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The Latest Technologies of J-ENG UE Engine

9 - New Engine Developments - Diesel

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ABSTRACT

UE engines feature high economic efficiency, high reliability, and environmental-friendliness. The high economic performance of the UE engine can save ship owner's operating costs. UE engines have been developed and improved for more than half a century. Now we have developed new line up of 33-60cm bore size engine mainly and for over the 50cm bore engine equips low pressure EGR (LP-EGR) system and low pressure SCR (LP-SCR) system for the purpose of NOx reduciton compliying with IMO-NOx Tier3 regulation. Also the LP-EGR sysetm and LP- SCR system had been tested and verified in service vessels. The IMO SOx regulation limits sulphur content of fuel under 0.5% m/m come into force on 2020 in global area. Therefore the ship owners, shipyards, engine maker,etc. need to take important decisions about which item to invest in SOx scrubbers or the use of low sulphur FO or LNG, also have to considerate the impact of designing change relative to the decisions. We, Japan Engine Corporation concentrate development of the new concept engine “UEC-LSJ” that use MGO mono-fuel in order to accommodate the above circumstance of marine diesel engine. In order to develop the “ UEC-LSJ”, we are launching and applying the new technology concept “JUMP”, that is J-ENG Unique Marine Power. The concept of “UEC-LSJ” engine is by using MGO(Marine Gas Oil) as mono-fuel, we can comply with 3(three) enviromental regulation (“SOx Regulation”, “NOx regulation” and “EEDI regulation”) at the same time. The advantages of using MGO are no SOx scrubber, no (or smaller) exhaust gas economizer, prolong mainanance interval. MGO costs relatively high than the other marine fuel in current market situation, but the exsessivly high efficiency (low fuel oil consumption) makes the impact smaller and low initial cost realize the supirior combination of operation and construction. It saves both initial and running cost. The first “UEC-LSJ” serise will be UEC50LSJ. The basic concept of UEC50LSJ consists of combination of “high efficiency combustion cycle” and “stratified water injection” to optimaize both fuel oil consumption and NOx emission. In this paper, we will summarize these latest concepts of UE engine mainly “UEC-LSJ”. In addition, the comprehensive verification test results of first UEC50LSJ engine will be also reported.

1 INTRODUCTION

Japan Engine Corporation (J-ENG) was established in April 2017 by merging the marine diesel engine business division of Mitsubishi Heavy Industries Marine Machineries & Engine Co., Ltd. (MHI-MME) and Kobe Diesel Co., Ltd.

Both MHI-MME and Kobe Diesel have a long term partnership by complementing each other as licensor and licensee relationship. J-ENG enhances this relationship by integrating the respective business from the upstream as the licensor to the down-stream as a licensee.

Figure 1 shows the development history of UE engine. The latest model of UE engine is "UEC50LSJ/UEC50LSJ-EGR" and its concept and features are shown in section 2. The first UEC50LSJ-EGR engine was built at J-ENG factory in December 2018 and verification test is undergoing (Figure 2).

This "UEC50LSJ/UEC50LSJ-EGR" engine is developed under the support of The Nippon Foundation.

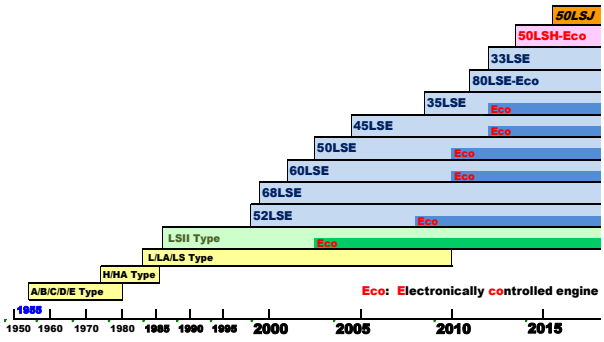

Figure 1. Development history of UE engine

Figure 2. The first 5UEC50LSJ-EGR

2 CONCEPT OF "UEC50LSJ"

2.1 "JUMP" the solution for future environment and market

IMO decided to implement a global Sulphur limit of 0.5% m/m in 2020. Therefore the stakeholders need to take important decisions about whether to invest in SOx scrubbers or the use of low Sulphur MGO/HFO or LNG. There are some concerns as follows;

- SFOC: Compliance with IMO-NOx Tier III regulations is also required. Generally, there is trade-off relation between NOx emission & Specific Fuel Oil Consumption (SFOC), and SFOC gets worse than ever. It means that complying with EEDI regulation becomes more difficult.
- Costs: If SOx scrubber or LNG (Dual Fuel engine) is applied, the initial cost becomes higher significantly.
- Engine room layout: If SOx scrubber or the Dual Fuel engine is equipped in ship, they require huge space for their unit and/or additional facilities. Engine room design becomes more complicated and the cargo space may be reduced.

