achieved by reducing the proportion of diesel fuel.

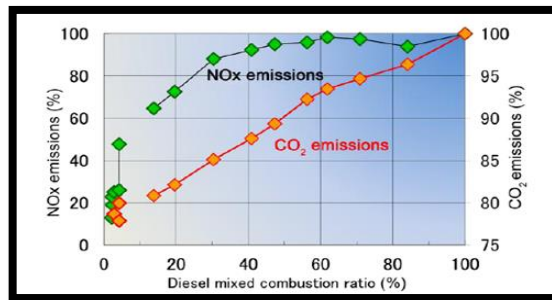


Fig. 5 Emissions in Mixed Diesel/Gas Mode

While achieving the IMO Tier 3 regulations (80% reduction in NOx) requires that the proportion of diesel fuel be reduced to 2%, no currently available nozzles are able to inject the full range of fuel injection quantities, from the amount required under rated load down to this very small quantity, in a reliable manner (without variation in the quantity injected for each cycle). To overcome it, adding a small dedicated nozzle (micro-pilot fuel injector) that supplies diesel fuel for the ignition when operating on gas fuel is necessary.

Fig. 6 shows a cross-section of a four-stroke dual-fuel engine. Gas fuel is supplied from a gas valve in the air intake manifold where it flows into the cylinder as a mixture with air. Two injectors, one is the main fuel injector used for diesel mode and another is the micro-pilot fuel injector used for gas mode, are equipped in the cylinder head, the engine can switch between diesel mode and gas mode freely with certain operating condition restrictions.

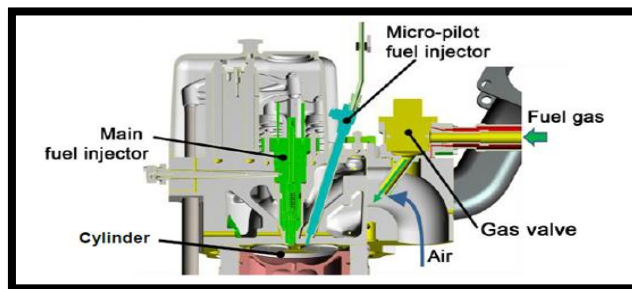


Fig 6. Cross Section of dual fuel four-stroke engine

2.3.2 Two-Stroke Dual-Fuel Engine

Because intake air is used for scavenging in a two-stroke engine, it is not allowed to mix the gas fuel with the intake air. Instead, the gas fuel is injected into the compressed air in the same way as diesel fuel, and then ignition is achieved by injecting fuel via the micro-pilot fuel injector (see Fig. 7). Because this results in diffusion combustion, as with diesel fuel, it can reduce CO₂ emissions by 20% or more, with a low level of unburned gas and CO emission and without knocking. However, the level of NOx emissions is high due to the same reason.

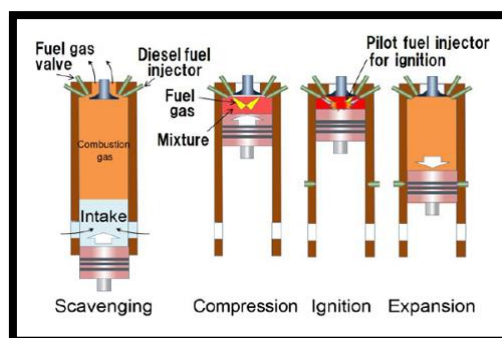


Fig. 7 Combustion Cycle for Two-Stroke Dual-Fuel Engine

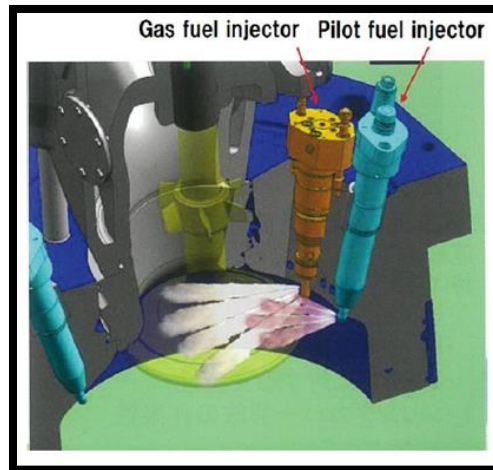


Fig. 8 Cylinder Cover Design for Two-Stroke Dual-Fuel Engine

Fig.8 shows the cylinder cover design for a two-stroke dual-fuel engine. In order to pressurize gas fuel injected into the compressed air up to 30 MPa, natural gas that has been pressurized in liquid form is vaporized and then injected into the cylinder. And because there is no risk of knocking, the switch between diesel fuel and gas fuel can be performed comparatively easily and quickly.

