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Environmental Friendly Two-stroke Marine Diesel Engine, "MITSUBISHI UEC Eco-Engine"

Masahide SUGIHARA*, Koji EDO, and Takuma TANIDA****

ABSTRACT

This paper introduces a new, integrated electronically controlled two-stroke diesel engine, UEC Eco-Engine. Its system construction, development concepts, major test results in the first commercial Eco-Engine, and its major advantages are reported.

This engine is named for the common letters of "Eco" found in the words of its design goals: ecology, economy, easy control, and excellent engine condition. Based on these concepts, we started fundamental studies with a single cylinder system in 1988. Then in 2001, we developed the first full-scale Eco-Engine "7UEC33LSⅡ-Eco," a stationary diesel generating set as a demonstrator. By replacing mechanical parts with an electronic control system, the engine is much simplified.

The first commercial Eco-Engine, "8UEC60LSⅡ-Eco," completed its shop and sea trials. The results proved the advantages of Eco-Engine: lower fuel oil and lubricating oil consumption, lower NOx emission, etc.

Key Words: UEC Eco-Engine, Electronic Control, Ecology, Economy, Easy control, Excellent condition

1. INTRODUCTION

In the large marine diesel engine industry, the trend for electronically controlled engines has jumped forward rapidly. UEC Eco-Engine was developed in response to the increasing demand for environmental friendliness.

In addition, the objective of Eco-Engine is to benefit ship owners and operators in terms of total operating costs, maintenance requirements, and compliance with stricter emission regulations anticipated in the near future.

Its development was based on experiences with research engines and a prototype engine. The first full-scale Eco-Engine, 7UEC33LSⅡ-Eco, has been proving its reliability and performance over three years of various operations, as a stationary diesel generating set at the Mitsubishi Heavy Industries Kobe Shipyard & Machinery Works.

In June 2005 the first commercial UEC Eco-Engine, 8UEC60LSⅡ-Eco, began service in a pure car and truck carrier.

2. CONCEPTS

The new engine is named for the letters of "Eco," which are found in its design goals: ecology, economy, easy control (better maneuverability), and excellent engine condition (higher reliability), all by electronic control.

*Mitsubishi Heavy Industries, Ltd. Kobe Shipyard & Machinery Works, Diesel Engine Department
1-1 Wadamisaki-cho, 1 Chome Hyogo-ku,
Kobe, Hyogo 652-8585, JAPAN
FAX: +81-78-672-3705,
E-mail: masahide_sugihara@mhi.co.jp
** Mitsubishi Heavy Industries, Ltd. Kobe Shipyard & Machinery Works, Diesel Engine Department

2.1 Electronic control

Fuel injection, exhaust valve actuating, and starting air systems are controlled electronically and are optimized for all operation loads.

2.2 Ecology

NO_x emission can be reduced and smokeless operation achieved. In addition, water injection system, a drastic NO_x reduction technology, may be applied in combination with the Eco-system to cope with the stricter NO_x emission regulations anticipated in the future.

2.3 Economy

Lower specific fuel oil consumption especially in partial loads can be obtained, and this can lead to less running cost.

2.4 Easy control

Eco-Engine assures stable low load operation with good engine performance. Easy change of operating modes and fine tuning of operating conditions are also possible during operation.

2.5 Excellent engine condition (higher reliability)

Appropriate fuel injection pressure and optimum injection timing, which are the most favorable for combustion conditions at each load, can further enhance the reliability of the hot components proven in UEC conventional engine.

3. HISTORY OF UEC ECO-ENGINE PROJECT

Anticipating possible future requirements, we began to study various solutions as early as 1988.

Over a long period, the fundamental system has been verified on single cylinder research engines, the NC45 (45 cm bore) and the NC33 (33 cm bore) at the MHI Nagasaki Research & Development Center.

The first generation of the electronic system was tested on the NC45 research engine from 1988 to 1993, and more than

1,200 hours of various operations verified the system's performance and reliability. The test results satisfied the concepts of the system.

The second generation of the electronic system followed on the NC33 research engine and was tested until 1997. Its results boosted our belief that an electronically controlled engine has advantages to comply with future industry requirements. Figure 1 shows the NC33 research engine.

Based on the above-mentioned good experimental results, UEC Eco-Engine project started in early 2000 to meet the growing market demand.

