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The latest developments and technologies of the UE engines

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Abstract: This paper reports the updated program of the UE engine, and focuses on the UEC45LSE now under development. It also discusses design methods using 3D-CAD, and offers the latest information about the SIP system. Furthermore, this report includes a description of a water injection system as an example of the new environmentally friendly technologies that are becoming available.

The latest UE series, the LSE, was introduced in 1998, and five LSE types appear in our brochure at present. The LSE is a new generation engine targeted for larger and faster ships in recent years, and its design concepts are excellent reliability, economy, easy maintenance and environmental friendliness.

The UEC45LSE is a new comer in the LSE and its development is now in progress. So far, many 6UEC52LA have been installed in Handysize BC due to their low fuel oil consumption and high reliability. However, the UEC52LA is heavy and large because it was developed 20 years ago; thus development of the UEC45LSE was commenced as a successor to the UEC52LA to overcome these disadvantages of engine dimensions. Based on comprehensive market research, the UEC45LSE has appropriate output that is not excessive for Handysize BC. Also, suitable engine speed, bore and stroke were decided. As a result, compact engine dimensions can be achieved.

Since Mitsubishi is the only 2-stroke engine designer in the world that is manufacturing engines, we are always taking production into consideration when developing engines. With this in mind, we apply 3D-CAD and CAM at developing the LSE, and these tools contribute to enhancing quality and reliability of engines. For designers, 3D-CAD is a useful tool for visually confirming three-dimensional configurations on a computer screen, even if the configurations involve complicated shapes. Additionally, since manufacturing section staff can also access the data base of 3D-CAD drawings, they can study the manufacturing procedures and offer feed-back on the drawings during the initial design stage. Furthermore, as for CAM, numerical control data for machining can be directly made from 3D-CAD data.

Shipowners reported that in case of large container ships, the rate of cylinder oil cost dominates more than 80% of the total maintenance costs of marine diesel engines. Therefore, reducing cylinder oil consumption can contribute to a reduction in ship operating costs. The SIP system is an epoch-making cylinder lubrication system that can decrease cylinder oil consumption, and the number of installations has been increasing each year. The SIP system injects cylinder oil like a spray, and eliminates cylinder oil being splashed up and down due to piston ring movement.

The regulation of Annex VI of MARPOL73/78 went into effect in 2005, and all UE engines are fully compliant with this regulation. However, in the future, NOx limits will be stricter and new regulation items will be added. For this reason, we have been developing new technologies that will comply with future regulations. In relation to NOx reduction, the electronically controlled engine and/or a water injection system can be applied after the second regulations.

INTRODUCTION

The UE engine is the only remaining marine two-stroke diesel engine in Asia, and a half century has passed since the first UE engine was developed, as shown in Fig. 1. The advantages of the UE engine are its high economy, high reliability, and environmental friendliness.

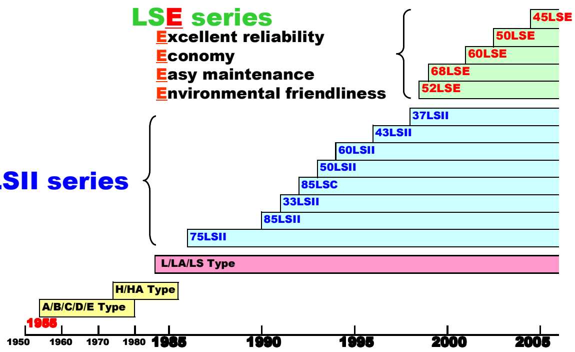

Figure 1. Development history of UE engines

The price of oil has continued to increase recently, and it has remained at a high level. This means that shipowners have to pay higher operating costs for both fuel oil and lubrication oil. The high economy of the UE engine can contribute to saving those costs.

Needless to say, high reliability is the key issue for the marine two-stroke engine. UE engines received high evaluations from users at previous CIMAC conferences. From a technical point of view, the three-dimensional CAD (3D-CAD) system and the CAM system, which were recently nominated as the design and manufacturing tools of UE engines, contribute to enhancing the reliability of UE engines.

In addition, environmental regulations of IMO were implemented in 2005, and they will become stricter in the near future. Of course, all UE engines are in full compliance with present regulations. Furthermore, technologies that meet expected future regulations are continuously being developed.

The latest developments and technologies of UE engines are reported in this paper, focusing on the latest program, design method, and emission controls.

ENGINE PROGRAM

Table 1 shows the latest UE engine program. The LSE series, which features excellent reliability, economy, easy maintenance, and environmental friendliness, is being expanded. LSE engines are more compact and have higher output in order to meet the demands for recent larger and faster ships. Total orders for the LSE series are currently 47 sets, and they are increasing rapidly.