One proposal for improving the level of NO_x emissions for two-stroke dual-fuel engines is to use a low-pressure gas fuel injection engine that can operate with a lean pre-mixed fuel mixture despite being a two-stroke engine. This involves using a fuel injection timing control method that enables the time delay of pre-mixing of gas fuel and air during the intake stroke described above that prevents the fuel-air mixture from coming into direct contact with the exhaust gas (see Fig.9). Such an engine is currently under development with the aim of achieving low-NO_x emissions similar to a four-stroke engine.

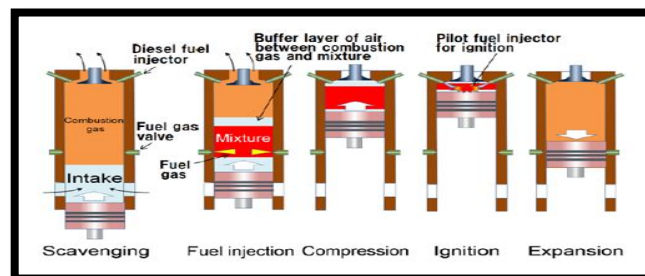


Fig. 9 Combustion Cycle for Low-Pressure Gas Injection Two-Stroke Dual-Fuel Engine

2.4 Working Modes of Dual Fuel Engines

There are basically 3 modes of operation for dual fuel marine engines used on-board ships:

- When engine is well supplied with natural gas, amount of pilot fuel injected is corresponding to 6% of the total engine load. In other words major contributor to the engine load is natural gas.
- When gas supply to the engine is constant and limited, then engine is said to be in “Specified Gas Mode”. Here gas supply is constant, but fuel oil quantity injected varies to meet changing engine load demand.
- In “Fuel Oil Only” mode, gas supply will not be available, and engine runs only on fuel oil. This mode is used when engine is unstable, such as during restricted waters, heavy weather, manoeuvring, etc.

Challenges for Dual-Fuel Engines

a) Because two or more different types of fuel are combusted in the same cylinder, one of the challenges for dual-fuel engines is lubrication. Whereas lubricants with high base numbers (30 to 40 mg KOH/g) are used when operating on low grade fuel (3.5% sulphur), lubricants with low base numbers (5 mg KOH/g) are used when operating on natural gas (0% sulphur). This is why the knocking margin would be reduced in natural gas fuel mode due to the build-up of alkalis deposit and other combustion deposit on the cylinder walls that act as a heat insulator causing the combustion temperature to increase. As a result, it can be difficult to select a lubricant for dual-fuel engines that will perform effectively with both diesel mode and gas mode.

b) Fuel characteristics are a problem specific to dual-fuel marine engines. Ocean-going vessels are supplied with fuel at their destinations (“bunkering”), but because the characteristics of natural gas differ depending on where it is produced, if a vessel takes on fuel with significantly different characteristics there is a risk for the engine to shut down due to knocking when it switches over to this new fuel. Currently though this problem can be overcome using particular operations such as restricting the range of fuels that can be used or limiting output, a challenge for the future will be to develop engine technology that can deal with different fuel characteristics.

2.4.5 Common Rail Technology

Common rail technology is used to eliminate visible smoke from the exhaust especially at low engine load. Visible smoke generation is partly due to low injection pressure and striking of large fuel droplets on hot surface during combustion process.