The 7UEC33LS Ⅱ engine, a stationary diesel engine generating set at the MHI Kobe Shipyard & Machinery Works, was converted to the first full-scale Eco-Engine in December 2001 and has proved its reliability through three years of various operations. In this engine, the electronic control system was retrofitted to a conventional engine. The aspects of the engine can be seen in Figure 2. The main particulars of the engine are listed in Table 1.

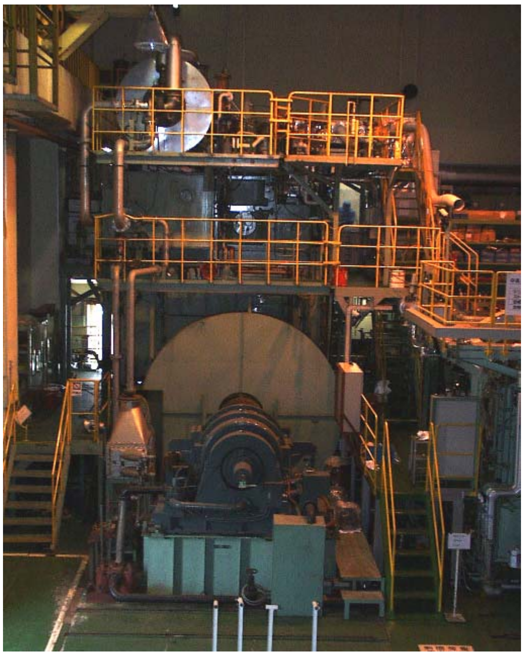


Fig. 1 NC33 research engine at MHI Nagasaki Research & Development Center

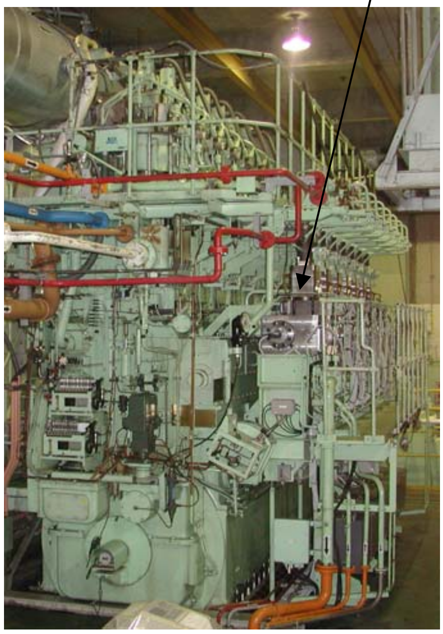
Table 1 Main particulars of 7UEC33LSII-Eco

Cylinder Bore	mm	330
Piston Stroke	mm	1,050
Number of Cylinders	-	7
Output	kW	3,775
Engine Speed	min^{-1}	212

As mentioned above, we concentrated on the reliability and performance of the electonically controlled engine through a long span of verification tests and successfully confirmed high reliability as well as high performance. We will introduce the first commercial project of UEC Eco-Engine in a later section.

Retrofitted electronic-control device

view from driving end



view from fore end

Fig. 2 7UEC33LSII-Eco at MHI Kobe Shipyard and Machinery Works

4. MHI'S LOW EMISSION TECHNOLOGY

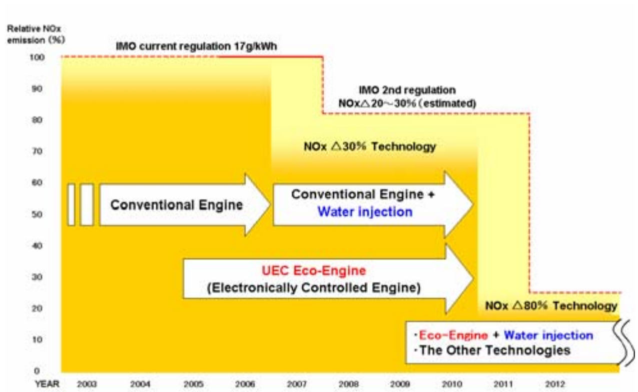


Fig. 3 Applications to low NO_x emission technology

In general, our technological plans to cope with further strict NO_x regulations are described in Figure 3.

To comply with the International Maritime Organization's (IMO) first regulation, which took effect in May 2005, we have already delivered all our engines in compliance with the regulation by optimization of the fuel injection nozzle and fine tuning of our traditional engines.