The UEC52LSE is the first engine of the LSE series, and has had a good service record for about five years. UEC52LSE engines are mainly used for the main engines of 1100 TEU class container ships, Ro-Ro vessels, and Pure Car (Truck) Careers (PC(T)Cs). Nine sets of the UEC68LSE are operated as the main engines of Capesize Bulk Careers (BCs), Aframax tankers, and 2500 TEU class container ships. We developed the UEC50LSE in collaboration with Wartsila Switzerland in 2005. That was the first collaboration in new engine development between Wartsila Switzerland and Mitsubishi. It has now progressed to a strategic alliance between two companies. The UEC45LSE is under development as the successor to the UEC52LA. The UEC45LSE suits Handysize BCs with six cylinders. The UEC60LSE has the appropriate particulars for 1700 TEU class container ships, PC(T)Cs, Panamax BCs, Aframax tankers, etc. The first engine of the UEC60LSE will be completed in Feb. 2007.

Details of the UEC45LSE and the UEC60LSE are described in the next paragraph.

Table 1. Latest program of UE engines

Series		LSII								LSE				
Bore		33	37	43	50	60	75	85	85 C	45	50	52	60	68
Stroke/ Bore		3.2～3.5			3.7～3.9				2.8	4.1		4.0		
BMEP	MPa	1.7～1.8								1.96	2.00	1.9		
Piston Speed	m/s	≦8.0								8.0	8.5			

UEC45LSE

The UEC45LSE as shown in Fig. 2 is the main engine targeted for the Handysize BC with six cylinders as the successor to the UEC52LA. The main particulars are shown in Table 2. The engine output and speed were decided based on market research, and are 7470 kW with 130 rpm. Market research indicated that extremely high output is unnecessary, because it results in a higher cost and bigger engine size. The engine speed meets the latest propeller design for the Handysize BC.

Engine length and weight are designed to be smaller than the UEC52LA. Therefore, cargo capacity of the vessel may be expanded, or the engine room can be more compact.

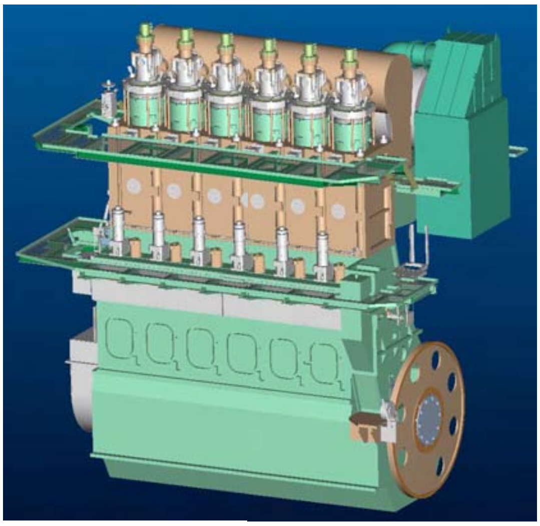

Figure 2. UEC45LSE

Table 2. Main particulars of 6UEC45LSE

Engine Type		6UEC45LSE	6UEC52LA
Bore	mm	450	520
Stroke	mm	1,840	1,600
Stroke/bore	—	4.09	3.08
Output	kW (PS)	7,470 (10,140)	7,080 (9,600)
Engine speed	rpm	130	133
B.M.E.P.	MPa	1.96	1.57
Piston speed	m/s	7.97	7.09
Engine length	mm	5,894	7,270
Piston overhaul height	mm	8,600	7,700
Crankshaft center	mm	1,000	930
Bedplate width	mm	3,000	3,000
Engine weight	ton	195	239

The design features of the UEC45LSE are shown in Fig. 3. Its basic construction is in line with the earlier model, the UEC52LSE, which is the same class bore engine; however, it has further compactness as a small bore engine. The minimum numbers of bolts were used on the cylinder cover, for example, six sets of cover bolts and two sets of exhaust valve cage bolts. Since the UEC45LSE is mainly manufactured by the licensee, it is designed taking the licensee into account, for example, the cast iron mainframe, etc. From a safety point of view, the oil mist detector and the piston cooling oil thermometers are located on the opposite side of the crank case safety valve to reduce the risk of injury by a crank case explosion. Also, the Swirl Injection Principle (SIP) system, which makes it possible to reduce the cylinder oil consumption dramatically, can be installed. The main fuel oil pipe is supported with a rigid bracket to reduce vibration. Accessibility to the piston underside from both port and starboard sides is significantly increased in comparison to the UEC52LA. The camshaft casing is integrated into the column. Parts such as the high efficiency MET turbocharger, reliable main bearing with white metal, exhaust valve hydraulic rotator, gear driven camshaft, and the emergency maneuvering stand arranged at the fore side follow the same construction features as in the existing LSE engines.