Therefore J-ENG has developed a new concept engine with "MGO mono-fuel engine" (our patent technologies) under the "JUMP" concept (Figure 3). "JUMP" means J-ENG Unique Marine Power. The concept is achieving low SFOC complying with both NOx and SOx regulations with MGO mono-fuel engine. The last code "J" of UEC50LSJ is the initial of "JUMP" and is developed to realize the "JUMP" concept.

Figure 3. Concept of JUMP

The concrete concepts of "JUMP" for UEC50LSJ are as follows;

- Low SFOC: Appropriate swirl flow by scavenging air port arrangement of cylinder

liner, optimization of atomizer design for fuel injection valve and fuel injection pressure, make the efficient combustion cycle.

- NOx reduction for IMO-NOx Tier II level: The Stratified Water Injection system reduces NOx emission complying with IMO-NOx Tier II regulation.

- NOx reduction for IMO-NOx Tier III level: For ECA area passing, the Low Pressure EGR (LP-EGR) system is used with the Stratified Water Injection system.

- SOx reduction: Using only MGO globally.

2.2 Advantages of UEC50LSJ

The advantages by use of UEC50LSJ are as follows;

- Low SFOC: Fuel oil consumption (during operation and at port) is 5% less than the conventional engine. It reduces the cost of fuel oil and enhances CSR due to environmental friendliness.

- High reliability and less maintenance cost: MGO contains few residues, so few deposit will be created in combustion chamber and turbocharger. There is also less risk for cold corrosion due to very low Sulphur content in MGO. This idea supports extended maintenance interval and high reliability.

- No fuel oil changeover operation: Because of the MGO mono-fuel type engine, there is no fuel oil changeover work which reduces workload and possible related human error.

- Less auxiliary systems for fuel oil: Because of the MGO mono-fuel type engine, the auxiliary system is required only for MGO, for example, fuel tanks, purifiers etc.

- Unnecessary use of SOx scrubber: Because of using MGO only, no after-treatment system for exhaust gas is needed. It means the technical difficulty of designing of engine room is the same as conventional engine.

- No heat trace system: Because of the low viscosity of MGO, no heating system is needed. It means the designing of engine room is simpler than the conventional engine.

For example, in case the UEC50LSJ is equipped on handy size bulk carrier with fuel oil consumption approximately 20ton/day, the fuel oil saving would be approximately 1ton/day. In case of MR tanker with fuel oil consumption approximately 30ton/day, the fuel oil saving would be approximately 1.5ton/day.

2.3 MGO (Marine Gas Oil)

On the selection of MGO for the future solution, the four kinds of fuel were compared for the various points of view. The four kinds of fuel are as follows and the summary is shown in Figure 4.

- HFO (Heavy Fuel Oil): It is major fuel oil for marine diesel engine so far and the availability is good currently, but the future availability is uncertain. The system also needs SOx scrubber for IMO-SOx regulation and fuel oil heating system. The SOx scrubber needs large space in engine room. Furthermore, if the open loop type scrubber is fitted, it should be considered that the discharging regulation of processed water may be restricted in some area and it may not be an effective solution for IMO-SOx regulation. The closed loop type scrubber needs huge amount of Caustic Soda and the running cost would be high. Also, production capacity of scrubber and number of repair docks are limited and must be in short supply when the demand boosts.

- MGO (Marine Gas Oil): It is already a major fuel oil for marine diesel engine. The availability is good currently, and future availability is also promising, because the land vehicles, cars and trucks, will be shifted to electrical motor driven and the surplus gas oil will be supplied for marine diesel engine. The low Sulphur content of fuel oil does not require to equip SOx scrubber. Also, because of the low viscosity, the heating system of fuel oil is unnecessary and the handling is easier than the other fuels. However the price of MGO is higher than the other fuels, therefore the cost of fuel oil should be compensated by the low fuel oil consumption of engine itself.

- LS-HFO (Low Sulphur Heavy Fuel Oil): It is the new kind of fuel oil and SOx-less fuel oil, but the specification and property is unknown. The properties will be very different to handle for port and supplier. It can make unexpected troubles for engine and engine room facilities. The price is assumed a little bit lower than the MGO but higher than HFO, but uncertain at present.

- LNG: It means that the engine should be a Dual Fuel engine. The price of fuel is forecasted cheaper among the other fuels. The future availability will be promising but the construction of bunker facility covering all over the world needs a long time, so the

availability will be limited for several years from now. The engine and the auxiliary systems for Dual Fuel system is much expensive and also requires large space for installation. Handling of fuel and engine itself becomes most difficult among the engines those use other fuels.

Considering the above points of view, MGO was selected for one of the best solutions for future environmental and marketing needs.