To satisfy the second regulation, which is estimated to be 20 to 30% stricter than the first regulation, we plan to apply UEC Eco-Engine or a water injection system in combination with a conventional engine.

To satisfy the third regulation, we will combine UEC Eco-Engine with a water injection system. According to the severity of the regulations, other technologies might be needed, for example, the Selective Catalytic Reactor (SCR).

Anticipating future demand, we will maintain our efforts to develop the necessary technologies.

5. FUNDAMENTAL STRUCTURE

The engine's fundamental structure is seen in Figure 4, where it is compared with a conventional engine.

By electronic control, engine structure is greatly simplified by eliminating such conventional large mechanical parts as the fuel and exhaust cams, the camshaft, and the driving gears. An electronic control system with a hydraulic oil supply system is added. Accordingly, maintenance on these mechanical components is also eliminated, and the computational tuning of engine operating conditions also eliminates the delicate adjustment work on these parts both in the shop and on board. Simple fine tuning of operating conditions are possible during operation, this means that engine operation will be much more flexible than conventional engine.

An overview of the fuel injection and exhaust valve actuating mechanisms are described in Figure 5.

The fuel injection pump and the lower exhaust valve driving gear are actuated by 320 bar hydraulic oil. This pressurized oil is accumulated in the accumulator block mounted at each cylinder. The connection blocks are applied to connect each manifold block. The accumulating mechanism is simple and reliable because pressure compensation during actuation is carried out by volume in the accumulating chamber. Therefore, a pressurized gas enclosed type accumulator is not necessary.

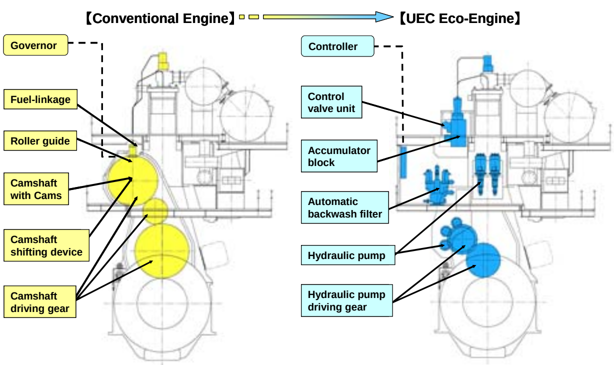


Fig. 4 Fundamental structure of engine

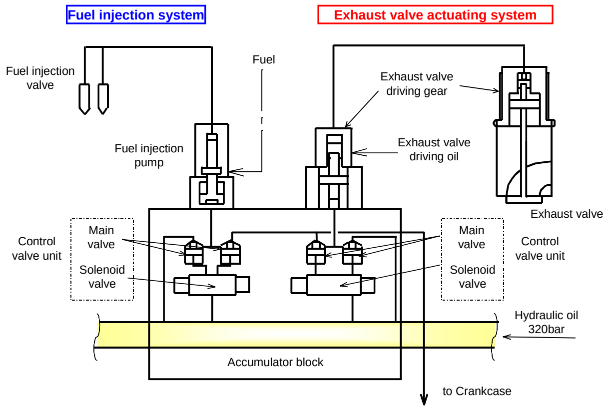


Fig. 5 System overview of cylinder component

The hydraulic power for fuel injection and exhaust valve actuation is controlled by an on/off type solenoid valve unit and an engine control system. The timings of fuel injection and exhaust valve open/close are also controlled electronically to achieve the best condition for any operation mode. This concept simplifies readjustments needed to maintain better operating conditions.

Downstream from the fuel injection pump and the lower exhaust valve driving gear, the same design concepts of the conventional system are applied to reduce crew education for new maintenance work about such components

6. FUEL INJECTION SYSTEM

Figure 6 shows a cross section of the fuel injection system for UEC Eco-Engine.

The fuel injection pump has a similar structure to the conventional mechanical models but is rather simplified. This means that the crew is already familiar with maintenance for the fuel injection pump, reducing overhaul time.