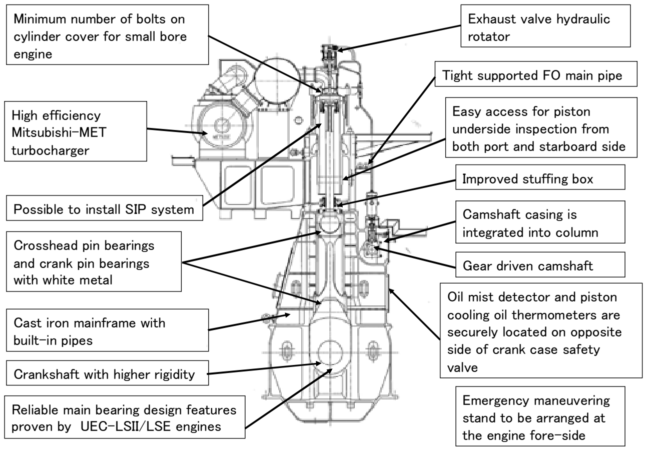

Figure 3. Construction features of UEC45LSE

These days, the UE engines are designed using a 3D-CAD system along with conventional methods such as FEM, CFD, and various simulators. The 3D-CAD system offers many advantages, but there are three main ones. First, the designer can recognize the configuration visually, even if it is complicated, such as the cast iron parts shown in Fig. 4. There is a very convenient function that makes it possible to create any cross section. In addition, the designer can check on the screen how to execute the maintenance in the design stage of development, as shown in Fig. 5.

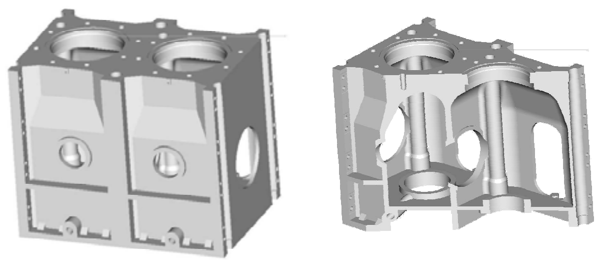

Figure 4. Cylinder jacket drawn by 3D-CAD

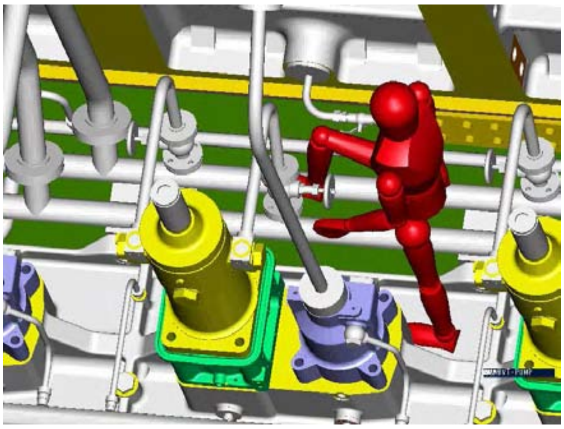

Figure 5. Pre-check of maintenance method on screen by 3D-CAD

The second advantage is that design data can be shared between the designer and the manufacturing staff. Therefore, the drawing can reflect the manufacturing procedures effectively. Figure 6 shows the cast iron coagulation analysis of the bedplate girder, for example. In conventional methods, a calculation model needs to be created in some software programs by referring to the drawings, which is very time consuming. Since it was impossible to do such time consuming work every time the drawings were revised, the calculation used to be done at almost the final stage of design. Therefore, if the manufacturing staff requested modification of the drawings because of the calculation results, the design had to go back to the earlier steps. This meant a lot of time was wasted. On the contrary, 3D-CAD data can create a calculation data directory at any design stage, and repeated calculations can be done easily. Therefore, manufacturing staff can pre-check the manufacturing procedures in the early stage of development, and feed the results back to the design. This close relationship between designer and manufacturing staff contributes to enhancing the reliability of the engine.