	HFO	MGO	LS-HFO	LNG
Price	Base	Higher	Higher	Closed to HFO
Availability	Now >Good Future >?	Promising	Promising	Limited
Heating	Necessary	Unnecessary	Necessary	Unnecessary
System	Expensive and complicated by Scrubber	Simple without heat trace and EGE	Same as current system	Expensive and complicated

Figure 4. Comparison of solution with fuels

2.4 Modification point of engine room

The fuel is MGO only therefore the tanks purifiers and piping are prepared only for MGO. It means the simple and easy designing. Furthermore heating trace system is unnecessary, the exhaust gas economizer will be smaller than the conventional type. Otherwise, the UEC50LSJ equipped the Stratified Water Injection system, the water supply system and piping are needed and fresh water generator capacity should be increased for suppling fresh water to engine. The modification points are shown in Figure 5.

Conventional vessel	MGO mono-fuel vessel
MDO or MGO and HFO tank	MGO FO tank
Purifier for MDO or MGO and HFO	Purifier for MGO
FO heating and relevant piping	No heating line
Exhaust gas economizer	Down size
MDO or MGO and HFO line	MGO line
Water supply system for cooling and accommodation etc.	Additional line for supplying water to water injection system
Fresh water generator	Increase capacity

Figure 5. Modification points for engine room

3 TECHNICAL FEATURES OF UEC50LSJ

3.1 Low SFOC and NOx emission

Figure 6 shows the technical concept of low SFOC of UEC50LSJ-EGR.

Sufficient mixture of fuel oil and scavenging air for higher combustion efficiency (Low fuel oil consumption) can be realized by appropriate swirl flow of scavenging air port arrangement of cylinder liner and optimization of atomizer design for fuel injection valve, fuel injection pressure, etc. After the Low fuel oil consumption tuning, the Stratified Water Injection is applied for NOx reduction under the IMO-NOx Tier II level. Figure 7 shows the relation between SFOC and NOx reduction ratio against water injection ratio on a single cylinder test engine.

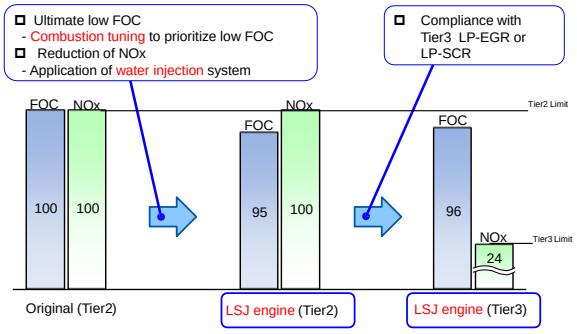

Figure 6. Low fuel oil consumption concept

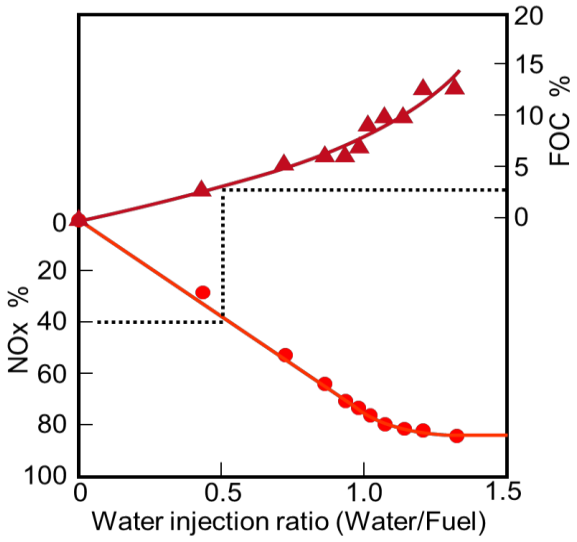

Figure 7. SFOC increasing/NOx reduction against water injection ratio (single bore test engine)

Another NOx reduction technology, EGR or SCR system can be applied instead of the Stratified Water Injection for the compliance of IMO-NOx Tier II regulation with low SFOC, but with the below points of view, it does not seem to be the best solution.

- EGR system: The costs of Caustic Soda for neutralization of scrubbing water and discharged sludge are higher than the merit of low SFOC. Also in case of the reduction of NOx for IMO-NOx Tier III level, the EGR rate would be too high.

- SCR system: The Urea water for NOx conversion is needed, therefore the merit of cost reduction by low SFOC would be reduced.

Considering above points of view for the Tier II operation, the Stratified Water Injection system is applied for NOx reduction with low SFOC on UEC50LSJ.