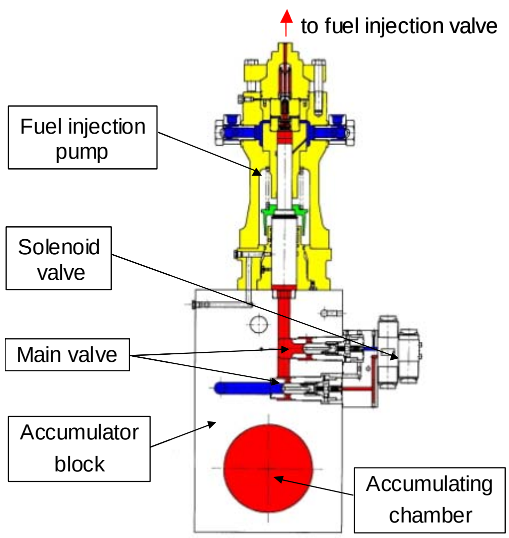


Fig. 6 Fuel injection system

As one of its main features, two sets of on/off type solenoid valves are mounted to control the injection pattern, which depends on the operating load, and to improve the trade-off relationship between thermal efficiency and NO_x emission.

The experimental results of this mechanism will be introduced in a later section.

The mechanism to change the fuel injection pattern is shown in Figure 7. This is our patented technology put into practice by a pair of on/off type solenoid valves.

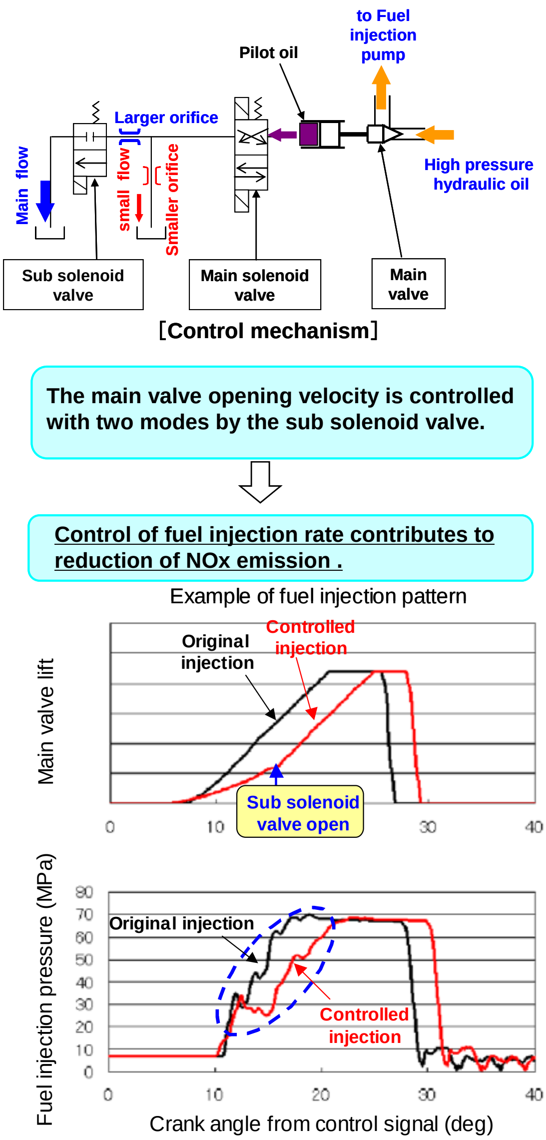


Fig. 7 Controlled fuel injection pattern

In addition, we are now incorporating a water injection system with Eco-Engine to comply with future anticipated stricter NO_x emission regulations.

A feedback control function is applied to control the fuel injection volume to compensate for the equivalent thermal load and individual cylinder control. Fuel pump stroke is monitored by twin gap sensors at each cycle. This emphasizes the system's reliability through observation of the control system.

7. EXHAUST VALVE ACTUATING SYSTEM

Figure 8 shows a cross section of the exhaust valve actuating system for UEC Eco-Engine.

The exhaust valve open and close timings are also controlled by electronic control system using the on/off solenoid valve unit. Accordingly, timings are optimized depending on the operating load. For precise timing control, a feedback control function is applied by observation of the exhaust valve lift.

The actuating mechanism is similar to conventional mechanical ones and inherits their reliability and method of maintenance.