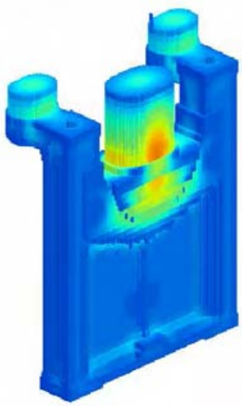

Figure 6. Cast iron coagulation analysis of bedplate girder

Third, a CAM system can be applied to the manufacturing, linking the 3D-CAD data. NC data used to be input manually, which sometimes resulted in human error in machining. In the CAM system, the design data made by the 3D-CAD system is automatically transferred to the NC data, and it can be utilized in the machining plan, as illustrated in Fig. 7. Consequently, the CAM system can contribute to enhanced reliability and machining efficiency due to the elimination of human intervention in NC data production. We just started a CAD/CAM linkage, and some parts are purchased from manufacturers that have not introduced the 3D-CAD system and/or the CAM system yet. Therefore, the CAD/CAM linkage is being applied to limited parts now. However, it will be expanded to other parts in the near future. Furthermore, regarding small pipes such as gauge pipes, specialists used to plan the piping route by looking at the actual engine in the shop and going by experience; they did not use detailed drawings. They bent and installed such pipes at the side of the engine on the plan they had made. However, since we can design such small pipes easily using the 3D-CAD system now and NC data is shared with the 3D-CAD system, the pipes are bent by the NC pipe bending machine automatically, as shown in Fig. 8. This system also contributes to enhancing engine reliability and manufacturing efficiency.

So far, four sets of the 6UEC45LSE are on order from domestic shipyards, and the first engine will be completed in the second quarter of 2008.

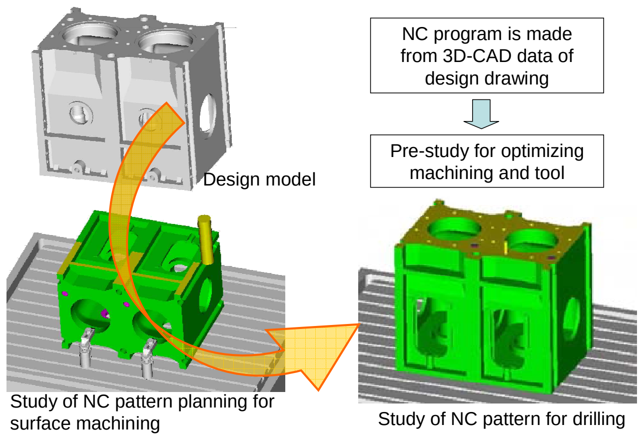

Figure 7. Example of CAM system

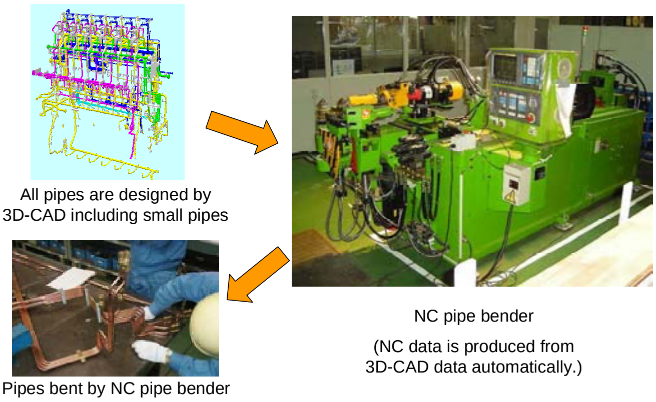

Figure 8. NC pipe bender

UEC60LSE

Table 3 shows the main particulars of the UEC60LSE. The output is 2255 kW per cylinder with 105 rpm, offering a brake mean effective pressure of 1.90 MPa and a mean piston speed of 8.40 m/s. The UEC60LSE features high reliability, high performance, and low vibration. It is also environmentally friendly. The main construction follows that of the UEC68LSE, which has enough service experience so far. For example, the crankshaft center height is designed to be the same as that of competitors' engine. Therefore, it is easy for a shipyard to replace an engine with the UE engine, even if the engine room was already designed for the competitor's engine. Also, the double wall construction of the column and the bedplate is used in order to achieve high rigidity and low vibration.

The first 7UEC60LSE will be completed in Feb. 2007 as the main engine of a 1700 TEU container ship. A test to verify the reliability and performance will be conducted at the shop.

Table 3. Main particulars of UEC60LSE

Bore	**mm**	**600**
Stroke	**mm**	**2,400**
Stroke/bore	—	**4.00**
Output	**kW/cyl (PS/cyl)**	**2,255 (3,065)**
Engine speed	**rpm**	**105**
B.M.E.P.	**MPa**	**1.90**
Piston speed	**m/s**	**8.40**
Engine length (6 cyl)	**mm**	**8,030**
Piston overhaul height	**mm**	**10,700**
Crankshaft center	**mm**	**1,300**
Bedplate width	**mm**	**3,770**
Engine weight (6 cyl)	**ton**	**355**

UEC ECO-ENGINE

The UEC Eco-Engine is an electronically controlled UE engine, as depicted in Fig. 9. We have been developing this type of engine since 1988. The first UEC Eco-Engine, the 8UEC60LSII-Eco, entered service in June 2005 as the main engine of a PCTC, as shown in Fig. 10. It features low NOx emissions, smokeless operation, low fuel oil consumption, and stable operation for all load ranges.