3.2 Stratified Water Injection system

There are three types of major water injection technology as follows;

- Emulsion fuel Injection
- Independent Water Injection
- Stratified Water Injection

Emulsion fuel Injection system makes water/fuel emulsion upstream of fuel injection pump and supplied to combustion chamber through fuel injection pump and fuel injection valve. The additional equipment is only emulsification apparatus and it is simple. However, fuel spray injected includes water and the ignitability is unstable especially on engine start up, and the water/fuel ratio control along with engine loads is difficult.

Independent Water injection system is composed of conventional fuel injection valve and another water injection valve on cylinder cover. The fuel and water is injected individually therefore the control mechanism of injection is simple. However, the efficient water injection nozzle matching over the all engine loads is very difficult.

Stratified Water Injection system complements those demerits of Emulsion Injection and Independent Water Injection. Figure 8 shows the outline of the Stratified Water Injection system of UEC50LSJ. There are two positions of water insertion to fuel oil at fuel injection valve, and two individual water injection pumps insert water at the two insertion positions of fuel injection valve. The insertion of water to fuel is carried out during the interval between fuel injection of every single cycle. After the two water layers are inserted, fuel injection pump lifts up and layered fuel and water is injected to combustion chamber through the fuel injection valve. Figure 9 shows the fuel injection valve illustration. The injected water from water pumps is inserted to fuel by layer via non-return valves. The non-return valves protect water injection pipe and water injection pump from high pressure during fuel injection. The tip of fuel injection nozzle is fuel and the ignitability is the same as fuel only. The layered water efficiently catches the flame because the water is injected through the same injection holes. The water injection pump is hydraulically driven piston pump and the pump lift value which is feedback controlled by the control system. Therefore the water/fuel injection rate is controlled accurately and optimally by engine load.

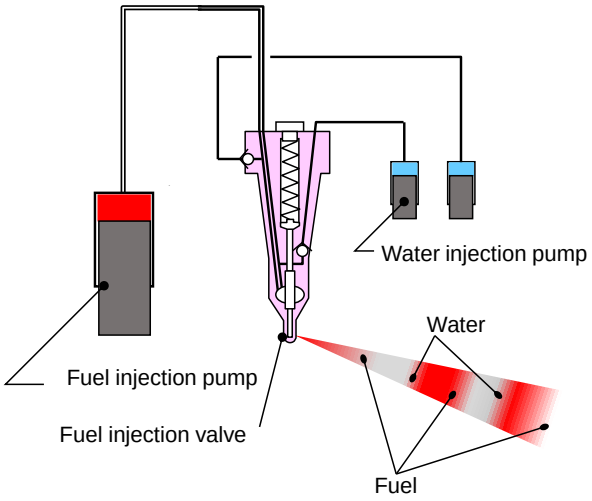

Figure 8. Outline of Stratified Water Injection system

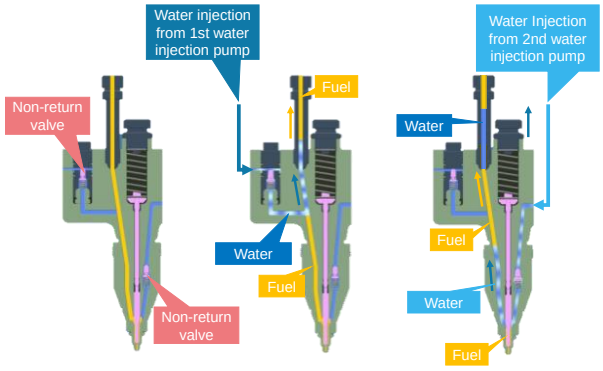

Figure 9. Fuel injection valve for the Stratified Water Injection

The Stratified Water Injection system had been developed as our unique technology in the past (Figure 10). There are four engines that integrated with the Stratified Water Injection system. For a marine diesel engine, 6UEC52/105D was integrated with the Stratified Water Injection system and on-board verification test had carried out for approximately 2,000hours on “Ginga Maru”, the training ship of Japan agency of Maritime Education and Training for Seafarers. This time, in order to suit for high performance and high flexibility engine, the Stratified Water Injection system has been re-designed completely. The water injection pump and actuating system are also completely re-designed and engine control system is designed as flexible

system which controls governing and water injection comprehensively and has some control mode including EGR system control.