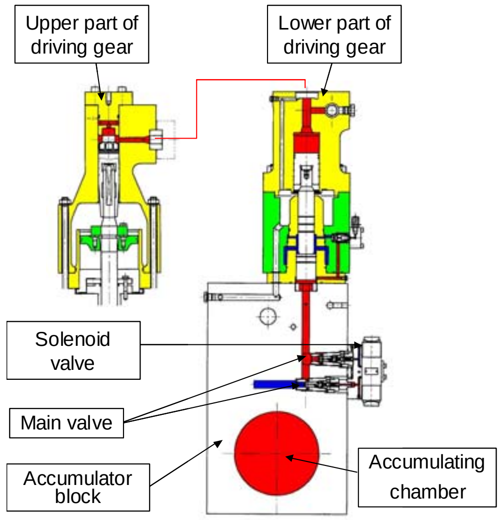


Fig. 8 Exhaust valve actuating system

8. CONTROL VALVE UNIT

Solenoid valve units are key components of an electronically controlled engine. The valve units of a large electronically controlled engine require very quick response, high flow rate, and long life cycle. We started valve development in 1999 and have already confirmed its performance.

The most important issue is reliability for a long life cycle. Thus, endurance tests were undertaken. The endurance test of valve unit finished 300 million cycle that corresponds to approximately six years of actual operation on board, and it satisfied its requirements.

The small size unit for a bore 40 cm class engine has also been verified in the 7UEC33LS Ⅱ -Eco prototype. The performance and endurance of the medium size unit for a bore 60 cm class engine were verified by a test bench similar to the fuel injection system in Figure 9.

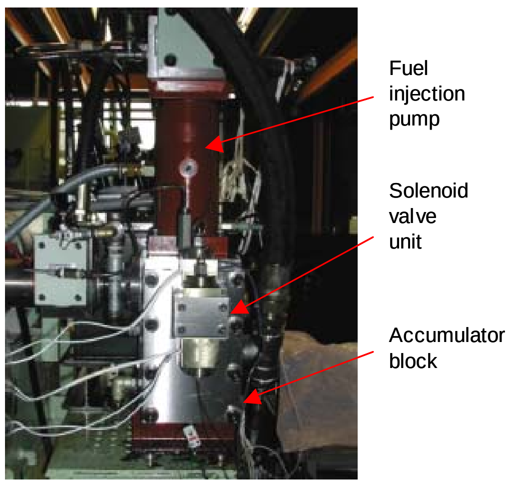


Fig. 9 Control valve unit on test bench

9. STARTING AIR SYSTEM

Figure 10 compares the starting air systems. The conventional starting air control valve is eliminated, and solenoid valves and a control air pipe are added. The starting valves are electronically controlled to achieve better performance and flexibility for engine start and crash astern.

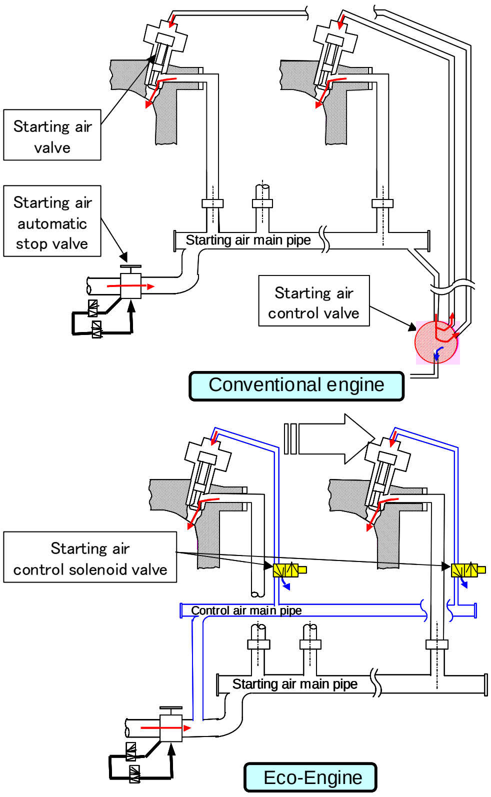


Fig. 10 Comparison of starting air systems

10. HYDRAULIC OIL SUPPLY SYSTEM

A hydraulic oil supply system (see Figure 11) is another key component of Eco-Engine.