Figure 9. 8UEC60LSII-Eco (First UEC Eco-Engine)

Figure 10. PCTC installed with 8UEC60LSII-Eco

The UEC Eco-Engine controls fuel injection quantity and timing by solenoid valves instead of the camshaft. Also, the exhaust valves and starting air are controlled by solenoid valves. Timing of fuel injection and exhaust valve opening/closing greatly affect the engine performance in terms of NOx emission and fuel oil consumption. The UEC Eco-Engine achieved a reduction in NOx emissions and fuel oil consumption via flexible timing control of fuel injection and exhaust valve opening/closing for all load ranges, even during operation of the engine.

NOx emission and fuel oil consumption can be reduced by changing the fuel injection pattern utilizing a combination of two solenoid valves, as illustrated in Fig. 11. Working oil is supplied to the fuel pump through the main valve. First, the main solenoid valve opens, but the pilot oil is discharged gradually through the small orifice. When the sub solenoid valve opens, the pilot oil is discharged rapidly through the large orifice. As a result, fuel injection pressure is controlled as shown in the figure.

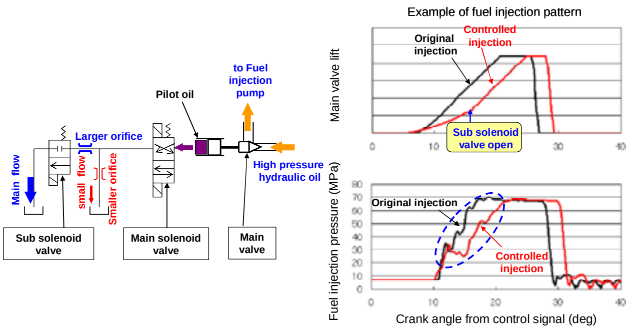

Figure 11. Fuel injection control

Fig. 12 shows the trade-off relationship between NOx emissions and fuel oil consumption. The UEC Eco-Engine has two operation modes, the low emission mode and the economy operating mode. If the low emission mode is selected, NOx can be reduced by 10 to 15% without any fuel oil consumption penalty. If the economy operating mode is selected, fuel oil consumption can be reduced by 1 to 2 % with the same level of NOx emissions.

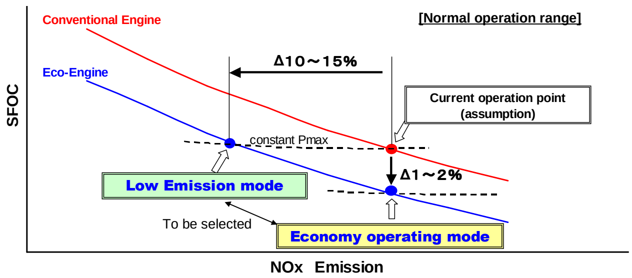

Figure 12. Reduction of NOx and S.F.O.C. by UEC Eco-Engine

Operation that is smokeless and stable is another advantage of the UEC Eco-Engine, especially at low load. Since the UEC Eco-Engine can inject fuel oil at a higher pressure than conventional engines at low load, combustion characteristics can be improved. As a result, smoke can be significantly reduced, as indicated in Fig. 13. Also, the engine can be operated stably without engine speed fluctuations even at low load.

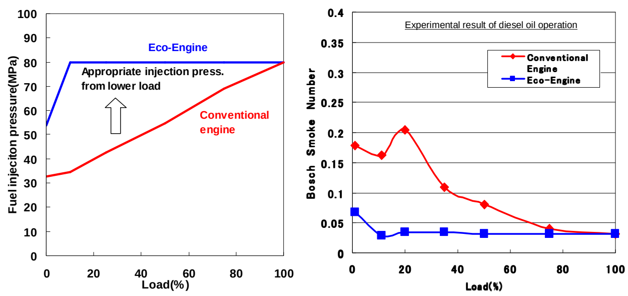

Figure 13. Smokeless operation by UEC Eco-Engine

The first UEC Eco-Engine, the 8UEC60LSII-Eco, has been operating without any serious problems. Some small problems that arose were resolved, and no shut downs have occurred so far, as shown in Fig. 14.