	Ship / Plant	Engine Model	Year in service	Running hour of water injection
1	Ginga Maru	6UEC52/105D	1994 (On-board test)	Approx. 2,000h
2	Company “S”	16KU30A	1995 – 2004	Approx. 16,000h
3	Company “S”	16KU30A	1995 – 2004	Approx. 16,000h
4	Company “T”	18KU34	1996 – 2006	Approx. 12,000h

- 1 set for 2 stroke engine
- 3 sets for 4 stroke engine
- 4 sets in total

Figure 10. Reference of engine integrated with the Stratified Water Injection system

4 OUTLINE OF UEC50LSJ-EGR

4.1 Development base engine

UEC50LSJ-EGR is designed based on UEC50LSH-Eco-C2. This engine is the latest line up of serviced UE engine. The UEC50LSH-Eco-C2 is targeted for Chemical Tankers, Supramax Bulk Carriers, Handy-size Bulk Carriers, Medium Range Tankers and Chip Carriers. The vessel which is equipped the first 6UEC50LSH-Eco-C2 entered service in September 2015 and the current total running hour is approximately 18,000hours. The service experience of the first 6UEC50LSH-Eco-C2 is excellent and it proves the high reliability and performance. For example, the piston rings and cylinder liner conditions are shown in Figures 11, 12. They are in excellent condition. The piston rings wear rate is less than 0.01 mm/1000 hours and the cylinder liner wear rate is less than 0.03mm/1000hours around piston ring TDC position. The main bearings, crosshead pin bearings and crank pin bearings are in good running marks (Figures 13-15). Even after approximately 18,000 running hours, no indication of damage is reported.

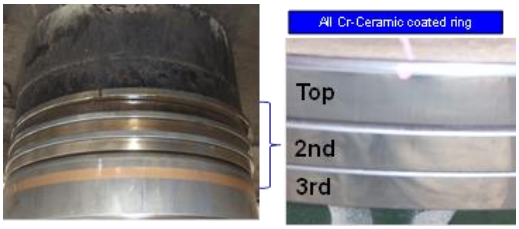

Figure 11. UEC50LSH-Eco-C2 Piston rings condition (13,663 running hours)

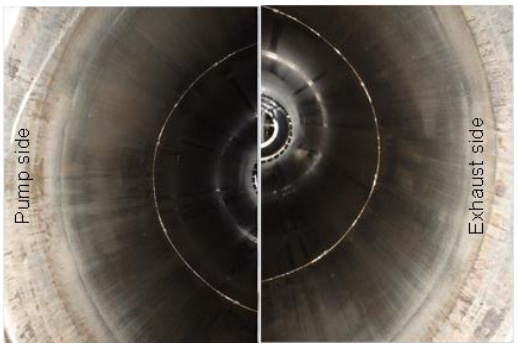

Figure 12. UEC50LSH-Eco-C2 Cylinder liner condition (13,663 running hours)

Figure 13. UEC50LSH-Eco-C2 Main bearing metal condition (13,663 running hours)

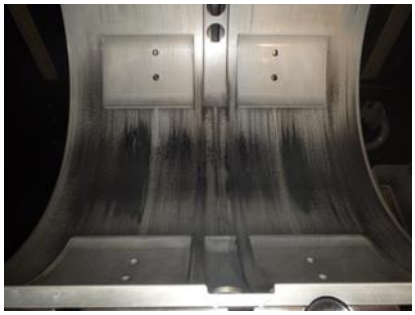

Figure 14. UEC50LSH-Eco-C2 Crosshead pin bearing metal condition (13,663 running hours)

Figure 15. UEC50LSH-Eco-C2 Crank pin bearing metal condition (13,663 running hours)

4.2 UEC50LSJ-EGR outline

Figure 15 shows the outline of UEC50LSJ-EGR. UEC50LSJ-EGR is a fully electronically controlled engine. Fuel injection pumps and water injection pumps are driven by the same hydraulic accumulator pressure on the upper platform. The exhaust valve actuators are mounted on the lower platform. The fuel and water injection pumps hydraulic source is supplied by the two electrical high pressure hydraulic oil pumps on engine driving end side of the upper platform. The exhaust valve actuators hydraulic source is supplied by the two engine driven pumps on engine driving end side of the lower platform. The pump type (electrical driven or engine driven) and the number (total capacity), layout are designed by low-cost, high reliability, high efficiency and performance of the Stratified Water Injection system.