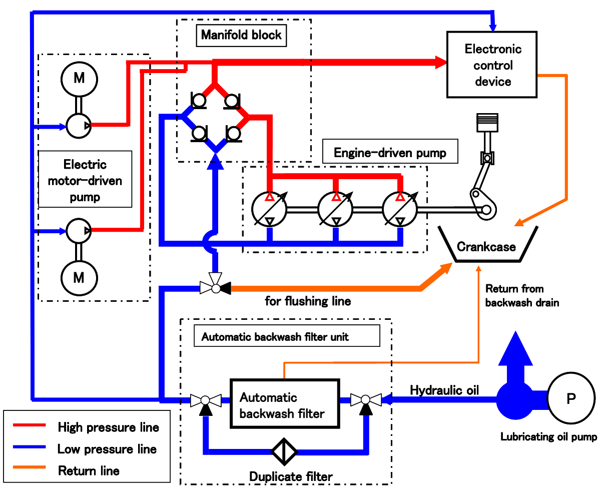


Fig. 11 Hydraulic oil supply system

11. ECO-ENGINE CONTROL SYSTEM

An engine control system is prepared for the Eco Main Controller (EMC) and installed in the control room to interface with the Remote Control System. The Local Control Box (LCB) and the Eco Cylinder Controller (ECC) are mounted on the engine. These controllers are connected by a duplicated network line. An overview of the control system is provided in Figure 12.

11.1 EMC

For duplication purposes, the controller is comprised of two units operating parallel and performing the same task; they are duplicates of each other. If the active EMC fails, the other unit will assume control without any interruption.

EMC performs the following tasks:

- Speed governor functions
- Start/stop sequences
- Timing control of fuel injection, exhaust valve actuation, and starting air systems
- Control of the hydraulic oil supply system
- Alternative operation and control modes
- Network functions
- Malfunction observation of entire control system

11.2 ECC

Each ECC, which is mounted on individual cylinder, performs the orders for the timing of fuel injection, exhaust valve actuating, and starting air systems.

11.3 LCB

This controller provides engine side control for emergency if the Remote Control System or both EMCs fail. This means that the operator can choose two operations, which are controlled by EMC or LCB.

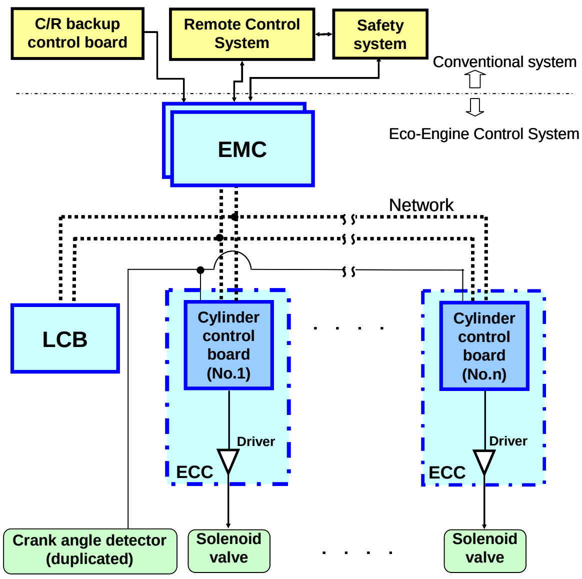


Fig. 12 Control system overview

We developed an evaluation tool called the Real Time Simulator (RTS), as shown in Figure 13, that verifies control sequences by simulating such engine running conditions as start/stop, crash astern, rough seas, and malfunctions. The image of this tool creates a virtual engine in the simulator.

We verified the first commercial control system by using this tool before running it in our shop. In addition, the reliability of the control system's hardware was evaluated against surrounding conditions, including vibration, temperature, and noise.

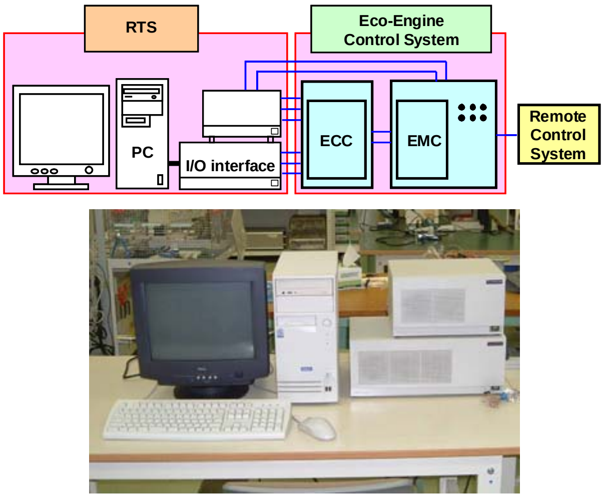


Fig. 13 Real Time Simulator


Fig. 15 Upper view of 8UEC60LSⅡ-Eco

12. THE FIRST COMMERCIAL ECO-ENGINE

In June 2004, the manufacture of the first commercial UEC Eco-Engine, 8UEC60LSⅡ-Eco, was completed. Its main particulars are listed in Table 2. Figures 14 and 15 show pictures of the engine in our shop.