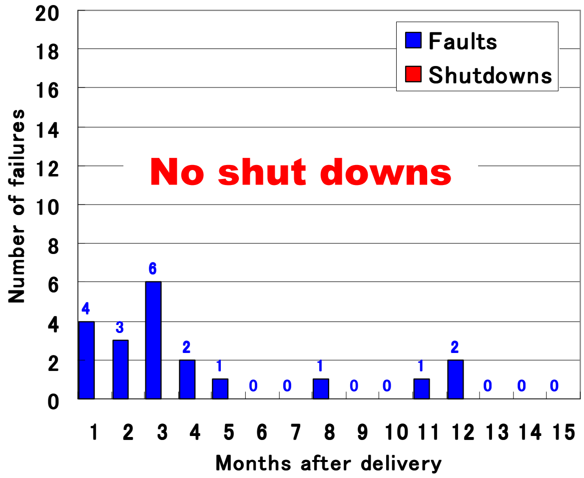

Figure 14. Number of failures of first UEC Eco- Engine

We have completed the Eco system for the UEC33LSII, UEC50LSII, and UEC60LSII engines. Because the UEC Eco-Engine effectively complies with the next phase of NOx regulations due to its NOx reduction aspect, we intend to expand the program of the UEC Eco-Engine further.

SIP SYSTEM

Cylinder oil prices keep increasing in accordance with rising crude oil prices. Therefore, shipowners are strongly requesting ways to reduce the cylinder oil feed rate. To meet such a demand, the Swirl Injection Principle (SIP) system was applied to UE engines. More than 100 sets of engines that implement the SIP system are already in service, including the Mitsubishi-Sulzer engines.

The SIP system can reduce cylinder oil consumption dramatically via the spray injection as shown in Fig. 15, because the thin and uniform oil film distribution is made on the liner surface, which is effective in reducing waste oil splashed up and down by the ring movement. In addition, use of the SIP system can achieve a reduction of the ring and liner wear rate, improvement of the ring and liner condition, and a reduction of particulate matter. Actually, service results have confirmed the good performance. Fig. 16 plots the cylinder oil feed rate trend for UEC50LSII, UEC60LSII, and UEC68LSE.

Not only is the feed rate after running-in lower, but the reduction speed is also faster than with a conventional cylinder lubrication system. In addition, the feed rate at the beginning of servicing is lower. Figure 17 shows the ring and liner wear rates. In general, the liner wear rate increases according to the reduction of the cylinder oil feed rate. However, it is still quite low despite the low cylinder oil feed rate because of the application of the SIP system. The photos of the ring and liner in Fig. 18 clearly reveal the good condition.