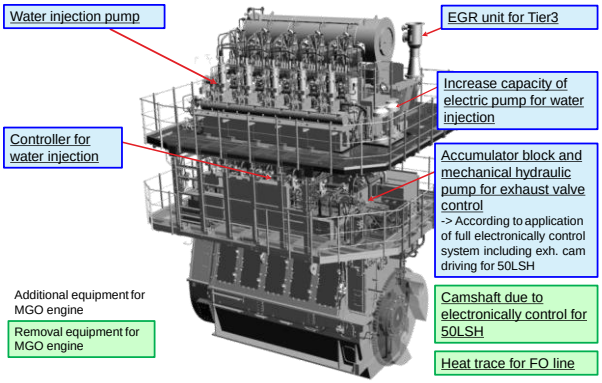

Figure 15. Outline of UEC50LSJ-EGR

4.3 Fuel and water injection system

Fuel injection pump is driven by the two hydraulic main valves per cylinder (Figure 16) and the individual motion of each main valves make the optimized fuel injection mode (Figure 17). The main valves of hydraulic system are driven by the pilot pressure from solenoid valves. Each solenoid valves are controlled by the electronically control system (Eco system). The optimized fuel injection mode improves the trade-off relation between fuel oil consumption and NOx emission as shown in Figure 18. Owing to UEC50LSJ has the Stratified Water Injection system, the injection amount is larger than the conventional engine. Therefore the fuel injection duration and the passage size inside fuel injection valve and high pressure pipe size, fuel injection pump size, pressure ratio of plunger/actuator are optimized for the injection amount. The water injection pumps for the Stratified Water Injection illustrated on 3.2 are set next to fuel injection pump as shown in Figure 19. The actual fuel injection valve is shown in Figure 20.