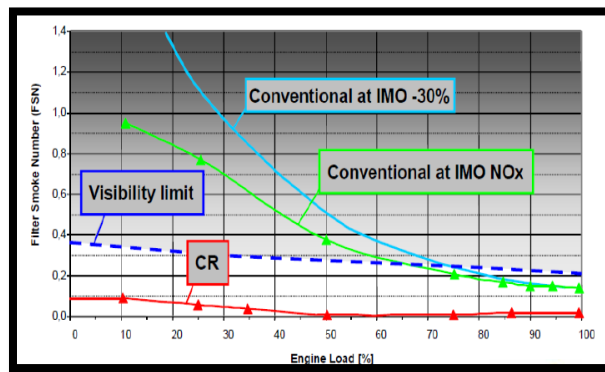


Fig. 10 Smoke Emission from Common-rail and conventional engine

2.4.5.1 Main Component Of Common Rail System

It has two main component-

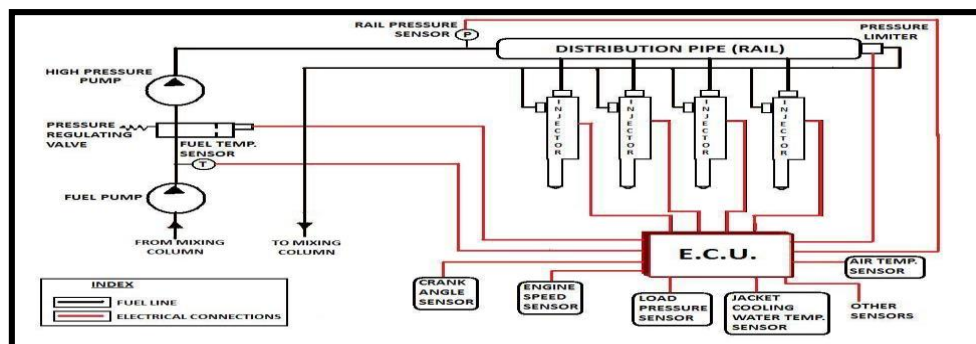


Fig. 11 Schematic Diagram of the common rail technology

a. **High Pressure pump:** It helps to pressurize the fuel oil upto 1000 bar or more than 1000bar as per system design. It can be cam driven or electrical driven or both.

b. Rail Unit: It consist of several parts such as fuel oil rail, control oil rail, servo oil rail, injection control unit, valve control unit.

i. Fuel oil rail: The fuel rail contains high pressure fuel of 600 -1500 bar delivered by the fuel pumps of the supply unit during engine operation. The rail pressure is regulated depending on engine load. For each cylinder, there is an Injection Control Unit (ICU) installed on the rail. The rail is heated by a trace heating piping system.

ii. Control oil rail: The control oil rail contains 200 bar control oil (constant pressure) delivered by the control oil pumps. Control oil is used to actuate the control pistons of the ICU's.

iii. Servo oil rail: The servo oil rail contains fine filtered (6-micron) high pressure servo oil, ~ 80-200bar, delivered by the servo oil pumps of the supply unit, depending on engine load. For each cylinder there is a Valve Control Unit / exhaust valve actuator installed on the rail.

iv. Injection control Unit: An ICU has two different sections-

➤ Control oil side: The rail valves (LP1-valves) control the control oil flow to the control oil block.

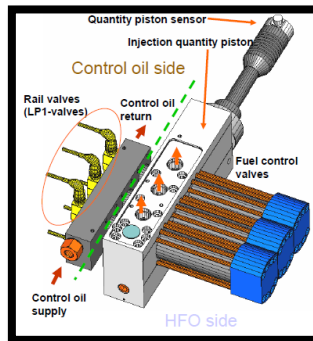


Fig. 12 Injection control unit of Wartsila RT-flex

➤ Fuel side: The fuel control valves are actuated by pistons in the control oil block via thrust pieces. There is one valve for one injector.

The main body of the ICU includes the injection quantity piston. Its stroke measurement sensor with housing is attached to the main body.

V. Valve Control Unit:

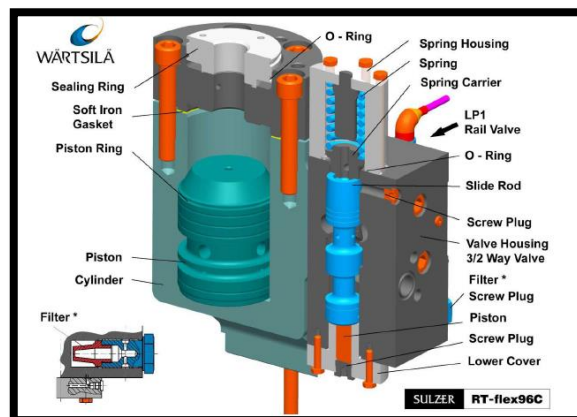


Fig. 13 Valve control unit of RT-flex96c

2.4.5.2 Advantages Of Common Rail Technology

- i. Lower fuel consumption: Injection timing and quantity of fuel is varied during engine running to optimize engine performance.
- ii. Reduced running costs: The reduced running costs due to extended time between overhauls and a lower part-load fuel consumption.
- iii. High reliability and redundancy: The common-rail concept has great reliability through inherent redundancy.
- iv. Lower NOx emissions: Electronically controlled injection timing can be optimized for fuel consumption or lower NOx emissions.
- v. Lower running speeds: Common rail engines can run very steadily, and without smoking, at 10–12 per cent of nominal speed.
- vi. Design is simpler, allowing elimination of one pump per cylinder.
- vii. Operational flexibility: Sequential cut off of fuel injectors at low loads as in case of Sulzer RT flex engines.