Its comprehensive tests were carried out in our shop for three months in 2004, and a sea trial was held in May 2005. This section introduces their major results.

Table 2 Main particulars of 8UEC60LSⅡ-Eco

Cylinder Bore	mm	600
Piston Stroke	mm	2,300
Number of Cylinder	-	8
Output	kW	15,540
Engine Speed	min^{-1}	104


Fig. 14 Overall view of 8UEC60LSⅡ-Eco

12.1 Economy and Low emission mode

We evaluated actual operating conditions by applying fuel injection controls. To operate Low Emission Mode, NO_x emission reduction can be obtained at the same SFOC. On the other hand, to select Economy Operating Mode, SFOC can be reduced 1 to 2% compared with conventional engines. The engine operation mode can be easily changed over by a switch on the controller.

From the results of 8UEC60LSⅡ-Eco shop tests, we found that trade-off between thermal efficiency and NOx emission can be improved as we planned.

Figure 16 compares SFOC and NOx emission between fuel injection controls ON and OFF in normal load. With fuel injection control, we achieved Δ 10.2% NOx emission in equivalent SFOC.

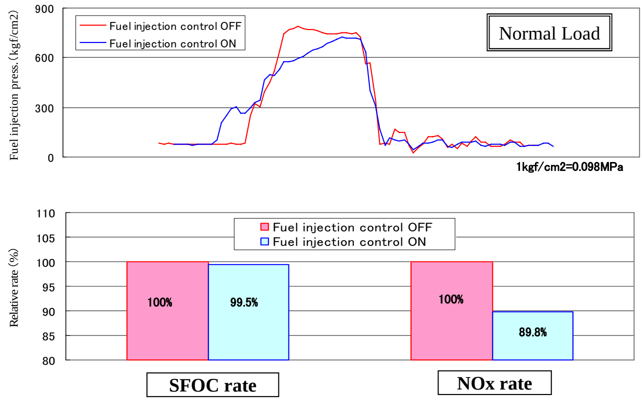


Fig. 16 Improvement by fuel injection control

12.2 Engine Performance

Figure 17 shows the performance curve of 8UEC60LSⅡ-Eco with the test results of economy and low emission modes. As expected, especially in lower loads, economy mode decreases SFOC, and low emission mode decreases NOx emission.

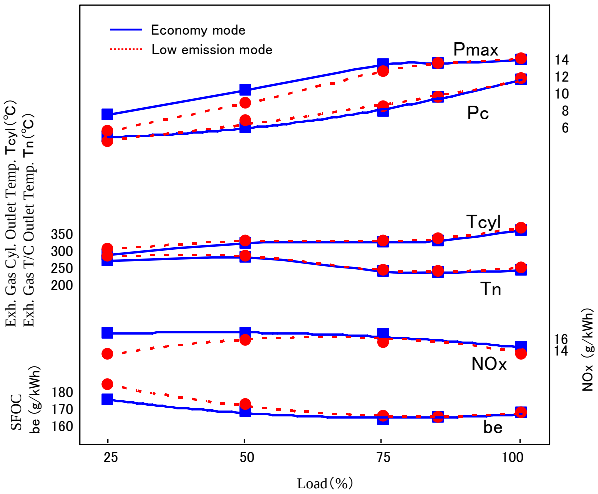


Fig. 17 Performance curve of 8UEC60LSⅡ-Eco

12.3 Smoke

The fuel injection system is significantly improved with electronic control system. Thus, smokeless operation can be achieved for whole operation load. Figure 18 compares the Bosch Smoke Number measured on 8UEC60LSII-Eco.