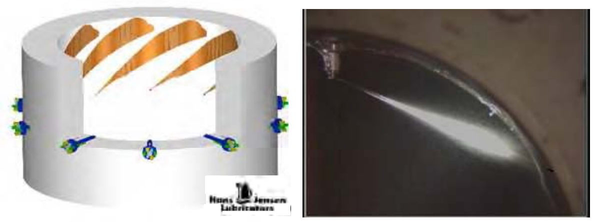

Figure 15. SIP system

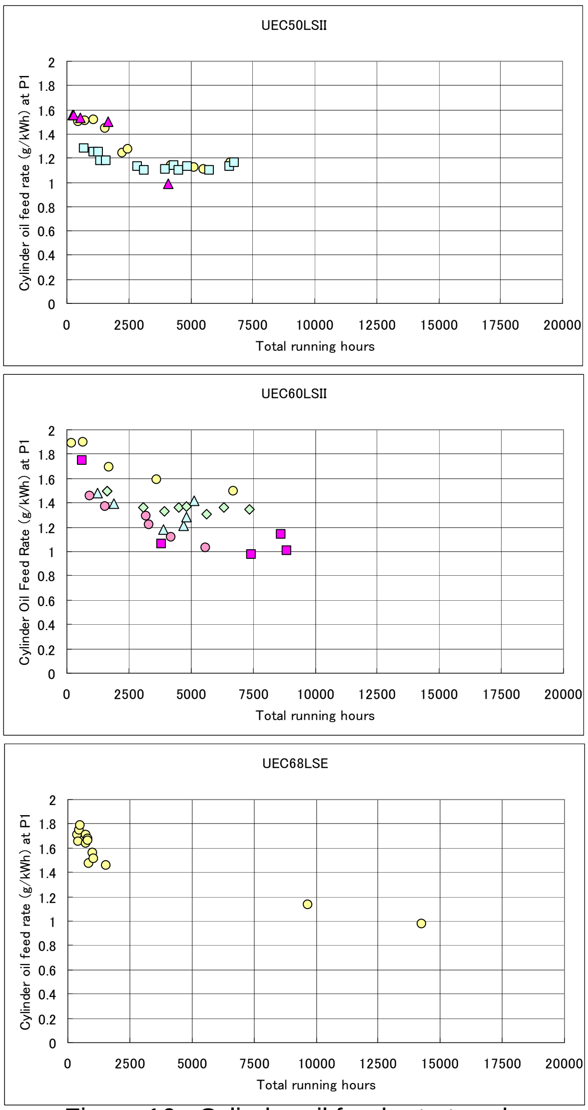

Figure 16. Cylinder oil feed rate trend

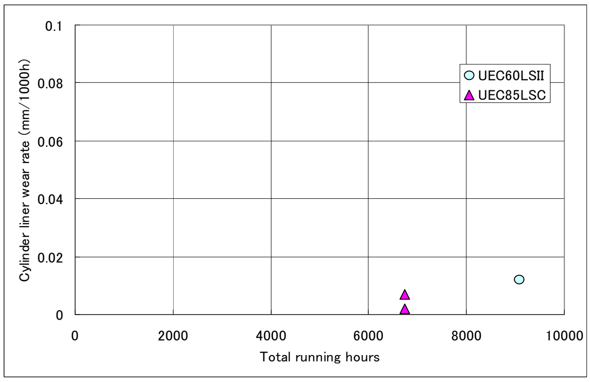

Figure 17. Service results of SIP system
- Cylinder liner wear rate -

Figure 18. Photos of rings 5755 hours after application of SIP system on UEC50LSII

EMISSION CONTROL

Emission control is the key technology in marine diesel engines now and in the future. Annex VI of MARPOL 73/78 went into effect in 2005, and it will be revised every five years. This means that the second phase of regulations will take effect in 2010. The UEC Eco-Engine will be in compliance with the second phase of regulations due to its NOx reduction capability, as mentioned previously. Furthermore, we have been developing new technologies toward future compliance with the third phase of regulations. One of these technologies is the water injection system, of which we have two. One is a stratified fuel water injection system. The other is an independent water injection system. The former has already been installed in stationary engines. We will now report on the first test of the latter system in an actual engine.

Fig. 19 shows the system layout. The water injection valves are installed separately from the fuel oil valves. Therefore, it is not necessary to increase the fuel pump capacity or the size of the camshaft driving gears and cams, unlike in the stratified fuel water injection system and the emulsion system. In addition, a large volume of water can be injected in this system, so NOx can be reduced greatly. The water is injected with appropriate timing that is controlled by the solenoid valves according to the crank angle. Since the electronic control system is similar to that of the UEC Eco-Engine, this system is easy to combine with that engine. Fig. 20 shows the water injection valve. The basic construction is the same as that of the fuel injection valve. Water is accumulated and injected at 20 MPa. The system was verified in a bench test before the test on the engine, as shown in Fig. 21. After the bench test, the whole system was installed in the 6UEC50LSE temporarily for the test, as shown in Fig. 22. The water injection valve is located in the upward position of the swirl air stream to the fuel injection valve, as shown in Fig. 23.

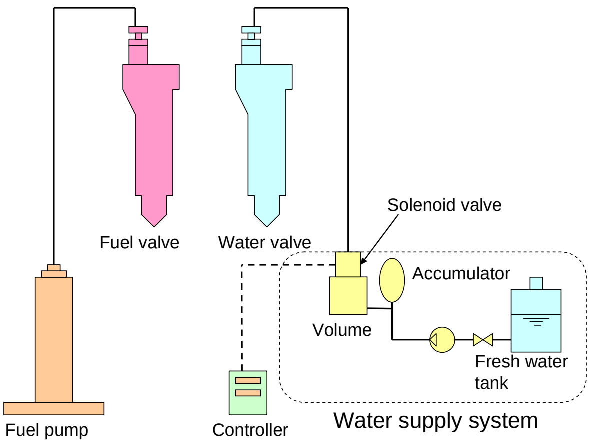

Figure 19. Independent water injection system

Figure 20. Water injection valve

Figure 21. Bench test of independent water injection system

Figure 22. Water injection system installed in 6UEC50LSE

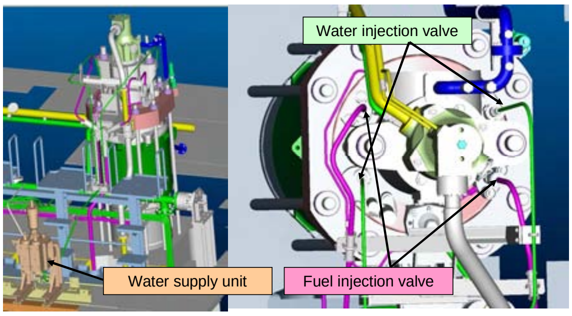

Figure 23. Water injection valve configuration

Fig. 24 shows the test results. NOx can be reduced relative to the water injection amount. In detail, a 69% NOx reduction can be achieved, along with a water injection amount of 169% to fuel quantity at a 75% load, which are the maximum weighting factors in the E3 mode in the IMO NOx calculation formula. Also, we obtained a 68% NOx reduction at a 100% load, along with 134% water injection amount. Here, water injection timing was optimized at each test point.