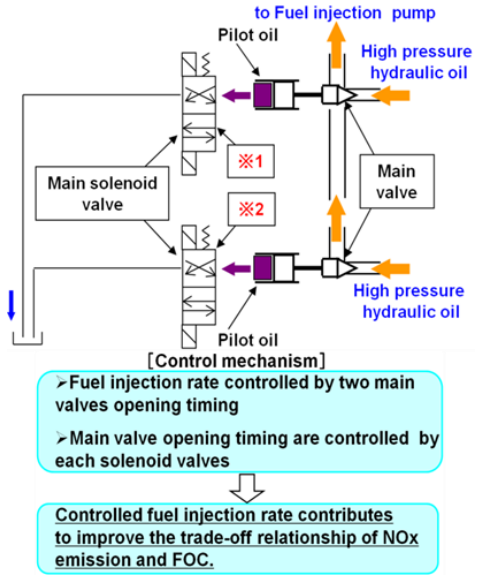

Figure 16. Fuel injection hydraulic system

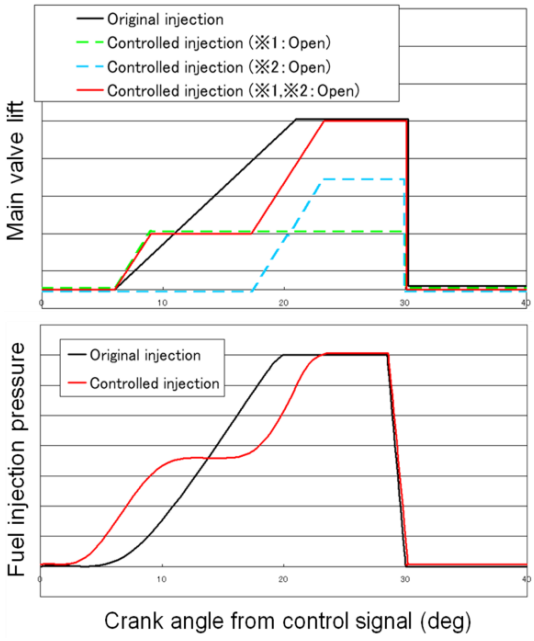

Figure 17. Fuel injection rate control mechanism

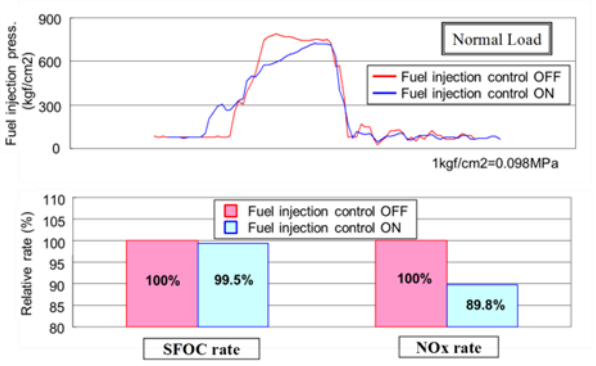

Figure 18. Improvement of fuel oil consumption and NOx emission trade-off

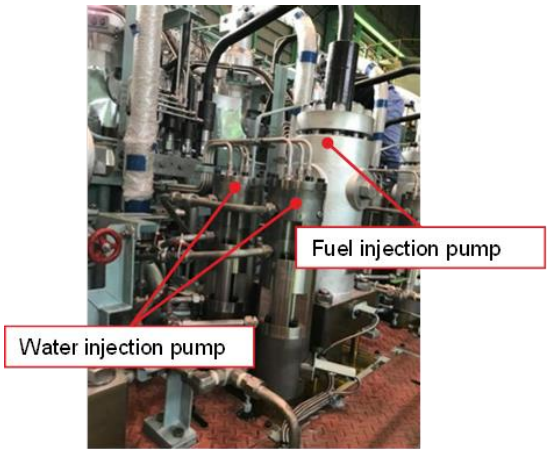

Figure 19. Fuel injection pump and water injection pumps

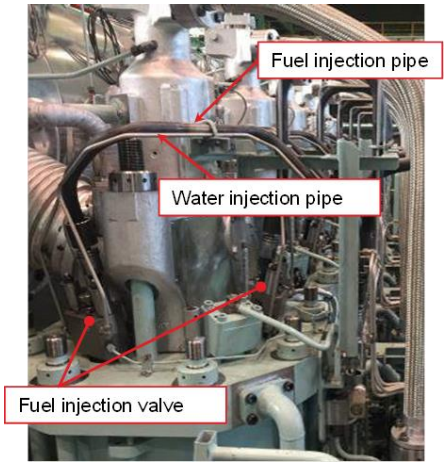

Figure 20. Fuel injection valve (with water injection system)

4.4 Exhaust valve driving system

UEC50LSH-Eco-C2 has camshaft for exhaust valve driving and the system is simple with high level of engine performance. However the realization of extreme low SFOC and low NOx emission ratio, good low load performance, tuning flexibility as UEC50LSJ, the exhaust valve driving system of UEC50LSJ was adopted with electronically controlled hydraulic system.

Figure 21. Exhaust valve driving system

4.5 LP-EGR system

This first UEC50LSJ-EGR complies with IMO-NOx-Tier III regulation by Low Pressure EGR (LP-EGR) system. On this type of EGR, the recirculation gas (EGR gas) is extracted from after stream of turbocharger. LP-EGR system has few additional parts (valves and pipes) and simple structure, therefore the maintenance cost is low and the reliability is high. J-ENG had already verified its excellent performance and reliability [1]. The system outline and the main components are shown if Figure 22-24.

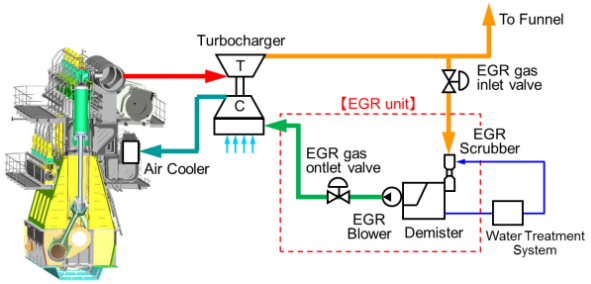

Figure 22. LP-EGR system outline

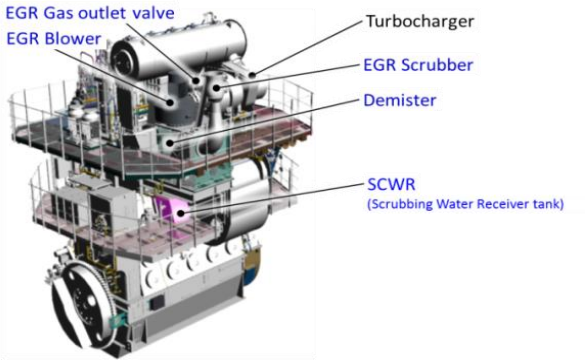

Figure 23. EGR system on UEC50LSJ-EGR

Figure 24. Close up of EGR components

4.6 Combustion chamber

The main features of the combustion chamber are as follows;

- Three fuel injection valves per cylinder: Uniform combustion and equalized thermal load.
- Zero-suc fuel injection valve: High reliability by reduction of carbon deposit.
- Cylinder liner: Plateau honed highly reliable and low mechanical loss, simplified shape by adoption of a non-bore cooling type liner and the cooling water temperature is controlled appropriately by a bypass line.
- Piston: Bore cooling and high top land to reduce the thermal load of the cylinder liner
- Piston ring: Reduced maintenance costs and prolonged service-life owing to hard coating rings in three stages

4.7 Structure of main components

The main feature of the body structures are as follows;

- Bed plate and column: Stiffer and lighter by adoption of a single wall structure
- Tie bolts: high stiffness and light weight with twin tie bolts of low alloy steel
- Main bearing and crankpin bearing: Aluminum metal for increasing fatigue strength
- Cylinder jacket: High stiffness and lighter weight owing to an optimized shape
- Piston rod and gland packing: induction hardened rod and high pressure rings for high reliability and reduction of consumption of system lubricating oil
- Crosshead: Reduced mechanical loss owing to high stiffness of column and optimized sliding parts shape.
- Crosshead pin bearing: Reduced oil film pressure by the adoption of oil pocket.