2.3.3 Intelligent Engines

1. What does intelligent engine means?

The brain of the system is an electronic control system which operates the engine and the operation of the engine's system (The fuel injection, exhaust valve, cylinder lube oil and turbo charging system

2. Concept:-

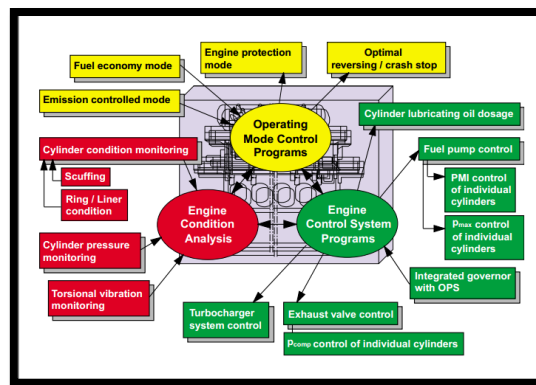


Fig. 14 Concept Diagram of Intelligent Engine

- i. The Engine should have electronic control for fuel injection timing and shape of fuel should also be controlled electronically.
- ii. The Engine conditions should continuously analysed by EDS system
- iii. The failures and any malfunctioning should immediately be rectified by the system.
- iv. The closing and opening of exhaust valves should also be controlled electronically
- v. Cylinder Lubrication system should be well tracked with respect to all engine conditions like cylinder temperature, peak pressure etc.
- vi. The engine should be capable of being operated in all loads condition.
- vii. The advent of electronic limited and injection according to the requirement of the engine led to the reduction of NOx emission

3. Exhaust gas emissions flexibility:

- i. The engine can be changed over to various 'low emission' modes, its NOx exhaust emissions reduced below the IMO limits if dictated by local regulations.
- ii. By appropriate selection of operating modes ships may sail with lower exhaust gas emissions in special areas, where this may be required (or be more economical due to variable harbour fee schemes) without having negative effects on the specific fuel consumption outside those areas.

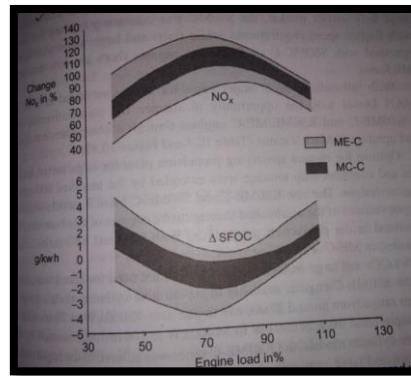


Fig. 15 Graphical Representation of NO_x Emission

4. Operation of MAN B&W Camless engine:

Oil from the main engine LO supply or from a dedicated hydraulic supply passes through 6 micron filters before being pressurized by three engine driven axial piston pumps of the swash plate type. There are also two electrically driven pumps for start-up purposes and emergency running.

In ME engines redundant computers are connected in a network to control functions of camshaft. The Intelligent Engine consists of 4 main control unit, they are as follows:-

- Engine Control Unit (ECU).
- Cylinder Control Unit (CCU).
- External Interface Control Unit (EICU).
- Auxiliary Control Unit (ACU).

5. CONCEPT OF ELECTRONICALLY CONTROLLED (CAMLESS ENGINE) BY MAN B&W:

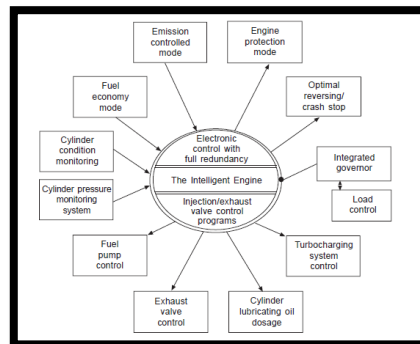


Fig. 16 Summary of MAN ME Engines

3. Conclusion

Both performance and preservation of environment should be given utmost importance. Thus it is essential to develop such engine which will indeed provide such desired services. This paper is an aid to that idea. This paper concludes with a note that various development are already done and yet many more to come for better and efficient operation of marine IC engines. As we see in this paper, Dual fuel engine can reduce CO₂ emission by 20-25% and NO_x emission which can comply to IMO Tier 3 regulations & its operation also cost saving. In common rail technology, we see that it is reduce smoke at low load and provides more reliability & it also reduce fuel consumption. In Intelligent engine we see that emission of NO_x is reduced and provide more reliability due to optimization in fuel injection. It also provide an opportunity to use the engine at various load. We expect that these technology will become a leading engine over the next decade.

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