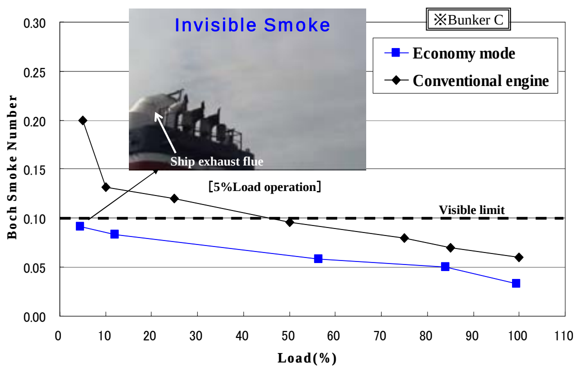


Fig. 18 Smoke measurement results of 8UEC60LSⅡ-Eco

12.4 Cylinder lub. oil consumption

Eco-Engine has electronically controlled cylinder lubricating system to obtain precise injection quantity and optimum injection timing at each load, which lead to higher reliability on piston rings and cylinder liner and lower operation costs. Figure 19 shows the transition of lubrication oil feed rate of 8UEC60LSⅡ-Eco in shop tests. At the end of shop tests, feed rate decreased less than 1.0 g/PSh.

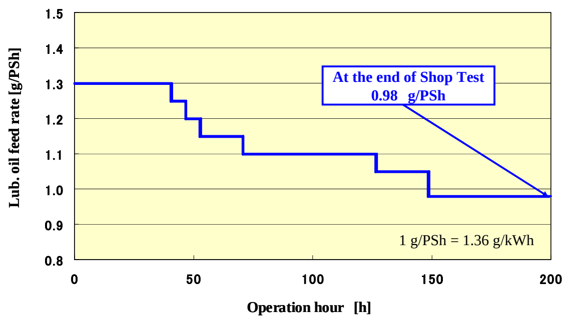


Fig. 19 Lub. oil feed rate on shop test

12.5 Inspection results

Inspection results after sea trials revealed that each part was maintained in excellent condition. Figures 20 and 21 show inspection results.

(a) Plunger of fuel injection pump (b) Hydraulic piston of fuel injection pump

Fig. 20 Inspection results after sea trial (1)

(c) Piston rings

(d) Cylinder Liner

Fig. 21 Inspection results after sea trial (2)

13. SUMMARY OF ADVANTAGES

As a summary, the distinctive advantages of UEC Eco-Engine are as follows:

13.1 Environmental friendliness

Smokeless operation can be achieved by appropriate fuel injection pressure at any load. Reduction of NOx emission can be obtained by tuning the fuel injection timing and pattern at any load.

13.2 Lower Specific Fuel Oil Consumption (SFOC)

The timing of fuel injection and exhaust valve actuation can be flexibly optimized by electronic control according to engine operating loads, atmospheric conditions, and fuel oil properties. Accordingly, lower SFOC can be obtained, especially in partial loads.

13.3 Easy control (better maneuverability)

Eco-Engine assures stable continuous low load operation, even for extremely low loads, with good engine performance because of improved combustion conditions thanks to appropriate fuel injection pressure and optimized fuel injection timing and exhaust valve actuating in lower loads.

13.4 Higher reliability

In Eco-Engine, appropriate fuel injection pressure, which is the most favorable for combustion conditions at any load, will further enhance the high reliability of the hot components proven on conventional UEC engines, such as piston crown, piston ring, cylinder liner, and exhaust valve.

13.5 Flexible operation

Easy changes of operating modes and fine tuning of operating conditions are possible during operation.

13.6 Less maintenance

With electronic control system, the engine structure is significantly simplified by eliminating conventional large mechanical parts. Accordingly, maintenance on these mechanical components is eliminated, and the computational tuning of engine operating conditions obviates the need for delicate adjustment work on these parts both in the shop and onboard.

14. CONCLUSION

UEC Eco-Engine was introduced with test results on the first commercial engine. Its advantages and features were also discussed.

In addition to the main features of a conventional UEC engine, which include lower fuel oil consumption, lower lubricating oil consumption and high reliability, etc., Eco-Engine’s features will bring such advantages to ship owners and operators as reduced operating costs and stable ship operation, which is attractive to clients within the industry.

The first commercial engine, 8UEC60LSⅡ-Eco, has been maintaining fine operation as the main engine of a pure car and truck carrier since June 2005.

We expect that Eco-Engine will become the leading engine over the next decade.

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