5 VERIFICATION TEST

5.1 Unit test

Before the UEC50LSJ actual engine running, the function and reliability of injection system was tested with a unit test bench. The main components of unit test bench are shown in figure 25. The unit test bench is consist of one fuel injection pump, two water injection pumps, three fuel injection valves, piping, hydraulic system and controller. The system configuration is same as actual UEC50LSJ one cylinder injection system. Figure 26 shows the unit test bench at shop. On the bench test, first, function of water and fuel injection system was tested and confirmed that the system accomplished designed function from the pressure waveform and lift signals (Figure 27). Next, the endurance test was practiced and after approximately 600 hours, the water pump was inspected and the running surface and other functional parts was normal condition.

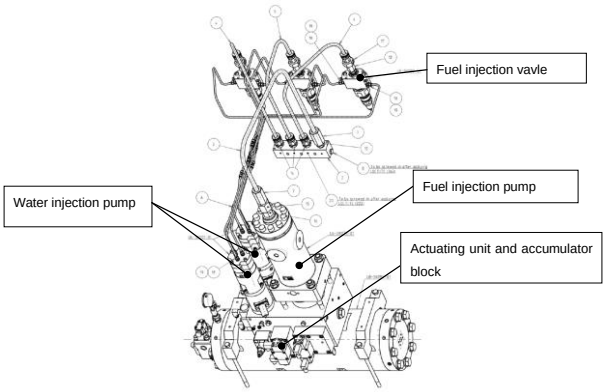

Figure 25. Unit test main component

Figure 26. Unit test equipment at shop

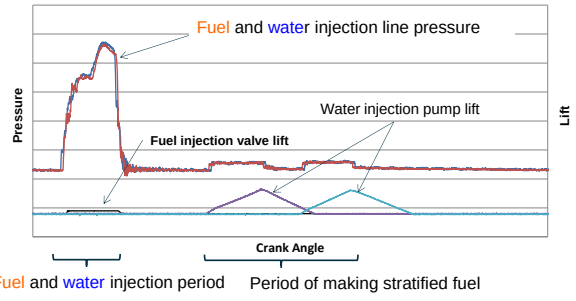

Figure 27. Pressure waveform on unit test

5.2 UEC50LSJ-EGR shop verification test

The first 5UEC50LSJ-EGR was constructed in December 2018. So far the various verification tests have been carried out in our shop.

5.2.1 Test and measurement items

- Engine function test (mode change (fuel only to the Stratified Water Injection, the Stratified Water Injection to the Stratified Water Injection with LP-EGR etc.) and governing.
- Alarm test
- Engine performance (SFOC and NOx emission) on the Stratified Water Injection (Tier II mode).
- Engine performance (SFOC and NOx emission) on the Stratified Water Injection with LP-EGR. (Tier III mode)
- Pressure wave forms of injection systems and hydraulic systems
- Temperature of combustion parts

5.2.2 Test results

The engine performance (Tier II/Tier III) tests were carried out. Mostly the test has been performed on 100%Load and SFOC at 100%Load had cleared the planned SFOC within 5% tolerance with IMO-NOx Tier II level NOx emission ratio. The trade-off relation on EGR with the Stratified Water Injection is the same as the engine of EGR only. Therefore the IMO-NOx Tier III level NOx emission ratio must be cleared. The E3 mode NOx and SFOC will be optimized from now and it will be cleared the target value.

5.2.3 Reliability verification

After the running with Stratified Water Injection, piston rings condition and cylinder liner condition were inspected and after approximately 80 hours running, the piston ring and cylinder liner running surface, piston head and land condition was normal.

Figure 28. piston ring condition (approx.80 running hours)

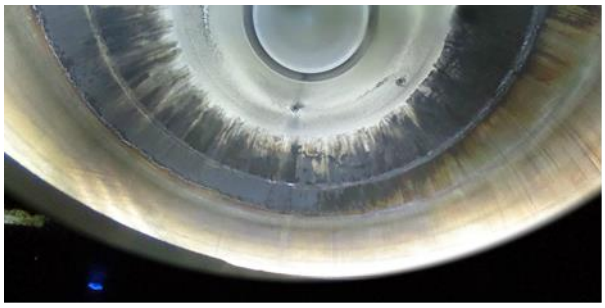

Figure 29. Cylinder liner condition (approx. 80 running hours)

6 CONCLUSION

This paper described the new generation engine “UEC50LSJ/UEC50LSJ-EGR” and the main concept is named as “JUMP” with “MGO mono-fuel engine” as its core. The verification test of UEC50LSJ-EGR stats that high performance with high reliability complying with both NOx and SOx regulations has been carried out. The feasibility of high performance and high reliability had been confirmed at the test. The endurance test will be carried out continuously. The first UEC50LSJ will be entered in service after 2020, and the performance and the reliability will be verified under actual service condition. “UEC-LSJ” engine will be improved further and regarded as one of the best solutions for future environmental technology.

J-ENG will contribute to the future shipping industry with the innovative and unique technologies.

7 ACKNOWLEDGMENT

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