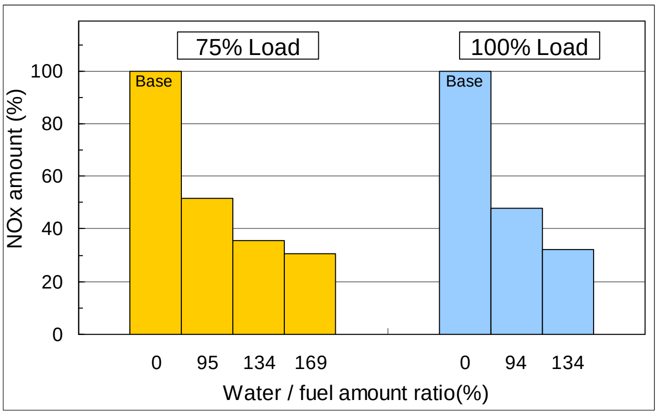

Figure 24. Test result of independent water injection system

We obtained good results, with more than 50% NOx reduction, which we had never achieved with a stratified fuel water injection system or emulsion fuel. However, we could not achieve our initial target of 80% NOx reduction, and some points to improve were discussed for the next step. Further NOx reduction with less water injection amount should be necessary by optimizing the water injection timing, the atomizer specification of the water injection, etc. Another point is how to get a large amount of water on board. According to some shipyard reports, a maximum 80% of water could be available by using a water generator that makes the most of the heat capacity of the jacket cooling water. However, approximately 200% or more of water would be necessary to gain an 80% NOx reduction by the said test results. Thus, practical installation of this system would be some problems. Hopefully, by resolving these issues in due course, this system will be a potential candidate for the future phase of NOx regulations.

CONCLUSIONS

More than 100 years have been passed since Rudolf Diesel invented the diesel engine, and the marine two-stroke diesel engine is still needed for logistics all over the world. These days, requirements for the marine two-stroke engine are getting more and more severe, and stronger demands are being made, such as higher engine power for new generation ships, high reliability, high economy due to high oil prices, and environmental friendliness to be in compliance with regulations.

To meet those requirements, we continue to develop new engines and technologies as described in this paper. Namely, the UE engine program, for development of such the UEC45LSE, the UEC60LSE, and the UEC Eco-Engine, is expanding steadily. The SIP system is quite helpful for economical operation with a low ring and liner wear rate. Regarding emission control, an independent water injection system was tested on the UEC50LSE engine at shop, and we clarified the potential for large NOx reductions. However, further NOx reduction with less water injection amount shall be achieved as the next step in our research.

The UE engine intends to contribute to the growth in the marine industry with high economy, high reliability, and environmental friendliness.

REFERENCES

[1] H. SAKABE and K. SAKAGUCHI, “The UEC engine program and its latest development” CIMAC 2004, Paper No.224

[2] H. SAKABE, “The latest technology of the UE engine with environmentally friendliness, enhanced reliability and high performance” ISME TOKYO 2005

[3] M. SUGIHARA, K.EDO, and T. TANIDA, “Environment Friendly Two-Stroke Marine Diesel Engine, “MITSUBISHI UEC Eco-Engine”” ISME TOKYO 2005

[4] K. TAKASAKI, H. TAJIMA, A. STROM, and S. MURAKAMI, “Visualization of Combustion and CFD Study for NOx Reduction with Water Injection” ISME TOKYO 2005

[5] K. WILSON and J. DRAGSTED, “Engine users views of poor quality parts from engine builder appointed subcontractors” CIMAC 2004, Paper No.93

[6] A. KUBO, K. OKAWARA, K. IWAYA, K. IGARI and N. OHNO, “Analysis of Reliability/Failure of Newly Built Diesel Engines”, CIMAC 2004, Paper No.95

[7] J. DRAGSTED, N. HANSEN and K. WILSON, ”SERVICE EXPERIENCE WITH DIESEL ENGINES AS COMPLIED BY THE CIMAC USERS WG”, CIMAC 2001, pp.772-783